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FLUVIAL ARCHITECTURE OF THE SEDIMENTARY AQUIFER COMPLEX IN THE AREA OF SANITARY LANDFILL PLOVDIV

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ABSTRACT
Aim of the study is to development a lithofacial and fluvial-architectural model of the deposits from the area of the sanitary landfill Plovdiv, which to allow the compilation of a reliable mathematical model for estimation and prognoses of the range and the scale of ground water contamination as result of the landfill exploitation. The developed sedimentological and stratigraphical models are based on field, borehole and geophysical data. Based of field studies and the available subsurface data in the area fluvial lithofacial types were defined and detail lithofacial profiles were developed. This allowed the revealing of the channel, the near-channel and the overbank fines deposits, the characterization of their architecture and determination of four elementary fluvial cycles (EFC). From the obtained 2-D lithofacial data and the information about the direction of the fluvial paleotransport 3-D architectural elements are defined, which further are differentiated according to their hydraulic properties.
Three basic units for the hydrogeological model are defined and identified - high-permeable and low-permeable water-bearing bodies and impermeable bodies (aquitards), and are localized zones of direct hydraulic connection between the high-permeable beds from different EFC.

INTRODUCTION

The Neogen-Quaternary aquifer complex in the area of the sanitary landfill Plovdiv is formed in fluvial gravels, sands and mud. The summary thickness of these sediments not exceed 40-50 m (Мерачев и др., 1982). The bedrock is from Upper Cretaceous granodiorite porphyrites which build up the lower aquiclude of this aquifer structure.

The wide spectrum of lithological and facial variety of the sediments where the aquifer complex is formed predetermines the wide heterogeneity of conditions that control the pollutant migration. That is why, it is more appropriate to apply the sedimentological approach in describing the spatial parameters of 3D bodies from the complex with homogeneous hydraulic characteristics (aquifers and aquitard), rather than the standard model of "multiple aquifer complex".

MATERIAL AND METHODS

For achievement of relevant of the fluvial architecture model, sequences of outcrops, situated transversally and longitudinally to the dominating directions of sedimentary paleotransport were studied and were carefully correlated. The collected field lithofacial data and the data from all drilled in the area the sanitary landfill exploration boreholes (Fig. 1) allowed the definition of 14 fluvial lithofacieses. For revealing the spatial distribution and interrelations of the determinated lithofacieses, a set of lithofacial profiles embraces the area of the sanitary landfill is developed. Based of the spatial interrelations and the genetic interpretation of the established lithofacieses, the systematic measurement of all type indicators of the direction of the sedimentary paleotransport and after the detailed study of the morphology and the orientation of the bounding surfaces of the established lithofacial units, three fluvial architectural-element elements were distinguished. The lithofacial and architectural-element schemes, as well as the nomenclature of the bounding surfaces order proposed by Miall (1996) were accepted. Because of the nature of the existing lithological data, some modifications in the architectural-element nomenclature are made.

The spatial distribution and interrelations of the architectural-element units define several *elementary fluvial cycles* (EFC) situated one above other. The base of every separate EFC is 5^{-th} order erosion surface. They correspond to the connotation of the described by Janev (Янев, 1982, p. 70) elementary sedimentary cycles. As a complex of genetically connected and regularly replaced lithofacieses EFC correspond to the first order cycles (elementary cycles) described by Logvinenko (Логвиненко и др., 1976, p. 123).

The proposed by Folk et al. (1970) criteria for definition of the gravel lithofacial units are accepted. According to them, the presence of 30% or more gravel clasts (coarser than 2 mm) is accepted as lower limiting value of this group. Matrix-supported and grain-supported gravel lithofacies varieties are distinguish.

The lithofacial units (as well as for the constructed by them architectural elements) are defined according to their hydraulic properties on the base of grain size data (using φ-scale) received from studies of representative samples.

The proposed by Friedman (in Friedman et al.,1992, p. 36) seven-step scale for estimation of the degree of sorting of the sediments is applied. The results are presented as I(σ)/Ski (standard deviation/skewness) diagram (Fig. 2).

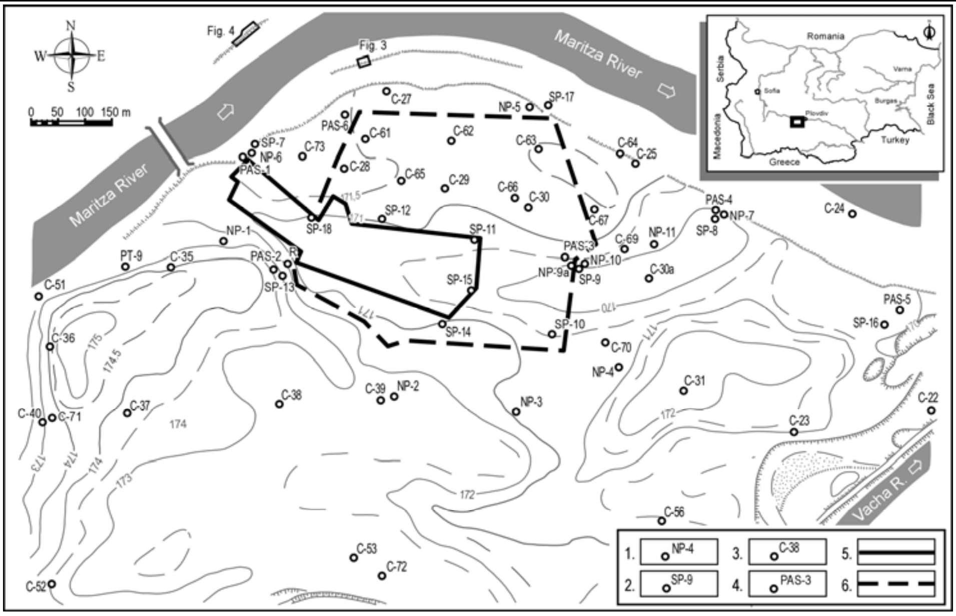

Figure 1. The area of sanitary landfill Plovdiv with the location of the studied boreholes: (1-2) – monitoring wells; (3-4) – exploration borehole; (5) – the area of sanitary landfill in year 1992; (6) – the area of sanitary landfill in year 2002.

LITHOFACIAL AND ARCHITECTURAL-ELEMENT STRUCTURE OF THE SEDIMENTS FROM THE AREA OF SANITARY LANDFILL PLOVDIV

The character of the outcropping and the available subsurface lithological data allowed the correct definition of three architectural elements: (1) *channels deposits* (element CH); *near-channel deposits* – element ND, which units elements LV (levee) and CS (crevasse-splay) in the Miall's scheme (Miall, 1996); and (3) *overbank fines* (element OF). The presented in the sedimentary section architectural elements inside and around the sanitary landfill area form four situated one over other EFC, which we numerated according to the sequence of their formation. Each one EFC represents independent complex of channels, near-channel and overbank deposits, restricted by the 5-th order bounding surface. The thickness of the determined EFC is in the range of 8-13 m and varies in the area.

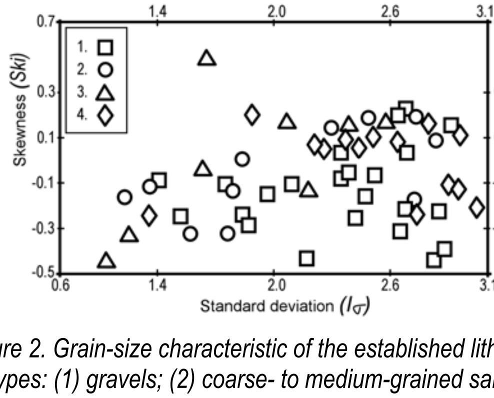

Figure 2. Grain-size characteristic of the established lithofacial types: (1) gravels; (2) coarse- to medium-grained sands; (3) fain-grained sands; (4) fine-grained clastic sediments.

According to their grain-size characteristics the distinguished in the area of the study lithofacial units are subdivided in three groups: (1) *gravely*, (2) *sandy* and (3) *fain-grained clastic* lithofacieses.

The matrix-supported and clast-supported gravels (lithofacies Gms and Gm) belong to the first group, as well as trough- and planar-cross-bedded gravels (lithofacieses Gtr and Gp). They build up about the half of the volume of the studied architectural element CH. Lithofacieses Gtr and Gp are most often presented in the lower and middle parts of the channel deposits (Fig. 3a) and represent in-channel gravely bars and banks.

Lithofacies Gm is observed under the guise of uneven, thin, ribbon-like (on the bottom of architectural element CH) or sheet-like (in the middle part and on the top of the channel deposits) bodies and is interpenetrated as lag, relatively washed, mainly channel deposit.

Lithofacies Gms is represent as ribbons and wedge-like bodies with several meters thickness, and very often build up significant part of the deposits of the corresponding EFC. More rarely this lithofacies is represented by small, isolated, lens-like bodies, developed out of scope of the channel deposits. Predominantly these sediments are very poorly sorted (I(σ)>2.0). Despite this fact, the units build up by lithofacies Gms display relatively high-hydraulic properties.

The generation of lithofacies Gms is connected with the results of single catastrophic flooding events, during which simultaneously is realized channels forming and their filling with poorly sorted or unsorted coarse materials (Бакалова и Айданлийски, 2003). Only the upper most parts of similar deposits undergo consequent stream treatment, while their main mass remains very poorly sorted or unsorted.

The sandy lithofacieses display the extreme diversity. The trough- and planar-cross-bedded, mainly medium to coarse grained sands of lithofacieses Str and Sp (Fig. 3b-c, 4) are widely distributed. They are presented by solitary and grouped sets (cosets), developed in all levels of the architectural element CH. In some cases they build up completely the channel deposits. The thickness of the single sets vary from 15-20 cm to over 80 cm, while that of the cosets reach up to 2 m. Moderately to poorly sorted varieties (I(σ)=0.7-2.0) prevail. Often, especially in the lower part of the channel deposits, on the laminas and on the base of the sets, plant detritus and/or intraformational muddy pebble to coble clasts are observed (Fig. 3b and 4).

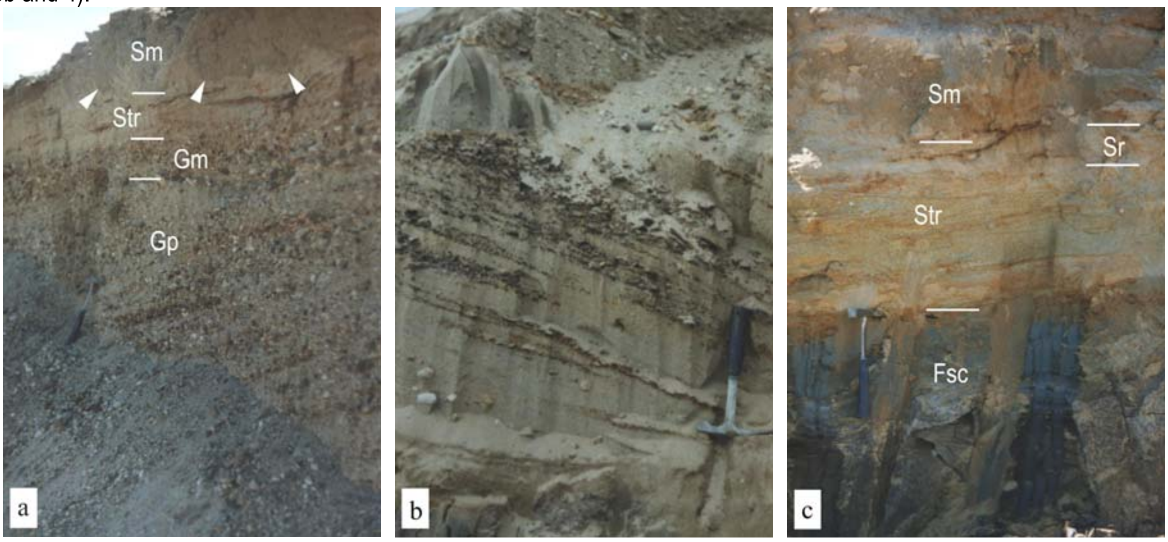

Figure 3. Lithofacial types: (a) lithofacies Gp from the lower part of channel deposits (architectural element CH), overlied by lithofacieses Str, Sr and Sm. The arrows mark load cast structure; (b) solitary, large scale, heterolithic (with plant detritus - black), plannar-cross-bedded sandy series (lithofacies Sp) from the IV-th EFC (a detail from Fig. 4); (c) lithofacies Fsc from the upper part of architectural element OF (lower part of the picture) overlaid by ripple and meso-scale cross-bedded coarse- and medium grained sands, that build up the periphery of the channel deposits of the IV-th EFC. Abbreviations – see in the text.

The creation of lithofacieses Str and Sp is a result of the processes of generation and migration of different in shape in-channel sandy mesoforms – transverse and longitudinal bars as well as point bars. In rare occasions they are produced by out of channel processes as well.

Ripple cross-bedded sands from lithofacies Sr are developed mainly on the top or in peripheral parts of the channel deposits. Together with lithofacieses Sl and Sh (low-angle-cross-bedded and horizontal laminated sands), lithofacies Sr takes parts in the structure of the architectural element ND as well. It is represent by fine- to coarse-grained, moderately to poorly (especially in the presence of flaser bedding) sorted sands. Lithofacies Sr builds up thin bodies, which overlie the horizontal laminated and meso-scale cross-bedded units (Fig. 3a and 4).

Lithofacieses Sl and Sh are presented by sheet-like or low-relief cones (architectural element ND), developed in the periphery of the channel deposits and rarely occur as isolated thin bodies among the overbank deposits of element OF. Only in one case when they occur within the typical channel deposits (Fig. 4). Poorly to very poorly sorted, medium- to fine-grained sands prevail.

The massive, poorly sorted (I(σ)>2.0) sands (lithofacies Sm) have most restricted development. They build up lens- and sheet-like bodies. Like lithofacies Gms, their generation is connected mainly with the results of flooding events. In the cases of significant thickness, they generate load cast structure (Fig. 3a).

The fine-grained clastic deposits are presented by three lithofacieses: laminated (lithofacies Fl) and massive (lithofacies Fm) sandy silts, sandy and silty muds and hyposediments, and laminated and massive clays (lithofacies Fsc). The sediments of lithofacieses Fl and Fm are very poorly sorted, while those of lithofacies Fsc are poorly to moderately sorted. The described fine-grained clastic lithofacieses build up composite, sheet-like, more rarely lens-like bodies. They are the main building unit of the architectural element OF.

In isolated areas of architectural element OF (that between boreholes C-51 and C-28 in III-rd EFC as well as between boreholes C-51, C-71 and C-38 in IV-th EFC) development of paleosols (lithofacies P) is established. The paleosols are characterized by the presence of small limy-rusty spots in the overbank deposits. The presence of lithofacies P leads to decreasing permeability of the sediments.

The morphology and the size of the determined architectural elements are rather variable inside the separate EFC and in the section as a whole. Architectural element CH is presented by solitary and composite channel deposits. Its width vary from several decameters to hundred of meters. In the solitary elements the w/d (wide/depth) ratio is in the range of 20.6-39.1, while in some areas of the composite elements it exceeds 80. As a rule the lower bounding surface is erosional and with complex 3D geometry. The upper surface of the element is subhorizontal to weakly concave. In the composite units the thickness of the architectural element CH reaches 8-9 m.

The study of the spatial development of architectural element CH from separate EFC reveals areas with erosional contacts between the channels deposits of adjacent EFC (Fig. 5).

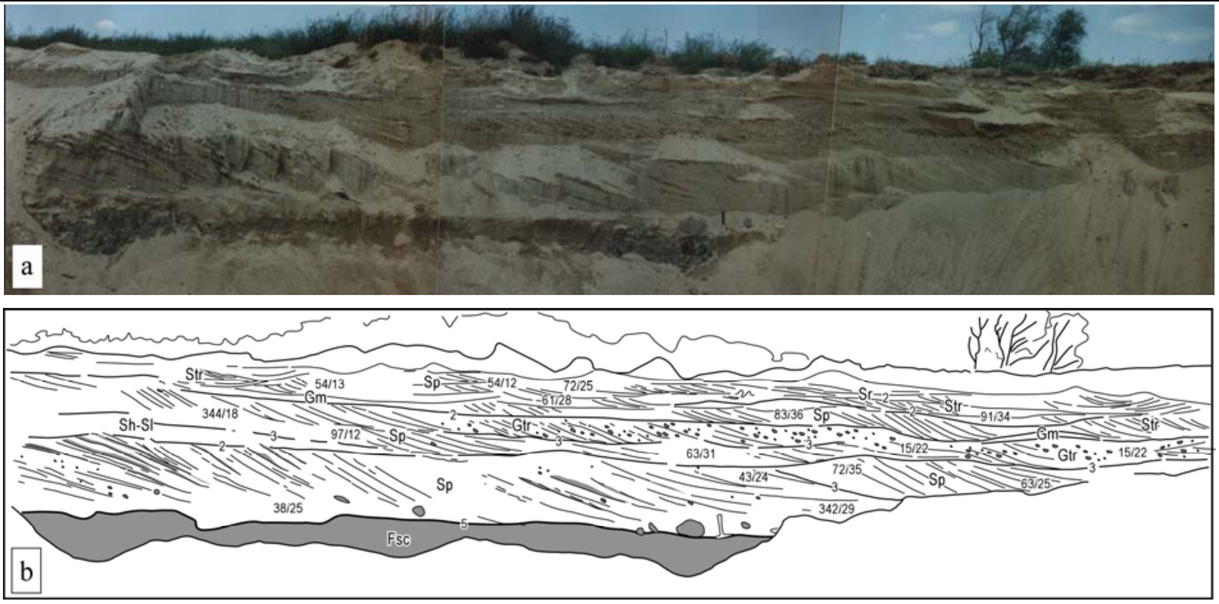

Figura 4. Photomosaic (a) and diagram (b) illustrating the lithofacial geometry of part of architectural element CH from IV-th EFC. The lower part of the outcrop is build up by lithofacies Fsc, representing the uppermost part of architectural element OF from III-th EFC. On the diagram are presented the order of the bounding surfaces and the orientation (strike/dip) of the cross-bedding. Azimuth of outcrop - 47º. Abbreviations – see in the text.

The boundary between architectural elements CH and ND could not always be traced precisely through the whole area of development of the channel deposit in the particular EFC. Often it represents a gradual lithological transition with complex geometry. In the detached EFC the thickness of the near-channel deposits do not exceeds 2.7 m. As a rule it varies in the range of 1.1-1.9 m. Laterally with the receding from the channel complex, the thickness of element ND decrease.

Architectural element OF has predominantly sheet-like form. Its average thickness is in diapason of 2.5-3.0 m. Element OF laterally replaces and vertically overlies the sediments of architectural elements CH and ND.

On Fig. 5 the spatial distribution of the described architectural elements in every particular EFC is demonstrated by hypsometrical maps of characteristic bounding surfaces. Because of the limited number of the boreholes that cross the I-st EFC, similar map for this cycle is not developed.

According to Stoyanov and Ajdanlijsky (Стоянов и Айданлийски 2002, Fig. 1) the sediments with prevailing medium-grained sand or coarser fraction are permeable to highly permeable media. Finer-grained deposits should be considered as low-permeable to practically impermeable media. According to the data obtained during the present investigation the group of permeable sediments includes all gravely and part of the sandy lithofacieses (Sp, Str, Sr and partially by Sh and Sl). To the group of aquitards belong mainly the fain-grained clastic and poorly and very poorly sorted sandy lithofacieses.

From hydrogeological point of view, according to the grain-size characteristics and the related hydraulic properties of the water-bearing media the determined above channel deposits are identified as *high-permeable water-bearing bodies*, near-channel deposits – as *low-permeable water-bearing bodies*, and the overbank fines – as *impermeable bodies (aquitards)*. The high-permeable water-bearing bodies are with rather complex geometry, uneven lateral development and complicate vertical communications between them. The other bodies are with plate-like shape, predominantly with even lateral development and with or without vertical connections between them.

The defined above low-rank hydrogeological units are relatively homogenous regarding to their hydraulic properties and migration parameters and their values in the different points and direction vary in narrow range.

DISCUSSION

In the Quaternary deposits from the area Plovdiv lowland Dragomanov et al. (Драгоманов и др., 1989) determines four to five fluvial cycles, which are integrated in two macrocycles. The restricted area of the investigation not allowed comparison between these cycles and the established here EFC.

The high-permeable water-bearing bodies have geometry similar to the fluvial channel set. As a whole their orientation, in spite of some variations in each EFC, coincides with the contemporary fluvial pattern in the area.

As a result of the paleo-fluvial activity the channel deposits of every EFC partially truncate erosionally the deposits form the lied below EFC. These interruptions in the impermeable and low-permeable bodies (so called “hydraulic windows”) determine possibilities for direct hydraulic connection between the high-permeable bodies from the different EFC.

The high-permeable water-bearing bodies in the sediments of IV-th and III-rd EFC have direct contact almost in the whole area of their occurrence (part of the area bounded by the contour line 160 on Fig. 5a). The formed in this unit groundwater flow is unconfined, because the measured in it groundwater level is in the range of levels 165-167 m. The water levels in

Maritza River and Vacha River varies in the same diapason. This fact, as well the position of the contemporaneous fluvial channels compared to the top of this hydrogeological unit, presumes the existence of direct hydraulic connection between the groudwaters in this unit and the both rivers.

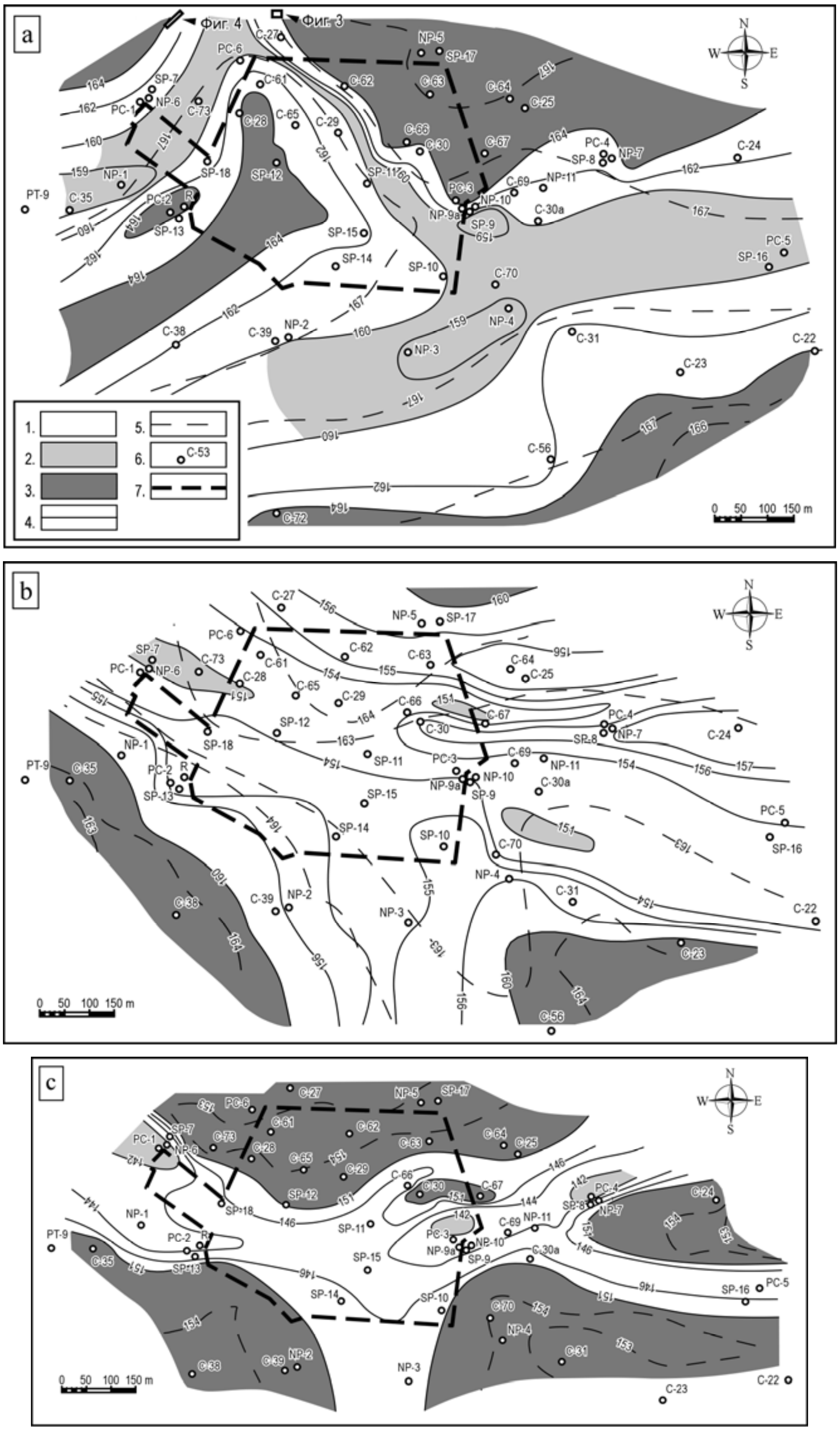

Figure 5. Hypsometrical maps of characteristic surfaces for the distinguished architectural element in (a) IV-th, (b) III-rd and (c) II-nd elementary fluvial cycle (EFC): (1) area of distribution of architectural element CH; (2) areas of direct contact between channel deposits from vertically adjacent EFC (hydraulic windows); (3) area of distribution of overbank fines (architectural element OF) from the underlying EFC, over which are not developed channel deposits from the displayed EFC; (4) contour lines of the lower bounding surface of architectural element CH; (5) contour lines of the top of the architectural element ND; (6) studied borehole; (7) – area of sanitary landfill in 2002 year. Abbreviations – same as in Fig. 1.

The interruptions of the impermeable and low-permeable layers from I-st and II-nd EFC are rather more limited as area and relatively small in size (Fig. 5b,c). This is the reason the ground waters, accumulated in the high-permeable bodies of these two EFC, to be semiconfined. The piezometric water level established in them is with about 10-15 cm higher than the groundwater level in the common for of IV-th and III-th EFC water-bearing body.

The differences in the hydraulic connections between the high-permeable water-bearing bodies give reason in the frame of the aquifer complex two hydrogeological units of higher-order to be defined:

- upper aquifer;
- lower aquifer.

The upper aquifer is formed in the sediments of the IV-th and III-rd EFC, and the lower – in the sediment of II-nd and I-st EFC.

The both aquifers are connected hydraulically. The water exchange between them is realized either directly through the several "hydraulic windows", either indirectly through the low-permeable unit of the II-nd EFC in the zone of partial interruption of the aquitard of the same EFC (Fig. 5b). These are the possible ways for depth infiltration of contaminants leaking from the bottom of the sanitary landfill.

Essentially, the divided in the EFC hydrogeological units are low-rank technical stratigraphical unites.

CONCLUSIONS

The applied in the study of the fluvial successions architectural-element approach significantly makes easier the identification and the spatial description of low-rank hydrogeological units in the Neogene-Quaternary aquifer complex. The obtained results are good base for more consistent geometric identification of the possible ways and conditions for pollutants migration in the developed 3D mathematical model for ground water contamination in the area of the sanitary landfill Plovdiv. As a base elements in this model should be used high-permeable, low-permeable and impermeable units, defined in the present study.

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DEFORMATIONS AND METAMORPHISM AT THE BASE OF THE DIABASE-PHYLLITOID COMPLEX IN ETROPOLE AND ZLATITSA-TETEVEN MOUNTAIN (CENTRAL BULGARIA)

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ABSTRACT

The low-grade metamorphic rocks exposed on the southern slopes of Etropole and Zlatitsa-Teteven Mts. are the object of present study. At first these rocks have been referred to the "diabase-phyllitoid formation", renamed later "diabase-phyllitoid complex". During the last decade they have been correlated with Berkovitsa Group or Dalgidel Group. The present investigations do not support the reliability of this correlation. According to petrologic and structural criteria, the complex is divided in two lithostructural units: lower one, represented mainly by tectonically stratified orthometamorphites and upper one, built up predominantly of metapelites and metaaleurolites. On the case study of several sections of the lower lithostructural unit, the sequence of the structural and metamorphic events as well as the metamorphic environment is determined.

INTRODUCTION

Along the southern slopes of Etropole and Zlatitsa-Teteven Stara Planina Mts., between the rivers of Brevene and Sanur Dere (Fig. 1), there are almost uninterrupted exposures of the diabase-phyllitoid complex, immediately above its boundary with migmatized gneisses referred to the so-called Arda Group (Cheshitev et al., 1995). They are very suitable for detailed study of the composition and the structure of its lowermost part, comprising mainly metabasitic rocks. It is designated here as lower lithostructural unit. The clarification of its metamorphic and structural evolution will allow more substantial interpretation of the nature of the boundary between the high-grade and low-grade rock complexes. The previous ideas concerning the composition and the structural peculiarities of these complexes as well as the character of their boundary could be found in a previous article (Antonov et al., 2001).

This paper aims to analyze the petrologic and structural data taken from 6 sections, intersecting different parts of the lower lithostructural unit of the diabase-phyllitoid complex. The study focuses on two aspects: 1) petrologic characterization of the rocks and morphological features of the deformational structures in microscopic and small mesoscopic scale and 2) determination of the structural sequence, the environment and grade of the metamorphic processes. The results from the detailed areal study of the lower lithostructural unit are to be discussed in another article.

GEOLOGICAL SETTING

With respect to the Late-Alpine structural setting, the studied region is situated in the embrace of the so-called Chelopech unit (Angelov et al., 1995; Cheshitev et al., 1995), which possesses fold-thrust structure (Fig. 1). Its northern boundary is traced along several subequatorial reverse faults-thrusts (Kashana, Mechesh, Jemina), and its recent southern boundary is along the Sub-Balkan normal fault, which separates the unit from the Neogene Zlatitsa semi-graben. Part of fold limb, built up of Upper Cretaceous sedimentary rocks, is represented in the region. Northeast of Tsarkvishte village, these rocks overlay transgressively and discordantly both the migmatized gneisses and the metamorphites of the diabase-phyllitoid complex. The boundary between the two metamorphic types is subparallel to their dominating planar structures, trending generally east-west and dipping from 40° to 60-75°/S. In Plevnyaka place as well as along the southern slope of Kaleto locality, it dips to north, northeast or northwest with different angles, due to local folding.

TECTONOSTRATIGRAPHY OF THE LOWER PART OF DIABASE-PHYLLITOID COMPLEX

In the previous articles about the geological structure of the region, the rocks of the complex are initially considered as Paleozoic "schist complex" (Toula, 1882; Zlatarski, 1883; Bonchev, 1908) or "Silurian shales" (Mandev, 1942). Later, they are assigned by Trashliev (1964) to the "diabase-phyllitoid formation" defined by Dimitrov (1946) and renamed by Boyadjiev (1970) in "diabase-phyllitoid complex". Belev (1967) refers the metabasites of the lowermost part of the green-schist complex to the so-called amphibolite formation of the "Precambrian high-grade serie" and the phyllites – to the "diabase-phyllitoid formation". According to Ivanov et al. (1987), this "formation" represents a "complicated rock unit, in which, due to tectonic reasons, mixing of fragments of oceanic and continental crust with comparatively deepwater epicontinental sediments has taken place". Haydoutov (1991) assumes that the diabase-phyllitoid complex in the region is an analogue to the Berkovitsa Group.

During the initial stage of the present study, a "marker level" was separated at the base of the diabase-phyllitoid complex. It comprises mainly metabasites (Antonov et al., 2001) and its thickness varies from 50 to 500 m.

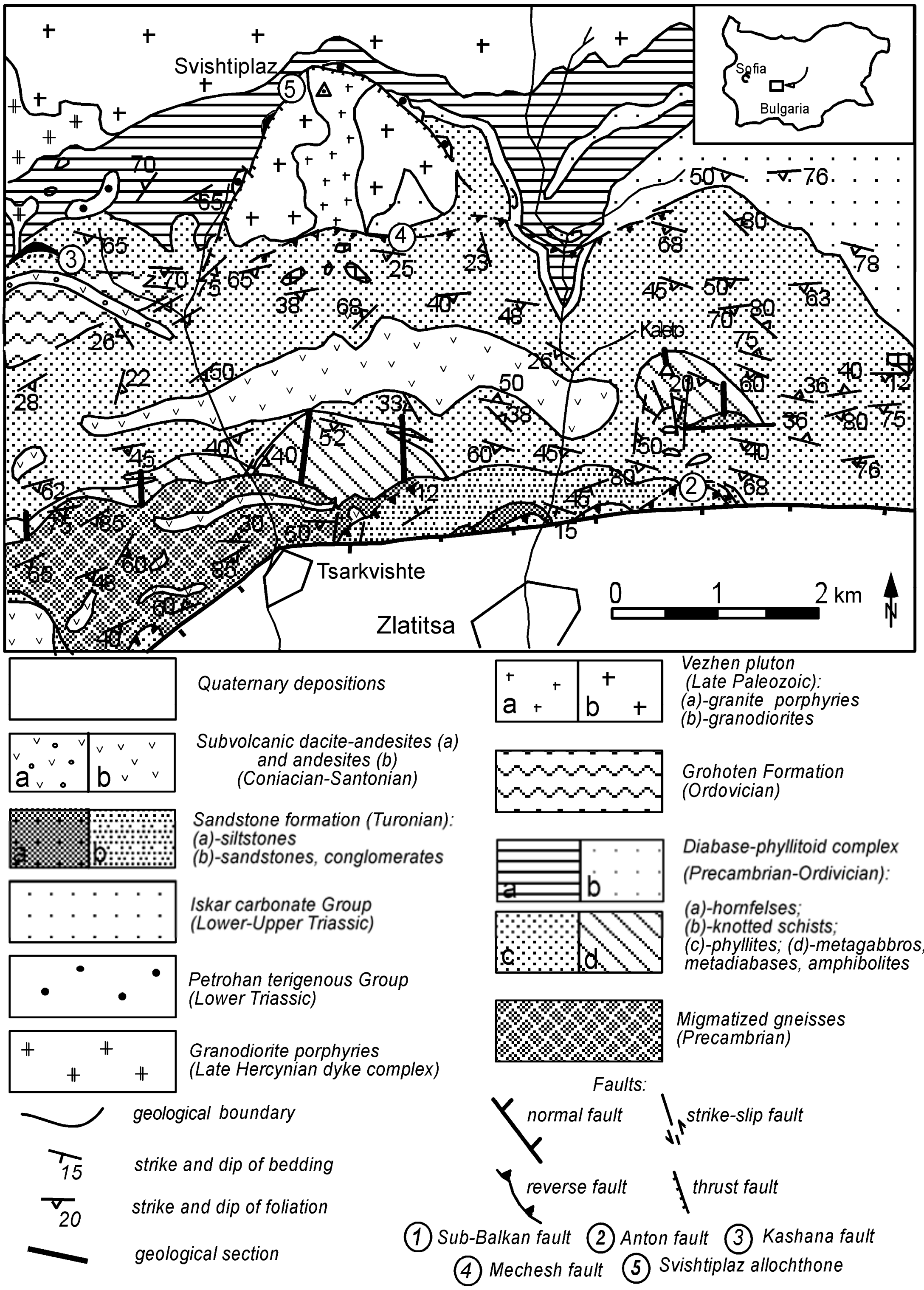

Figure 1. Geological map of the southern slopes of Etropole and Zlatitsa-Teteven Stara Planina

The new data about the petrographic composition and the structural features of this "level" as well as of the upward following association of parametamorphic rocks do not support its correlation with the Berkovitsa Group in the embrace of the region under consideration (Cheshitev et al., 1995). This is because of the lack of volcano-sedimentary and turbidite sequences, lydites and marbles, characteristic for the "island arc association" of the West Balkan. There are no grounds for its correlation with the "olistostrome" Dalgidel Group (Cheshitev et al., 1995), due to the insignificant presence of coarser terrigenous sediments as well. That is why, proceeding from the contrast differences in the rock composition, the character of metamorphism and the deformation style, two mappable lithostructural units at the lower part of the diabase-phyllitoid complex could be defined, which we provisorily designate lower and upper.

The lower lithostructural unit is built up only of metamorphosed igneous rocks – mainly metabasites (metagabbros, amphibolites, amphibole schists, green schists) and subordinate quantity of metagranitoids (metaplagiogranites, metafelsites and metapegmatite-aplite). The lower boundary of this unit with the migmatized gneisses is a sharp metamorphic contact (Table. I; d), but its upper boundary is delineated along its contact with metapelites (mylonitized phyllites). Its total thickness in the region varies from 80 to 450 m.

As a result from the intensive syn-metamorphic ductile and brittle-ductile deformations, all of the rock varieties are featured by distinct SL-fabric. Dominating planar structure in mesoscopic scale is the tectonic stratification, resulted from isoclinal folding and transposition of an early foliation (metamorphic banding) in regime of heterogenous simple shearing. This foliation is determined by repeatedly alternation of homogeneous and/or heterogeneous "layers", which thickness varies from several mm up to 1-1,5 m as well as of sheets, from several meters to 30-40 m thick. Planes or narrow zones of ductile and brittle-ductile shearing always represent the boundaries between the "layers" and/or the sheets. The deformation style is unchangeable both in vertical and horizontal direction. The distribution of the rock varieties in the tectonostratigraphic section is irregular but in some localities (e.g. Kaleto) it could be subdivided in superpositionally situated sub-units: amphibolite-metafelsite, of the banded and massive amphibolites, metaplagiogranite with orthoquartzite marker and amphibolite with thin sheets of metaplagiogranites (Fig. 2).

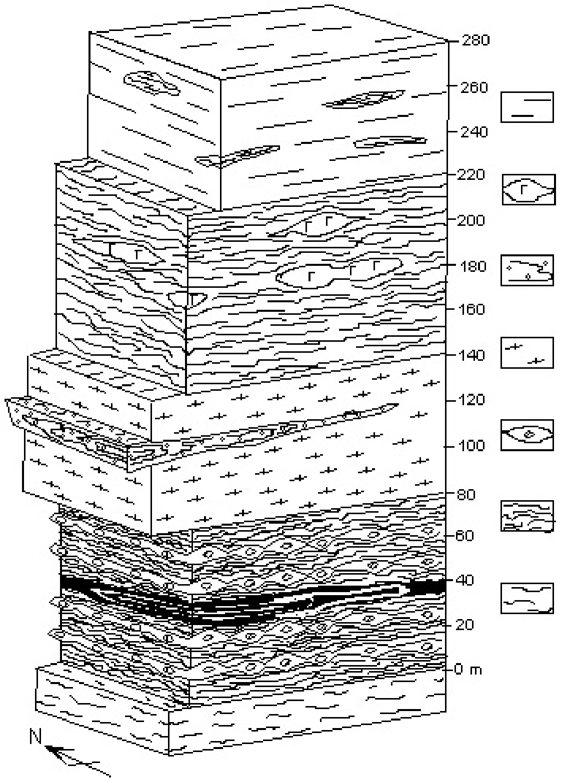

Figure 2. Generalized block-diagram demonstrating the rocks distribution of the lower lithostructural unit
1 – migmatized gneisses; 2 – amphibolites; 3 - metafelsites; 4 – metagranitoids; 5 – quartzites; 6 – metagabbros and metagabbrodiorites; 7 – phyllites.

The upper lithostructural unit includes metamorphosed in green-schist facies sedimentary rocks (pelites, aleuropelites and aleurolites), comprising allochthonous fragments of different size and composition - metabasites (ophiolithoclasts), granitoids, aplites and quartzites. Its lower boundary is traced along the first appearance of strongly mylonitized phyllites. To the north of the region, they are altered in hornfelses and knotted schists. The dominating planar structure of the metasediments is the axial cleavage, formed during the metamorphism and folding of the primary bedding. It is parallel both to the boundaries and to the foliation of the allochthonous fragments.

PETROLOGICAL CHARACTERIZATION

The lower lithostructural unit defined by the authors is built up only of metamorphosed igneous rocks. The detailed studies allow the separation of several petrographic varieties as follows: metabasites represented by massive metagabbros to metagabbrodiorites, massive amphibolites with or without garnet, banded amphibolites, amphibole schists and green schists as well as metagranitoids, comprising metagranites, metagranodiorites, metafelsites and metapegmatite-aplites.

Metabasites. Metagabbros to metagabbro-diorites could be observed along the entire section of the lower lithostructural unit. They form lenses and boudins varying from 0,8 up to 1,5 – 2,0 m. It strikes, that some of them are concentrated in the middle part of the unit and they are always present next to its contact with the upper lithostructural units. These rocks comprise large crystals and possess massive and/or spotty structure. Moreover, they have very well preserved gabbro to hypidiomorphic-grained texture. Although that all of the primary minerals are metamorphosed, they could easily be recognized after their forms. Their mineral composition includes two parageneses: magmatic (plagioclase, amphibole and pyroxene - only like relict "spots") and metamorphic (plagioclase, amphibole, quartz, rutile and epidot minerals). The minerals of the metamorphic paragenesis are represented by plagioclase (An45) and two types of calcium amphiboles – ferrohornblende and actinolite hornblende. The first one forms well crystallized grains, but the second one is developed along the cleavage planes of the magmatic pyroxene. *The banded amphibolites* are referred to this group of metabasites. They possess fine to rough banded structure, determined by alternation of femic and salic component. They are built up of relict magmatic association – plagioclase (An60), amphibole (edenite type) and metamorphic association including amphibole (magnesiohornblende), zoisite and plagioclase (An30). *The massive amphibolites* are represented along the entire section. In some places they comprise garnet in other ones they do not. The latter ones are always in boudinage structures. Microscopically, the amphibolites possess heterogranoblastic structure, porphyroblastic after the garnet (Table I; e). They are built up of amphibole (magnesiohornblende), garnet (Alm$_{60-56}$; Pyr$_{25-27}$; Gross$_{9-10}$; Andr$_{4,4-5}$; Spess$_{1,66-1,87}$), plagioclase (An20), quartz and rutile. Along the boudins periphery these rocks are blastomylonitized (Table I; f) and form new mineral paragenesis comprising amphibole (actinolite hornblende), garnet (Alm$_{62-63}$; Pyr$_{17-18}$; Gross$_{10-11}$; Andr$_{4,5-5}$; Spess$_{3-3,2}$), plagioclase (An25) and chlorite. *The amphibole schists* are small-grained with fine-schistous character and microgranonematoblastic texture. They consist of amphibole (magnesiuo- and ferrohornblende, ferroactinolite hornblende and ferroactinolite), plagioclase (An0-7), quartz, epidot, brown mica, apatite and ore minerals (ilmenite). *The green schists* are very rare in the studied lithostructural unit. They consists of fine granolepidoblastic mass of chlorite (up to 80%), epidot, rutile, titanite, plagioclase (albite), quartz, white mica, titanium-leucoxene products and ore minerals (ilmenite). Larger part of them is strongly blastomylonitized (Table I; l).

Metagranitoids. Metamorphozed magmatic rocks of acid compositions are referred to this rock group – plagiogranites, granodiorites, felsites and pegmatite-aplites. They are small- to coarse-grained, gray-whitish with very distinct banded structure. They posses mark of clear cataclasis and blastomylonitization. These rocks are featured by cataclastic to mylonitic and blastomylonitic texture, porphyroclastic after the plagioclase crystals (Table I; b, c). In the more slightly deformed districts it is blastogranite, blastoporphyry (e.g. with the felsites) and blastoaplite. All of them possess very well preserved magmatic mineral association comprising plagioclase, potassic feldspar, quartz, amphibole and biotite. The metamorphic association of these rocks is represented by plagioclase, quartz, epidote and zoisite, chlorite and amphibole. More detailed petrographic characterization of the metagranitoids is made by Antonov et al. (2001).

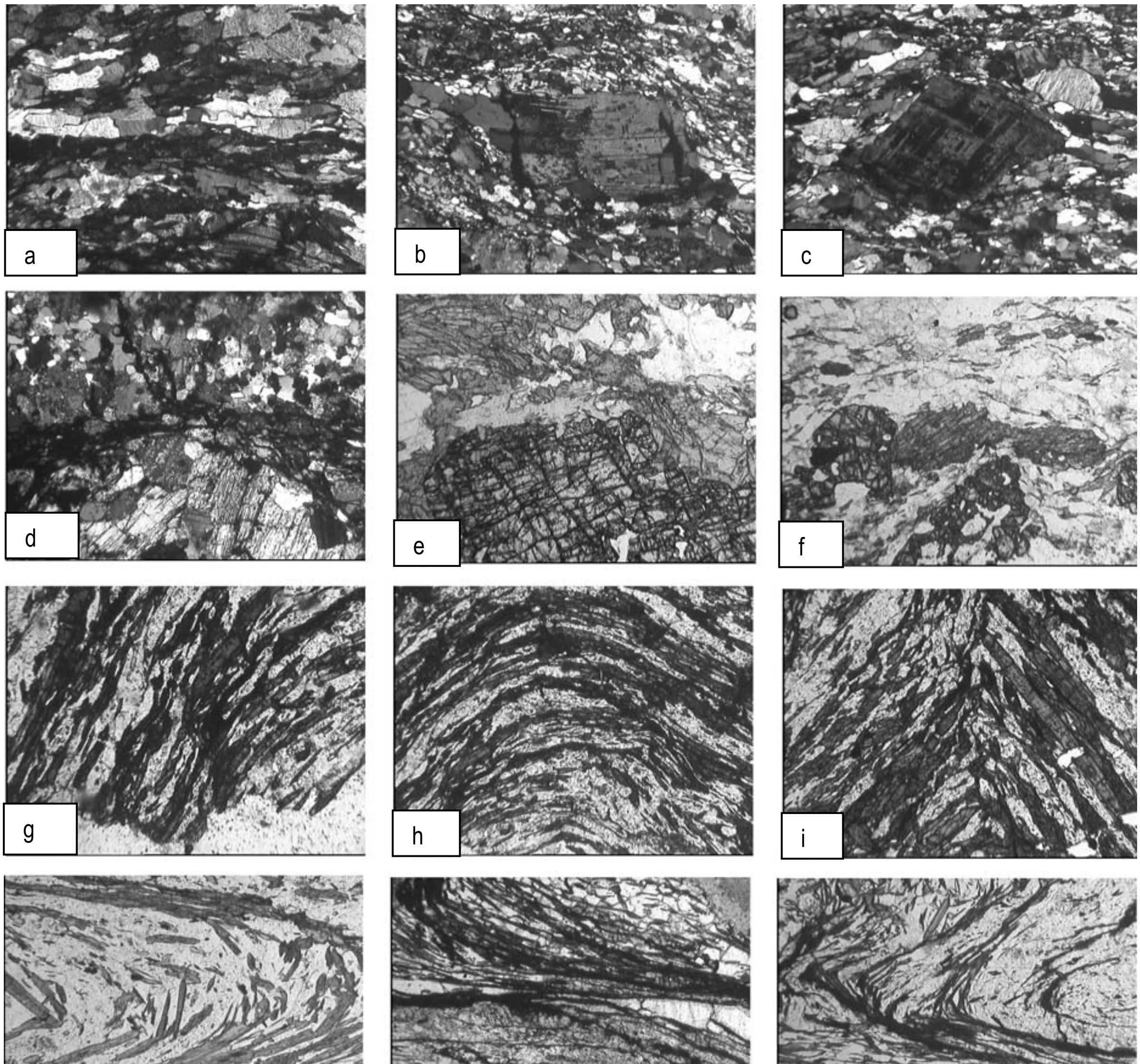

Table I

a – contact between migmatized gneisses (down the arrow) and metagranitoids (up the arrow); b, c – porphyroclastic after the plagioclase texture in metagranitoids; d – tectonic contact between massive amphibolites and metafelsites; e – garnet amphibolite; f – blastomylonite on garnet amphibolite; g, h – transposed foliation in the limb (g) and the hinge (h) of fold in amphibole schist; i – shearing in hinge zone of fold in amphibole schist; j – two amphibole generations in a narrow fold in amphibole schist; k, l – reduction of the "layers" in the limbs of isoclinal folds. X50.

STRUCTURAL CHARACTERIZATION

The presence of gneisses ("crystalline") in the valley of Sanar Dere river and along the massive of Kaleto peak is at first marked by Mandev (1942). It opines that they are slipped to north over the Paleozoic schists, which as a result from the stress related to the thrusting, have been metamorphosed up to amphibolites. The assumption of Belev (1967) is similar. He thinks that these gneisses and amphibolites build up a "tectonic klippe".

During the present study it was established that a fragment from the core and the recumbent northern limb of a relatively big antiform fold is preserved in Kaleto locality. It is broken by longitudinal, transversal and oblique faults (Fig. 1). The fold core comprises migmatized gneisses, which crop out in a narrow strip to the north of a subequatorial normal fault. The relatively competent rocks of the lower lithostructural unit form the recumbent limb. Its general trend is subequatorial but the dip varies from 20° to 40°/S. The migmatized blastomylonite gneisses, situated immediately to the contact with the green-schist rocks, are diaphtorized. Due to insignificant areal distribution and lack of relevant outcrops, their structural peculiarities are characterized in more details to the west of the region, along the southern slope of Plevnyaka hill.

Planar structures. In the strongly metamorphosed rocks of the lower unit, several morphological types of foliation could be distinctly recognized: metamorphic banding, schistosity, mylonite foliation, transposed foliation and crenulation cleavage. *The metamorphic banding* is manifested in the metabasite rock varieties. It is determined by the alternation of strips of different composition and/or color. *The schistosity* is determined by the plan-parallel trend of the prismatic minerals and mineral aggregates in the metabasites (the banded amphibolites, amphibole schists and green schists). *The transposed foliation* is the dominating planar structure in microscopic and small mesoscopic scale (Table. I; g, h). It resulted from the intensive isoclinal folding and refolding of the preceding foliations. In larger mesoscopic scale, the repeated transposition is expressed as tectonic stratification, which most frequently is subparallel to the other foliations. *The mylonite foliation* is developed everywhere parallel to the transposed foliation (Table I; k, l). *The crenulation cleavage* is locally manifested in relatively narrow zones up to 10-15 m thick. According to morphological peculiarities it is most frequently represented by fracture-like crenulation cleavage, related to kink-folds and crenulations, deforming the transposed foliation.

Linear structures. Intersection lineation, stretching lineation, slickenside lineations and crenulation lineation are observed on the planes of the different morphological types of foliation. Boudinage structure could be met in all levels. *The intersection lineation* is almost everywhere manifested on the surfaces of the "layers". It resulted from the intersection of the metamorphic banding or schistosity with the tectonic stratification. It is parallel to the fold hinges developed after this banding. *The stretching lineation* could be surely identified only in the metafelsites. It is determined by the elongated mineral aggregates. Moreover, on the surfaces of the transposed metamorphic banding are observed slickenside lineations of different trends compared to the fold hinges. *The crenulation lineation* is locally manifested in relatively narrow zones of brittle-ductile shearing. It is marked by the crenulations of the transposed foliation. *The liniation after the long axes of the boudins* formed by relatively more competent «layers» of metafelsites, coarse-grained metagabbros and metagabbrodiorites could be met in all parts of the lower unit.

Folds. The fold structures have got significant importance for characterization of the deformation style of the lower lithostructural unit. During the present study, several fold generations have been recognized. The earliest generation comprises isoclinal micro- and small mesoscopic folds (Table I; g-l), which morphology can not be characterized due to later refolding and transposing. Only intrafoliation hinge zones pictured by the metamorphic banding are preserved from them. The folds of the second generation are coaxially superimposed on the folds of the earliest generation. They are also represented by small mesoscopic isoclinal or narrow folds of big amplitude and insignificant wavelength, formed after the transposed foliation. The third generation includes kink-folds and kink-zones after the transposed foliation, which are superimposed crosswise or oblique on the earlier folds. Mesoscopic and relatively larger open and undisturbed folds of local distribution, formed after the tectonic stratification, refer to the fourth generations.

Metamorphism. In the published literature prevails the opinion that the rocks of the separated here lower lithostructural unit are regionally metamorphozed in green-schist facies environment (Antonov et al., 2001). The data obtained during the present study give grounds to suppose that this unit unites rocks both with contrast protolithic composition and with different metamorphic evolution. For example, part of the separated varieties of *metabasites* brings clear marks of polymetamorphism. This could be best seen in the massive amphibolites and amphibole schists. Their metamorphic paragenesis (magnesiohornblende – garnet – plagioclase) is typical for the rocks of the amphibolite facies. The superimposed on it paragenesis of ferroactinolite – chlorite – plagioclase possesses clear diaphthorite character. It is in close relation to the transposition of the early foliation (Table I; g, h) and/or is localized in the zones of blastomylonitization of these rocks. The green schists have got a mineral paragenesis, featured for the green-schist facies, which in the zones of transposition recristalizes in the same mineral phases. Metabasites of very well preserved relict magmatic minerals and structures are also an element of the composition of the level studied. On the other hand, the exposed *metagranitoids* possess the marks only of the typical dislocation metamorphism and all of them could be united in the general term - blastomilonites.

Structural sequence. The relationships of the structures allow determination of the supposed sequence of the structure-forming process. Several stages are recognized which are provisorily designated D_1, D_2, D_3, and D_4. *The deformation stage D_1* comprises syn-metamorphic formation of the metamorphic banding, early isoclinal folding and initial banding transposition; coaxial superimposing of the second generation of isoclinal and tight folds and repeated transposition of the foliation. The similar trend of the fold hinges and axial planes of the two generations as well as of the intersecting lineation demonstrates that they resulted from two episodes in the framework of one deformation event. The deformation represents heterogeneous simple shearing. *The deformation stage D_2* is related to the formation of boudinage structures and oblique shear fractures, resulted from flattening and shearing in pure shear conditions. Slickenside lineations develope on the surfaces of the transpozed foliation. During *the deformation stage D_3*, in relatively narrow zones of brittle-ductile shearing, kink-folds, crenulation cleavage and crenulation lineation form. During *the deformation stage D_4*, open and uninterrupted folds of subequatorial trend are established.

CONCLUSIONS

The most important results of this study are as follows:

1) According to petrologic and structural criteria, the lower part of the diabase-phyllitoid complex is divided in two lithostructural units, provisorily noted as lower one and upper one. The lower unit comprises tectonically stratified ortho-rocks – mainly metabasites and subordinate quantity of metagranitoids. The upper unit is built up of metapelites and metaaleurolites with fragments of metabasites, granitoids etc. Lithologically, this part of the diabase-phyllitoid complex can not reliably be correlated with the Berkovitsa Group or Dalgideltsi Group, defined in the West Balkan.

2) The planar, linear and fold structures of the lower lithostructural unit are interpreted according to their trends and geometrical relationships as a result of four deformation stages.

3) The data about the mineral composition, micro- and meso-structural peculiarities, the grade and type of the metamorphic processes of the rocks in the embrace of the lower lithostructural unit give grounds to assume, that this unit “unites” rocks of both contrast protolithic composition and different metamorphic evolution.

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A MODEL OF FLUVIAL ACCUMULATION LOCATED AFTER A GORGE

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ABSTRACT
The suggested model of fluvial accumulation is just one of the possible. The model is based on an examined area of the Topolnitza River in the periphery of the Thracian Lowland, directly after the gorge of the river in Sredna Gora Mountain.
In this area the fluvial deposits and the floodplain terrace of the Topolnitza River are mainly interpreted as a result of large scale erosion, transport and accumulation during the catastrophically flooding events. During each of them the water element has widely overflowed its banks, destroyed a great number of anthropogenic structures, transported a large quantity of material at the time of hollowing wide channel incision to the badrocks and simultaneously backfilled it. The flooding events are followed by relatively quite periods of several centuries each, with frequent, small-scale and larger, but not catastrophic floods. They caused transport and reworking of the fluvial sediments only from the uppermost levels of the section.
According to the authors this model of fluvial accumulation is valid for analogical areas of other streams comparable to the Topolnitza River flowing in a humid zone.
This is a model of humid fluvial accumulation in the valley-like areas in the periphery of flatland morphostructures directly after gorges, close to mountains.

INTRODUCTION

The object of the reason work is the valley bottom of the Topolnitza River in the periphery of the Thracian Lowland, directly after the gorge of the river in the Sredna Gora Mountain. The subject is the fluvial sediments of the valley bottom and mainly the ceramic fragments founded in these sediments and the aim – a commentary of a model of humid fluvial accumulation in the periphery areas of flatland morphostructures (flatlands, lowlands, cockpits) right after grogs in enclosed mountains.

The Topolnitza River originates in the central parts of the Sredna Gora Mountain. Its length is of 155 km. 130 of them is in the mountain and only the last 25 km are in the Thracian Lowland. The catchments area is about of 1800 km^2. These features define the Topolnitza River as a mainly mountainous one with small catchments area (according to the classification scheme of Solomontcev et al. 1976, p. 129). The climate of the region is a humid one. The river has an unstable snow-rain regime. The river leaves the mountain at Kalugerovo village (Fig. 1, 2) and flows into the Thracian Lowland where it runs into the Maritsa River.

The Topolnitza River mainly is deeply incised in gorge valley in its upland part. The valley bottom is in width of dozens of meters to a few hundred and more meters in the enlargements. It is entirely covered with fluvial sediments.

After the gorge in the area by the foot of the mountain follows the valley transition from a mountainous to a lowland type. The valley still has well outlined slopes here. Its bottom is enlarging fast. In it, in a 9 km. area exploration shafts on 4 profile lines for exploration of a gold-bearing placer were excavated (Fig. 2). In some of the fluvial sediments were established ceramic fragments of bricks, root tiles and pottery. They are not a subject of study in the fund reports (Ivanov et al., 1989) about the completed geo-exploration works. A report about them is published for the first time by Bakalova et al. (2003) where their archaeological aspect is commented in details. The launching model of fluvial accumulation is studied in the present publication

MATERIAL AND METHODS

The lithological description of the fluvial deposits, the definition of their grain size and the roundness of their gravel fragments as well as the collecting and the documentation (numbering and location) of the connected in them ceramic fragments were done during the excavation of the shafts for the explorations of the gold-bearing placer (Иванов и др., 1989). Generally the ceramic fragments are 98 and are from 1 to 7 in any single sample (on an average of 1-2). They are established in 49 samples of 33 shafts.

The ceramic fragments which age can be determined are dated by the archaeologists (Bakalova et al. 2003).

The grain size and the roundness of the ceramic fragments are examined by the authors of the present publication. It is done a classification of the age to the fluvial sediments using the locality of the dated fragments and the demarcating erosion incisions are established as well.

The grain-size distributing of the ceramic fragments is realized through the Udden-Wenworth scale (in Friedman et al., 1992, Fig. 1 and in Pettijohn, 1981, Fig. 3-6) and is used the width of the fragments. The description of the hard coursed lithological varieties is based on the proposed from Folk et al. (1970) scheme.

The degree of roundness of the fragments is defined on the scale proposed by Greensmith (1981, Fig 5.4) with the specialty, that the fragments with very angular and angular degree of roundness are united in one group. In this way the degrees of roundness which are used are *angular*, *subangular*, *subrounded*, *rounded* and *well rounded*. If there are two degrees of roundness visible in a fragment, following fracturing during the transport and subsequent smoothing is considered the older one i. e. the smoother one.

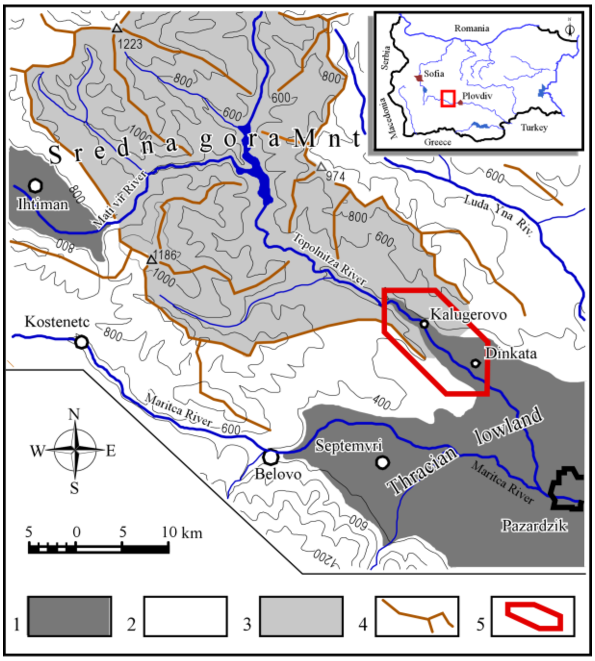

Figure 1. Geological-morphohydrographical schematic map of the studied part of the Topolnitza River valley. Geological data (1-2): 1 – undivided Quaternary sediments; 2 – undivided pre-Quaternary sedimentary, magmatic and metamorphic rocks. Morpho-hydrographical data (3-4): 3 – part of the catchment's area of Topolnitza River; 4 – ridges; 5 – studied area.

For studying the grain-size and roundness of the ceramic fragments initially they were separated in groups according to their presence in fluvial sediments of a defined age. After the subgroups are formed in every group and the fragments are divided into such of undated and such of dated, and the second ones are placed according to the respective ages. Histograms for the ceramic fragments of each groups and subgroups are designed on the base of grain-size and degree of roundness.

STATE OF PROBLEM OF THE MODELS OF THE RIVER ACTIVITY

It is generally known that the destructive, transport and accumulative force of the rivers are in a close connection in between. Widely discussed in a different expense in the specialized geological, geomorphologic and hydro-geologic literature are the models of their mechanisms of going off and mutuality. We will pay attention only on some aspects of them which are connected to the present investigation.

The destructive and the accumulative activity of the streams is takes place mainly on high waters (Zukov et al., 1970, p. 227).The question with the moving bottom sediments is vexed. Widely practiced in the hydro-geological is the attitude that that width is small and it is limited within the sweep of the moving alluvial dunes (banks) and to some decimeters beyond them (Solomontcev et al., 1976, p. 227). Geologists and geo-morphologists have another attitude, especially those of them who study fluvial placers. According to Bilibin (1955, p. 105) for example, with the overflowing of the waters become to wash away and to be involved in moving the deeper layers of the bottom sediments, due to the width of the moving layer marked of him as an active layer increases continuously. The supreme quantity of the active layer depends on the high water. The highest high waters can involves such layers of the fluvial sediments, which in course of a long period have not felt any moving.

AGE SUBDIVISION OF THE FLUVIAL SEDIMENTS FROM THE TOPOLNITZA RIVER VALLEY IN THE STUDIED AREA

The subdivision of the fluvial sediments from the Topolnitza River valley in the studied area by age has been done mainly on geomorphologic and geological data and refined according to the archaeological evidence.

Geomorphological subdivision by age

Geo-morphologically there are a distinctive fluvial channel, floodplain and non-flooded terraces in the valley bottom of Topolnitza River (Fig. 2).

The fluvial channel is an incision in the floodplain terrace. It is well-formed in the beginning of the area and it is missing in its end. The floodplain terrace is situated on the both parts of the fluvial channel. It is distinguished with a well marked step high 2-3 m by the non-flooded terrace which is lying out in the foot of the valley slopes.

The bottom of the fluvial channel is covered by sandy-pebbly sediments.

According to the data from the exploratory shafts, the uppermost levels the floodplain terrace are represented by sands and silts. They are overbank facies. Below them follow the sandy pebbles of the channel facies. Between the sediments of both of the facieses and in the upper level of the channel facies are founded clay lenses with different degree of sandiness, dark gray and with traces of plants from the facies of the abandoned channels. All of these deposits, except of the clays, are not compacted and they are rather loose.

The sediments of the non-flooded terrace were presented of analogical lithological varieties but due to their insufficient proficiency they have clarified facial relationship. Probably between them there are facieses of the proluvial deposits. Distinctive feature of the non-flooded terraces are the reddish-brown colors and the compacting of the gravels and sands, result of secondary input of clay component.

The pointed out geomorphologic (a presence of a fluvial channel and terrace shoots) and lithological (differences colors and the compaction of the sediments) data defined as a youngest the sediments to the bottom of the fluvial channel following by the relatively older sediments of the floodplain terrace and even older – the deposits of the non-flooded terrace.

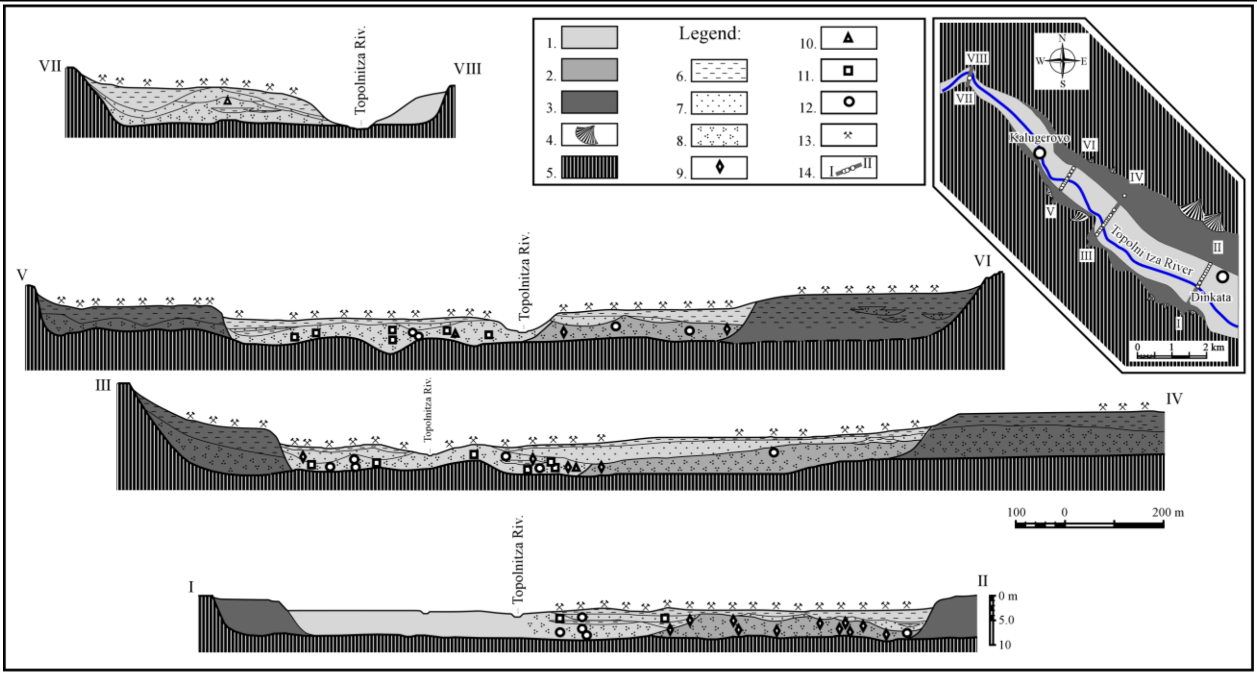

Figure 2. Geological sketch and cross-sections of the studied area of the valley of Topolnitza River with the location of the shafts and the samples with ceramic fragments (after Ivanov et al., 1989, with additions and new interpretation). Geological-morphohydrographical-archaeological data (1-12): Quaternary sediments (1-4): floodplain deposits (1-2): 1 – fluvial, not lithified, with ceramic fragments mainly from XVIII-XIX c. A. D. and single fragments from XII-XIV and IV-VI c. A. D.; 2 – fluvial, not lithified, with ceramic fragments only from IV-VI c. A. D.; 3 – non-floodplain terrace deposits: fluvial, compacted, red-brown; 4 – proluvial deposits; 5 – undivided pre-Quaternary sediments and magmatic rocks. Fluvial lithologies (6-8): 6 – clays and silts; 7 – sands; 8 – sandy gravel. Ceramic fragments (9-12): 9 – dated to IV-VI c. A. D.; 10 – dated to XII-XIV c. A. D.; 11 – dated to XVIII-XIX c. A. D.; 12 – of undetermined date; 13 - exploration shaft; 14 – profile line.

Detailization of the subdivision by age of the floodplain deposits on the base of archaeological data

The examined ceramic fragments are pieces of bricks, roof tiles and pottery. They are found only in the sediments of the floodplain mainly in the pebbles and partly in the sands (Fig. 2). The dated ceramics belong to three epochs: *first* – IV–VI c. A. D.: *second* - XI-XIV c. A. D. and *third* – XVIII-XIX c. A. D. (Bakalova et al. 2003).

On the base of the dated ceramic fragments we separate the deposits of the floodplain terrace into two laterally differentiated types: 1^{st} – ceramic fragments only of IV-VI c. A. D.: 2^{nd} - ceramic fragments mainly of XVIII-XIX c. A. D. but on some places of XII-XIV and IV-VI c. A. D. The age of the older deposits is on the range of IV-VI c. A. D. We conditionally accepted that the age coincides with the end of that rang and that is VI^{th} c. A. D. (but it can be as IV^{th}, as VI^{th} c. A. D.). The age of the younger deposits is in the range of XVIII-XIX c. A. D. and we accepted that is XIX^{th} c. A. D. by the same considerations.

There is no morphologic step between the two types of different aged sediments. Based on this we accept that the fine-grained sediments that cover them belong to the overbank facies of the deposits of XIX^{th} c. A. D.

Generalized subdivision by age of the fluvial deposits

According to the above-mentioned, the examined fluvial sediments are divided in four different ages:

- *before IV c. A. D.* – these are the deposits of the non-flooded terrace. They contain no ceramic fragments. They are compacted and have secondary red-brown colors;
- *VI c. A. D.* – they fill an incision in the older sediments. These deposits contain fragments only from the 4^{th} – 6^{th} c. A. D. They are not compacted and only the channel facieses are preserved;
- *XIX c. A. D.* – they form the morphology of the floodplain terrace. They fill an incision. They contain ceramic fragments from XVIII-XIX c. A. D. as on some places can be found single fragments from XII-XIV and from IV-VI c. A. D. The sediments are not compacted and represent both the over-bank and the channel facieses. The second ones covered the deposits from 6^{th} c. A. D.;
- *contemporary* – they cover the bottom of the fluvial channel. Part of the near-surface levels of the overbank facies of the floodplain terrace belongs to them.

DISTRIBUTION, GRAIN SIZE AND ROUNDNESS OF THE CERAMIC FRAGMENTS

Distribution

The distribution of the ceramic fragments in the host depositions is uneven (Fig. 2). There is a trend of increasing their number in the sediments down the river course.

Initially, the sediments of VI c. A. D. contain single ceramic fragments (Fig. 2, profile line V-VI and III-IV). To the SE parts of the studied area their quantity increases rapidly (Fig. 2, profile line I-II).

The sediments of XIX c. A. D. are almost sterile of ceramic fragments in the NW parts of the valley (Fig. 2, profile line VII-VIII). Their quantity stay significant, but with irregular distribution in the lower part of the studied area (Fig. 2, profile line V-VI), continue to increase (Fig. 2, profile line III-IV) and it is obscure in the SE part of the area (Fig. 2, profile line I-II) due to the limited number of shafts.

Grain size

The fluvial sediments containing ceramic fragments are mainly sandy pebbles (Fig. 3). They are polymodal with poorly presented modes in the fractions *small cobbles* (-6φ/-7φ), *medium pebbles* (-3φ/-4φ) and *coarse sands* (1φ/0φ).

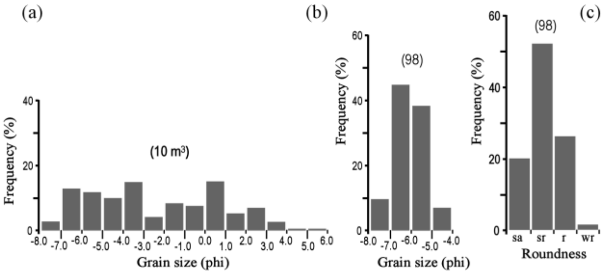

Figure 3. Diagrams of (a) grain size of the sandy gravels, (b) grain size of the ceramic fragments and (c) degree of roundness of the ceramic fragments. Abbreviations: sa – subangular; sr – subrounded; r – rounded; wr – well rounded.

The ceramic fragments have a maximal width of 154 mm and a minimal one of 29 mm. They are classified by grain size in the four coarsest fractions presented in fluvial deposits. The ceramic fragments (Fig. 3) have size of *small cobbles* to *very coarse pebbles* in roughly equal quantities. The fractions *coarse pebbles* (-4φ/-5φ) and *large cobbles* (-7φ/-8φ) are poorly represented.

The ceramic fragments in the fluvial sediments from the VIth c. A. D. are presented by four fractions, as the *small cobbles* (-6φ/-7φ) fraction is modal (Fig. 4). The dated fragments have a similar size distribution. The coarsest and finest fractions are missing among the undated fragments, while the two intermediate fractions *small cobbles* (-6φ/-7φ) and *very coarse pebbles* (-5φ/-6φ)) are presented in almost equal quantities.

The ceramic fragments in the fluvial sediments from the XIXth c. A. D. (Fig. 5) are also presented by the four fractions, but here the very coarse pebbles (-5φ/-6φ) fraction is modal. The ceramic fragments that can be dated are mostly of the *small cobbles* (-6φ/-7φ) and *very coarse pebbles* (-5φ/-6φ) fractions. The latter ones being somewhat better presented, and the *large cobbles* (-7φ/-8φ) and *coarse pebbles* (-4φ/-5φ) fractions are attested with few examples. The grain size distribution of the fragments from the XVIII-XIX c. A. D. found in these sediments is similar, with a better presented *small cobbles* (-6φ/-7φ) fraction. The redeposited older fragments from IV-VI and XII-XIV c. A. D. are generally smaller, with mainly *very coarse pebbles* (-5φ/-6φ) and without *large cobbles* (-7φ/-8φ) and *coarse pebbles* (-4φ/-5φ).

Generally, the ceramic fragments in the sediments from the XIXth c. A. D. are finer than the ones in the sediments from the VIth c. A. D. The undated fragments are finer than the datable ones. In the sediments from the IV-VI and XII-XIV c. A. D. the redeposited earlier ceramic fragments are finer than the ones from the XVIII-XIX c. A. D.

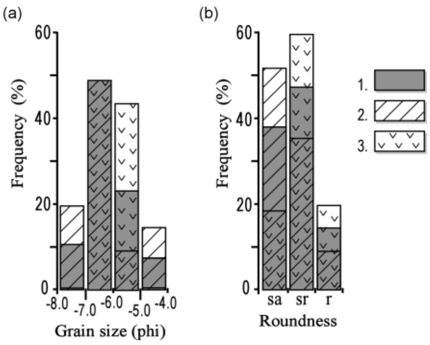

Figure 4. Diagrams of (a) grain size and (b) degree of roundness of the ceramic fragments in the fluvial sediments from the VIth c. A. D.: 1 – total fragments (34 pieces); 2 – dated fragments (19 pieces.); 3 – undated fragments (15 pieces). Abbreviations – as in Fig. 3.

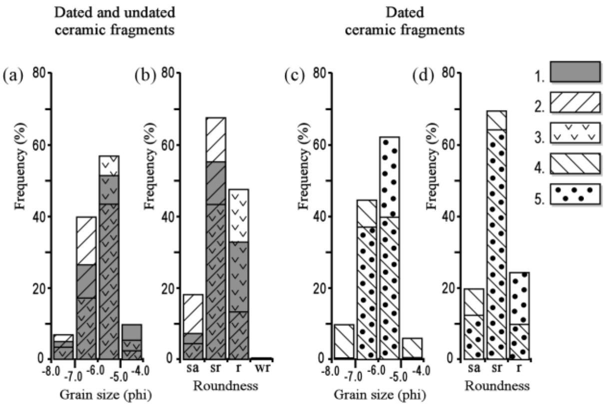

Figure 5. Diagrams of (a, c) grain size and (b,d) degree of roundness of the ceramic fragments in the fluvial sediments from the XIXth c. A. D.: 1 – total fragmentse (64 pieces); 2 – dated fragments (28 pieces); 3 - undated fragments (36 pieces); 4 - fragments from XVIII-XIX c. A. D (20 pieces); 5 – resedimented fragments from IV-VI and XII-XIV c. A. D (8 pieces.). Abbreviations – as in Fig. 3.

Roundness

Regardless to their petrographic composition and affiliation to sediments of one or another age, the fluvial clasts are mainly subrounded to rounded, rarely subangular to well rounded, while angular clasts are practically absent.

The roundness of the ceramic fragments is low. Subrounded fragments are the most abundant (Fig. 3). The subangular and rounded fragments are presented in equal proportions. Only one fragment is in the well-rounded class. The angular class is totally absent.

The roundness of the ceramic fragments is much varying when it is discussed differentiated according to their distribution in the fluvial sediments of various ages and to their datability.

The subrounded ceramic fragments dominate in the fluvial sediments from VIth c. A. D. (Fig. 4). The subangular and notably less the rounded fragments are with similar participation. The fragments that can be dated are mainly subangular, followed by subrounded and rounded. Their degree of roundness is lower than the one of the fragments that cannot be dated, which are mainly subrounded.

In the fluvial sediments from XIXth c. A. D. (Fig. 5) the general degree of roundness of the fragments is higher. Here the subrounded fragments are most numerous too, followed by the rounded class, while the subangular fragments are very few. The roundness of the datable fragments here is lower than that of the undated ones.

Generally, the ceramic fragments in the sediments from the XIXth c. A. D. are better rounded than the ones in the sediments from the VIth c. A. D. Furthermore, the undated fragments are better rounded than the datable ones in both groups.

MODEL OF AFTER GORGE FLUVIAL ACCUMULATION IN PART OF TOPOLNITZA RIVER VALLEY

It should be reminded that the Topolnitza River is in the humid zone, has a small catchment's area, does not dry out over the year, and has an unstable snow-rain regime. The studied valley segment is in the periphery of the Thracian Lowland, located after the gorge. In this area is presented the transition from a mountainous to a flatland river type.

The suggested model of accumulation is offered mainly with the ceramic fragments established in the fluvial deposits.

Discussion on the spatial distribution of the ceramic fragments

The spatial distribution of the datable ceramic fragments allows the differentiation of two erosion incisions in the floodplain completely filled with sediments (Fig. 2):

- *an older one* - the incision reaches the bedrock. The sediments include ceramic fragments of which the datable ones are only from the period IV-VI c. A. D.
- *a younger one* - the incision also reaches the bedrock. The sediments include ceramic fragments, the dated ceramic fragments are mainly from the XVIII-XIX c. A. D., but there are also some fragments from the XII-XIV and from the IV-VI c. A. D.

These two erosion incisions can be identified as the result of catastrophic floods. During every one of these the water flooded all the valley bed and destroyed the anthropogenic structures situated in it, the stream deepened and widened its channel, and almost simultaneously backfilled it. The stream is probably debris flow type i. e. with high viscosity, transporting the rock material in a floating mood. It could be nominated as a *stream of dilution* by the classification of Leeder (1986, p. 106).

The uneven distribution of the ceramic fragments in the fluvial sediments can be interpreted as an independent or combined result of: (1) "spot" sources for these fragments, of "cluster" character of their transport i. e. a near feeding up; (2). changes of the transporting capacity of the stream, influenced by the morphology to the formed channel (together with the widening of the vertical section the transporting capacity was falling down, which was driving to simultaneously precipitation of a ceramic fragments).

Two catastrophic floodings are proved and it can be suggested an intermediate one by the distribution of the dated ceramic fragments. The fluvial sediments containing ceramic fragments only of IV-VI c. A. D. indicates an older one. Such a second flooding is proved by the fluvial sediments, containing ceramic fragments of XVIII-XIX c. A. D. These sediments include fragments of XI-XIV c. A. D and even of IV-VI c. A. D.

It can be suggested that the intermediate catastrophic floods which stream load has included newly received ceramic fragments of XII-XIV c. A. D. and resedimented ones of IV-VI c. A. D. These deposits probably are entirely reworked by the catastrophic flooding in the range of XVIII-XIX c. A. D. because of the coincidence of their erosion incision.

Discussion on the grain size and the roundness of the ceramic fragments

The differences in the grain size and in the roundness of the ceramic fragments are explained reasonable with the presuming that they were stood the work of the transporting water medium to a different degree.

The periods between the catastrophic floods were at least several centuries each and are relatively quite ones. During them series of small and bigger floods caused the transport of the clastic material in the uppermost levels of the fluvial section, mainly as moving dunes (bars). That is the way that in these levels the erasing and the rounding have continued and it has began the rounding of the newly joined ones.

The dated ceramic fragments have better preserved details, they are with lower degree of roundness and they are more coarsely grained than the undated ones. This is an indication that the dated fragments have been longer in peace.

Locality of the model

The suggested model is applicable to fluvial accumulation in a valley segment incorporating the transition from a mountainous to a flatland type.

During a catastrophic flood all the valley sediments can be involved in the transport and mixed together due to the small width of the valley bottom and the high hydrodynamic energy of the stream in the gorge above the studied part of the valley of Topolnitza River.

In the inner area of the Thracian Lowland the river spreads wide during a flooding event, its destructive energy and the ability to form deep channels decrease, changing the model of accumulation.

CONCLUSIONS

The model of fluvial accumulation in the studied area of the Topolnitza River valley is based mainly on the ceramic fragments found in its fluvial sediments.

According to the duration and character of the accumulation processes, the resulting model is a catastrophic one. It covers the period between the IVth and VIth c. A. D. and it is continuing nowadays including:

- *main stages of accumulation* repeated every 5 to 8 centuries (we accept that there is entire denudation of the sediments in the result of the catastrophic flood in XII-XIV c. A. D.). Every one of them goes off with a catastrophic development simultaneous backfilling of wide and deep erosion incisions reaching the pre-quaternary bedrocks and possibly with the partial preservation of older sediments in the valley sides;
- *repeated intermediate reworking, transportation and accumulation* of the sediments only from the uppermost levels of the fluvial successions.

The model is applicable mainly for valley parts emitting into lowland located after gorges, to rivers in humid zones, with a small catchments area and unstable water regime, with rare catastrophic floods.

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PETROLOGICAL CHARACTERISTIC OF ALKALINE BASALTOIDS FROM THE REGION OF ST. SPAS BAKADJIK, YAMBOL DISRICT

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ABSTRACT
The alkaline basaltoids are spread in the northern and western slopes of St. Spas Bakadjik and near Pobeda village, Yambol district. They have the form of small sub-volcanic bodies and dikes located among the Upper Cretaceous pyroclastites of the Bakadjik formation and are also found as lithoclasts in the agglomerates in the region. The alkaline basaltoids are built by clinopyroxene and olivine phenocrysts and pseudoleucite subphenocrysts. Pseudoleucite is idiomorphic in the form of single crystals with well preserved primary morphology or in the form of groupings. It is composed of analcime (on places with zones of clinopyroxene inclusions) and K-feldspar. The main mass is composed of clinopyroxene and plagioclase microlites, olivine, pseudoleucite, K-feldspar. The accessory minerals are magnetite, titanomagnetite (in the form of complex framework-nucleation crystals) and apatite. Volcanites are undersaturated in SiO_2, olivine and nepheline, normative. They are with increased potassium alkalinity (K_2O/Na_2O - 1.01-1.47) and shoshonitic series. The index of hardening (SI - 38-42) and the index of differentiation (D.I. -18-23) are close to those of the primary weakly differentiated magma.

INTRODUCTION

The alkaline basaltoids are relatively rare rocks in nature. Their specific, in some cases, exotic mineral composition catches the attention of many researchers. In Eastern Srednogorie these rocks are distributed predominantly in Tamarino Bakadjik, where they have been subjected to specialized investigations (Stanisheva, 1968, 1969). The alkaline basaltoids in St. Spas Bakadjik are of more restricted distribution and are not so well studied. The alkaline basaltoids from the region of Pobeda village (Yambol region) are described by Stoinov (1955) as melanocratic shoshonites. Later, these rocks have been defined as analcimic basalts (Stanisheva, 1968). On the base of normative composition calculated following the system of Rittmann they have been nominated as tephrites (Popov & Antimova, 1982). The interest towards these volcanites is provoked both by their unclear classification and nomenclature position as well as by the supposition stated for the first time by Stoinov (1955) that analcime in them is at the expense of leucite. The paper presents the results of the petrologic investigations of the alkaline basaltoids from the volcanic and explosive facies as well as first the first evidence for the composition and genesis of psedoleucite in the volcanites from the region of St. Spas Bakadjik.

GEOLOGICAL SETTING

The alkaline basaltoids crop out in restricted areas to south of Pobeda village (Tepeto site) and along the northern and western slopes of St. Spas Bakadjik. They are in the form of small subvolcanic bodies and dikes located among the Upper Cretaceous pyroclastites of Bakadjik Formation. These rocks are also found in the products of the explosive facies, which is widely spread in the region. The pyroclastites in the region of Bakadjiks have been related to different lithostartigraphic units. According to Petrova and Simeonov (1989) they belong to the Bourgas Group while the volcanites - to the Michurin Group. Popova and Antimova (1982) relate the rocks from Bakadjiks to the Novopanicharevo Formation. Later, the same rocks have been related to the Bakadjik (Popov et al., 1993) and Draganovo (Savov and Filipov, 1995) Formations.

PETROGRAPHIC CHARACTERISTIC

The alkaline basaltoids of the volcanic facies are black with porphyric texture and massive structure. They are built by pyroxene, olivine, pseudoleucite, plagioclase, K-feldspar, analcime, magnetite, titanomagnetite, and apatite. The phenocrysts (50-55%) are of pyroxene and olivine. Clinopyroxene (30-35%) is light green, fresh, short-prismatic or isometric (2-5 mm), and with a clear zonal structure. Contains inclusions of olivine and magnetite and on places is magmatically corroded as a result of interaction with melt enriched in potassium. In these case the peripheral part of olivine are densely contoured by pseudoleucite crystals (Fig. 1a). Olivine (15-20%) is relatively fresh (in many cases with regular crystal forms) and with peripheral serpentinization locally penetrating the central parts of the crystal along fissures. The subporphyric generation is represented by pseudoleucite, clinopyroxene, and olivine. The pseudoleucite aggregates (0.08 to 0.12 mm) are composed of analcime with a peripheral stripe of K-feldspar (Fig. 1b) and form pseudomorphoses after leucite with not preserved relics. The aggregates comprise 15% of the rock volume and are irregularly distributed. The pseudoleucite subphenocrysts are in the form of single crystals or are groupings of several individuals. They are with a well preserved primary morphology - isometric, rounded, and on places with zonings of clinopyroxene inclusions (Fig. 1c). The groundmass is fully crystalline and is composed of disordered crossing relatively large plagioclase microlites. They are without clear contours and are partially altered to K-feldspar. The interstitial space is occupied by a great quantity of prismatic clinopyroxene microlites with square sections, rare olivine grains, K-feldspar,

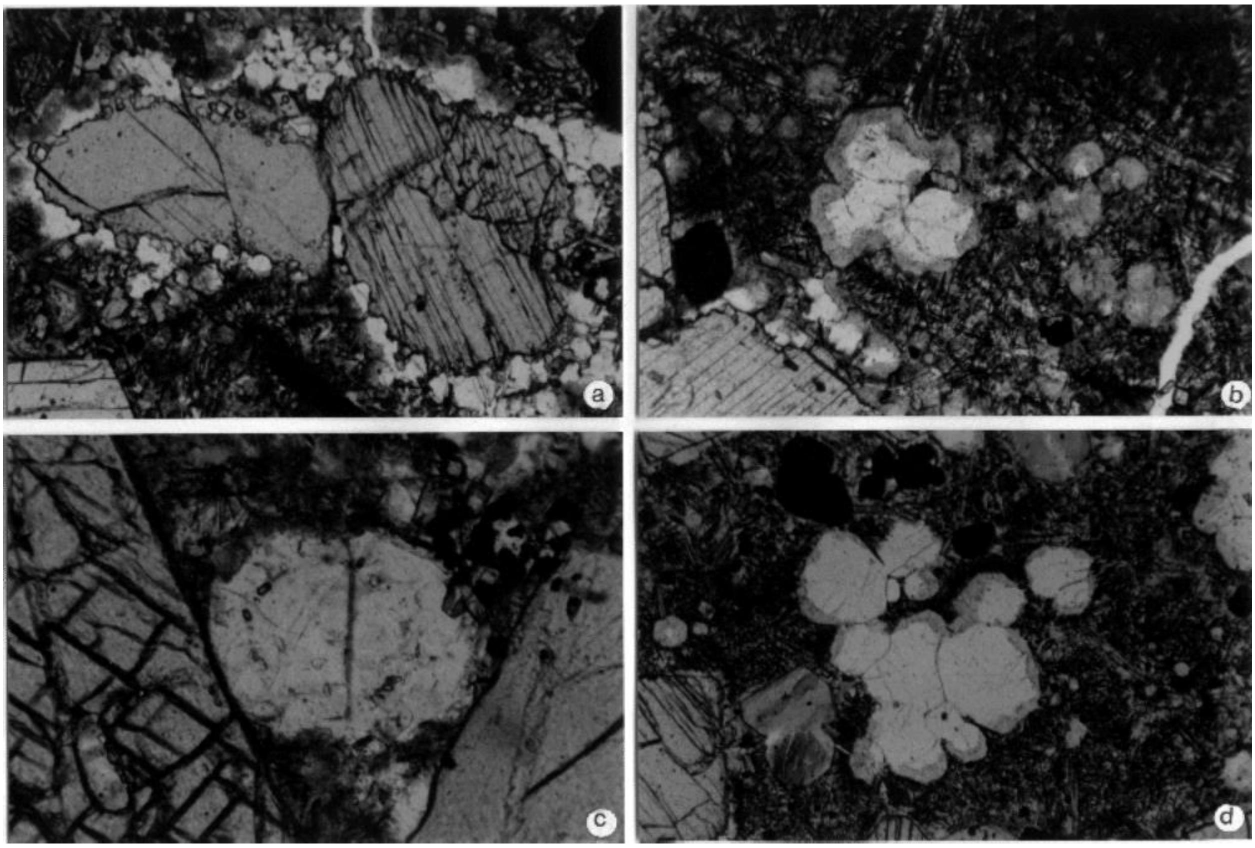

Figure 1. Microphotographs of pseudoleucite aggregates from alkaline basaltoids from the St. Spas Bakadjik: a - magmatically corode diopside with pseudoleucite crystals are disposed on the periphery; b - pseudoleucite aggregates of analcime with a peripheral stripe of K-feldspar (in the center) or entirely replaced by K-feldspar (to the right); c – psedoleucite subphenocryst with zonal inclusions of clinopyroxene; d - pseudoleucite aggergates of analcime with a peripheral stripe of K-feldspar. Figures a÷d II N. Base of figures a, b and d – 1.46 mm, figure c – 0.55 mm

and small biotite scales. Except as subphenocrysts pseudoleucite participates in the composition of the groundmass as well. It has irregular distribution and is most often in the form of irregular aggregates of isometric, rounded crystals with prevailing size of 0.03 to 0.07 mm. On places, between the separate individuals there are localized small biotite scales, which emphasize more clearly the morphology of the crystals. Opposite to the subphenocrysts the pseudoleucite aggregates of the groundmass are most often composed only of analcime or K-feldspar. In rare cases analcime is contoured by a peripheral stripe of K-feldspar. In the regions of greater concentration of pseudoleucite crystals the texture is ocellar. The accessory minerals are represented by magnetite, skeletal-nucleus crystals of titanomagnetite and markedly elongated needle-like apatite. The amygdales are relatively rare and are filled with zeolites.

The alkaline basaltoids from the explosive facies of the northern and western slopes of St. Spas Bakadjik are of analogous composition. They are black, fine porphyric, and with a massive structure. Built are by clinopyroxene and olivine phenocrysts and subphenocrysts, pseudoleucite, plagioclase, analcime, K-feldspar, magnetite, and titanomagnetite. The phenocrysts are about 35-40% of the rock volume. Clinopyroxenes are the prevailing ones (25-30%). They are fresh and with a zonal structure type sand watch with inclusions of serpentinized olivine and magnetite. In some cases corrosion bays are observed in the peripheral parts of pyroxenes being probably a result of interaction with the melt. Olivine (8-10%) is sized 0.7-0.8 mm and is replaced along the periphery and the fissures by serpentine. On places it is fully altered in serpentine. Pseudoleucite (0.08-0.30 mm) is predominantly subphenocrysts and clearly idiomorphic with fully preserved primary morphology in the form of single isometric rounded crystals or groups of several individuals (Fig. 1d). It is replaced by analcime having a reaction stripe of K-feldspar. The groundmass is composed of thin-prismatic to needle-like clinopyroxene and poorly shaped plagioclase microlites, crystallites, and a great quantity of skeletal-nucleus crystals of titanomagnetite forming a dense network. The crystallization row of the minerals from the porphyric and subporphyric generation of both facieses (determined by crystal morpholgy and mineral relations) is: magnetite - olivine - clinopyroxene - pseudoleucite. The row of crystallization in the groundmass is first olivine then clinopyroxene, pseudoleucite, apatite, titanimagnetite, and finally plagioclase.

The mineral composition of the pseudoleucite alkaline basaltoids of volcanic and explosive facies is close but displays some differences. Most of all they can be related to quantitative relations (gerater quantity of olivine and pseudoleucite in the volcanites, with psedoleucite being mainly in the groundmass while in the lithoclast it is mainly in the form of subphenocrysts) of the rock forming minerals and to textural features (degree of crystallinity) of the rock. Probably, the textural differences between the alkaline basaltoids of the two facieces are due to different crystallization conditions. It can be proposed that the coarse porphyric and with fully crystalline groundmass volcanites near Pobeda village had been formed in subvolcanic conditions while the alkaline basaltoids of the explosive facies - in conditions characterized by much more intense crystallization.

MINERAL CHEMISTRY

The clinopyroxenes are magnesium rich **(**Mg# – 74.3-81.6) with the value of Mg# being higher in the lithoclasts. According to the classification of Morimoto (1988) the clinopyroxene of the volcanic facies is diopside and from the explosive one – mainly augites and diopsides. The clinopyroxenes are zonal. The composition of their central parts if $Wo_{43-50}En_{38-45}$ and of the peripheral zones is $Wo_{46-50}En_{36-42}$. In a chemical aspect there is observed an increase in Fe content and a decrease of Mg content from core to rim of the crystals (Table 1). The alkaline oxides mark a weak increase towards the periphery.

The olivines are magnesium rich ($Fo_{76-83}Fa_{17-24}$) and the content of the forsterite molecule in the olivines of the volcanite is higher than that in the lithoclasts. From the central to peripheral parts of the crystals the content of Si and Fe increases while that of Mg decreases (Table 1).

The pseudoleucite aggregates are built by analcime and K-feldspar. Analcime is with a constant composition with only insignificant variations and without major differences between the volcanites and lithoclasts including analcime in the peripheral parts of the magmatically corroded clinopyroxene (Table 2, sample 376/19). The most characteristic feature of the chemistry of K-feldspar from the alkaline basaltoids of the facieses is the high content of Or molecule ($Or_{76-97}Ab_{1-19}$). A relationship was found in the change of K_2O content in the K-feldspars of the subphenocryst pseudoleucite and in the small crystals of the groundmass. The content of Or molecule in K-feldspar ($Or_{76-83}Ab_{14-19}$) from the reaction cover of analcime is lower compared to the pseudoleucite crystals of the groundmass ($Or_{96-97}Ab_{1-2}$) (Table 3). The composition of the **plagioclase** microlites is ($An_{27-33}Or_{10-14}Cn_{1-1.4}$).

Table 1. Representative microprobe analyses of the clinopyroxenes and olivines from the alkaline basaltoids from the St. Spas Bakadjik region: c – core; r - rim

Mineral	clinopyroxenes						olivines			
Sample	376/1c	376/2r	376/14c	376/15r	361/1c	361/2r	376/12c	376/A r	361/7c	361/8r
SiO_2	52.25	50.98	52,58	52,67	52.17	50.41	40.11	41.04	38.66	40.42
TiO_2	0.44	0.51	0,34	0,24	0.55	0.50	0.11	0.12	0.00	0.00
Al_2O_3	3.01	4.19	2,07	1,99	3.13	4.34	0.69	0.57	0.00	0.37
$FeO^{(t)}$	6.73	7.29	6,95	7,67	6.46	6.85	15.49	16.17	19.59	20.85
MnO	0.04	0.20	0,18	0,20	0.09	0.12	0.72	0.63	0.37	0.42
MgO	14.45	13.64	13,11	12,45	16.04	14.61	42.72	41.59	40.52	36.83
CaO	23.29	22.46	24,20	24,24	21.48	22.40	0.22	0.15	0.35	0.60
Na_2O	0.02	0.05	0,00	0,00	0.16	0.44	0.00	0.00	0.00	0.00
K_2O	0.18	0.30	0,00	0,00	0.15	0.11	0.05	0.05	0.00	0.03
Total	100.41	99.62	99,43	99,46	100.23	99.78	100.11	100.32	99.49	99.52
Wo	47.84	47.50	50.41	50.81	43.92	46.50				
En	41.30	40.13	38.00	36.31	45.63	42.20				
Fs	10.86	12.37	11.59	12.88	10.45	11.30				
Mg#	79.3	76.9	77.1	74.3	81.6	79.2				
Fo							83.1	82.1	78.7	75.9
Fa							16.9	17.9	21.3	24.1

Analyses 376/1-13 и 361/1-5 (table 1-3) were carried out on JEOL Superprobe 733 by K. Rekalov
Analyses 376/14-19 и 361/6-12 (table 1-3) were carried out on JEOL JSM 35 CF Tracor Northern TN – 2000 by H. Stanchev

Table 2. Representative microprobe analyses of analcimes of the pseudoleucite aggregates from alkaline basaltoids from the St. Spas Bakadjik region: s – analcime subphenocrysts; g – analcime from groundmass

Mineral	analcimes										
Sample	376/6s	376/5s	376/19	376/4g	376/8g	376/7g	376/13g	376/17s	361/10s	361/5s	361/11s
SiO_2	53.26	54.19	54.44	54.82	55.15	55.67	55.76	55.78	53.36	54.08	55.41
TiO_2	0.23	0.04	0.00	0.06	0.13	0.02	0.00	0.00	0.10	0.00	0.06
Al_2O_3	23.61	22.19	21.66	22.46	22.30	22.89	24.05	23.09	22.64	22.23	21.63
$FeO^{(t)}$	0.62	054	0.63	0.48	0.34	0.52	0.33	0.71	0.52	0.51	0.48
MnO	0.00	0.05	0.00	0.04	0.12	0.00	0.02	0.00	0.03	0.00	0.02
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	0.59	0.48	0.46	0.43	0.14	0.20	0.57	0.24	0.44	0.41	0.42
Na_2O	11.64	11.53	12.93	11.81	12.31	12.16	9.50	12.19	11.27	12.09	10.75
K_2O	0.07	0.00	0.00	0.06	0.09	0.06	0.07	0.00	0.42	0.30	0.44
H_2O*	9.98	10.98	9.88	9.84	9.42	8.48	9.70	7.99	11.22	10.38	10.79
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

*H_2O is calculated by difference to 100%

Table 3. Representative microprobe analyses of K-feldspars (from pseudoleucite aggregates), plagioclases, titanomagnetites: r – peripheral cover around analcime; g – groundmass; m – microlites

Mineral	K-feldspars						plagioclases		titanomagnetites	
Sample	376/11r	376/3g	376/10g	376/18r	361r	361/6r	376/16m	376/9m	361/9	361/12
SiO_2	61,74	63.18	63.24	64.88	63.64	65.48	58.12	59.41	0.28	0,17
TiO_2	0.14	0.01	0.04	0.00	0.09	0.13	0.00	0.00	4.27	3,89
Al_2O_3	21.32	19.05	19.35	16.68	20.33	15.48	23.94	24.46	1,02	0,86
$FeO^{(t)}$	0.89	0.29	0.17	0.23	1.06	0.90	0.42	0.39	92.07	93,10
MnO	0.09	0.00	0.00	0.13	0.00	0.00	0.02	0.04	1.63	1,57
MgO	0.53	0.00	0.00	0.00	0.69	0.00	0.00	0.00	0.24	0,26
CaO	0,77	0.26	0.33	0.58	0.63	0.40	7.62	5.43	0.37	0,20
Na_2O	1.92	0.16	0.24	1.71	1.93	2.50	6.83	6.37	0.00	0,00
K_2O	12.42	16.36	16.42	15.54	11.25	15.17	2.03	2.39	0.00	0,00
BaO	0.06	0.00	0.00	0.00	0.00	0.00	0.70	0.74	0.00	0,00
Total	99.88	99.31	99.79	99.75	99.62	100.06	99.68	99.23	99,88	100,05
Or	77.6	97.3	96.2	83.4	76.5	78.6	10.6	14.2		
Ab	18.2	1.4	2.2	14.0	19.9	19.7	54.6	57.4		
An	4.1	1.3	1.6	2.6	3.6	1.7	33.7	27.0		
Cn	0.00	0.00	0.00	0.00	0.00	0.00	1.1	1.4		

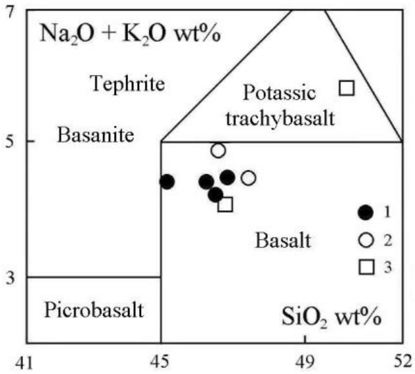

Figure 2. Total alkali vs. silica classification diagram (after Le Maitre et al., 1989) with the point of alkaline basaltoids from the St. Spas Bakadjik: 1 – Volcanic facies; 2 – Explosive facies; 3 - (shoshonite after Stoinov, 1955)

PETROCHEMICAL FEATURES

On the total alkali-silica classification diagram the studied volcanites fall in the field of the basalts and some being on the border with basanites. Only the described by Stoinov (1955) shoshonites from the Bimbal bair locality are in the field of the potassium trachybasalts (Fig. 2). According to the degree of SiO_2 saturation the basalts from field B on the TAS diagram can be subdivided into alkaline and subalkaline (Le Maitre et al., 1989). The content of normative nepheline give reason to relate the studied rocks to the alkaline basalts (Table 4). On the normative tetrahedron of Yoder and Tilley (1965) these volcanites dispose to the left of the critical plane of undersaturation of SiO_2 in the field of the alkaline basalts. In correspondence to the leading principle of IUGS for classification of the magmatic rocks, which is based on the modal composition (for any case when it can be determined) the described volcanites around Pobeda village, Yambol region have to be nominated as pseudoleucite basanites (containing modal clinopyroxene, olivine (>10%), plagioclase, and pseudoleucite), while the alkaline basaltoids of the explosive facies in the northern slopes of St. Spas Bakadjic – as pseudoleucite tephrites (with modal clinopyroxene, olivine (5-8%), plagioclase, and pseudoleucite).

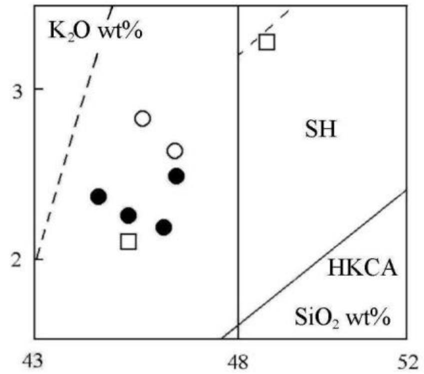

Figure 3. SiO_2 vs. K_2O (Peccerillo and Taylor, 1976) diagram with the point of alkaline basaltoids from the St. Spas Bakadjik Series: HKCA – high K calc-alkaline, SH – shoshonitic. Symbols as in Fig. 1.

The alkaline basaltoids are low-silica and high magnesium containing. They are undersaturated in SiO_2 with normative olivine and nepheline and with shoshonitic series (Fig. 3). With dominating shoshonitic series are also the other volcanic products of St. Spas paleovolcano (Banushev, 2001). K_2O dominates above Na_2O. The ratio K_2O/Na_2O is between 1.01 and 1.47 and is higher for the lithoclasts while the peralkaline index (P.I.) is from 0.56 to 0.63 (Table 4). The index of hardening (SI – 38-42) and the index of differentiation (D.I. – 18-23) are close to that of the primary weakly differentiated magmas.

The main petrogenic oxides of the volcanites and the chemical composition of the clinopyroxenes are used for discrimination of the tectonic environments. Using the diagram $MgO-Al_2O_3-FeO^*$ (Pearce et al., 1977) one can see that the alkaline basaltoids of St. Spas Bakadjik display the character of within-plate ocean-island basalts (Fig. 4). This conclusion is confirmed also by the chemical composition of the clinopyroxenes (Fig. 5).

DISCUSSION

There is no doubt that one of the most interesting features of the alkaline basaltoids in the region of St. Spas Bakadjik is the established therein pseudoleucite aggregates (composed of analcime and K-feldspar), which form pseudomorphoses after leucite. The genesis of pseudoleucite is related to various processes. Many of researchers consider it being firstly crystallized as leucite, which, as a result of reaction with the enriched in Na residual magma transforms into nepheline-feldspar pseudomorphoses, the so-called pseudoleucite reaction (Bowen and Ellestad, 1937). Later, Fudali (1963) has proved that the sodium leucites can undergo a subsolidus breakdown resulting in the formation of twins of nepheline with K-feldspar. There are cases described for which it is considered that the primary pseudoleucite phase is analcime rich in K (Larsen, Buie, 1983).

Table 4. Chemical composition of alkaline basaltoids from St. Spas Bakadjik region

	Volcanic facies				Explosive facies	
	376/3	376/1	376/2	376	361/1	361
SiO_2	44.56	45.58	46.13	46.55	45.88	46.30
TiO_2	0.71	0.56	0.58	0.62	0.63	0.65
Al_2O_3	10.55	10.23	10.26	9.97	10.14	10.57
Fe_2O_3	8.83	8.92	7.90	9.36	8.18	7.44
FeO	4.17	3.78	4.62	4.10	3.87	4.75
MnO	0.18	0.14	0.13	0.19	0.19	0.18
MgO	12.54	12.41	11.95	11.15	11.87	11.03
CaO	12.42	11.89	12.60	12.31	12.16	12.09
Na_2O	2.09	2.17	2.16	1.89	2.02	1.82
K_2O	2.23	2.27	2.18	2.52	2.84	2.69
P_2O_5	0.42	0.44	0.41	0.43	0.53	0.47
LOI	1.06	1.58	1.21	1.15	1.56	2.21
Total	99,76	99.97	100.13	100.24	99.87	100.20
K/Na	1.11	1.04	1.01	1.33	1.40	1.47
P.I.	0.57	0.59	0.58	0.59	0.63	0.56
$K_Φ$	50.9	50.5	51.1	54.0	50.3	52.4
CIPW						
Or	13.36	13.65	13.04	15.04	17.09	16.24
Ab	4.48	8.59	7.97	10.35	5.68	8.52
An	12.95	11.63	11.96	11.35	10.35	12.96
Ne	7.27	5.45	5.68	3.13	6.33	3.89
Di	36.53	35.54	38.12	37.11	37.20	35.74
Hy	0.00	0.00	0.00	0.00	0.00	0.00
Ol	10.40	10.56	9.64	7.66	9.07	9.40
Mt	12.15	11.19	11.58	12.14	11.46	11.01
Hm	0.56	1.35	0.00	1.07	0.42	0.00
Il	1.37	1.08	1.11	1.19	1.22	1.26
Ap	0.93	0.98	0.90	0.95	1.18	0.98

K/Na = K_2O/Na_2O; P.I. = $(Na_2O + K_2O)/Al_2O_3$ (mol);
$K_Φ$ = 100. $(Fe_2O_3 + FeO)/(Fe_2O_3 + FeO + MgO)$

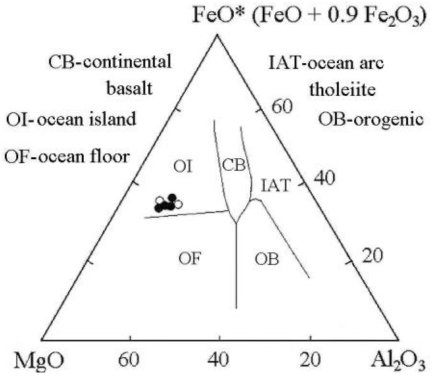

Figure 4. MgO-Al_2O_3-FeO discrimination diagrams (after Pearce et al.,1977) with the point of alkaline basaltoids from the St. Spas Bakadjik

Known are also pseudomorphose of analcime into leucite. According Barrer and Hinds (1953); and Deer et al. (1992) analcime and leucite transform into each other through irreversible ion-exchange: $NaAlSi_2O_6.H_2O + K_{aq}^+ \leftrightarrow KAlSi_2O_6 + Na_{aq}^+ + H_2O$. The experiments show that the solid solution of leucite undergoes exchange reaction with the sodium glass or with the enriched in Na water vapor. It can be transformed into sodium variety by ion exchange in the subsolidus zone and subsequent cooling causes differentiation of the solid solution (Taylor and MacKenzie, 1975) The processes of transformation of leucite into pseudoleucite are accompanied by destruction of the mineral structure by with preservation of the crystal morphology. The described reactions have to be looked upon as a result of adopting of the mineral to the changing conditions. In this aspect pseudoleucite corresponds to association, which is stable in the new P, T conditions.

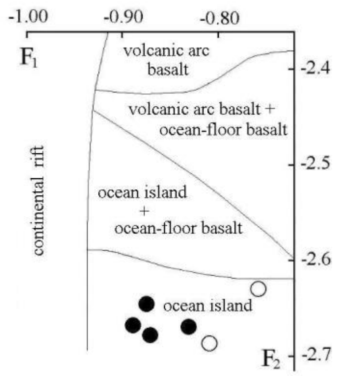

Figure 5. F_1-F_2 discrimination diagram of the composition of the clinopyroxene phenocrysts (after Nisbett and Pearce, 1977)

The first published data in the Bulgarian literature about pseudiomorphoses of analcime after leucite in the melanocratic shoshonites in the region of Pobeda village, Yambol district has been given by Stoinov (1955). Later, Yanev (1994) has reported about metaleucite replaced by analcime in absarokites in Eastern Rhodopes. According to Stanisheva (1969) the mineralogical and structural changes of leucite from Tamarino Bakadjik had taken place in two stages. During the first one pseudoleucite formed being a fine mixture of K-feldspar and nepheline, which replaces entirely the leucite crystal preserving its morphology. The second stage is connected with a change of pseudoleucite and the formation of epileucite.

The pseudoleucite aggregates in the alkaline basaltoids from the region of St. Spas Bakadjik are represented as subphenocrysts as well as small crystals in the groundmass. The microprobe analyses show that the smaller crystals are built entirely by analcime or K-feldspar while the bigger subphenocrysts – by analcime with a peripheral stripe of K-feldspar. The morphology of the crystals and the zonal arrangement of clinopyroxene inclusions give reason to suppose that the pseudoleucite aggregates have firstly crystallized as leucite and then as a result of ion exchange in the subsolidus zone have transformed into analcime and K-feldspar. The released potassium enters the composition of the newly formed K-feldspar, which localizes in the peripheral parts of the analcime crystals and in the interstitial space. During this process a part of the small analcime crystals is partially or entirely replaced by K-feldspar while the subphenocrysts are preserved with a stripe of K-feldspar stripe around them of varying thickness. The K-feldspars (especially those in the groundmass) are characterized by a high content of Or molecule ($Or_{96-97}Ab_{1-2}$) corresponding to K-sanidine. Such high values of K_2O are typical for some sanidines of the alkaline volcanites (Deer et al., 1963). Data exists showing that during a rapid crystallization the K-feldspars in volcanites display a tendency of enrichment in K_2O (Edgar, 1976). Similar petrochemical features of the rocks (increased alkalinity) and rapid crystallization are found also for the studied volcanites. However, it can not be excluded that part of K-feldspar in the interstitial space with a very high content of Or molecule could be a result of a later hydrothermal activity.

CONCLUSION

The alkaline basaltoids (pseudoleucite tephrites and psedoleucite basanites) are a product of a mantle, weakly differentiated, olivine-basalt magma with increased K-alkalinity. Crystallization of leucite had taken place in conditions of low pressure and from SiO_2 undersaturated melt. It can be proposed that as a result of ion exchange leucite had transformed into K-feldspar pseudoleucite aggregates. The alkaline basaltoids of St. Spas Bakadjik are comparable with the products of the widely developed in the region Tamarino Bakadjik olivine-basaltic volcanism with which they display a definite petrochemical similarity.

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EARLY CRETACEOUS DEVELOPMENT OF THE MOUNTAUN CRIMEA

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ABCTRACT

Recent studies of the Crimea give us new data for the interpretation of Early Cretaceous history of the region, which differs from the previous data. Shortly, it could be established as following. (1) The compression and later extension in the latest Berriasian – E. Valanginian resulted in the formation of complex graben system. The Plain Crimea was an uplift; the basin deepen to the S and the Mountain Crimea was mostly submerged. (2) L. Valanginian – E. Hauterivian phase was marked by the northward tropical sea transgression and formation of complex facial system in slow extensional conditions. (3) During the L. Hauterivian – Aptian the whole area quickly subsided. The Mountain Crimea was overlapped by uniform pelagic facies. The sea covered Plain Crimea almost completely and Boreal water mass reached this area in the Late Hauterivian. (4) The new uplift and folding event of the Mountain Crimea took place in the E. – M. Albian. In contrast, back-arc rift system was formed in the Plain Crimea, where volcanic sediments appeared. (5) During the latest M. Albian – L. Albian rifting event and a series of transgressions lead to the submersion of the Mountain Crimea and possibly to the Black Sea opening.

INTRODUCTION

Lower Cretaceous deposits of the Mountain Crimea is a complex object for investigation because of the facial variability and polyphase tectonic activity. So, there is no uniform view on the structure and geological history of the region even if its investigations have been started a long time ago.

The most complete "classic" summary on the Lower Cretaceous of the Mountain Crimea was published in several monographs: by N.I.Karakasch (1907), V.V.Drushchits et al. (Drushchits, Kudryavtsev, 1960) and M.V.Muratov et al. (1969). Since that time new discoveries in geology and stratigraphy of the Lower Cretaceous of the Mountain Crimea (Arkadiev et al., 1997, 2000; Baraboshkin, 1997a-b, 2001; Baraboshkin, Mikhailova, 1994, 2000; Baraboshkin, Yanin, 1997; Bogdanova et al., 1981; Yanin, Vishnevsky, 1989; etc.) were made. Additionally, many geological objects not aloud for investigations during Soviet time start to be available for the visits. These facts together with new sedimentological and tectonical concepts make possible to revise geological history of the region.

STRATIGRAPHY

Lower Cretaceous deposits are exposed along the First and (mainly) Second Range of the Crimea Mountains (fig.1). Their completeness and composition are very different in different parts of the region. Because of it several sections were proposed as reference sections for the whole Lower Cretaceous succession.

Study of these and other sections made possible to work out a detailed biostratigraphic scheme for the Mountain Crimea (table).

Lower Berriasian is well exposed and paleontologically characterized by fauna in pelagic limestone-marly facies of Theodosia section (fig.1: loc.4). It was described by O.Retowski (1893) and restudied in numerous publications (Bogdanova et al., 1981; Kvantaliani, 1989, etc.).

Upper Berriasian is well-documented in a shallow-water carbonate to terrigenous facies of Balki – Pasechnoe Village sections (fig.1: loc.3), near Belogorsk City. It was described details by T.N.Bogdanova et al. (Bogdanova, Kvantaliani, 1983; Bogdanova et al., 1981; Kvantaliani, 1989, etc.).

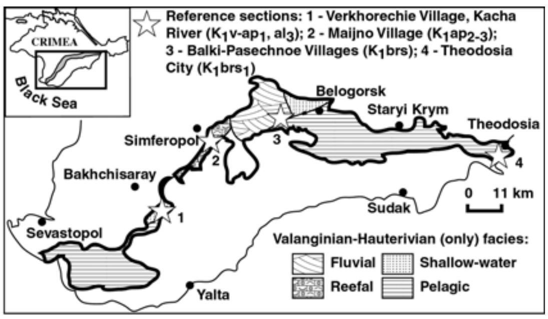

Figure 1. Distribution of the Lower Cretaceous in the Mountain Crimea (thick line), reference sections and main types of facies for the Valanginian – Hauterivian time

The best Valanginian - Lower Aptian shallow- to deep water terrigenous succession is located in Kacha River basin, near Verkhoirechie Village (fig.1: loc.1). After the work of N.I.Karakash (1907) this section was described for many times (Drushchits, Kudryavtsev, 1960; Yanin, Vishnevsky, 1989, etc.). The latest revision of the section was published recently by the author (Baraboshkin, 1997a-b, 2001).

Middle-Upper Aptian pelagic clays are badly exposed with the exception of Simpheropol City region, where they were studied in the Marjino Village quarry (fig.1: loc.2) by V.V.Drushchits et al. (1981).

The existence of the uppermost Aptian - Lower Albian deposits in the Mountain Crimea is very probable. Normally this interval is missing due to the folding event. Uppermost Middle Albian sections are known in Balaklava City (near Sevastopol) region, but they need further examination.

STAGE	SUBST.	"STANDARD" ZONATION OF WESTERN MEDITERRANEAN (HOEDEMAEKER, RAWSON, 2000)		MOUNTAIN CRIMEA (BARABOSHKIN, 2001)	
		ZONE, SUBZONE		ZONE, SUBZONE, BEDS WITH FAUNA	
ALBIAN	UPPER	Stoliczkaia dispar	Stoliczkaia dispar	Mortoniceras perinflatum	
			Stoliczkaia blancheti	Mortoniceras rostratum	
		Mortoniceras inflatum		Mortoniceras inflatum	
				Hysteroceras varicosum	
				Hysteroceras orbignyi	
			Dipoloceras cristatum		
	MIDDLE	Euhoplites lautus		Anahoplites daviesi	
		Euhoplites loricatus			
		Hoplites dentatus	Hoplites spathi	MISSING	
			Lyelliceras lyelli		
		Douvilleiceras mammillatum			
		Leymeriella tardefurcata		? Leymeriella tardefurcata	
APTIAN	UPPER	Hypacanthoplites jacobi		MISSING	
		Nolaniceras nolani			
			Diadach. nodosocostatum	? Nolaniceras nolani	
	MIDDLE	Parahoplites melchioris		?	?
					Acanthohoplites aschiltaensis
					Parahoplites multicostatus
		Epicheloniceras subnodosocostatum		Aconeceras nisum	Colombiceras crassicostatum
	LOWER	Dufrenoya furcata		Aconeceras nisoides	?
		Deshayesites deshayesi			Deshayesites deshayesi
		Deshayesites weissi			?
		Deshayesites tuarkyricus			
BARREMIAN	UPPER	Pseudocrioceras		Patruliusiceras uhligi	
		Colchidites sarasini			
		Imerites giraudi			
		Hemihoplites feraudianus			
		Gerardthia sartousiana	Gerardthia provincialis	Gerardthia provincialis	
			Gerardthia sartousiana		
		Ancyloceras vandenheckii			
	LOWER	Montoniceras moutonianum		Holcodiscus caillaudianus	
		Kotetishvilia compressissima			
		Kotetishvilia nicklesi		Niklesia pulchella	
		Avramidiscus hugii		Taveraediscus hugii	
HAUTERIVIAN	UPPER	Pseudothurmannia angulicostata auctorum	Pseudothurmannia catulloi	Pseudothurmannia catulloi	
			P. angulicostata auct.	Pseudothurmannia ohmi	
		Balearites balearis		Milanowskia speetonensis	
		Plesiospitidiscus ligatus		Speetoniceras inversum	
		Saynella sayni		Crioceratites duvali	
	LOWER	Lyticoceras nodosoplicatum		Lyticoceras nodosoplicatum	
		Crioceratites loryi	Olcostephanus jeannoti	? Crioceratites loryi	
			Crioceratites loryi		
		Acanthodiscus radiatus		Leopoldia desmoceroides	
VALANGINIAN	UPPER	Teschenites callidiscus		Eleniceras tauricum	
				Teschenites callidiscus	
		Himantoceras trinodosum	Criosarasinella furcillata	Himantoceras trinodosum	
			Olcostephanus nicklesi		
		Saynoceras verrucosum	Vahrleideites peregrinus	Neohoploceras submartini	? Vahrleideites peregrinus
			Karakasch. pronecostatum		?
			Saynoceras verrucosum		
	LOW.	Busnardoites campylotoxus		Campylotoxia campylotoxa	
		Thurmanniceras pertransiens		Thurmanniceras pertransiens	
		Thurmanniceras otopeta		Kilianella otopeta	
BERRIASSIAN	UPPER	Fauriella boissieri	Tirnovella alpillensis	Megadiceras koinautense Beds	
				Weberithyris moisseevi Beds	Zeillerina baksanensis Beds
					Symphythyris arguinensis Beds
			Berriasella picteti		Tauricoceras crassicostatum
			Malbosiceras paramimounum	Euthymiceras euthymi	
	LOWER	Tirnovella occitanica	Dalmasiceras dalmasi	Dalmasiceras tauricum	
			Berriasella privasensis	Tirnovella occitanica	
			Tirnovella subalpina		
		Berriasella jacobi		Pseudosubplanites ponticus	

At last, the Upper Albian ingressive and shallow-marine facies were described by B.T.Yanin (1976), R.Marcinowski and D.P.Naidin (1976) in Prokhladnoe Village region, not far from the Kacha River section (fig.1: loc.1).

Distribution of different fossils (ammonites, belemnites, bivalves, brachiopods, forams, etc.) was studied for the mentioned sections, but only two biostratigraphic scales covering the whole Lower Cretaceous interval were developed for the region. They are based mainly on ammonites (Baraboshkin, 2001: see the table) and foraminifers (Gorbachik, 1986).

Ammonite scale is quite detail, but it combines ammonites of different ecological position: mostly neritic nectobenthic, but also shallow to deep-water pelagic hemiplanktonic (according to classification of Westermann, 1996). Moreover, most of them are Tethyan, but some endemics and even Boreal (lower Upper Hauterivian). In case of uppermost Berriasian ammonite indexes were not found. It is the reason of using rudists and brachiopods for biostratigraphy as index fossils for carbonate platform facies of this interval. Such kind of biostratigraphic set reflects complex geological history of this part of the world with episodes of uplifts, deepening, isolation and Boreal water mass influence.

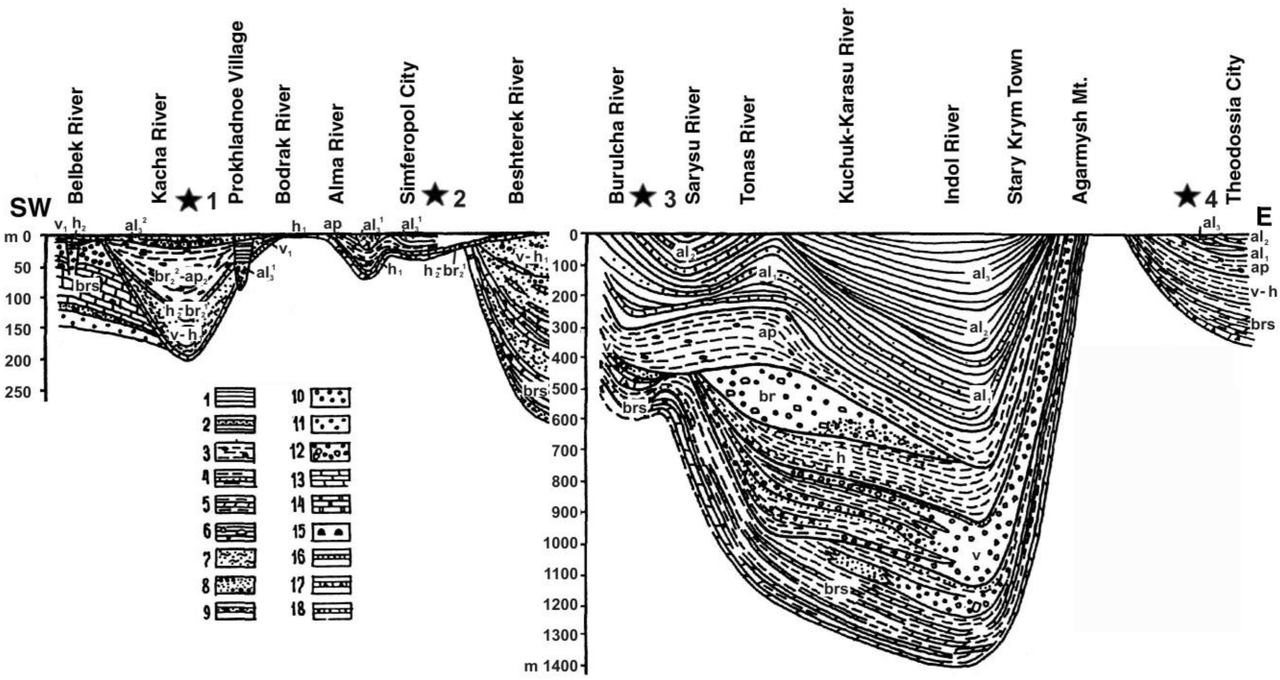

Figure 2. The Lower Cretaceous of the Mountain Crimea (after Nikishin et al., 1993, modified). Stars mark the position of reference sections (1 to 4), figured on fig.1. 1 - black clays (al); 2 - alternation of clays and sandstones; 3 - clays with ankerites (ap); 4 - clays with sandstone beds (brs, v, h); 5 - alternation of clays and marls (br_1); 6 - clays with boulders (al_2^1); 7 - siltstones and sandstones (brs-h_1); 8 - alternation of soft and hard sandstones; 9 - sandstones (v-h); 10 - quartz conglomerates (brs_2); 11 - polymict conglomerates (brs_1); 12 - conglomerates (brs-h); 13, 14 - biogenic limestones (brs_{1-2}); 15 - coral - algal bioherms (brs, h_1); 16 - cephalopod limestones (h_2-br_2); 17 - breccied limestones (brs_1); 18 - "pudding" conglomerates and sandstones (v)

Major paleogeographic features

Lower Cretaceous basin of the Mountain Crimea consists of two major "bathes", opened to the south: western, shallow-water with lower thickness of deposits, and eastern – deeper-water with thick succession (fig.2). The deposition in both regions was controlled by (1) climatic changes, (2) local block movements and (3) major tectonic events in the Peri-Tethyan area. Climatic control is reflected in the style of sedimentation: carbonate in the Berriasian and mainly terrigenous in Valanginian – Albian. Block movements affected depth and rate of sedimentation.

Depth changes were determined recently (Enson, Baraboshkin, 2002) by the calculation of siphonal and septal strength indexes of ammonites (fig.3) using the technique of R.A.Hewitt and G.E.G.Westermann (1990) with facial, ichnofossil and paleoecological control.

The Early Berriasian in the Crimea – Caucasus region was characterised by separation of the Boreal Basin and the Tethys. The arid climate led to carbonate sedimentation in the Crimea – North Caucasus - Kopet-Dagh area and formation of an evaporate belt to the north (Baraboshkin, 2001). In the Mountain Crimea Berriasian deposits together with Upper Jurassic carbonates participate in the structure of carbonate platform of the First Range. Deeper-water clayey – carbonate facies of destroyed platform margin fill the eastern Crimea basin.

The Early/Late Berriasian transition is marked by a interruption of carbonate sedimentation and deposition of the clastic facies almost everywhere in the Mountain Crimea. Short-term deformations took place in the terminal Berriasian, just before the Barriasian / Valanginian boundary. During this stage the First Range was compressed, uplifted and affected by the block movements (Mileev et al., 1998). Some of these blocks were consequently eroded. The compressional phase changed into extensional just before the Valanginian, which led to formation of graben systems.

During the Early Valanginian terrigenous lacustrine to near-shore sediments (fig.1, 2) cover the Mountain Crimea (Baraboshkin, Yanin, 1997). They lay with structural unconformity and fill karst cavities in the Upper Jurassic – Berriasian carbonates. The outer part of the First Range was submerged and pelagic clays deposited there.

Early Hauterivian was the time of developed transgression, which covered the whole Mountain Crimea (Baraboshkin, 1997a, b, 2001). The terrigenous marine to near-shore sandy facies was present in central Crimea and in the Kacha River reference section in particular (fig.1, 2). They were divided from the Simferopol uplift to the north by a narrow belt of small coral reef buildups. These buildups replaced by lacustrine to near-shore facies to the east and controlled by block movements. The area of the first Crimea range was submerged and clay sedimentation took place there. The age of the succession is confirmed by the presence of ammonite genera *Leopoldia*, *Breistrofferella*, *Lyticoceras* and some of *Crioceratites* (table).

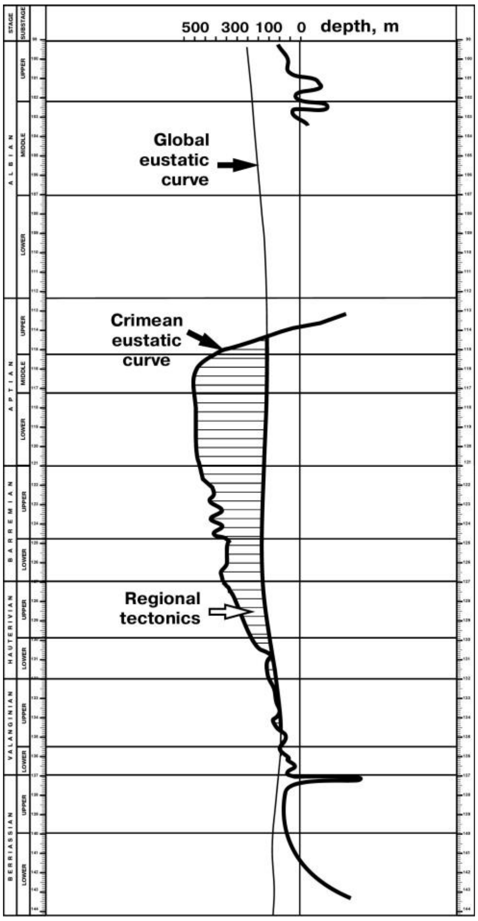

Figure 3. Calculated depth of the Early Cretaceous basin in the Kacha – Bodrak watershed, Bakhchisaray Town region (Baraboshkin, 2001; Enson, Baraboshkin, 2002). Difference between Crimean eustatic curve and Global eustatic curve reflects the regional tectonic component

Unlike the Early Hauterivian, the Late Hauterivian was the period of the strongest Boreal transgression (Baraboshkin, 2001, 2002), which covered almost the complete studied area. This fact is confirmed by the presence of mixed Tethyan – Boreal ammonite and bivalve assemblages in the SW of Mountain Crimea (Kacha reference section), which contain *Speetoniceras, Simbirskites, Milanovskia* and *Heteropteria* (see the table) together with *Melchiorites, Paraspiticeras, Anahamulina*, etc. The transgression penetrated into Plain Crimea (Leschukh, 1987), where terrigenous sedimentation started. In Mountain Crimea highly condensed "Ammonitico Rosso" facies were formed and in the outer part of the basin clayey sedimentation took place (Baraboshkin, 1997b).

The Barremian palaeogeography is characterised by further transgression in the Plain Crimea, where terrigenous Barremian sediments overlay Hauterivian and older deposits (Leschukh, 1987). In Mountain Crimea they partially represented of the upper part of "Ammonitico Rosso" limestones and partially – the lower part of the deep-water clayey sections (Yanin, Vishnevsky, 1989; Baraboshkin, 1997a). Block movements led to the appearance of the thick olistostrom member in the Eastern Crimea.

During the Aptian pelagic clays were deposited all over the Mountain Crimea under disoxic conditions. Ammonites are very rare and the age of the clays is mainly determined by the foraminiferal data (Gorbachik, 1986). The Kacha River reference section is very typical for Mountain Crimea.

Uppermost Aptian is missing in the succession because of the new stage of deformations and tectonical uplift of the region (Yanin, Vishnevsky, 1989; Baraboshkin, 2001). During the Early – Middle Albian the most part of the Mountain Crimea was a dryland. Stratigraphy of the Lower – Middle Albian in the Eastern Crimea needs further investigations. In the Plain Crimea shallow sea with terrigenous sedimentation has developed in the Early Albian (Leschukh, 1987). In the Middle Albian volcanogenic sedimentation started in the Karkinit back-arc basin of the Plain Crimea (Nikishin et al., 1997).

The latest Middle Albian – early Late Albian was marked by mixed estuarine – shallow-water sedimentation in the Second Range. The sea ingressed in the palaeovalleys of Mountain Crimea from the north and north-west and filled them with clays and sands (Yanin, Vishnevsky, 1989).

An extension event took place in the Crimea-Caucasus region during the latest Albian – Cenomanian. The sea transgressed onto the Mountain Crimea from the south. Carbonate sedimentation started again, but on the south-west (Sevastopol region) and in the north (Karkinit basin) a strong influence of pyroclastics is occurred. The pike of volcanic activity falls on the Albian / Cenomanian boundary, because pyroclastic rocks covers the whole Crimea. It is supposed that this magmatic event was connected with the Black Sea origin (Nikishin et al., 1997).

CONCLUSIONS

As could be seen from this short review, the Early Cretaceous history of the Mountain Crimea is very complex. Intensive study of Lower Cretaceous deposits during the last years led to recognition of a series important events. (1) Determination of the Valanginain in the shallow-water and lacustrine facies (Baraboshkin, Yanin, 1997) made possible to define the time of extensional event, characteristics of block movements and to separate Early Hauterivian complex facial paragenesis from the Valanginian, more slmple paleogeography; (2) to quantify depth changes for the Early Cretaceous and to recognise sudden deepening of the Mountain Crimea basin on the Early / Late Hauterivian boundary (Baraboshkin, 2001; Enson, Baraboshkin, 2002); (3) to determine more precisely (Latest Albian) the beginning of the extension phase of back-arc system for the SW Crimea.

There are, however, a lot of questions waiting for further study.

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VOLCANIC AND METALLOGENIC EVOLUTION OF THE MOMCHILGRAD DEPRESSION (EASTERN RHODOPES)

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ABSTRACT
Preceding volcanic activity epithermal low-sulfidation quartz-gold-adularia ore mineralizations are localized within the various Paleocene and Late Eocene sedimentary rocks in the Momchilgrad depression. Hydrothermal-metasomatic deposits of montmorillonite bentonite are formed within tuffs of the Beli Plast rhyodacite and Rabovo latite-andesite complexes. Agate occurrences associate with the latite-andesites of the Rabovo complex. Volcanogenic-sedimentary clinoptilolite zeolite deposits are formed within the tuffs of the Perperek complex. Perlite deposits are localized within the extrusive bodies of the Perperek trachyrhyolite and Ustren rhyolite complex. The formation of the quartz-Au-polymetallic Zvezdel-Pcheloyad ore field spatially and genetically is related to the Zvezdel volcano (built by basaltic-andesites of the Zvezdel complex).

The Momchilgrad depression is situated in the area between the Central and Southeastern Rhodopes blocks of the Rhodopes Massif. Various breccias, conglomerates, sandstones, marlstones and limestones deposited within the depression during the Paleocene and Late Eocene.

PRIABONIAN

The metallogenic processes preceded intense volcanic activity in the depression. Epithermal low-sulfidation quartz-gold-adularia ore mineralizations (Mavroudchiev at al., 1996) formed in the southeastern parts of the depression within the Paleocene and Late Eocene sediments (Fig. 1). Linear stockwok or stratiform ore bodies (Han Krum, Sarnak, etc.) are located within the favourable for replacing rocks and tectonic zones (detachment).

These ore mineralizations seem to have preceded the volcanic activity but probably resulted from its initial stages and were genetically related to the magma reservoir. The occurrences in the southeastern parts of the Momchilgrad depression were connected with still not erupted Irantepe volcano.

The volcanic activity also began from the southeastern parts of the Momchilgrad depression. The beginning was in the Priabonian when formed the Kalabak andesite complex. The Irantepe volcano (Ivanov, 1960), having diameter of about 10 km, as well as several smaller satellite volcanoes developed (Fig. 1).

The initial stages of the volcanic activity was dominated by explosive processes. Various lapilli tuffs, agglomerates, and epiclastics deposited upon the coal-sandstone and marl-limestone units and on the metamorphic basement as well. Locally, the tuffs and epiclastics are interbedded by reef limestones indicating that volcanoes grew up in a shallow marine basin. The tuffs are cut or covered by Amph-Py andesites. Agate occurrences associate with the andesite lavas of this complex.

RUPELIAN

The Momchilgrad depression extended to the east of the Varbitsa fault near by the town of Djebel (Djebel depression; Boyanov, Goranov, 1997) where the pre-Paleogene basement and rhythmic marlstone-sandstone unit were covered by conglomerates and sandstones (Fig. 2) hosting Makedontsi epithermal low-sulfidation quartz-gold-adularia deposit.

The tuffs of the Beli Plast rhyodacite complex covered these sedimentary rocks in the whole basin. Their vents were located to the north of the considered area in the outlines of the Krushka (the village of Skalna Glava; Yanev, 1995) and Zornitsa grabens. The Kardjali coastal reef developed in the area of the towns of Kardjali and Djebel as the limestones were not affected by the wallrock-alteration of the Makedontsi deposit. It is considered that this volcanism took place either in the boundary interval Priabonian-Rupelian or in the very beginning of the Rupelian.

What was coming next is the formation of the **Rabovo latite-andesite and Madjarovo latite complexes**.

The Rabovo latite-andesite complex covered larger parts of the Momchilgrad depression. In the base of its section are deposited ash- and lapilli-tuffs and epiclastics covered by vesicles-bearing lava of latite-andesite and andesite composition. They built the basic parts of the large

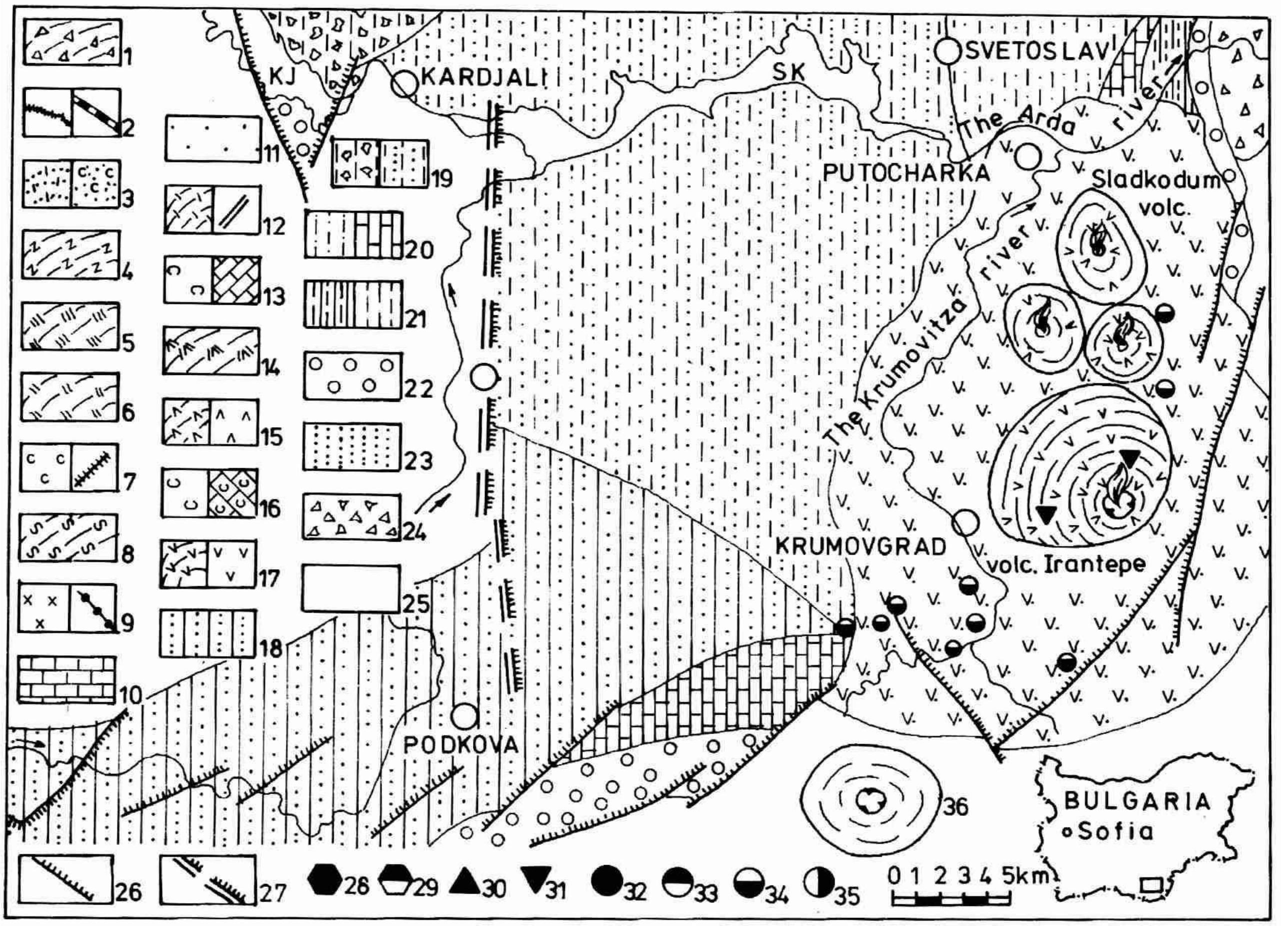

Figure 1. Formation of the Kalabak andesite complex.
Oligocene: 1, 2 - Pcheloyad dyke complex - rhyolite bodies (1), rhyolite dykes (2a), and latite dykes (2b); 3 - Raven rhyolite complex - bodies (3a), tuffs and tuffaceous limestones (3b); 4 - Momchilgrad trachydacute complex; 5 - Ustren rhyolite complex; 6, 7 - Sveti-Ilia trachyrhyodacite complex - bodies (7), tuffs and tuffaceous limestones (7a), dykes (7b); 8, 9 - Zvezdel basaltic-andesite complex – basaltic-andesite epiclastites, lavas and tuffs (8), monzonitoid intrusion (9a), basaltic-andesite dykes (9b); 10 - Stomantsi rhyolite complex - tuffs and tuffaceous limestones; 11 - Djebel Sandstone Formation; 12, 13 - Perperek trachyrhyolite complex - bodies (12a), dykes (12b), tuffs and tuffaceous sandstones (13a), tuffaceous limestones (13b); 14 - Madjarovo latite complex - bodies; 15 - Rabovo latite-andesite complex - lava flows (15a), epiclastites, tuffs and tuffaceous limestones (15b); Eocene-Oligocene: 16 - Beli-Plast rhyodacite complex - tuffs and tuffaceous sandstones (16a), tuffaceous limestones (16b); Paleocene(?)-Eocene: 17 - Kalabak andesite complex - lava flows (a), epiclastites and tuffs (b); 18 - rhythmic sandstone-marlstone unit; 19 - volcano-sedimentary unit - olistostrome packet (19a) and rhythmic packet (19b); 20 - marlstone-limestone unit - marlstone packet (20a), limestone packet (20b); 21 - coal-sandstone unit - lower coal-sandstone packet (21a), sandstone-conglomerate packet (21b); 22 - breccia-conglomerate unit; 23 - Leshnikovo Formation; 24 - Biser Formation; 25 - pre-Paleogene basement; Faults: 26 - normal-slip fault; 27 - Varbitsa fossilized fault; 28 - volcanic cone or extrusion and its magma conduit (vent); Deposits and mineralisations: 29 - bentonite; 30 - perlite; 31 - agate; 32 – quartz-galena-sphalerite); 33 - quarts-Au; 34 - epithermal low-sulfidation quartz-gold-adularia; 35 - quarts-antimonite.

polyphase volcanoes Dambalak, Bivolyane, Sveti Ilia, Studen Kladenets (Ivanov, 1960, 1961) having diameters of about 8-12 km, as well as some smaller satellite monophase volcanoes with diameters up to 4-5 km (Fig. 3).

The Madjarovo complex built a volcano (4-5 km in diameter) located in the Northwestern parts of the Depression - Kartal volcano (Fig. 3). It is a not large satellite edifice of the Madjarovo volcano, developed to the east of the considered area.

Montmorillonite bentonite deposits with kaolinite and halloysite associate with the tuffs of the Beli Plast rhyodacite (Enchets) and Rabovo latite-andesite (Zimzelen, Propast, and Dobrovolets) complexes. Bentonites resulted from the argillization of the tuffs and the bentonite bodies are stratum- or lens-like shaped. According to Atanasov, Goranov (1989) they are of hydrothermal-metasomatic origin. Agate occurrences are related to the vesicles-bearing latite-andesites.

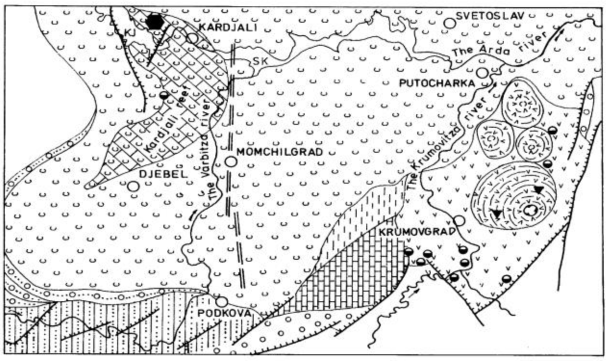

Figure 2. Formation of the Beli-Plast rhyodacite complex. For the key see Fig. 1

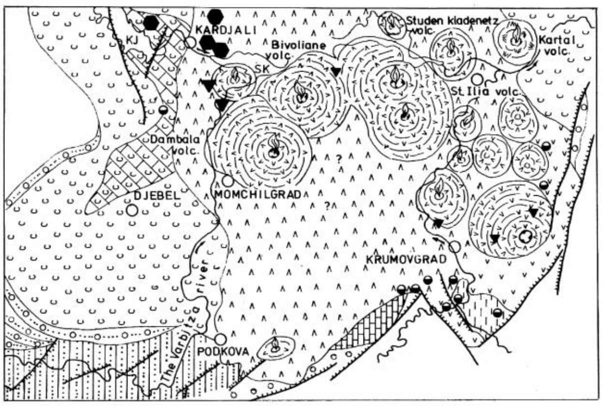

Figure 3. Fformation of the Rabovo latite-andesite and Madjarovo latite complexes. For the key see Fig. 1

Transgression continued. Breccia-conglomerates deposited in the western parts of the Momchilgrad depression (Djebel depression) on the tuffs of the Beli Plast complex and in the base of the Perperek complex.

Various tuffs belonging to the **Perperek trachyrhyolite complex** alternate upward. Several extrusions 3-4 km in size - Kogjadaa, Dyuzkaya, Yumrukkaya (Perperek volcano; Yanev et al., 1968), Hisara, Esberlik as well as an new phase of the Studen Kladenets volcano intruded the northern parts of the depression. Svetoslav reef developed in this area (to the south of the Ibredjek horst) and Sindeltsi reef - in the south parts of the depression.

Perlite deposits and occurrences are related to the rhyolite extrusions of this complex (Goranov, Popov, 1989). They form irregular bodies along the peripheries of the extrusions. Clinoptilolite zeolite deposits and occurrences of volcanogenic-sedimentary origin (Djourova, Aleksiev, 1989) are localized within the acid tuffs of the same complex (Jelezni Vrata, Belia Bair).

The marine basin deepened in the area of the Djebel depression, to the west of the Varbitsa fault (Fig. 4) where the sandstones of the **Djebel Formation deposited** (Goranov, Shilyafova, 1992). In the western parts of the this depression initially deposited epiclastics up to 20 m thick, andesite and latite in composition. They are covered by finegrained sandstones with thin and fast disappearing interbeds of conglomerates, limestones and acid tuffs (epiclastics ?). The thickness of the formation reaches up to 200 m in the central parts of the Djebel depression.

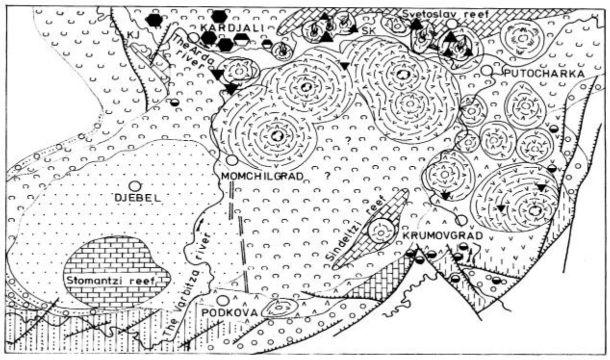

Figure 4. Formation of the Perperek trachyrhyolite complex, deposition of the Djebel Sandstone Formation and Stomantsi rhyolite complex. For the key see Fig. 1

The Djebel sandstones are covered by tuffaceous reef limestones and tuffs of the **Stomantsi rhyolite complex**. Stomantsi coastal reef developed in the southwestern parts of the Momchilgrad depression.

A new violent manifestation of the volcanic activity followed**.** **Zvezdel basaltic-andesite complex** formed. Zvezdel stratovolcano - the largest volcano in the depression, having diameter of about 15 km, developed. Two new phases of the Dambalak and Sveti Ilia volcanoes generated, as the diameters of the bodies are 8-12 km. They are associated by nearly 20 satellite and parasitic volcanic edifices (Fig. 5).

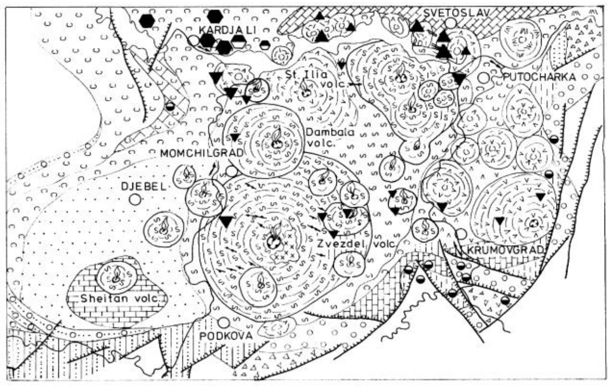

Figure 5. Formation of the Zvezdel basaltic-andesite complex. For the key see Fig. 1

The basal levels of the Zvezdel complex are occupied by pyro- and epiclastics. Effusive facies, represented by lava flows and bodies of andesite and basaltic-andesite composition, prevails upward as andesite varieties are more typical of the lower parts of the section while the upper ones are dominated by basaltic-andesites. The Zvezdel volcano is intruded by numerous basaltic-andesite dykes of the Pcheloyad dyke swarm (Galenit tensional zone; Ivanov, 1960). Zvezdel monzonitoid intrusion and its satellite Metlichka intrusion are emplaced in the central parts of the Zvezdel volcano.

Some **agate** occurrences associate with the effusive products of the Zvezdel complex.

Several extrusions of the **Ustren rhyolite complex**, up to 3-4 km in diameter, erupted in the westernmost parts of the depression - Ustren, Schupenata Planina, Jaltika, Zli Vrah (Fig.6).

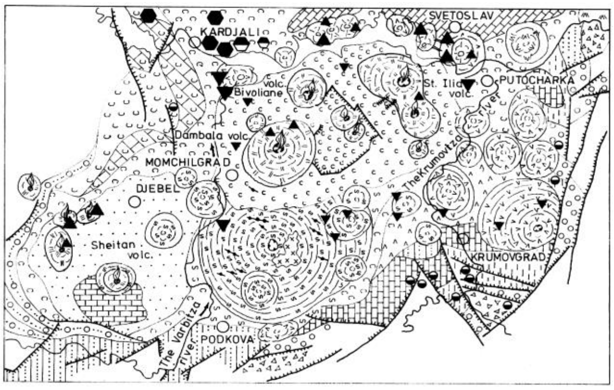

Figure 6. Formation of the Sveti Ilya trachyrhyodacite complex. For the key see Fig. 1

Magmatic **perlite** deposits are localized in these rhyolite bodies (Goranov et al., 1960). The largest perlite deposit is ocated in the Schupenata Planina extrusion cut by a subequatorial fault of current activity, fact giving the name of the rhyolite body (meaning broken mountain).

The **Sveti Ilia trachyrhyodacite** complex was generated next (Fig. 6). Mainly ash- and lapilli-tuffs as well as reef limestones initially deposited. Over them flowed reddish-violet flow-banded trachyrhyodacite lava. 10-12 km sized extrusives emplaced at Sveti Ilia, Dambalak and Bivolyane volcanoes. Several smaller parasitic extrusive bodies erupted on the slopes of these volcanoes. Radially oriented trachyrhyodacite dykes cut the Sveti Ilia volcano.

The **Nanovitsa caldera** originated between the mentioned volcanic edifices probably close to the end of this stage. It has irregular geometry and encloses an area of about 50 km^2. The caldera subsidence resulted from the roof collapse over an underlying magma reservoir that might have been common for the three volcanoes

Some **perlite** occurrences associate with the rhyodacites of the Sveti Ilia complex.

The **Momchilgrad trachydacite** complex was generated next. Lapilli-tuffs and agglomerates are deposited in the base of its section. They are interbedded and covered by trachydacite lava in the upper parts. These products composed a new phase at the Dambalak volcano as well as some parasitic volcanic edifices on the northern slope of Zvezdel volcano (Fig. 7).

Agate occurrences are related to the Momchilgrad trachydacite complex.

The tuffs of **Raven rhyolite complex** are exposed mainly within the Nanovitsa caldera. The base of the section is occupied by tuffaceous reef limestones and the upper levels - by ash-tuffs and xenotuffs. A rhyolite extrusion few km in diameter erupted in the most southern parts of the Nanovitsa caldera (Fig. 8).

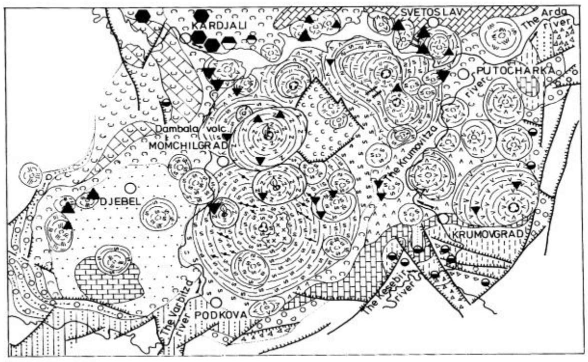

Figure 7. Stage of formation of the Momchilgrad trachydacite complex. For the key see Fig. 1

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The magmatic activity terminated with the emplacement of subvolcanic bodies and dykes of the **Pcheloyad dyke complex**. They are part of the Pcheloyad dyke swarm trending to WNW, about 25 km long and nearly 10 km wide. Several parasitic extrusions having diameters of 2-3 km are located on the slopes of Zvezdel volcano (Fig. 8).

The formation of the **quartz-gold-polymetallic Zvezdel-Pcheloyad ore field**, both spatially and genetically is related to the latest products of the Zvezdel volcano. The ore bodies are mainly of vein type. Stratiform metasomatic bodies are also formed within the sediments and the metamorphic basement (limestones and marbles) underlying the volcano. A horizontal zonality that is an element of the dome-like hypogenic zonality (Breskovska, Gergelchev, 1988) can be observed in the distribution of the mineral paragenesis. Quartz-galena-sphalerite deposits and mineralizations are formed in the central parts of the ore field while along the periphery these are quartz-gold-polymetallic. Polymetallic deposits of no economic significance are typical of the areas still farther from the volcano.

Chernichevo antimonite deposit as well as some polymetallic occurrences formed in the metamorphic rim of the Momchilgrad depression.

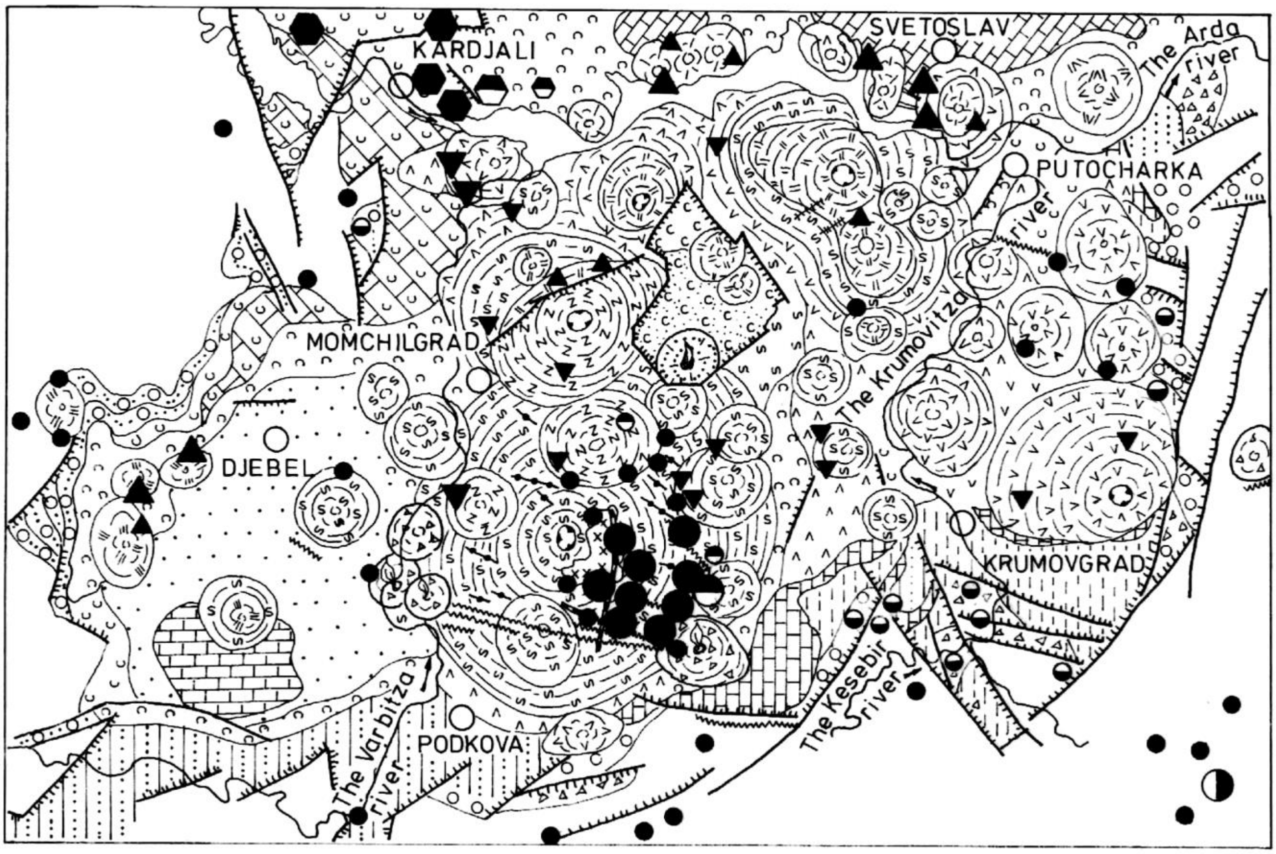

Figure 8. Stage of formation of the Raven rhyolite and Pcheloyad complexes. For the key see Fig. 1

CONCLUSIONS

The volcanic activity in the Momchilgrad depression took place in shallow marine basin as the volcanic cones are islands. Coral reefs often grew up around them as well as along the periphery of the basin. The tuffs of the Beli Plast rhyodacite and Perperek trachyrhyolite complexes deposited chiefly within the basin and are absent on the slopes of the large volcanic edifices.

A counter-clockwise migration of the magmatism can be noticed within the Momchilgrad depression (Fig. 1-8). The Irantepe, Sveti Ilia, Bivolyane, Dambalak and Zvezdel volcano successively formed. The Nanovitsa caldera, filled with the tuffs of the Sveti Ilia trachyrhyodacite and Raven rhyolite complexes, collapsed in the middle between them.

Deposits and occurrences mainly of non-metallic mineral resources (perlite and zeolites related to acid phases, agates - to intermediate phases, and bentonites) formed in the northwestern parts of the depression. Chiefly metallic ore deposits - quartz-gold-adularia (within the Paleocene and Late Eocene sediments) and quartz-gold-polymetallic (related to Zvezdel volcano) are typical of central and southeastern part of the depression.

The connection between metallic mineralization and volcanic activity from the peripheral parts and the rim of the depression is more distant and unclear. Although they probably resulted from one ore-magmatic system. Some polymetallic ore mineralizations associate with not-large, relatively isolated volcanic edifices, as for example Jaltika.

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MAGMATIC COMPLEXES IN THE MOMCHILGRAD DEPRESSION (EASTERN RHODOPES)

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ABSTRACT
The products of the Paleogene magmatic activity in the Momchilgrad depression have been divided into several magmatic complexes. The Kalabak andesite, Rabovo latite-andesite, Zvezdel basaltic-andesite, Sveti Ilia trachyrhyodacite, Momchilgrad trachydacite and Raven rhyolite complexes, formed into Dambalak group, have the same area of distribution and similar geochemical and isotope features. They might have resulted from the evolution on a intermediate magma reservoir as their composition evolved from intermediate to acid. Extrusive bodies of the Perperek trachyrhyolite and Ustren rhyolite complexes are located apart from the main volcanic edifices and have specific geochemical features, and probably resulted from evolution of separate acid magma reservoirs.

INTRODUCTION

Two general papers concerning Paleogene deposits and magmatic activity were published in one issue in 1960 (Goranov, 1960; Ivanov, 1960). They have many similarities - both authors used the lithostratigraphic approach in the subdivision of magmatic products and they both recognized three intermediate and three acid vocanic horizons. According to Goranov these horizons are Pr_4, Ol_2, Ol_5 (intermediate) and Ol_1, Ol_3, Ol_5 (acid). Ivanov localized the most of the magmatic centers and described Borovitsa and Momchilgrad volcanic areas and Arda volcanic strip. He also suggested three magmatic cycles as an acid phase follows every intermediate one – I, II, III intermediate and I, II, III acid phases, respectively.

These investigations are a great achievement in studying of the magmatic activity in the Eastern Rhodopes. As popular has been accepted the scheme of Ivanov (1960). During the following 40 years the concept of cyclic character of the Eastern Rhodopes magmatism has been in the basis of the most subdivisional schemes of the Eastern Rhodopes magmatic rocks. Only the number of the cycles (three or four) and the spanning of the horizons or units used have been changed (Ivanov, 1961; Goranov, Shilyafova, 1995; Yanev et al., 1998).

NOTES ON METHODOLOGY

The aspiration for creating of an universal lithostratigraphic scheme of the Paleogene magmatic products in the Eastern Rhodopes had led to the idea of cyclic character of the volcanism. Paleogene magmatism in the Eastern Rhodopes is localized in several areas - products of the evolution of separate magma reservoirs originated in common collision-related tectonomagmatic setting (Harkovska et al., 1989; Yanev et al., 1995). However, these separate magma reservoirs had different composition and probably resulted from mobilization of earth crust different types (Yanev et al., 1995). They had similar but not identical and concurrent evolution. Therefore, the correlation and integration of the rocks generated by different magma chambers in an uniform scheme is not correct. Independent subdivision of the separate areas produced by different reservoirs is more advisable.

The term "complex" is used in the reported subdivision of the magmatic rocks in the sense of the Stratigraphic code of Bulgaria (Nikolov, Sapunov, 2002) as an official lithostratigraphic unit applied to mixed rocks. This term is preferred because of the great diversity of the rocks varieties included in the complexes - stratified effusives, pyroclastics, epiclastic and sedimentary rocks as well as cross-cut subvolcanic bodies, dykes and intrusive rocks.

The criteria for the recognizing of the complexes are: similar mineral and chemical composition, similar age, same spatial and time relations to the neighbouring units, same area of distribution (inferring same magma source), "mappability" of the separate units.

The volcanic activity in the Momchilgrad depression occurred in shallow marine basins as volcanoes formed islands (atolls). Only rocks of volcanic facies (explosive, effusive and subvolcanic) were emplaced near volcanic vents areas in subaerial setting. Rocks of sedimentavy facies (epiclastics, terrigeneous sediments and reef limestone) overlap volcanics on the volcanic slopes and in the base of cones. Some of the magmatic complexes (phases) are present in several different volcanic edifices, as in between tuffs and lava flows, erupted from different vents but having same or similar composition (belonging to one complex).

The thickness of the lava flows and tuffs fast decrease with increasing the distance from volcanic centers. And vice versa; the sedimentary deposits increase in thickness apart from the vents. The maximum thickness of the units is reported below, were the description of the composite type sections is given. Pyroclastic and epiclastic rocks have been classified according to Le Maitre (1989). Available K-Ar ages are summarized in

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DESCRIPTION OF THE COMPLEXES

Kalabak andesite complex (Калабашки андезитов комплекс)

Nomenclature: Named after the Kalabak Peak, Krumovgrad District.

Defining characteristics: Porphyritic andesites with phenocrysts of Pl, Amph, Py, and Bi - subvolcanic bodies, lava flows and tuffs.

References: Pr_4 (Goranov, 1960), I intermediate volcanism (Ivanov, 1960; Goranov, 1995).

Composite-stratotype: At Irantepe volcano, in the area of town the Krumovgrad.

Cover: Beli Plast rhyodacite complex (not described here as its vent area is out of the considered area); Rabovo latite-andesite complex.

K_3 - Amph-Py andesites; subvolcanic bodies and lava flows (100 m);

K_2 - lapilli-tuffs and aglomerates (300 m);

K_1 - epiclastites - conglomerates, breccias, sandstones, siltstones, tuffites, limestones;

Basement: Marlstone-limestone and coal-sandstone units (Priabonian);

Distribution: Outcrops in the area between the town of Krumovgrad and the villages of Sbor and Sladkodum over an area of about 400 km^2. Builds the Irantepe volcano as well as several smaller edifices to the north of it.

Chronostratigraphy: According to available K-Ar measurements its age is 35.0-39.0 Ma. Based on the field observations it is defined as being of Priabonian age.

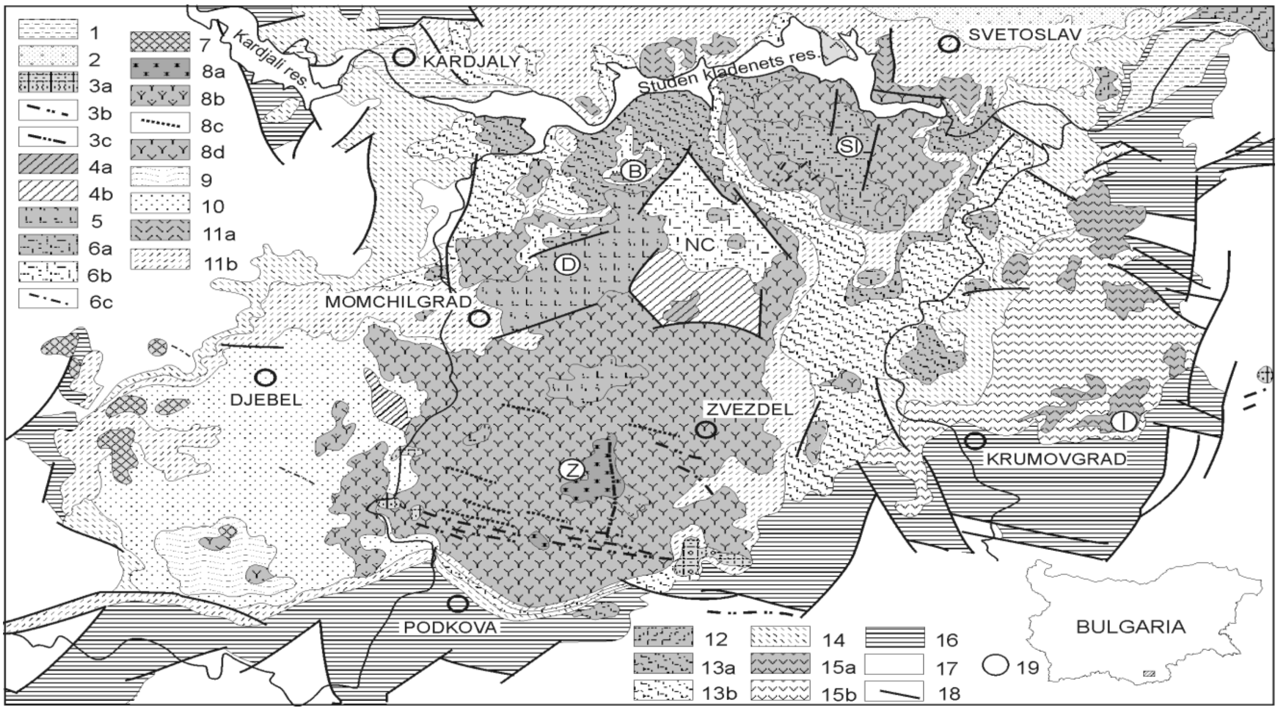

Figure 1. Geological map of the Momchilgrad depression

1 - Quaternary; Oligocene-Miocene: 2 - Valche Pole unit; Oligocene 3 - Pcheloyad dyke complex - rhyolite bodies (a), rhyolite dykes (b), and latite dykes (c); 4 - Raven rhyolite complex - bodies (a), tuffs and tuffaceous limestones (b); 5 - Momchilgrad trachydacite complex]; 6 - Sveti-Ilia trachyrhyodacite complex - bodies (a), tuffs and tuffaceous limestones (b), dykes (c); 7 - Ustren rhyolite complex; 8 - Zvezdel basaltic-andesite complex - monzonitoid intrusion (a), subvolcanic bodies (b), dykes (c) epiclastites, lavas and tuffs (d),); 9 - Stomantsi rhyolite complex - tuffs and tuffaceous limestones; 10 - Djebel Formation; 11 - Perperek trahyrhyolite complex - bodies (a), tuffs and tuffaceous limestones (b); 12 - Madjarovo latite complex - bodies; 13 - Rabovo latite-andesite complex - lava flows (a), epiclastites, tuffs and tuffaceous limestones (b); Eocene-Oligocene: 14 - Beli-Plast rhyodacite complex - tuffs and tuffaceous limestones; Eocene: 15 - Kalabak andesite complex - lava flows (a) epiclastites, tuffs and tuffaceous limestones (b); 16 - Eocene-Paleocene – sedimentary rocks; 17 - pre-Paleogene basement; 18 - fault; 19 - volcanic vents: Z - Zvezdel volcano, D - Dambala volcano, B - Bivoliane volcano, SI - Sveti-Ilia volcano, I - Iran-Tepe volcano; NC - Nanovitsa caldera.

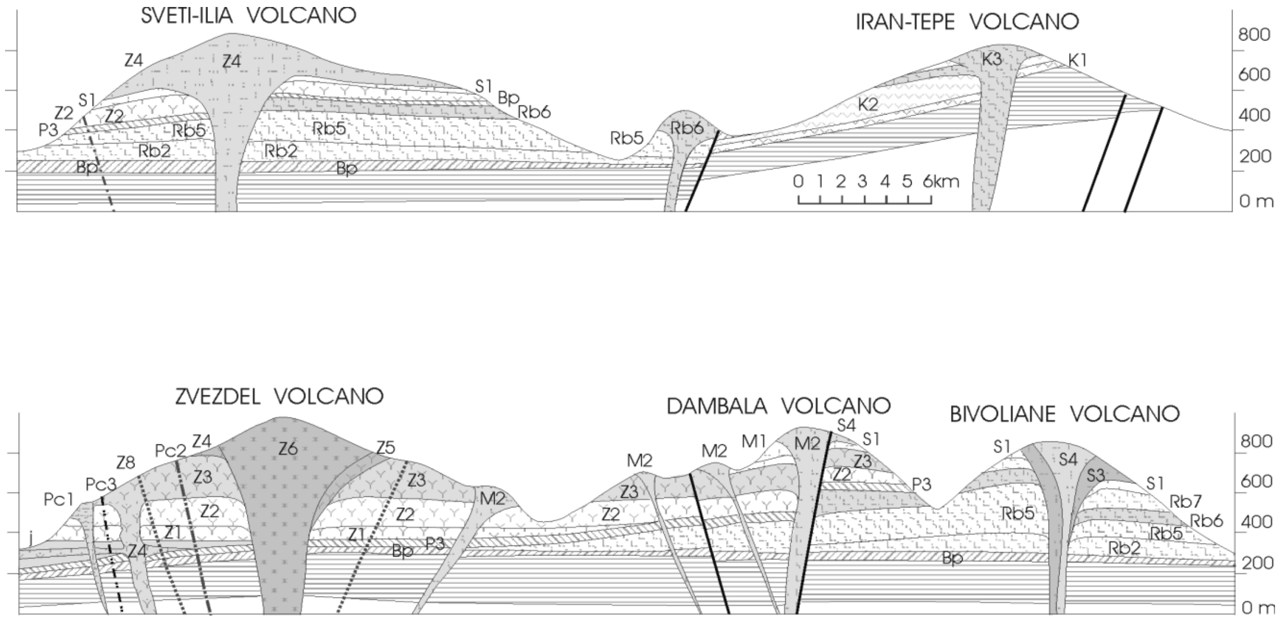

Figure 2. Geological sections of the Momchilgrad depression. For the key see Fig. 1

Rabovo latite-andesite complex (Рабовски латиандезитов комплекс)

Nomenclature: The name comes from the name of Rabovo village, Kardjali District.

Defining characteristics: Vesicle-bearing greyish-black latite-andesites and trachydacites (with phenocrysts of Pl, Py, Amph, and Bi) - subvolcanic bodies, lava flows and tuffs.

References: Ol_2 (Goranov, 1960); II intermediate volcanism (Ivanov, 1960; Goranov, Shilyafova, 1995; Goranov, 1995).

Composite-stratotype: The area of the village of Rabovo.

Cover: Perperek trachyrhyolite complex, Zvezdel basaltic-andesite complex.

Rb_7 - andesite pyroclastic breccia (70 m);

Rb_6 - fine-porphiritic andesites - lava flows (30 m);

Rb_5 - lapilli-tuffs (40 m);

Rb_4 - coarse ash tuffs (30 m);

Rb_3 - vesicle-bearing latite-andesites - lava flows and cross-cutting bodies (100 m);

Rb_2 - epiclastites (tuffites, tuffaceous sandstones, 100 m);

Rb_1 - ash- and lapilli-tuffs (80 m).

Basement: Beli Plast rhyodacite complex.

Distribution: Outcrops in the area between the towns of Kardjali, Krumovgrad, and Momchilgrad and the villages of Potochnitsa and Podkova covering an area of nearly 750 km^2. This complex builds the firs phases of Studen Kladenets, Sveti Ilia, Bivolyane, and Dambalak volcanoes as well as some smaller volcanic edifices.

Chronostratigraphy: The field observations define it as Rupelian in age.

Perperek trachyrhyolite comlplex (Перперешки трахириолитов комплекс)

Nomenclature: Named after the village of Perperek, Kardjali District.

Defining characteristics: Porphyritic trachyrhyolites with phenocrists of Pl, Kfs, and Bi - extrusive bodies and tuffs.

References: Ol_2, Ol_3, Ol_5, Ol_6 (Goranov, 1960); II intermediate and II acid volcanism (Ivanov, 1960; Goranov, 1995); III acid volcanism (Goranov et al., 1992); II acid volcanism (Yanev, 1995).

Composite-stratitype: The area of the village of Perperek.

Cover: Zvezdel basaltic-andesite complex, Djebel Formation, Valche Pole unit.

P_{10} - pinkish-violet massive trachyrhyolites - extrusions (100 m);

P_9 - brownish-red flow-banded trachyrhyolites – extrusions and subvolcanic dykes (160 m);

P_8 - trachyrhyolite agglomerates and pyroclastic breccias with perlites (200 m);

P_7 - coarse ash tuffs (40 m);

P_6 - tuffaceous reef limestones (70 m);

P_5 - lapilli xenotuffs (80 m);

P_4 - coarse ash-and agglomerate tuffs (100 m);

P_3 - lapilli xenotuffs (50 m);

P_2 - greyish-beige tuffites (50 m);

P_1 - tuffaseous reef limestones (60 m).

Basement: Rabovo latite-andesite complex.

Distribution: It is exposed in the area between the town of Kardjali, the villages of Most, and Dolen Chiflik, the town of Krumovgrad and the villages of Podkova and Ustren occupying an area of about 1200 km^2. According to Yanev (1995) the tuffs of this complex are erupted by vents located in the Borovitsa volcanic region. We consider that they resulted from initial stages of activity of the Perperek and Hisar volcanoes, where their thickness is greatest (up to 500 m). Some authors attribute the xenotuffs to the II intermediate volcanism.

Chronostratigraphy: Available K-Ar datas vary between 29.1 and 33.0 Ma. On the basis of the field observations it has also been considered as being of Rupelian age.

Stomantsi rhyolite complex (Стомански риолитов комплекс)

Nomenclature: It is named after the village of Stomanovo, Djebel District.

Defining characteristics: Rhyolite tuffs and tuffaceous limestones.

References: Ol_6 (Goranov, 1960); III acid volcanism (Ivanov, 1960; Goranov, Shilyafova, 1995).

Composite-stratitype: The area of the village of Stomantsi.

Cover: Zvezdel basaltic-andesite and Ustren rhyolite complexes.

St_2 – rhyolite ash-and lapilli-tuffs (100 m);

St_1 – tuffaseous reef limestones (70 m).

Basement: Djebel Formation

Distibution: It crops out in the area of the village of Stomantsi over an area of about 20 km^2.

Chronostratigraphy: The fossil species found by Atanasov et al. (1970ô) indicate Rupelian age.

Zvezdel basaltic andesite complex (Звезделски андезитобазалтов комплекс)

Nomenclature: The name comes from the name of the village of Zvezdel, Krumovgrad District.

Defining characteristics: Porphyritic andesites and basaltic-andesites with phenocrysts of Py, Pl, Ol, Amph (subvolcanic bodies, dykes, lava flows, and tuffs) and co-magmatic intrusives of Q-monzogabbros and Q-monzodiorites.

References: Ol_5 (Goranov, 1960); II, III intermediate volcanism (Ivanov, 1960); III intermediate volcanism (Goranov, Shilyafova, 1995).

Composite-stratotype: At Zvezdel volcano

Cover: Sveti Ilia trachyrhyodacite, Momchilgrad trachydacite and Raven rhyolite complexes. It is intruded by the Pcheloyad dyke complex.

Z_7 - subvolcanic post-intrusive basaltic-trachyandesite dykes;

Z_6 - hypo-abyssal intrusives of fine-grained Q-monzogabbros and Q-monzodiorites;

Z_5 - high-K basaltic-andesites - subvolcanic bodies and dykes;

Z_4 - fine-porphyritic Py-basaltic-andesites - subvolcanic bodies (magma conduits), sills, dykes, lava flows (100 m);

Z_3 - Py-andesites to basaltic-andesites - lava flows and lava breccias with interbeds of lapilli- tuffs and agglomerates (over 500 m). At the Dambalak volcano are interbedded by acid epiclastics. Z_2 gradually replaces Z_3. Z_2 is dominated by tuffs while in Z3 lava flows prevail.

Z_2 - andesite and basaltic-andesite ash-and lapilli-tuffs and agglomerates (350 m) interbedded by lava flows and limestones (up to 100 m);

Z_1 - epiclastics - conglomerates, breccias, sandstones, siltstones, tuffs and tuffites (50 m);

Basement: Djebel formation, Perperek trachyrhyolite and Rabovo latite-andesite complexes.

Distribution: Occurs in the area between the towns of Momchilgrad and Krumovgrad and the villages of Podkova, Studen Kladenets and Letovnik over an area of about 500 km^2. It composes the largest Zvezdel volcano, separate phases of Dambalak and Sveti Ilia volcanoes as well as sills within the Djebel Formation and subvolcanic bodies in the area of Krumovgrad.

Chronostratigraphy: K-Ar ages vary from 27.7 to 35.0 Ma. Field observations define it as Rupelian.

Ustren rhyolite complex (Устренски риолитов комплекс)

Nomenclature: Named after the village of Ustren, Djebel District.

Defining characteristics: Porphyritic rhyolites with perlites containing phenocrysts of Pl, Kfs, Q, and Bi.

References: Ustren rhyolite massif (Goranov, 1960); III acid volcanism (Ivanov, 1960; Goranov, Shilyafova, 1995).

Type-locality: Exstrussions occupying up to 10 km_2 in the area of the village of Ustren. They intrude the rocks of the Zvezdel basaltic-andesite and Stomantsi rhyolite complexes, Djebel Formation and Perperek trachyrhyolite complex.

Distribution: Between the villages of Mishevsko, Ustren and Stomantsi.

Chronostratigraphy: K-Ar age are 31.0-31.5 Ma. Field relationships with the neighboring lithostratigraphic units indicate Rupelian age.

Sveti Ilia trachyrhyodacite complex (Светиилиски трахириодацитов комплекс)

Nomenclature: It is named after the Sveti Ilia Peak, Kardjali District

Defining characteristics: Redish-violet flow-banded trachyrhyodacites and trachydacites - subvolcanic bodies, dykes, lava flows and tuffs.

References: Ol_3, Ol_6 (Goranov, 1960); II acid volcanism (Ivanov, 1960; Goranov, Shilyafova, 1995).

Composite-stratype: The area of the Sveti Ilia volcano.

Cover: Momchilgrad trachydacite complex, Raven rhyolite complex.

S_4 - redish-violet flow-banded trachyrhyodacites (with phenocrysts of Kfs, Q, Pl, Bi) - subvolcanic bodies with perlite and lava flows (150 m);

S_3 - Redish-violet trachydacites (having phenocrysts of Kfs, Pl, Py) - subvolcanic bodies and lava flows (70 m);

S_2 - tuffaseous reef limestones (70 m);

S_1 - ash and lapilli-tuffs interbedded by xenotuffs (150 m);

Basement: Zvezdel basaltic-andesite, Perperek trachyrhyolite and Rabovo latite-andesite complexes.

Distribution: Occurs between the town of Momchilgrad and the villages of Studen Kladenets and Nanovitsa over an ara of nearly 300 km_2. It builds separate phases of Sveti Ilia, Bivolyane, and Dambalak volcanoes and is also found in the Nanovitsa caldera.

Chronostratigraphy: The foraminifers found in the limestones are dated as Rupelian. K-Ar ages are 29.5-31 Ma.

Momchilgrad trachydacite complex (Момчилградски трахидацитов комплекс)

Nomenclature: It is named after the town of Momchilgrad.

Defining characteristics: Greyish-black trachydacites with phenocrysts of Amph, Py, Bi, Kfs - lava flows and tuffs.

References: Basaltic-andesite effusion of III intermediate volcanism (Ivanov, 1960; Goranov, Shilyafova, 1995); IV intermediate volcanism (Ivanov, 1961)

Composite-stratotipe: Dambalak volcano

Cover: Raven rhyolite complex

M_2 - trachydacites - lava flows (400 m);

M_2 - lapilli tuffs and agglomerates (200 m).

Basement: Zvezdel basaltic-andesite complex.

Distribution: Outcrops to the east and southeast of the town of Momchilgrad over an area of about 70 km^2. It builds the latest phase of Dambalak volcano and some parasitic cones on the slope of the Zvezdel volcano.

Chronostatigraphy: K-Ar ages are 31.0 Ma. Field observations indicate Rupelian age.

Raven rhyolite complex (Раженски риолитов комплекс)

Nomenclature: It is named after the village of Raven, Momchilgrad District.

Defining characteristics: Redish-brown rhyolites and tuffs.

References: Ol_6 (Goranov, 1960); III acid volcanism (Ivanov, 1960; Goranov, Shilyafova, 1995).

Composite-stratotype: To the east of the village of Raven.

Cover: Not observed.

Rv_4 - redish-brown rhyolites - subvolcanic bodies;

Rv_3 - redish-brown rhyolite ash-tuffs (60 m);

Rv_2 – ash-tuffs interbedded by xenotuffs (150 m);

Rv_1 - tuffaceous reef limestones (100 m).

Basement: Momchilgrad trachydacite and Sveti Ilia trachyrhyodacite complexes.

Distribution: Fills in part of the Nanovitsa caldera between the villages of Raven and Nanovitsa over an area of about 30 km^2.

Chronostratigraphy: Field observations indicate Rupelian age.

Pheloyad dyke complex (Пчелояден даиков комплекс)

Nomenclature: It is named after the village of Pcheloyad, Krumovgrad District.

Defining characteristics: The latest rhyolite and latite subvolcanic bodies and dykes.

References: Extrusion of felsitic rhyolites, Galenit tensional zone (Ivanov, 1960); tensional dyke complex (Goranov, Shilyafova, 1995).

Type-locality: The area of the village of Pcheloyad .

Pc_3 - greyish-pink rhyolite-trachyrhyolite subvolcanic dykes (with phenocrysts of Pl, Kfs, Q, Py, Amph, Bi);

Pc_2 - greyish-green latites and trachydacites (Pl, Kfs, Q, Py, Amph, Bi) - subvolcanic dykes;

Pc_1 - greyish-pink trachydacites and trachyrhyodacites (Pl, Kfs, Py, Bi, Amph) - subvolcanic bodies and dykes;

Distribution: It forms dyke swarm of WNW direction long more than 30 km and 8 km wide in the area between the villages of Mishevsko, Stareishino, Pheloyad and Sedefche.

Chronostratigraphy: K-Ar ages are 26.5-32.2 Ma. Field observations are indicative of Rupelian-Chatian age.

Dambalak Group (Дамбалска група)

Nomenclature: The name comes from the name of the of Dambala Peak, Dambalak volcano, where phases of the most of the complexes are present.

Defining characteristics: Andesites, basaltic-andesites, latites, trachyrhyodacites, trachydacites, and rhyolites (subvolcanic bodies, lava flows and tuffs) having same area of distribution and similar geochemical and isotope features (Georgiev, Milovanov, 2003b,c). They resulted from the evolution of an intermediate magma reservoir as their composition evolved from intermediate to acid.

Constituent complexes: Kalabak andesite, Rabovo latite-andesite, Zvezdel basaltic-andesite, Sveti Ilia trachyrhyodacite, Momchilgrad trachydacite and Raven rhyolite complexes.

Distribution: It crops out in the area between the town of Kardjali, the hamlet of Sladkodum, Irantepe Peak, the village of Podkova, the towns of Djebel and Momchilgrad and occupies an area of nearly 1000 km^2. It builds the Irantepe, Sveti Ilia, Bivolyane, Dambalak and Zvezdel volcanoes, numerous smaller parasitic and satellite volcanic edifices around them as well as sills within the Djebel Formation. It also fills in the Nanovitsa caldera situated between the main volcanoes in the middle of the depression.

Chronostratigraphy: K-Ar ages vary between 39.0 and 26.5 Ma. Observed relationships with the neighboring lithostratigraphic units (paleontologically dated) show Priabon-Rupelian age.

Field relations with neighbouring units: The materials of the Dambalak Group intrude and cover the coal-sandstone, marlstone-limestone and volcano-sedimentary units having Priabonian age. They laterally interfinger with rocks of Beli Plast rhyodacite (Priabonian) and Perperek trachyrhyolite complexes, Djebel Formation and Stomantsi rhyolite complex (Rupelian).

The intermediate Kalabak andesite, Rabovo latite-andesite and Zvezdel basaltic-andesite complexes are grouped into **Putocharka subgroup (Путочарска подгрупа),** named after the hamlet of Putocharka of the Potochnitsa village where the three complexes are exposed. The leter Sveti Ilia trachyrhyodacite, Momchilgrad trachydacite and Raven rhyolite complexes are formed into **Zdravets subgroup (Здравецка подгрупа),** named after the Zdravets Peak, Dambala volcano, Momchilgrad District.

CONCLUSIONS

The volcanic activity in the Momchilgrad depression can not be described as being of cyclic character. The volcanoes composed by the Dambalak Group register an evolution of the magma composition from intermediate to acid. Some recurrence from the Rabovo latite-andesite to the Zvezdel basaltic andesite complex and from the Sveti Ilia trachyrhyodacite to the Momchilgrad trachydacite complex can be traced but there is no alternation of intermediate and acid phases. Extrusive bodies of the Perperek trachyrhyolite and Ustren rhyolite complex are situated apart from the main volcanic edifices. They have specific geochemical and isotope features and may have resulted from the evolution of the separate acid magma reservoirs.

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MESOSCALE INDICATORS FOR SYNKINEMATIC MIGMATISATION: EXAMPLES FROM THE RHODOPE MASSIF

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ABSTRACT
A large number of mesoscale structures testify about the synkinematic nature of the migmatisation in the central parts of the rhodope massif. Most of them are structures linked with the formation and the migration of the melts. Often in the domains of great structural complexity, relations between folds, shear zones and migmatites provide a good evidence for the penecontemporaneity of ductile deformation and migmatisation.

Structural patterns in the migmatitic complexes are often rather complex and traditionally have been regarded as indicators for polymetamorphic and polideformational nature. On the other hand, mesoscale structures in migmatites have a number of implications, such as (1) mechanical conditions of aplitoid-pegmatoid dyke emplacement; (2) synkinematic intrusive history.

In the central Rhodopes the migmatitic rocks crop out in the lowermost parts of the metamorphic complex – Prarhodopian supergroup and lower levels of Rhodopian supergroup (Kozhoukharov, 1983) or Arda tectonic unit (Ivanov, 1989, Burg et al., 1990). Detailed structural investigation in these areas have been conducted by Dimov and collaborators - along the Vacha river valley (Cherneva et al., 1995) and along the Chepelarska river valley (Dimov et al., 1996). This paper is mainly based on field work carried out in the central parts of the Arda unit. According to Ivanov (1999) and Ivanov et al. (2000) these high-grade rocks represent the core of the Central Rhodopian dome exhumed during the Tertiary. In recent years a wealth of new data (Arkadakskiy et al., 2000; Peytcheva et al., 2000; Ovtcharova et al., 2002) confirmed Tertiary age of migmatisation in the Arda unit (Arnaudov et al., 1990).

According to the scale of the melt migration two main types of migmatites could be distinguished – in situ melts and allohtonous. A great number of observations prove the allohtonous nature of some of the migmatites. (1) Sharp, intrusive contacts are a clear evidence for magmatic veining. (2) In a number of places magmatic breccias are clear indicator of magmatic behavior of granitoid material. High fluid pressures of the magma are required to explain such veining in the light of high confining pressures that prevailed during amphibolite facies shear event. In most places aplitic-pegmatitic magma is inferred to have been injected as an overpressured, anatectically derived fluid generated from greater depths.

For simplicity various migmatic rocks (aplitic, pegmatitic, granitic) are described as leucosome. The mesoscale indicators for synkinematic migmatisation could be devided in two main groups: (1) Mesoscale structures reflecting tectonic control on the formation and migration of the leucosomes; and (2) Mesoscale structures indicating overlapping in time of the processes of migmatisation and ductile deformation.

MESOSCALE STRUCTURES REFLECTING TECTONIC CONTROL ON THE FORMATION AND MIGRATION OF THE LEUCOSOMES

One of the strongest evidence of syntectonic migmatisation is the indication that the melt formation and migration is controlled by regional deformation and a great number of structures demonstrate this interaction. In these cases the position and the geometrical particularities of the leucosomes are dependent on: (1) foliation and lineation orientation; (2) the degree of noncoaxiality of the deformation; (3) sense of shear (in case of noncoaxial deformation). These structures are one of the unambiguous indicators for synkinematic migmatisation. Most often, they are formed by leucosomes generated in situ.

- Melt filled shear zones. Such structures are widespread in the Vacha river valley. They are linked with asymmetric folds described by Ivanov et al. (1985) as late migmatic folds.
- Melt filled boudin necks.
- Melt filled pressure shadows (strain shadows) around stiff objects – boudins, porphyroclasts, porphyroblasts, etc.
- Melt filled tension gashes. They are typical for the shear zones with higher strain rates.
- The development of a synmigmatic layering (Vanderhaeghe, 2001). This type of structure is underlined by regular alternations of continuous centimeter- to meter-thick granitic and mesosome layers. Several processes are supposed to lead to the formation of this structure: (1) metamorphic segregation; (2) intrusion of veins; and (3) transposition during deformation of the partially molten rock. The synmigmatic layering must be used carefully as indicator for synkinematic migmatisation, because similar banding could

be generated via intense ductile deformation and rotation of the older leucosomes.

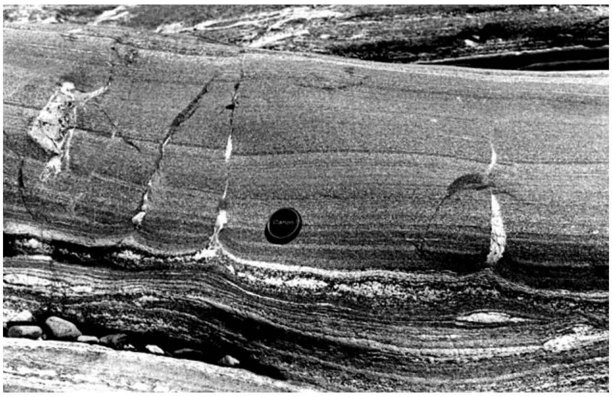

Figure 1. Example of foliation boudunage. The boudin necks are filled with generated in situ melt. The valley of Davidkovska Arda

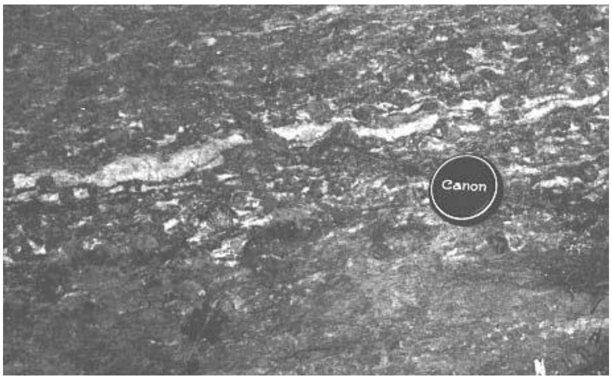

Figure 2. Localisation of leucosome in the sheltered domains around garnet porphyroblasts. East from the town of Chepelare.

MESOSCALE STRUCTURES INDICATING OVERLAPPING IN TIME OF THE PROCESSES OF MIGMATISATION AND DUCTILE DEFORMATION

The simplest types from this structure group are based on the type and orientation of penetrative planar and linear fabric in the leucosomes:

- Magmatic internal fabric in a cross-cutting leucosomes, parallel to the external foliation (Druguet & Hutton, 1998).
- Isoclinally folded magmatic foliation in the leucosomes with axes parallel to the regionally consistent trend of the folds in the host rocks.
- Other types of structures are based on relations between leucosomes and folds:
- Axial-surface leucosomes. This is a rather common association, often interpreted as result of melt emplacemet synchronous to the folding (Gosh, 1994). But as Vernon and Paterson (2001) showed, this type of structure must be used more carefully.
- The folds of the leucosomes are coaxial with those in the country rocks but more open. These examples could be regarded as a result of leucosome emplacement during the development of the folds.

Even the most complex structural patterns in migmatitic terains could give a lot of information about relations deformation-migmatisation. Mutual cross-cutting relationships between structures (shear zones, folds) and leucosomes indicate that deformation occurred in presence of a melt phase (Hollister & Crawford, 1986; Davidson et al., 1992; Davidson et al., 1994; Vanderhaeghe, 2001). The deciphering of such complex structures is only possible with integration of precise petrological and geochemical investigations (eg. Cherneva et al., 1995) as well as isotopic age determinations.

Figure 3. Leucosomes in the axial surfaces of mesoscale folds in a biotite gneiss. West from the town of Zlatograd.

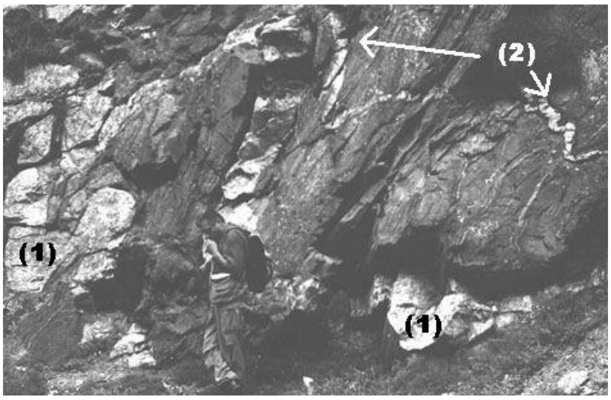

Figure 4. Weakly transgressive aplitic and pegmatitic veins emplaced synchronously to the folding. Later vein (2) is forming more open folds.

CONCLUSION

The structural analyses of the migmatites in a part of the Central Rhodopes indicate clearly the synkinematic nature of the migmatisation. Very often the structural patterns in the migmatites are rather complex and sometimes are interpreted as an indicator for polydeformational and polymetamorphic reworking of the crystalline basement (Zagorchev, 1976). But in fact they are a result of overlapped in time processes of ductile deformation and migration of melt. On the other hand, the existence of obviously postkinematic aplitic and pegmatitic veins (Костов, 1954; Dimov et al., 1996) is an indication that the magmatic activity, linked with migmatisation, outlasted ductile deformation.

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ON THE GENETIC MODEL OF CHELOPECH VOLCANIC STRUCTURE (BULGARIA)

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ABSTRACT
The Chelopech volcanic structure is genetically related to sinistral strike-slip movements along en-echelon left step-like segments of the Sub-Balkan deep fault, as a result of transtension stress regime. During the Late Cretaceous (Coniacian-Santonian), in the "bridge" between them (the fault segment trending 50° and connecting the two subequatorial segments), an open space resembling pull-apart basin forms. The explosive and effusive products of the Chelopech volcano are created in this gap. The volcano edifice is represented by an elongated bank trending 50°. At the end of the stage, andesite bodies elongated in the same direction occupy its central (neck) part. In the volcano basement these andesite bodies form predominantly sills. Their intrusion initiate a hydrothermal system, which predestines the main ore mineralization of Chelopech and Vozdol deposits. During the Campanian, the transtension regime changes into transpression as a result of dextral strike-slip movements along the fault. The volcanic activity is suspended and a flysch trough forms along the strike-slip faults. After the Maastrichtian it is folded two times: first subequatorial reverse faults, thrusts and folds form, which at the end of transpression are re-folded and create a positive "palm-tree" duplex structure. The neotectonic extension forms the Zlatitsa semi-graben, which north boundary is the Sub-Balkan normal fault. Its step-like trajectory in plan view inherits the traces of the deep faulting that has created Chelopech volcanic structure.

STRUCTURAL SETTING

Chelopech volcanic structure is situated close to the village of Chelopech (Sofia district) on the boundary between Balkan and Srednogorie structural zones (Bonchev, 1971). Its locality is controlled by two regional faults: Sub-Balkan deep fault (Bonchev, 1961) and Panagyurishte cryptorupture (Tsvetkov, 1974). In the recent structural plan the volcanic edifice is separated in two parts (northern and southern) by the Sub-Balkan normal fault considered to be a young neotectonic manifistation of the Sub-Balkan deep fault. Chelopech volcano is formed during the Late Cretaceous (Coniacian-Campanian). Its products are nominated Vozdol Member of Chelopech Formation (Moev and Antonov, 1976). This Formation represents a volcano-sedimentary association of Coniacian-Campanian age. Part of the volcanic structure is exposed on the surface in the northern foot-wall of the Sub-Balkan normal fault. It builds up mainly the eastern pericline of Chelopech syncline. Its basement could be observed here. It consists of Precambrian high-grade metamorphites, green-schists of Dulgidel Group (Ordovician) which are transgressivly overlain by a sandstone formation (Turonian). Significant part of the volcanic structure is covered by a thin (0-40 m) Mirkovo Formation (Campanian) represented by gray and pink limestones as well as several handred meters thick Chugovitsa Formation (Campanian-Maastrichtian). In the southern hanging wall, the volcanic structure as well as its basement and sedimentary cover are buried under 250-300 m thick Quaternary fan sediments. The structure is prospected in depth on the both fault walls by a multitude of boreholes and galleries related to the prospecting and mining of the Chelopech copper-gold-pyrite deposit which is localized entirely in the volcanic edifice as well as to the prospecting of the Vozdol vein-like gold-polymetal deposit. The latter is situated several km to the north of Chelopech deposit, mainly in the volcano basement.

PREVIOUS IDEAS

The ideas about the genesis and the main stages of evolution of the volcanic structure have been discussed in a number of geofund reports and published papers. In the papers published until 1967-1968 (Vrablyanski et al., 1959; Tsankov, 1961; Terziev, 1966; 1968 and others) the volcano is considered to be formed as a result of one andesitic eruption, followed by hydrothermal alteration and ore mineralization. Mutafchiev (1967a; 1967b; 1968) create a detail scheme for the genesis of the volcano structure. Its key point is the separation of the volcanic rocks of Chelopech ore field into two groups: "early northern dacites (andesito-dacites)" and "late southern andesites". In a number of subsequent papers (Antonov and Moev, 1977; Moev and Antonov, 1976; Popov and Mutafchiev, 1980; Popov, Vladimirov. Bakardjiev, 1983; Vladimirov, 1984; Vladimirov and Goncharova, 1987; Popov and Kovachev, 1996 and others.) this scheme is clarified. Popov and Kovachev (1996) best summarize the present-day ideas on the genetic model of the volcano. They have recognized one complex Elatsite-Chelopech magmatogenic structure formed during the Late Cretaceous. It comprises several independent magmatogenic structures demonstrating subsequent stages during the evolution of the magmatic process. The following structures have been recognized: early subvolcanic intrusions, Chelopech volcano, late subvolcanic intrusions and Vozdol volcano. It is considered that the early subvolcanic intrusions are hosted by faults trending ENE and WNW. Two of the multitude bodies cropping out to the north of Chelopech village are described as independent stock-like intrusions (named Petrovden and Murgana) intruded in Precambrian, Paleozoic and Turonian rocks. New faulting and erosion of the uplifted blocks followed the intrusion. As a result the later effusives locally covered the early intrusiones. Chelopech volcano was formed during a next stage (Senonian). The volcanic cone includes block, bomb and lapilli tuffs as well as lava flows and sheets. It is considered that the vent of volcano is complex, including several necks accompanied by radial-concentric faulting around (interpreted by the underground workings). Post-volcanic Late Senonian sediments cover large part of the volcano but the rest part is eroded. At the end of the effusive activity a radial-concentric faulting take place. As a result a caldera forms by means of reactivation of older linear faults. This process explains why in the central part the fundament is situated at a depth of 1700 m, to the west - at several hundred meters but in other places it crops out on the surface. The caldera diameter is 4 km. It is full of thick sandstone formation (two mica sandstones cropping at the upper part of the Chelopech Formation, N. B.). The late subvolcanic intrusions are exposed on the central (Chelopech) and northern (Elatsite) part of the ore field. In the embrace of Chelopech volcano they are intruded after caldera formation along ENE or WNW trending faults inherited from the first stage and remobilized. The intrusive bodies are dyke-like. The biggest one is more than 2 km long and 300 m wide. The subvolcanic bodies in the central volcanic parts are predominantly arc-like to concentric in plan view and reactivate the earlier ring faults. The linear elongated bodies hosted by radial faults are rare. The Vozdol volcano is described as younger, intersecting Chelopech volcano and created in an independent stage after the main ore-formation of Chelopech deposit. As an argument for this Popov et al. (1983) put forward the existence of ore-clasts in its products, revealed by Mutafchiev (1967a) and Popov and Mutafchiev (1980). The volcano neck is described north of Chelopech village, along the river of Vozdol. It is localized on the intersection of two faults (radial and ring) belonging to the Chelopech caldera fault system. Lava flows interfingering the post-caldera sandstones are described south of the neck.

Almost all of the previous authors emphasis on the importance of the subequatorial (100-110º) and the oblique (40-60º) faults and related fold parageneses. They have been studied in details by Antonov and Moev (1977), which explain the later fault-and-fold paragenesis trending 40-60º by a sinistral strike-slip movements along the Panagyurishte crypto fault. Recently we have proposed (Antonov and Jelev , 2000; 2001) a new interpretation of the post-volcanic structure in the frame of Chelopech deposit that served as a base for searching of a new genetic interpretation of the syn-volcanic structures as well.

SCOPE AND APROACH

This paper aims to introduce a new hypothesis about the formation and evolution of the Chelopech volcanic structure. It is a synthesis of the ideas, created as a result of field observations and laboratory investigations, carried out during 1999 as contractual work for Navan Chelopech AD (Jelev et al., 1999). The data from the revision geological mapping in scale 1:25 000 on an area of about 130 m^2 around Chelopech deposit (Chelopech licensed area) as well as from the detail geological mapping in scale 1:5 000 of Chelopech deposit between Brevene river and Aramudere river are taken in consideration. The medium-scaled mapping is carried out by the method of geological profiling, but the detail mapping – mainly by the method of the geological boundaries tracing. The results of the micro-petrographic studies of volcanic rock samples, borehole data and reinterpreted remote sensed images are taken into consideration as well. Only the final results of these investigations, which give grounds for a new hypothesis about the genesis of Chelopech volcano, are discussed in this paper. The detail consideration of the regional geological structure, illustrated by proper graphical enclosure is to be a subject of another paper.

RESULTS AND PROBLEMS DISCUSSION

Some key problems related to the embrace, composition, structure and stages of evolution of the Chelopech volcanic structure are discussed here.

We opine that Chelopech volcano comprises not only the stratified lavas, lava-breccias, tuffs and the subvolcanic bodies intruded in them but also the separated in independent stage "early subvolcanic bodies", exposed along the rivers of Ravnishka, Belishka and Vozdol, described as dacites (Mutafchiev, 1967) or andesito-dacite (Popov and Mutafchiev, 1980). Both the field observations and the laboratory studies do not allow to establish criteria for recognition and separation of the "early (dacite, dacito-andesite)" from the "late (andesite)" intrusions. The field investigation reveal that the subvolcanic bodies considered to be "early" are intruded not only in the fundament of Chelopech volcano but also in its volcanic edifice. The Petrovden fault, described as magma-controlling structure, separating "the northern early dacito-andesites" from "the southern late andesites", represents an intensively haydrothermally altered zone, developed along the contact of the Vozdol volcanic Member of Chelopech volcano-sedimentary Formation and the subvolcanic andesites, but south of Petrovden peak – on its contact with the sandstone formation (Turonian). It is very obvious towards Brevene river, that along this contact are intruded andesites referred to "the late andesites". The micropetrograpy results also do not give grounds for separating of subvolcanic rocks of different composition. All of the 15 samples taken from the outcrops around Chelopech and Vozdol deposits, Klissekyoi and Kurudere rivers are determined as uniform amphibole andesites. It is impostant to mention that Toula (1881) determines the three subvolcanic bodies in the section of Klissekyoi river as andesites. Vutov (1962) describes the same rocks as diorite-porphyrites but marks the presence of transitional between andesites and diorite-porphyrites varieties. The different depth of formation could explain the existing macro- and micro-structural differences: the northern one (in the upstream of Vozdol) are intruded mainly in the volcano fundament while the southern ones – in the volcanic edifice. Mutafchiev (1967a) gives the only arguments for this separation, which we found in the literature. The first argument is the presence of sericitized, silicified and pyritized dacite clasts, resembling the dacites from the northern limb of Chelopech syncline inside the southern andesites.The second one is the stratigraphic situation of the dacites – above the strongly broken and sericitized Turonian sandstones and Precambrian gneisses. Having in mind this, Mutafchiev (1967a) concludes that "the dacites are established before the main volume of the volcanic rocks of andesite type". We opine that the determination of "sericitized, silicified and pyritized" clasts as "dacites" is fairly uncertain and it is not confirmed by our investigations. The lower stratigraphic position of the "dacites" in the northern limb of Chelopech syncline" is due to the fact that they form sill-like bodies here intruded mainly in the volcano fundament.

Speaking about the composition of the volcano products we have to mention that they are not properly studied. Vladimirov and Goncharova (1987) describe their petrochemistry separating two series: normal and sub-alkaline. Unfortunately, we failed to use these data because they are not spatially related and could not be revised.

The field investigations and borehole data interpretation demonstrate that the subvolcanic andesites between Vozdol river and Murgana chalet represent a large sill-like body, intruded partly in the fundament and partly in the volcano edifice. The meso-structural measurements confirm this. In the northern outcrops the plan-parallel structures (after the plagioclase) are gently dipping (20-40°) to south. Their trends here coincide with the trends of the dips of the sandstone formation (Turonian) but to the south they become steeper. The linearity after the amphibole is very well expressed. The prevailing trend is SSE and probably marks the situation of the feeding magma chamber to the south of the recent exposures of the subvolcanic bodies.

Another problematic structure is "the Vozdol volcano". As mentioned above, it was described as post-ore structure on the basis of two facts which could be observed along Vozdol river: ore-clasts, included in its products (Mutafchiev, 1967a; Popov and Mutafchiev, 1980) as well as interfingering of the latter ones with the two-mica sandstones from the upper part of Chelopech Formation. During the present investigations, hydrothermally altered clasts, accompanied by malachite and sulphide minerals were found out to the west (south and east of Debeli Rut place) in the upper part of Vozdol Member (including the products of Chelopech volcano). Moreover, it was found that the materials referred to "Vozdol volcano" represented by lavas, lava-breccias and bomb tuffs exposed in Tsigansko Dere (east of Sharlo Dere and south of Petrovden peak), are strongly hydrothermally altered and comprise visible sulphide and copper-oxide mineralization. That means that these volcanic products could not be post-ore. The lateral interfingering of the two-mica sandstones in the upper part of Chelopech Formation with the Vozdol Member could be observed in other places as well (e.g. in Chugovitsa Dere, Aramu Dere etc.). There are no macro- and microscopic petrographic criteria to separate the Chelopech volcano products from the "Vozdol volcano" ones. Stratigraphically they are situated in one level: underlain by the sandstone formation (Turonian) and laterally interfingering the two-mica sandstone from the upper part of Chelopech Formation. Structurally "Vozdol volcano" products crop out in the north limb of Chelopech syncline occupying the whole section of Chelopech Formation. Where does the Chelopech volcano (Vozdol Member) disappear? We failed to find out criteria for recognizing of the products of the two volcanoes. That is why we accept in the new model that the volcanic rocks under consideration resulted from a late impulse of the Chelopech volcano.

An important mark for the end of the syn-volcanic structure-forming and accompanying hydrothermal activity is represented by two silica beds: the first one is enriched in hematite and the second one – in manganese. The most representative outcrop of them is situated in the ravine east of Debeli Rut ridge but this event could be observed along the contact of Chelopech and Mirkovo Formations all over the region. The red colors of the limestones of Mirkovo Formation are due namely to these rich in iron and manganese hydrotherms. Except for event mark, these beds mark the proximal part of the volcano and give evidence for the lack of significant hiatus between the Vozdol Member of Chelopech Formation and Mirkovo Formation. There is a washout between the two formations but it is local and probably related to more intensive denudation around the volcanic edifice. The olistostrome phenomena observed in Mirkovo Formation and the upper parts of Chelopech Formation are other evidences for this. In some places (e.g. Aramu Dere) the olistostromes include olistoliths of volcanites up to 2 m^2.

The syn-volcanic faults are marked by intensive hydrothermal alterations, which are linear elongated and obviously have got fault predestination. On the surface outcrops some of these faults are related to the contact zones of the subvolcanic andesites, where the principal ore mineralization is also concentrated. Syn-volcanic faults trending 50° prevail. This trend coincides with the trend of the Sub-Balkan fault between the villages of Chelopech and Tsatkvishte.

Another significant for the genetic model problem is the radial-concentric fault system (pattern) defined by Popov, Vladimirov, Bakardjiev (1983) and then multiplicated in many later papers, mentioned above. This pattern is related to an independent caldera-forming stage. The post-volcanic sediments of Mirkovo limestone Formation (Campanian) and Chugovitsa flysch Formation (Campanian-Santonian) cover large part of this system. In the recent structural setting Vozdol river and Garvan Dere really form an almost isometric ring structure, which center is around the shaft "West". We opine that it could be due to the mosaic block structure of the fundament, predestined by the two main regional fault systems: 120° and 50°. Only the west fragment of this structure (along Garvan Dere) coinsides with one of the ring faults interpreted by Popov, Vladimirov, Bakardjiev (1983). During both the field investigations and remote-sensed image interpretation in scales 1:25 000 and 1:50 000 we fail to find such complicated fault pattern. Having in mind that a large part of the syn-volcanic structures in the embrace of Chelopech deposit are allochthonous (Chelopech thrust described by Vrablyanski et al., 1961 and confirmed later by all investigators) we think that the post-Cretaceous deformation phases (Laramian and Illyrian) have entirely reworked the syn-volcanic structure in this district and to look for their primary location is very hypothetical.

The interpretation of the two-mica sandstones, exposed in the rivers of Vozdol and Chugovitsa, as filling of the Chelopech volcano caldera is also hypothetical. The new stratigraphic investigations demonstrate that these sandstones interfinger the products of Chelopech volcano. That means they are partly synchronous to the volcanic activity and mark the periphery of the volcanic edifice. In the uppermost part, next to the contact with Mirkovo Formation, they laterally interfinger redeposited volcanoclastic materials (epiclastites), comprising hydrothermally altered and mineralized clasts but in the lower stratigraphic levels they alternate with lava flows (e.g. Aramu

Dere section). In some outcrops they are even contact-altered (welded) by the subvolcanic andesite intrusions. Such phenomenon could be observed on the outcrops along the road Chelopech - Frunkaya place, south of the deviation for shaft "North", where fragments of Chelopech thrust are exposed.

A problem for clarification the character of volcanic and subvolcanic structures of Chelopech and Vozdol deposits is the big thickness of the Vozdol Member in the central part of Chelopech syncline and its rapid decrease in the periphery parts. The structural interpretations accept most of the volcanics as stratified. That pictures a very steep volcanic edifice, which is not typical for volcanoes with such explosive coefficient. The facies of the drilled in the deep borehole (C-500) volcanics is not clear. A large length of the core exposes altered colcanoclastites, which facies is difficult to be recognized. They are accepted to represent an alternation of lava-breccias and bomb tuffs without any special petrographic investigations. We assume that it is possible these rocks to be formed in the volcanic vent.

The intensive syn- and post-volcanic rework obstacles the interpretations of the structures, which have predestined the formation of Chelopech volcano. Going out from the neotectonic structural setting and its connection with the post-volcanic deformations of the Chelopech volcanic structure (Antonov and Jelev, 2000; 2001) we suppose that it is a result of a transtensional zone, inherited later by an young transpression, which took place along the Sub-Balkan fault and its intersection with Panagyurishte crypto-rupture (Tsvetkov, 1974).

The structural control of the Late Cretaceous ore mineralizations is broadly discussed in the papers mentioned above. Here only the new data will be summarized. The principal ore-hosting and ore-generating structure is Chelopech volcano. The main ore-mineralization of Chelopech and Vozdol deposits is related to the intrusion of the subvolcanic andesites. In Chelopech deposit it is hosted mainly by the porous bomb tuffs but in Vozdol – around the contacts of the subvolcanic bodies and hosted rocks. Vozdol ore mineralization is not related to independent hydrothermal flow, which interrupted the volcano fundament (including and "the early subvolcanic dacito-andesites"). It resulted from the intrusion of these subvolcanic andesites, i. e. the ore mineralizations of Chelopech deposit and Vozdol deposit are genetically related to the same rocks (subvolcanic andesites) intruded in one impulse into the neck part of the Chelopech volcano and its basement. The differences of the mineral parageneses of the two deposits could be explained by the vertical and lateral zonality of the mineralization as well as by the different depth of the erosion level.

ESSENSE OF THE NEW GENETIC MODEL

Chelopech volcanic structure is supposed to be genetically related to strike-slip movements along the Sub-Balkan deep-seated fault. During the Late Cretaceous (Coniacian-Campanian) sinistral strike-slip movements along the en-echelon segments of the fault create an open space in the bridge between them (the fault segment trending 50° and connecting the two subequatorial fault segments) as a result of transtension stress regime. It resembles an initial stage of formation of a pull-apart basin. The explosive and effusive products of Chelopech volcano are concentrated in this space. Volcanic edifice elongated in direction 50° forms. At the end of the stage subvolcanic andesitic bodies elongated in the same direction intrude its central (vent) part. In the fundament these bodies crop out predominantly as sills. Their intrusion forms a hydrothermal system that predestines the principal ore mineralisation of Chelopech and Vozdol deposits. During the Campanian the transtensional regime changes in transpressional as a result of dextral strike-slip movements along the fault. The volcanic activity terminates and a flysh trough forms along the strike-slip faults. After the Maastrichtian this trough is double folded and faulted. First, subequatorial reverse faults, thrusts and folds form, which to the end of the transpression have been refolded. As a result, a positive duplex structure of "palm tree" type forms. A new neotectonic transtension forms Zlatitsa one-sided graben. The step-like in map view trajectory of the bounding Sub-Balkan normal fault is inherited by the trajectory of the deep faulting that has formed the Chelopech volcano edifice.

PROSPECT IMPLICATION

The new view on the structural model of formation and evolution of Chelopech volcano implies a new approach to the perspectives of Chelopech ore field. Only a narrow strip of about 2-3 km around the oblique segment of the Sub-Balkan fault is supposed to be perspective both in its foot-wall and hanging-wall. This is due to the fact that only this space was open during the volcanic activity and related ore mineralisation as a result of the transtenssion. The areas along the subequatorial segments of the fault are considered to be non-perspective because they were shear structures (strike-slip faults) at that time. Moreover, different type of deposits could be expected in the perspective area. Gold-copper massive-sulphide (volcanic-hosted) mineralisation is to be expected in the Chelopech volcanic edifice but vein-like (Vozdol) or porphiry copper (Elatsite, Karlievo) type - in the rocks of its basement.

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BARDO RING MORPHOSTRUCTURE (BULGARIA)

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ABSTRACT
Bardo ring morphostructure is marked by a concentric pattern of the drainage network observed in the region of Ihtiman Sredna Gora Mts. It is imposed on Precambrian high-grade metamorphites, Triassic terrigenous and carbonate sediments, Late Cretaceous sedimentary, volcano-sedimentary, volcano and intrusive rocks. It embraces a multitude of ore deposits and occurrences related to the Late Cretaceous magma activity. Several geophysical anomalies of different types are interpreted here. On the basis of the coincidence of the morphostructure with the geophysical anomalies as well as with the Late Cretaceous volcanic and intrusive rocks, the Bardo morphostructure is considered to be a reflection in the recent structural setting of a big Late Cretaceous volcano-plutonic ring structure, which has controlled the Late Cretaceous magma activity and the related ore mineralization in the region studied.

INTRODUCTION

The morphostructure of a part of Ihtiman Sredna Gora Mts. is the subject of the study, represented in this paper. Due to the presence of a multitude of ore occurrences and deposits of different type, which have been subjected to prospecting and mining for a long period, this part is known as "G. Rakovitsa region". This paper aims to introduce an interesting ring morphostructure (named after the village of Bardo). The principal tasks are as follows: 1) description of Bardo morphostructure and its related morphostructural elements; 2) clarification of its spatial and temporal relations to the regional geology; 3) interpretation of the regional geophysical fields and their relations to the morphostructure; 4) interpretation of the genesis and regional setting of this morphostructure.

PREVIOUS STUDIES

Baltakov (1975) was first who revealed several positive morphostructures in the Ihtiman Sredna Gora, which he described as morphodynamic localities. Investigating the endogenetic predetermination of the recent morphodynamic processes he comes to the conclusion that "the plutonic bodies exposed on the earth surface have significant influence on the recent relief mobility, but the rate of their morphodynamic impact is controlled by the rupture lines of the live tectonics. Baltakov also reveals that some of the plutonic bodies have no influence on the recent morphostructural setting (e.g. the Paleozoic Poibrene pluton in the region studied). According to him the morphodynamic localities have got a decisive impact on the morphostructural setting, configuration and dynamics of the low-ordered morphostructures of the Ihtiman block system. More likely they represent unexposed plutonic bodies or apophyses of intrusive cropping out next to the corresponding morphostructure.

During his studies, Baltakov (1975; 1983) paid attention mainly to the hypsometrical levels of the erosion surfaces and to the radial patterns of the river network, which mark his morphodynamic localities. During the present investigation we discovered a very well delineated ring pattern of the drainage network, which marks a big ring morphostructure. Bardo morphodynamic locality of Baltakov (1975) is situated in its central part. Along its periphery are localized Belitsa locality (G. Ikouna peak), Leskovoprisoe locality, Farchilsky locality etc. (Baltakov, 1975). Despite of the different embrace and methodology applied to reveal the Bardo ring morphostructure, we use the same name for it because the only village in its embrace (as well as the Bardo morphogenetic locality) is the small village of Bardo.

Regionally the studied area is considered as Belitsa block (Spiridonov, 1999), which is a part of the eastern arc of the bigger Sofia ring morphostructure (Petković et al., 1989; Popov and Spiridonov, 1990; Spiridonov, 1999). Panagyurishte ring structure (Popov and Spiridonov, 1990) is situated to east. The boundary between the two ring morphostructure is along the river of Topolnitsa. Juxtaposing the geological and geophysical data these authors prove that the Panagyurishte ring morphostructure marks the area of distribution of the intensive igneous and ore-forming activity of the Panagyurishte ore region and it reflects a big deep-seated magma chamber.

SCOPE AND APPROACH

The Bardo ring morphostructure was revealed during prospecting of gold mineralization in the region of G. Rakovitsa, carried out during 1993-1995. It was delineated by means of topographic maps in scale 1:25 000 and 1:50 000 as well as Landsat images in scale 1:50 000. Moreover, the primary information about the geophysical fields was used and interpreted. Revision geological mappings in scale 1:25 000 (in some places in scale 1:5 000) were carried out. As a result a morphostructural map of the drainage network is completed including the river order determination (Fig. 1). Parts of the geological maps (Fig. 2) of Iliev and Katskov (1990) and

Angelov et al. (1992) are reinterpreted. Interpretation scheme of the regional geophysical fields is prepared (Fig. 3). On the basis of the fulfilled investigations, a comparative analysis of the spatial and temporal relationships of the Bardo ring morphostructure to the rocks exposed on the region and to the geophysical fields is completed and its genesis is interpreted.

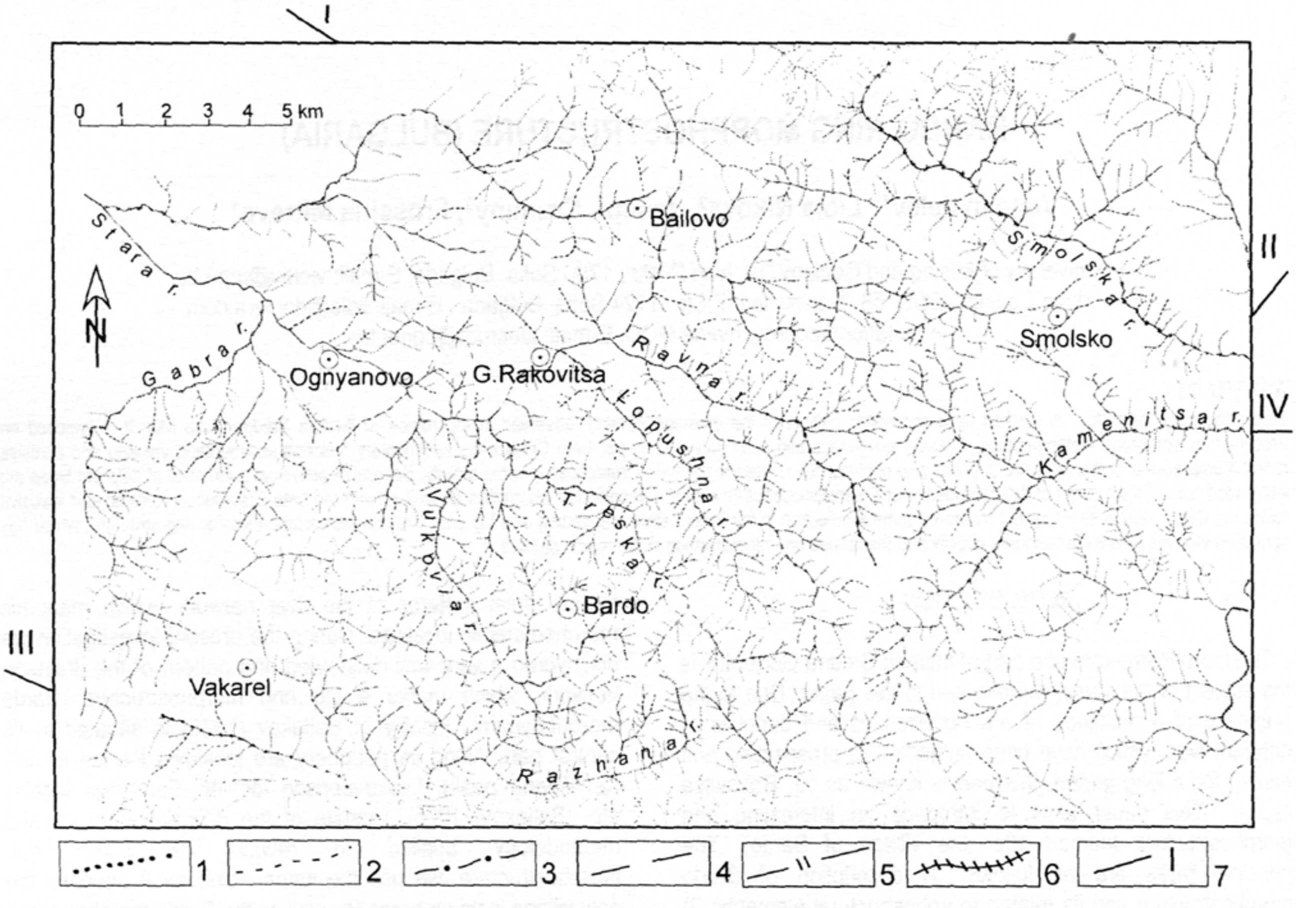

Figure 1. Picture of the drainage network in the region of G. Rakovitsa village
(1 – 6) – order of the drainage network (from 2nd to 7th order respectively); 7 – principal lineament direction of the region

RESULT DISCUSSION

Direct and indirect criteria have been searched while the work hypothesis for prospecting of gold mineralization on G. Rakovitsa region was elaborated. Direct criterion is the presence of gold in the hydrothermally altered zones of "G. Rakovitsa" (NE of G. Rakovitsa village), "Ostra Mogila" and "Dvata Bouka" (south of G. Rakovitsa village) as well as gold presence in the schlich from the catchment area of Stara Reka (Lesnovo) river. There are many indirect criteria, as follows:

- Closeness to Panagyurishte ore region and to its principal ore-generating structure (Panagyurishte deep-seated fault zone).
- Presence of regional faults trending NW-SE, which intersect this structure.
- Similar stratigraphic position of G. Rakovitsa altered zone and the neighboring deposits of proven gold potential (Chelopech, Krassen etc.) of Panagyurishte ore region.
- the ore mineral paragenesis of the same zone is similar to the parageneses of Chelopech deposit and Krassen deposit.
- Comparatively low erosion level of the hydrothermally altered volcanics of "G. Rakovitsa" zone, which is favorable for formation of massive-sulphide and/or vein type ore mineralization.
- Deep erosion level of the hydrothermally altered rocks in the districts of "Ostra Mogila" and "Dvata Bouka" (resp. Triassic sediments and intrusions of Late Cretaceous diorite-porphyrites in the first and Precambrian high-grade metamorphites *in the second one), where the roots of a* porphyry-copper hydrothermal system could be searched.
- The established by Popov and Spiridonov (1990) Panagyurishte ring morphostructure, related to deep-seated magma chamber, which is considered to be the generator of the igneous and ore potential of the adjacent Panagyurishte ore region.

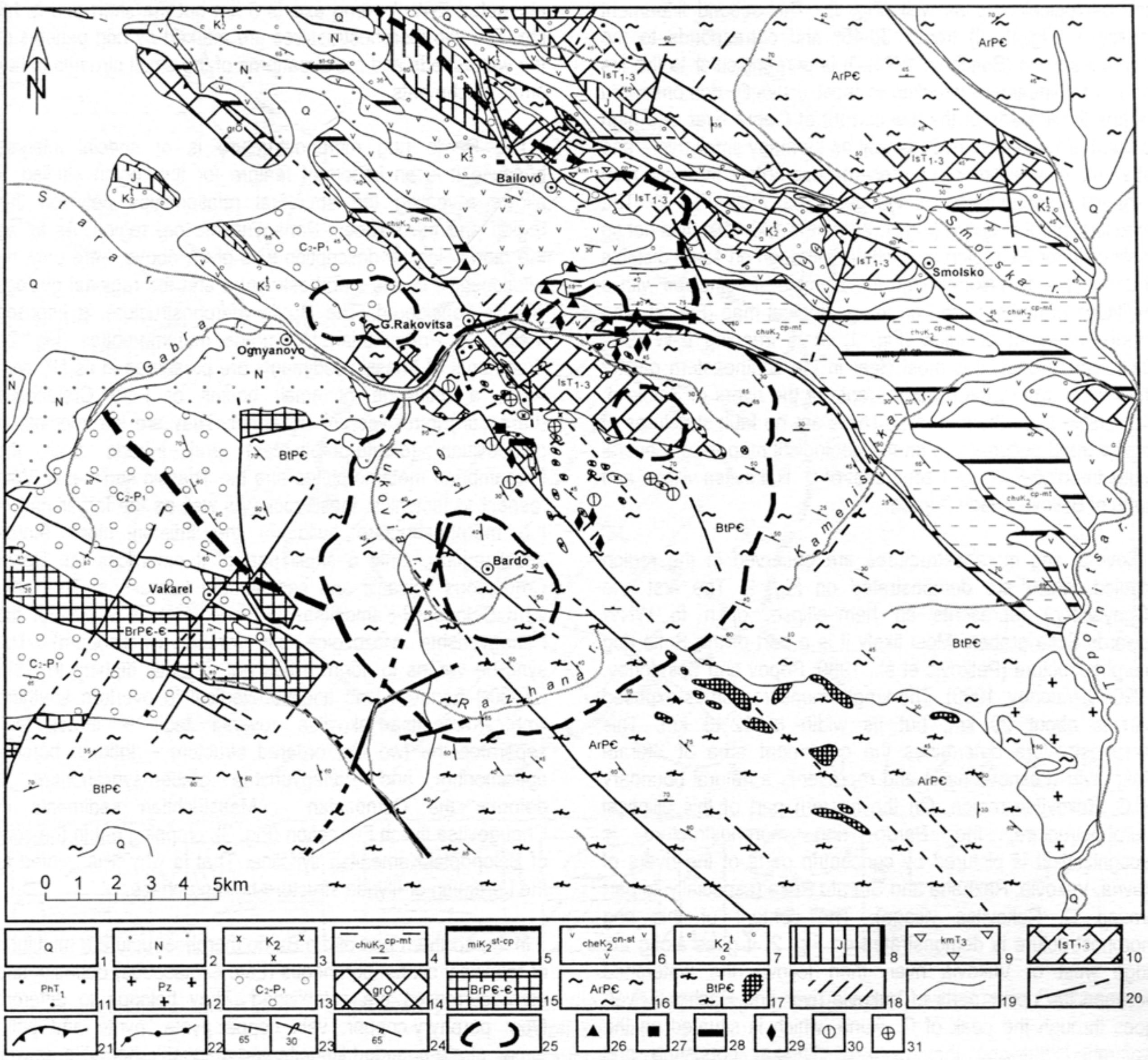

Figure 2.. Geological map of the G. Rakovitsa region, demonstrating the interpreted ring morphostructures and their relationships to the regional geology (after Iliev and Katskov, 1990 and Angelov et al., 1992 with supplements and changes)
1 – Quaternary (alluvial and drift depositions); 2 – Neogene (alluvial-limnic depositions); (3 – 7) – Upper Cretaceous: 3 – Late Cretaceous (Laramien) intrusions; 4 – Chugovitsa flysch Formation (Campanian-Maastrichtian); 5 – Mirkovo limestone Formation (Santonian-Campanian); 6 – Chelopech volcano-sedimentary Formation (Coniacian-Santonian); 7 – conglomerate-sandstone formation (Turonian); 8 – Jurassic (terrigenous, terrigenous-carbonate and carbonate sediments); (9 – 11) – Triassic: 9 – Komshtitsa terrigenous-carbonate Formation (Upper Triassic); 10 – Iskar carbonate Group (Lower-Upper Triassic); 11 – Petrohan terrigenous Group (Lower Triassic); 12 – Paleozoic (Poibrene pluton – granodiorites and quartz-diorites); 13 – Late Carboniferous-Early Permian (terrigenous sediments); 14 – Ordovician (Grohoten shale Formation); 15 – Precambrian-Cambrian (undivided Berkovitsa Group – diabases, phyllites, quartzites); (16 – 17) – Precambrian: 16 – Arda Group (gneisses and amphibolites); 17 – Botourche Group (a – mica schists, gneisses and amphibolites; b – serpentinites); 18 – hydrothermally altered rocks; 19 – geological boundary; 20 – normal fault or strike-slip fault; 21 – reverse fault-thrust; 22 – detachment fault; 23 – dip and strike of bedding (a – normal; б – overturn); 24 – dip and strike of foliation; 25 – ring morphostructure; (26 – 31) – ore deposits and manifestations, related to the Upper Cretaceous magma activity: 26 – manganese; 27 – limonite; 28 – magnetite-hematite; 29 – polymetal; 30 – copper-pyrite; 31 – pyrite.

One of the main tasks of this investigation was related to clarification of the regional geostructural setting of G. Rakovitsa region and looking for its link to Panagyurishte ore region. The work began with study of one of the indirect searching criteria, namely the regional morphostructure. The latter is demonstrated on a simple morphostructural map (Fig. 1), demonstrating the spatial setting of the drainage network of different order. Four principal lineament directions are distinctly visible on the map. The first one (Fig.1, I) trends 120-135° and coincides with the so called Berkovitsa trend revealed by Bonchev (1971) and characteristic for the Western Balkanides. This trend is very well pictured by the linear parts of the rivers of Lopushna, Treska, Ravna and others. It is documented on the geological map as well (Fig. 2). The second lineament direction (Fig. 1, II) trends 30-45° and corresponds to the Tvarditsa trend (Bonchev, 1971). It is perpendicular to the firs one. This lineament direction is most distinctly demonstrated by the linear parts of the low current of Gabra river and high current of Kamenitsa river as well as by many small rivers and streams of lower order. It represents also one of the main fault systems, demonstrated on the geological map (Fig. 2). The third lineament direction (Fig. 1, III) trends 100-110°. It is not so distinctive for the region as a whole, although on some districts it dominates. In Vakarel ridge for example, it coincides with a multitude of faults, traced on the geological map (Fig. 2). The fourth lineament direction (Fig. 1, II) is trending E-W (90°, Balkanides trend). It is most clear in the southeastern part of the region, where the lower currents of the rivers of Smolska, Kamenitsa and others mark it. There are no fault structures of similar trend documented on the geological map here. Several faults trending E-W are traced east of G. Rakovitsa village and north of Bailovo village (Fig. 2).

Several ring morphostructures are observed in the region studied, which are demonstrated on Fig. 2. The first one (Ognyanovo) represents an hemi-ellipse, open to WNW towards Sofia graben. Most likely it is a part of the Sofia ring morphostructure (Petkovič et al., 1989; Popov and Spiridonov, 1990; Spiridonov, 1999). The length measured on its exposed part is about 20 km, but its width is 12-13 km. This morphostructure determines the catchment area of Starata Reka river (Lesnovo river) and represents a natural boundary of G. Rakovitsa region. On the eastern part of this elliptical morphostructure, the Bardo ring morphostructure is recognized. It is pictured by concentric parts of the rivers of Ravna, Vukovia, Razhana and Starata Reka (especially its part around G. Rakovitsa village). The contour of this ring morphostructure is demonstrated on Fig. 2. It goes along the ridge west of Vukovia river, then follows the watershed between the upper parts of Vukovia river and Razhana river, goes through the peak of G. Ikuna, which is situated on the watershed between the rivers of Treska, Lopushna and Kamenitsa (Lesnovo catchment) and the rivers of Kamenitsa, Matnitsa and others (Topolnitsa catchment). Then it follows the ridge NE of Ravna river and around G. Rakovitsa village coincides with Starata Reka river. The Bardo ring morphostructure resembles an ellipse in plan view. It short axis is 11 km and the long one is 14 km. The directions of the two axes coincide with the main lineament trends: the short one - with Berkovitsa trend but the long one – with Tvarditsa trend. Eccentrically, in the SW part of the Bardo morphostructure is imposed another ring morphostructure (entirely coinciding with the Bardo morphodynamic locality of Baltakov, 1975). Its shape is elliptical as well. The long axis is 4,5 km, but the short one is 3 km. The directions of the two axes are reverse to the previous one: the long axis possesses Berkovitsa trend but the short one – Tvarditsa trend.

The patterns of two other morphostructures are recognized in the region. They are not so distinctive. The first one (Mishkovets) is situated SE of G. Rakovitsa village, between the rivers of Ravna and Lopushna. In plan view it resembles a circle with diameter about 2 km (фиг. 2). The second one is situated west of G. Rakovitsa village. It represents an ellipse, elongated E-W. Its long axis is 3 km but the short one is 1,8 km. The two morphostructures are marked by ring patterns of the watersheds and radial patterns of the small streams of two small catchments.

The Bardo ring morphostructure is of special interest, because it is an important feature for the region studied. It allows revealing the structural relationships between this region and the adjacent Panagyurishte ore region. As far as the morphological description was given above, here only the relationships of this morphostructure and the regional geology will be considered. The Bardo morphostructure is imposed mainly on Precambrian high-grade metamorphites (Fig. 2). Fragments of Triassic sediments are preserved in its NE part. Here, a multitude of small bodies of Late Cretaceous (Laramian) intrusives are observed. They are intermediate in composition (diorite-porphyrites) and intrude both the Precambrian metamorphites and the Triassic sediments. With respect to tectonics, these rocks as well as the larger part of the morphostructure build up the Ihtiman block (horst-anticlinorium). Only a small part of it embraces the Upper Cretaceous volcanic and sedimentary formations. The latter form Belopoptsi-Kamenitsa syncline, which is a part of the Panagyurishte Mezozoic strip (graben-synclinorium). The syncline verges to north. It has got a gently dipping to SSW (20-30°) northern limb and sub-vertical to overturn southern limb. Kamenitsa-Rakovitsa reverse fault – thrust fault separates the two first ordered structure – Ihtiman horst – anticlinorium and Panagyurishte graben-synclinorium. It deforms the Campanian – Maastrichtian sediments of Chougovitsa flysch Formation (Fig. 2), cropping out in the core of Belopoptsi-Kamenitsa syncline. That is why it is related to the Laramian or Illyrian structure-building phase.

In the northern part of the Bardo morphostructure a multitude of relatively contemporaneous (Late Cretaceous) deposits and ore-occurrences are established. They belongs to different type: porphyry-copper, vein copper-pyrite, pyrite and poly-metal, strata-bounded limonite and magnetite-hematite as well as sedimentary – exhalation manganese mineralizations are described here. The most abundant of ore mineralizations is the district of the hydrothermaly altered rocks NE of G. Rakovitsa village. The hydrothermal alteration is superimposed on the volcanites of Chelopech Formation (Coniacian - Santonian). It resulted from the intrusion of subvolcanic bodies predestined by faults. A big subvolcanic body was reveal by boreholes between the villages of G. Rakovitsa and Bailovo. It is situated among volcanic products of andesite composition (hornblende-biotite andesites) with prevalence of lava flows and bomb-tuffs. Laterally to NW, NE and SE the thickness of Chelopech Formation rapidly decreases and Mirkovo Formation (Santonian – Campanian) replaces it. This peculiarities gives ground to supposed the existence of a central type volcanic edifice (G. Rakovitsa volcano), fragment of which is preserved between the villages of G. Rakovitsa and Bailovo (Fig. 2).

The spatial relationships between the Bardo ring morphostructure and the regional geophysical fields are demonstrated in Fig. 3.

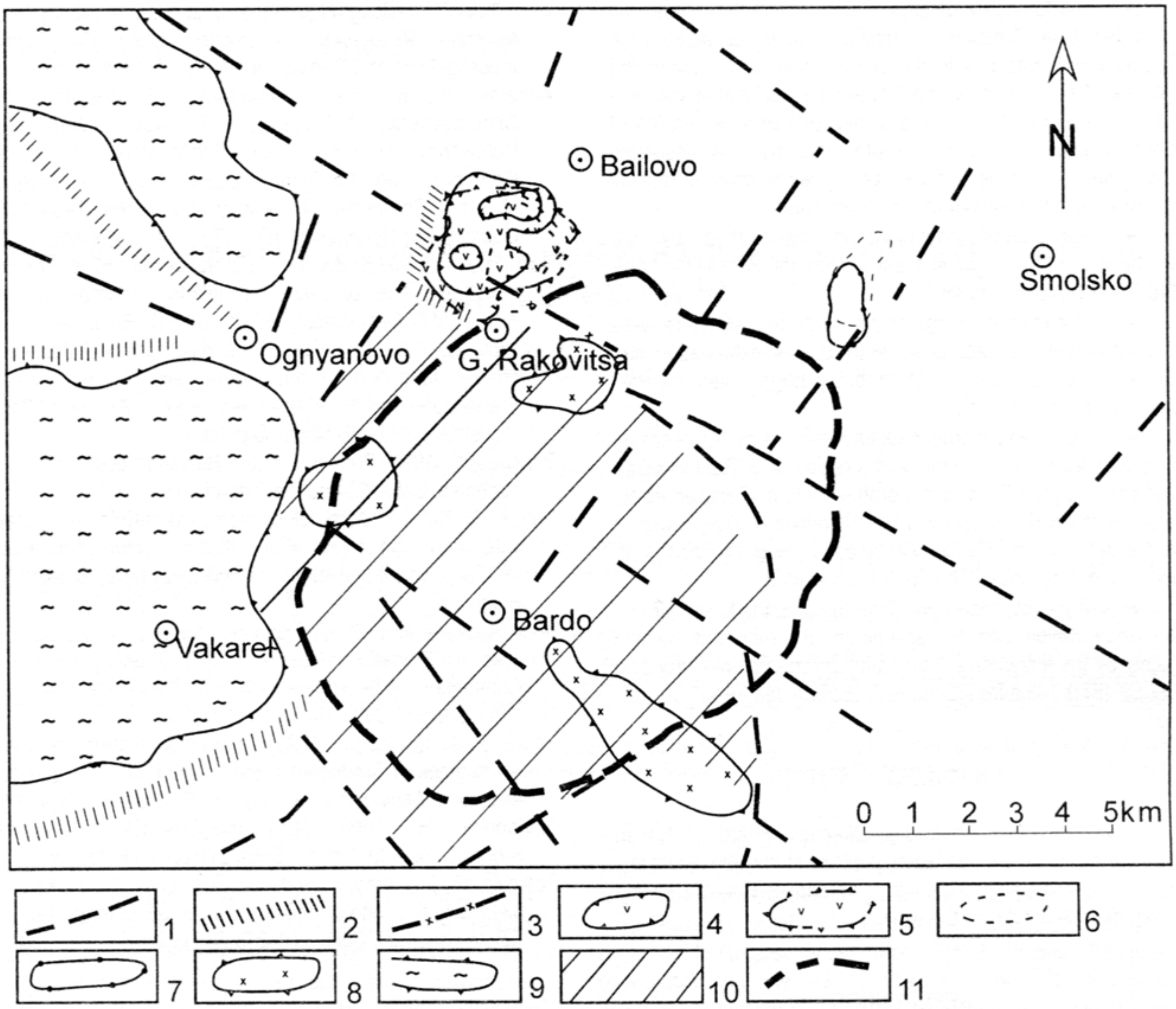

Figure 3. Interpretation scheme of the geophysical fields on the G. Rakovitsa region and their relationships to the Bardo ring morphostructure

1 – gravity lineament, probably related to intensive granitization (Δg minimum); 2 – gravity lineament, probably associated with a contact of rocks of different density (Δg gradient); 3 – magnetic lineament, interpreted as a zone of hydrothermal alteration of the rocks; 4 – volcanic centre, marked by Δg minima; 5 – volcanic centre, marked by ΔT maximum; 6 – above the background potassium values according to the aero-gamma spectrometry; 7 – above the background uranium values according to the aero-gamma spectrometry; 8 – crypto-intrusion of diorite to granodiorite composition, marked by Δg maximum; 9 – area of distribution of dense Paleozoic (?) rocks of basic composition (Δg maximum); 10 – Δg maximum related to deep-seated magma rocks of relatively high density ; 11 – contour of the Bardo ring morphostructure.

The gravity lineaments coincide with the two principal lineament directions (Berkovitsa and Tvarditsa ones), which are demonstrated on fig. 1 and fig. 2 as well. Three crypto-intrusions of diorite to granodioite composition are recognized both in the embracement and along the periphery of the morphostructure according to Δg highs. Spatially they coincide both with the morphostructure and with Δg maximum, related to deep-seated magma rocks of relatively high density. These crypto- ruptures as well as the multitude of small intrusive bodies (diorite porphyrites), cropping out on the surface in the embrace of the morphostructure, could be interpreted as apophyses of a deep seated intrusive body. The coincidence of several anomalies (ΔT maximum, Δg minima and potassium values above the background after aero-gamma spectrometry) between the villages of G. Rakovitsa and Bailovo confirms the geological facts mentioned above about the existence of a fragment of volcanic edifice, preserved in the northern periphery of the Bardo morphostructure. The areas of distribution of dense Paleozoic (?) rocks of basic composition, marked by two Δg maxima, coincide with the distribution of the undivided Berkovitsa Group (Precambrian-Cambrian) and Grohoten Formation (Ordovician) comprising diabases, phyllites, quartzites and shales as weel as with the exposures of the Upper Carboniferous-Permian conglomerates enriched in clasts extracted from theses lithostratigraphic units (diabases, phyllites, shales, quartzites).

The principal conclusions from the analysis of the morphostructural data and their juxtaposition with the regional geophysical and geological data are, as follows:

- Bardo ring morphostructure is a superficial reflection of a big Late Cretaceous volcano-plutonic association. A fragment of its upper (volcanic) part is preserved between the villages of G. Rakovitsa and Bailovo (G. Rakovitsa volcano) but its plutonic part comprises a multitude of small bodies of diorite-porphyrites and crypto-intrusions representing apophyses of a large intrusive body, which contour roughly coincides with the contour of morphostructure.
- Bardo morphostructure is predestined by the combination of two regional lineament trends: Berkovitsa (120-140°) and Tvarditsa (30-45°).
- The main elements of the Bardo ring structure were created during the Late Cretaceous but its exhumation and formation in the recent relief probably began after the last phase of folding (Illyrian).
- Bardo ring morphostructure as well as the rest ring morphostructures recognized on the region of G. Rakovitsa are part of the bigger Sofia ring morphostructure (Petkovič et al., 1989; Popov and Spiridonov, 1990; Spiridonov, 1999), which is responsible for the Late Cretaceous magma- and ore-generating processes in the West Srednogorie.
- The link between the morphostructures of G. Rakovitsa region and Panagyurishte ore region is fulfilled mainly by the lineaments (faults and crypto-ruptures) trending NW-SE (Berkovitsa trend) and E-W (Balkanides trend).

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PRINCIPLES AND POTENTIAL FOR SEQUESTRATION OF CO_2 IN GEOLOGICAL SECTION OF BULGARIA

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ABSTRACT
Nowadays, there is a consideration that anomalous accumulation of greenhouse gases in the atmosphere is caused b the anthropogenic activity of mankind. The CO_2 represent the major technogeneous emission and it is believed to be holding the decisive role in formation of greenhouse effect. The present contribution is focused on the issue of CO_2 deposition in appropriate geological structures.
In compliance to the Minutes of Kyoto, Bulgaria has undertaken the responsibility to reduce emissions of greenhouse gasses with 8 % in comparison to 1988 г. and for the years 2008-2012 they should not exceed 92.261 MT/per year of CO_2 equivalent.
The option for significant reduction of emissions by catching and deposition of CO_2 within natural hosting medium are estimated as the most prospecting approach. It is practiced in two major versions: deposition in the deep water of the world ocean; deposition in natural geological reservoirs. The second version most often consists in deposition of mined out coal deposits; exhausted oil deposits, deeply deposited aquifers, non-economical gas localizations, water traps, oil-bearing layers of slight permeability, etc.
Based on the experience of studying the reservoir properties of Mesozoic and Neozoic section in North Bulgaria, it may be estimated that professionals from the petrophysical sector of applied geology are able to deliver acceptable and economically advisable decisions for significant emitters of Bulgarian industry and transboundary exchange, as well.

INTRODUCTION

The objective of the present work is focussing the attention on the role of greenhouse gases and in particular on the issue of CO_2 deposition into appropriate geological structures. That idea is comparatively new in world practice and it has not been a subject of detailed study yet in Bulgarian specialized literature. Emphasizing the above topic, the author believes that new opportunities will open for Bulgarian geologists and engineers and together with professional from the energy sector they will be able to suggest a platform for implementation of activities for reducing CO_2 emissions in the atmosphere. At present Bulgarian enterprises emit greenhouse gasses below the critical boundary of accepted responsibilities, however, standards are expected to become stricter in the nearest future and therefore the topic will become debatable.

GENERAL INFORMATION ABOUT HARMFUL EMISSIONS AND THEIR ROLE FOR CLIMATE CHANGE

Nowadays, it is considered that anomalous accumulation of greenhouse gases in the atmosphere is caused by the anthropogenic activity of mankind and, in particular, by the industrial revolution, which originated at the end of the 17 century. The major technogeneous emission consists of CO_2, which is believed to play a decisive role in the formation of greenhouse effect.

Series of models (emission scenarios for estimation of greenhouse effect) are developed to solve the issue, and the main working scheme for prediction and management of emissions of greenhouse gases is derived. That scheme is based on the individual warming effect, the index Greenhouse warming potential – GWP compared to the basic greenhouse gas - CO_2. The GWP index shows the cumulative increase of greenhouse potential for a unit mass of any particular gas, compared to the greenhouse effect of the basic gas. The index shows not only the link to basic gas, but also allows a prediction in inverse direction, i.e. in case of reduction of CO_2 what is the equivalent that may be expected for the other greenhouse gases (table 1). A large scope of information is collected, according to that scheme, and its balance witnesses the decisive role of anthropogenic activity of mankind on the global climate change. Based on the above analyses, numerous international forums alarm about the need of international agreements on issues of climate. As a result of those efforts the UN General Assembly established an *Intergovernmental Panel on Climate Change-IPCC* in 1990 with the general goal of developing a Framework Convention on Climate changes – FCCC. It was approved on May 9th 1992 in the UN Centre in New York. It is approved by 154 countries in June 1992 in Rio de Janeiro, including the countries of the European Union. A top body of the Convention is the Conference of the countries, which holds its first meeting in 1995 in Berlin, then in 1996 in Geneva and in December 1997 in Kyoto. In fact, the principal document, known to the world society as the Minutes of Kyoto was approved at the last meeting. Formally, the 39 National Assembly of the Republic of Bulgaria ratifies the Minutes on 17th July 2002 and thus take the responsibility to reduce emissions of greenhouse gases for the period of years 2008-2012 with 8 % in comparison to the basic year of 1988.

According to Annex A of the Minutes, the greenhouse gases comprise carbon dioxide (CO_2), methane (CH_4), fluorhydrocarbons (HFCs), per-fluor-carbons (PFCs), sulfur hexafluoride (SF_6) (table1).

Table 1. Predicted values for CO_2 generation from Bulgarian industry for the period up to 2015, equaled to CO2 equivalent (MT/year) and a reserve quotation according to the limit of the Minutes of Kyoto (according to data of Ministry of Environment and Waters, the quotation of the Minutes of Kyoto represents 92. 261 MT/year

Year	Total emissions of CO2 equivalent (MT/year)					
	General scenario		Sub-scenario with reduced export		Sub-scenario with incrased export	
	Mass Emissions	Reserve according to Minutes of Kyoto	Mass Emissions	Reserve according to Minutes of Kyoto	Mass Emissions	Reserve according to Minutes of Kyoto
1998	57.4		57,4		57,4	
2005	63.2		57,1		68,3	
2010	73.4		67,0		79,9	
2015	77.9		73,4		85,2	
2008-2012 (average)	72.9	18,7	66,6	25,66	78,5	13,79

Brief information about emissions of greenhouse gases from economic medium in Bulgaria.

According to the Minutes of Kyoto, Bulgaria is responsible to reduce emissions of greenhouse gases with 8 % in comparison to year 1988, approved as a basic year. The level of emissions for the basic year is recorded as 100.28 MT/year emissions, transformed into equivalent of CO_2. Reduced with 8 % emissions for the period of years 2008-2012 should not exceed 92.261 MT/year CO_2 equivalent, which is the limit of responsibilities, accepted by the country.

The Ministry of Environment and Waters as well as the Ministry of Energy and Energy Resources, with the aim of monitoring and control of emissions, developed structural models with a number of scenarios, which predict the level of emissions not only for the monitored period of time but even after it (table 2). In general, results obtained for the period of time, considered within Bulgarian responsibilities, show that economic media in the coutry is still below the critical values, however in future periods of stricter limitations, emissions reach the critical level, which requires in time activities. If intentions of the Government take place and Bulgaria is positioned as an energy center on the Balkans and sustainable power production is achieved with the cease of energy blocks of the "Kozloduy" power plant, emissions of thermal power plants will increase significantly reaching the critical 90 MT/year. Concurently to responsibilities of the Kyoto mitutes, Bulgaria is expecting to become a part in a number of Directives of the European Union and in particular the 2001/ 80/EC Directive for large combustion installations, where requirements are rather high. In that sense discussing and managing the emissions is an issue of strategic planning.

PRINCIPLES FOR SEQUESTRATION OF CO_2

Activities in two directions are possible:

- reducing the emissions of greenhouse gases in the atmosphere;

- increasing the options for absorption of emission (refers to absorption by aqueous masses, absorption by biosphere etc).

Subject of the present study is the options for reducing of emissions of greenhouse gases in the atmosphere, in particular, opportunities for reduction of CO_2.

Principle directions for reducing CO_2 emissions in the atmosphere

Approximately one third (35%) of CO_2 emissions come from power plants on fossil fuel and nearly the same quantity (39%) is emitted by numerous industrial installations (refineries, cement plants, steel industry). Share of transportation sector is estimated as 21 % and insignificant share (5 %) is occupied by other sources (fig. 1). Power production and some other industries are referred as industries with controllable and effective reduction of emissions. However, transportation sector and households are not believed to experience noticeable results in emission reduction for well-known reasons. In that aspect, three major principles for reduction of emission from the two large groups of emitters may be defined:

- pure technological decisions;

- reduction of emissions by capturing and deposition of CO_2 in purposefully constructed containers for short-time storage and subsequent technological processing, on the principle of technological deciisons of the reaction of Fischer-Tropsch, commonly applied by the "Sasol" in the Republic of South Africa.

- reduction of emissions by capturing and deposition of CO_2 in natural hosting medium with a large capacity and long-term reliability against migration of deposited gas.

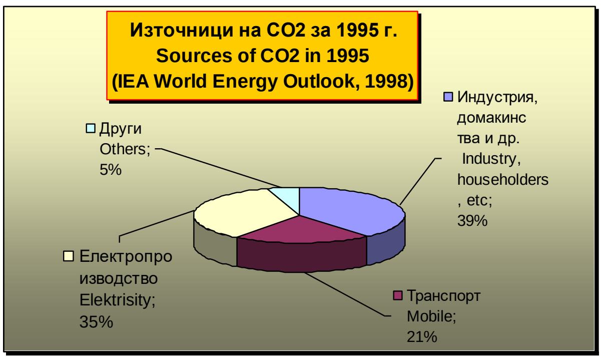

Figure 1. Sources of CO_2

There are numerous approaches for pure technological reduction of CO_2 from both major sources, for example improving the technological parameters of combusting installations, transformation from one fuel to another one etc. Estimations show that those measures do not correspond to a large potential for reduction needed to comply the requirements of the Kyoto minutes. Similar is the estimation for container storage. For that reason, other decisions are needed, one of them being the capturing and long-term deposition of CO2 into appropriate natural hosting medium. Recently acquired practical results showed that the above method is extremely prosperous. .Furthermore, that approach does not require radical changes in the infrastructure of delivery of energy sources.

Table 2. Some important projects for capturing and deposition of CO_2 in projects all over the world

Continent	Geographic affiliation	Brief information about the project
North America	Oklahoma Shady Point Power Plant;	Reduction of CO_2 by absorption in liquid medium
	Weyburn Oilfield	Depositing in low productive oil-bearing layers, volume of deposited mass - > 5000 MT/day
	New Mexico Can Juan Basin	In deeply occurring non-economical coal seams
	Salt Lake Sity	Experimental project of formation of fractures and subsequent injection of CO_2
	Utah, Ohio	Aquifers with a high level of total dissolved solids.
	Alabama	Deposition in coal seams
	New York	Deposition in basalt massif
Africa	Algeria, Salah project	Deposition in exhausted gas reservoirs
Middle East	Abu Dabi Deposits Mubarras, Umm Al-Anbar, Neewat Al-Glahann	Injecting significant quantity of gas mixture, where the CO_2 is prevailing
Europe	Project Sleipner Field Gas field	CO_2 from a system of heating installations is deposited in the aquifers
	Norway Snohvit	Depositing the gas from a plant for production of LNG by means of 160 км ducts
	The Netherlands	Depositing in aquifers
	United Kingdom	Depositing in oil-bearing reservoirs
Asia	Japan	Depositing in aquifers of known reservoir properties
	China Liaohe Oilfield	Injection of CO_2 for intensifying the oil liberation
Australia	Australian Petroleum Research Centre	Depositing of CO2 in aquifers from convection of natural gas into LNG; Depositing in exhausted gas reservoirs

PRINCIPLES OPTIONS FOR REDUCING THE EMISSIONS BY DEPOSITION IN NATURAL HOSTING MEDIUM

Experience of compulsory introduction of CO_2 in the oil deposits and results from the efforts of the International Energy Agency (IEA), as well as efforts of private energy companies, forced to invest in reduction of greenhouse emissions revealed that principle efforts in that direction need to be focussed as follows:

- options for deposition in the deep sea of the world ocean;

- options for deposition in natural reservoirs of the geological medium (fig. 2);

Deep waters of the oceans are estimated as very prosperous for deposition mainly due to the expected lower levels of investments and lower exploitation cost. Large potential of World Ocean is also an important advantage. Furthermore, it is well known that within the World Ocean there is a continuous and equalized process of CO_2 absorption by the atmosphere without certain knowledge about the thermal-barometric and physical-chemical behavior of deep-sea ocean waters in case of compulsory injection of CO2. That means that initial obstacles before the practical application of that opportunity are still not overcome.

As it is well-known, CO2 was injected into oil-deposits for increase of oil liberation. Recently, number of experiments was carried out and interesting results were obtained for the deposition of CO_2 in reservoir rocks, saturated with mineral waters. That gave an additional advance and today a number of projects on other modifications of geological reservoir deposition are developed and financed. In that case processes of interaction and behavior of the rock-fluid system are described with higher reliability. In practice, the following main directions are considered for deposition of CO2 in geological hosting medium (fig. 2):

- mined out coal deposits;
- mined out or exhausted oil deposits;
- deeply occurring aquifers;
- non-economical gas localizations;
- water-bearing trap structures;
- oil-saturated layers of slight permeability;

- etc. .

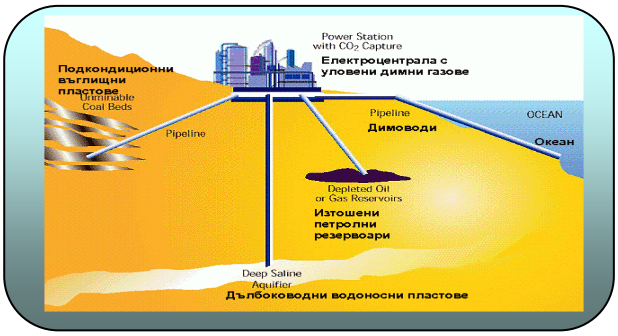

Figure 2. Storage Options for CO2

Information about important projects from the international practice for deposition of CO_2 in the geological hosting medium is shown in table 3 to support the author's opinion. Worldwide distribution of that activity and positive consideration of energy companies give a reason that underground deposition has its own future, including its future in Bulgarian economy.

POTENTIAL OF BULGARIA FOR UNDERGROUND SEQUESTRATION OF CO_2

Matters of regions and dimensioning of noxious emissions from industrial enterprises in Bulgaria are an object of precise investigations that may be found in specialized bibliography. At that preliminary stage we will discuss only some important zones from a point of view of CO_2 emissions. Those are:

- coal mining and power production plants "Maritsa-East" and "Bobov dol";
- industrial area near Devnya, including the "Varna" power plant";
- industrial areas of Sofia and, firstly, district heating plants;
- metallurgical plant of "Kremikovtsi";
- industrial area near Rouse and, firstly, "Rouse" power plant;
- cement-producing plants;
- others.

Perspectives for the major emitters in North Bulgaria may be outlined as referred to the following:

- regional, zonal- and local natural reservoirs, affiliated to established and comparatively well studied Paleozoic, Mesozoic and Neozoic aquifers;

- the numerous trap structures, outlines by seismic and borehole exploration, but considered for a certain reason as non-economical and therefore not-involved into development;

- mined out and exhausted oil-bearing and gaseous areas, the further exploitation of which is estimated as economically non-effective;

- larger structures, formed as a result of salt excavation.

One may consider that due to broad experience from exploration of reservoir properties of the Mesozoic and Neozoic section in North Bulgaria, professionals from the petrophysical sector of applied geology are able to provide acceptable and economically reasoned decisions for both significant emitters of Bulgarian industry and trans-boundary exchange, as well.

As It is well-known, geological cross-section in South Bulgaria has not been explored to a satisfactorily extent from a point of view of natural reservoirs. That makes the formulation of a strategy for sequestration of CO_2 from the main emitter in the country – the power production site of "Maritsa-East" with its four power plants, where local, low quality lignite coal are burned, extremely difficult. Limited number of boreholes and their low depth do not reveal the perspectives for sustainable control of noxious emissions from power production in that region. For periods of later future, if directives of the EU introduce much more strict restrictions, the author believes that there are reasoned opportunities for investing in exploraion within the perimeter of the Eastern Rhodopes depression. Preliminary data for that region show that at a depth below 800 m significant quantities of noxious emissions may be deposited in a sustainable way.

BRIEF INFORMATION ON FINANCIAL ASPECTS OF PROJECTS FOR SEQUESTRATION OF CO_2

For reasons of different kind there are no unified cost models for estimating the projects for deposition of CO_2 in the geological hosting medium. Only, general information is available, which reveals that cost of kWh will become higher with 1.5 cents. Additionally, the efficiency of technological process will be reduced with at least 10 %. The integral estimations show that sequestration of emissions will cost within 40-60 US dollars for ton of CO_2.

NEXT STEPS

The following matters are considered as the main priorities in development of technologies for sequestration of CO_2 :

- more complete investigation of the mechanism of dissolving of gases in the layer fluids of different physical-chemical characteristic;
- development of simulation models and systems for monitoring the migration of deposited gaseous material into the hosting geological medium;
- development of information and reliable cost models with the aim of developing cost-efficient projects;
- reasoning a strategy, which will stimulate the crediting of projects for sequestration of greenhouse gases;
- assistance in the development of regulating norms that will generate sustainable interest within financial institutions and energy companies, which invest in activities of climate protection.

CONCLUSION

The option for capturing and depositing of CO2 in natural reservoirs of the geological medium is estimated as extremely prosperous and beneficial. The high rate of exploration of the geologic section in North Bulgaria is a precondition in favor of development of activities not only for depositing emissions from Bulgarian industry but also for trans-boundary exchange. That is expected to be normal practice, at least for the countries of the EU, similarly to the opportunity for guaranteeing obligatory reserves of oil and oil products.

It is evident that each financial loading will be critically accepted by energy companies, however severe consequences of climate change are the moving force for reduction of greenhouse gas emissions.

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HYDROTHERMAL ORE-BEARING FEATURES OF IGNEOUS INTRUSIVE COMPLEXES

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ABSTRACT
This article is an attempt to generalise information on hydrothermal ore mineralization presence, connected with different petrochemical types intrusive magmatic complexes. In the table ore-bearing intrusive complexes are distinguished and characteristic economic types of deposits are given, main morphogenetic types of ores and types of wallrock alteration, as well as mineral types of deposits are specified. Typical examples are adduced and distribution of each mineral type in Bulgaria is given. The typical ore objects cited usually are ore fields or ore districts with maximum presence of economic mineralization and thoroughly investigated. Metallogenic specialisation of different petrochemical types of igneous intrusive complexes is drawn. Spatial and genetic relations of ores and intrusive bodies are considered. Main types of geodynamic environments, in which discussed hydrothermal deposits were formed, are outlined. It should be underlined that they are mainly Phanerozoic.

INTRODUCTION

The most of hydrothermal deposits are connected temporally and spatially with intrusive (plutonic) complexes, so conclusion that the link between ore mineralization and igneous rocks is genetic one is accepted. It should be mentioned that isotopic data prove also presence of non-magmatic substances – water and dissolved components. This brings up a matter about existing of genuine, not only thermal, but also substantial-genetic relation of ore mineralization with relevant igneous complexes. Conceptions on this till the middle of XX century vary within wide range – from universal ore-bearing granitoid plutons (Emmons, 1936 et al.) to quite narrow specialisation of intrusive complexes (Smirnov, 1937). Meanwhile, till the end of the century a lot of information on this problem was obtained without drawing general conclusion. The recent work represents an attempt along these lines.

SOURCE DATA AND RESULTS

The information on hydrothermal ore-bearing evidence of different petrochemical types igneous intrusive complexes is summarised in the table. Hydrothermal deposits, connected with intrusive complexes from Europe, countries from former USSR, China, Japan, Canada, USA, Australia, Southern Africa, Northern Africa, partially western part of Southern America were taken into account, while for Cu-porphyry deposits, deposits of Mo, Sn, Sb, Hg, Au, U, fluorite – the whole World. The references include only the most important papers on this problem, because of the limited space. Information is quite comprehensive, but is not complete, due to its limited character on deposits in Southern America, Africa, India, Middle East, SE Asia. It should be mentioned that Au and Sb deposits in greenstone belts (mainly Archaean), recently are assumed partially or completely as plutonogenic hydrothermal type. During the past years the predominating opinion is that these deposits in some extent are sub-aqueous, of volcanogenic-hydrothermal type. They are not taken into account in this article due to their controversial origin.

INTRUSIVE COMPLEXES AND RELATED ORE DEPOSITS

1. Ultrabasic complexes
Mainly Phanerozoic (alpinotype) peridotite complexes. Allochtonous bodies in orogens. Ore deposits:
a) Main deposits: chrysotile-asbestos, talc. Widespread in Ural and Appalachian Mt.
b) Subordinate deposits: anthophyllite-asbestos (Ural, RF; Eastern Rhodopes).
c) Rare and very rare deposits: nephrite, magnesite.

2. Basic (gabbro) complexes
Ore deposits: Fe (Mt-skarn, very rare). Subduction zones.

3. Intermediate complexes
Diorite, quartz-diorite, syenite, monzonite, mixed. Subduction zones. Ore deposits:

a) Main deposits
- a_1) Fe: Mt-Sk (carbonate host rocks), Mt-Act (mafic host rocks). Typical for oceanic parts of subduction zones. The former ones are widespread in Ural, the latter – in Turgai, Kazakhstan and in ore belt El Romeral, Chile. Ore-bearing complexes are mainly diorite and syenite, direct, or in regional aspect genetically connected with tholeite-basaltic volcanites.
- a_2) Cu $\pm$ Mo: Mo-Cu porphyry (main), skarn (subordinate), vein-type (rare – Bourgas ore district; dep. Butte, Montana, USA; Cuba). Typical for subduction zones, mainly of Andean type. Deposits are concentrated within two large ore belts: Cordilleran-Andean and Mediterranean (Banat, Romania – Minor Caucasus, Armenia – Iran – Pakistan). The former belt is extremely rich (hundreds of deposits, some of them of world class – El Teniente et al.). Ore-bearing complexes are mainly monzonitoid, syenite, quartzdiorite, often direct, or in regional aspect genetically related with andesite volcanism.

Hydrothermal deposits related to intrusive complexes

Ore-bearing intrusive complexes	Economic types of deposits	Main morpho-genetic type of ore bodies	Type of wallrock alteration	Mineral types of deposits	Typical examples	Occurrence in Bulgaria
1	2	3	4	5	6	7
Ultrabasic (mainly peridotite)	Nephrite	M	Serp ? Tre[1]	Act and/or Tre	Dep. Ospinskoe, Western Sayan, RF Dep. Maritosa, Vermont, USA	
	Asbestos	V	Serp ? Ant	Ant-Asb	O. f. Susertskoe, Ural, RF	Ihtiman Sredna gora Mt.: dep. Belitza, Muhovo, Tzerovo et al. Western Rhodopes: dep. Dorkovo, Kostandovo Eastern Rhodopes: dep. Yakovitza, Avren, Goliamo Kameniane, Kamilski dol et al.
			Serp ? Act, Tre	Tre-Asb, Act-Asb		Eastern Rhodopes: o. oc. Jalti chal, Boturche et al.
				Chrys-Asb	Ore belt Alapaevsko-Bajenovski, Ural, RF – dep. Bajenovskoe Ore belt Thetford, Quebec, Canada – Vermont, USA, dep. Jeffrey Mine	Eastern Rhodopes: ore occurrences Yakovitza, Goliamo Kameniane
				Pic-Asb*		Dep. Brusevtzi, Eastern Rhodopes
	Talc	M	Amph[2] ? T-car	Amph-Tal		Sakar Mt. – dep. Ovcharovo Eastern Rhodopes: dep., Avren, Goliamo Kameniane et al.
			Serp ? T-car	Chl-Tal*	Dep. Seg, Carelia, RF	O. oc. Krainovo, Yambol district
				Tal $\pm$ Mag	Dep. Shabrovskoe, Ural, RF	Ihtiman Sredna gora Mt.: dep. Poliantzi, Gabrovitza et al. Western Rhodopes: dep. Pletena, Stanchavitza, Kochan et al. Eastern Rhodopes: dep. railway station Djebel, Genovo, Yakovitza, Boturche et al.
	Magnesite*	M	Serp ? T-car	Mag+Tal, Chl et al.	Dep. Mantudi, Is. Euboea, Greece	Dep. Gornoslav. Assenovgrag district – partly magnesite
Basic (gabbro)	Fe*	M	SK (Mgsk ? Cask)	Mt-Gar, Px, Fo*		Ore field Krumovo, Manastir Heights
			Act	Mt-Act*	Dep. Anzaskoe, Western Sayan Mt., RF	

[1] On contact with gabbro also rodingites are formed (grossular, diopside, chlorites, etc.)
[2] Amph (here and further) – mainly Act, Tre

1	2	3	4	5	6	7
Intermediate mantle (diorite, quartz-diorite, syenite, monzonite, mixed)	Fe	M	SK - Mgsk ? Cask	Mt-Gar, Px, Fo	Dep. Sheregeshskoe, Upper Shoria, RF	
			- Cask	Mt-Gar, Px	Dep. Sokolovskoe, Turgai, Kazakhstan	
			Act	Mt-Act	Dep. El Romeral, Chile	
	Cu ± Mo/Fe	M	SK - Mgsk ? Cask ? Act, Chl, Ep	Chp-Gar, Px, Fo±Mt		Ore field Malko Tarnovo, Strandja Mt.
			- Cask ? Act, Chl, Ep	Chp-Gar, Px ± Mt	Dep. Morenci, Arizona, USA	
		St (Mo-Cu-porphyry)	Bt-KFs-Q	Mol-Chp-Q	Dep. El Teniente, Chile	Dep. Studenetz, Plana Mt.; Panaguirishte ore district: dep. Elatzite, Central Stara planina Mt., dep. Medet, Sredna gora Mt.; Dep. Prohorovo, Sveti Ilia Heights; Dep. Bardtzeto, Strandja Mt. (Malko Tarnovo ore field)
		V	Ser-Q	Chp-Q ± Mol /En, Chal/ Gal, Sph, Au	O. f. Butte, Montana, USA (+ En, Chal)	Bourgas o. d.: Varli Briag o. f., Rossen o. f. (+ Mo), Zidarovo ore field (+ Pb, Zn, Au)
	Au* (diorite complexes)	M	Cask ? Act, Chl, Ep	Au-Sul[3] - Gar, Px	Dep. Nickel Plate, Brit. Col., Canada	
		V	Ser-Q	Au-Sul-Q	Dep. Porgera, Papua New Guinea, Au	
Intermediate, crystal (mainly monzonite, syenite)	U*	V	Ser-Q	Pitch-Sul-Car-Q		Bouhovo ore field. Western Stara planina Mt.
Acid, M-type granitoids (granodiorite plagiogranite)	Fe*	M	Sk (Cask)	Mt-Gar, Px + Sul	Dep. Dashkesan, Minor Caucasus, Azer	Dep. Martinovo, W St. pl. Mt. (controversial origin)
	Co ± Ni*	M	Sk (Cask)	Gla, Cob, Aspy c Co*	Dep. Dashkesan cobalt, M Caucasus, Azer	
			Sk (Cask ? Ab, Tre)	Sma-Sku, Chlo-Gar + Nic, Ram*	Dep. Hovuaksinskoe, Tuva, RF	
		V	Tu-Q+Chl	Gla-Cob-Aspy-Q	Dep. Verhne Seimchanskoe, Far East, RF	
	Cu ± Mo	M	Sk (Cask ? Act, Chl, Ep)	Chp-Gar, Px	Ore field Turinskoe, Ural, RF	
		St (Mo-Cu-porphyry)	Bt-KFs-Q	Mol-Chp-Q	Dep. Chuquicamata, Chile	
	Mo+W*	M	Sk (Cask ? Fs)	She-Mol-Gar, Px*		Ore occurrence Prekop, Western Stara planina Mt.
	W+Au*	V	?	She-Sul-Q+Au*	Dep. Blagoev Kamen, Serbia	
	Au	M	Sk - Mgsk ? Serp	Au-Sul-Fo (Serp), Px	Dep. Suian, North Korea	
			- Cask ? Act, Chl, Ep	Au-Sul-Gar, Px	Dep. Fortitude, Battle Mt., Nevada, USA	
			Jas	Au-Sul-Q	Dep. Cove, Nevada, USA	
		V, St	Tu-Q	Au-Sul-Q*	Dep. Kluchevskoe E Zabaikalie, RF	
			KFs-Q	Au-Q*	Dep Muruntau Tian-Shan, Uzbekistan	Etropole ore field – dep. Svishti plaz (w Aspy), Central Stara planina Mt.

[3] Sul (here and further) – Py, Chp, Gal, Sph ± Aspy, Pyr

1	2	3	4	5	6	7
Acid, M-type granitoids (granodiorite plagiogranite)	Au	V, St	Ser-Q	Au-Sul-Q	Ore field Mother Lode, California, USA	W St. pl. Mt.: Govejda o. f. (w Aspy, 3.9 t Au mined); C. St. pl. Mt.: dep. Dolna Kamenitza and Negarshtitza, o.f. Etropole (w Aspy, 0.17 t Au mined); Kraishte: o. f. Zlata (w/out Aspy, > 3.9 t Au mined)
	Sb, Au	V	Ser-Q	Au-St-Q ± Berth	Ore belt Yano-Kolimskii, Yakutia, RF, dep. Saralah	Ore occurrence Dobroseletz, Manastir graben, Topolovgrad area (w/out outcrop)
	Sb	V	Ser-Q	St-Q + Berth	O. f. Bruide-Massiak, Massif Central, Fr	
Acid, I_1 type granitoids (granodiorite, granite, mixed)	Pb, Zn ± Bar and/or Fl	M	Sk - Mgsk ? Cask ? Act, Chl, Ep	Gal >< Sph - Gar, Px, Fo (Serp)	Dep. Santa Eulalia, Chihuahua, Mexico	
			- Cask ? Act, Chl, Ep	Gal >< Sph - Gar, Px	Dep. Altyn-Topkan, Tian-Shan, Tajikistan	Ardino ore field, Central Rhodope Mt. (+ Chp)
			- Mnsk ? Q, Mn-cal	Gal >< Sph - Joh	o. f. Dalnegorskoe, Far East, RF	Madan ore field, C. Rhod. Mt. – dep. Mogilata, etc.
			Jas	Gal >< Sph - Q	Ore zone Priargunskaia, Eastern Zabaikalie, RF – dep. Ekatherino-Blagodatskoe Dep. Leadville, Colorado, USA	
		V ± M	Ser-Q ± Sk	Gal ><Sph-Q ± Fl, Bar ± Gar, Px, Joh	O. f. Freiberg, Erzgebirge, Germany O. f. Coeur d'Alene, Idaho, USA	Osogovo Mt.: Ruen o. f. (V, M – Mnsk); C. Rhod. Mt.: Davidkovo o. f. (V), Laky o. f. (V, M – Mnsk), Eniovche o. f. (V, M – Mnsk), Madan o. f. (V, M – Mnsk, one of the largest in the world: 39 dep. >2.41 Mt Pb and >1.99 Mt Zn mined); Sakar Mt.: Ustrem o. f. (> Fl, Bar) – relation with magmatism uncertain
	Pb, Ag ± Fl	M	Car (Ank, Sid) *	Agss-Gal-Q	Dep. Szabadbattyián, Hungary (+ Ank)	
				Agss-Gal-Fl-Q		? Dep. Chiprovtzi, Western Stara planina Mt. (+ Sid) – relation with magmatism uncertain
		V	?	Agss-Gal-Q	O. f. Linares – La Carolina, Spain	
			Arg-Q	Agss-Gal-Fl-Q*	Dep. Garahov, Cz	
	Bi*	M	Sk (Cask ? Tre,Act, Car)	Bis-Biss-Q + Gar, Px, Tre, Act, Car*	Dep Ustasarai, Tian-Shan, Uzbekistan	
	Fl*	V	Arg-Q	Sul(Gal, Sph)-Fl-Q	Dep. Pakozd, Hungary	
Acid, I_2 type granitoids (granite, granodiorite, mixed)	Mo ± W/Pb, Zn	M	Sk - Cask ? Mu	Sche-Mol-Gar, Px	Dep. Verhnee Kairati, Central Kazakhstan	
			- Cask ? Act, Chl, Ep	Mol-Gar, Px	Dep. Yangzi Changzhi, Liaoning, China	
				Sche-Mol-Gar, Px	Dep. Tyrnyauz, Greater Caucasus, RF	
		St, V	Gr	Mol-Q	Dep. Orekitkanskoe, E Zabaikalie, RF	O. f. Babiak, Western Rhodope Mt.
				Wol-Mol-Q	Dep. E Conrad Central Kazakhstan	
			KFs-Q	Mol-Q	Dep. Climax, Colorado, USA	
			Ser-Q	Mol-Gal, Sph-Q*	Dep. Bugdainskoe, E Zabaikalie, RF	
	W + Mo/Pb, Zn	M	Sk - Cask ? Mu	Sche-Gar, Px	Dep. Fujigatani, Is. Honshu, Japan	

1	2	3	4	5	6	7
Acid, I_2 type granitoids (granite, grano-diorite, mixed)	W + Mo/Pb, Zn	M	Sk - Cask ? Fs	Sche-Gar,Px	Dep. Sangdong, South Korea O. f. Macmillan Pass, Yukon-NW Ter. Can	Ore occurrence The Seven Rila Lakes, NW Rila Mt.
		V, St	Gr	Wol-Q	Dep. Antonovogorskoe, E Zabaikalie, RF	Dep. Polski Gradetz, Manastir Heights
				Mol-Wol-Q	Dep. Akchatau, Central Kazakhstan	
				Hüb-Q*	Dep. Bom Gorhon, W Zabaikalie, RF	
			KFs-Q	Sche-Py-Q*		Dep. Grancharitza, Western Rhodope Mt.
				Sche-Aspy-Q*	Dep. Barruecoparado, Spain	
				Hüb-Gal, Sph-Q*	O. f. Djidjinskoe, Eastern Zabaikalie, RF	
			Ser-Q	Sche-Py-Q*	Dep. Boguti, Central Kazakhstan	
	Fl*	V	?	Sul (Gal, Sph), Fl-Q		Yugovo ore field, Central Rhodope Mt.
Acid, S type granitoids (mainly granite)	Sn ± W/Be	M	Sk - Mgsk ? Cask	Cas-Gar, Px, Fo	Dep. Brooks Mountain, Alaska, USA	
			- Cask	Cas-Gar, ± Ves, Px	Dep. Moina, Tasmania	
				Cas-Gar, Px + Chryb*	Ore field Lost River, Alaska, USA	
		V, St	Gr	Cas-Q	Dep. Lailishan, Yunnan, China	
				Wol-Cas-Q	O. f. Altenberg, Germany – Cinovec, Cz	
				Cas-Wol-Q	O. d. Nanling, SE China – dep. Xihua-shan; Dep. Panasqueira, Portugal	
	Sn + Li ± Ta*	V, St	Gr	Lep-Cas-Q*	Dep.Trasquillon, Spain	
			Ab	Tan-Lep-Cas-Q	Dep. Montebras, France	
	Sn + Sul[4] +Cu/Pb, Zn±W	V, St	Tu-Q ± Chl, Hüb, Cham	Wol-Cas-Tu-Sul-Q	Dep. Ilin-Tas, Yakutia, RF	
				Cas-Tu-Pyr +Chp/Aspy/Py+ Chp-Q (Tür)	RF: ore zone Derbeke-Negliahinskaya, Ya-kutia – dep. Alis Haia; O. d. Kavalerovskii, Sikhote-Alin, dep. Dubrovskoe (Lifudzin)	
				Cas-Chp-Tu-Q	O. d. Cornwall, England – dep. Dulcote	
			Ser-Q	Cas-Gal, Sph-Q*	O. f. Krasnorechenskoe, Far East, RF	
	Be ± Fl	M	Sk (Cask ? Mu)	Hel-Fl-Mt-Gar,Px	Dep. Iron Mountain, New Mexico, USA	
		V	Gr	Ber, Bert-Q + Fl	O. f. Lake George, Colorado, USA	
			Fl, Mu[5]	Phe, Fl	Dep. in former USSR	
			Serp ? T-car	Ber, Phl	Dep. in former USSR	
	U ± Ag, Bi, Ni, Co	V	Ser-Q ?	Pitch-Ars-Sul-Car-Q (5-ел. формация)*	O. d. Schneeberg-Yahimov: dep. Schnee-berg – Germany, dep. Yahimov – Cz	
			Desilification ? Ab, Cal, Q ? Hem	Pitch-Q ± Fl	O. f. Morvan, Massif Central, France	

[4] Sul (here): Pyr + Chp/Aspy/Py, Chp
[5] Greisen in carbonate rock

1	2	3	4	5	6	7
Acid, S type granitoids (mainly granite)	B*	M	Sk			
			- Mgsk	Kot-Fo, Px	Dep. Hol Gol, North Korea	
				Lud-Mt-Fo, Px	Dep. in former USSR	
			- Cask ? Ep	Dat-Gar, Px + Dan*	Ore field Dalnegorskoe, Far East, RF (with Pb-Zn ores)	
	Fl*	M	Cask ? Gr	Mu-Fl-Cal+Gar,Px,Cas	Dep. Solnechnoe, Central Kazakhstan	
		V	Arg-Q	Fl-Q±Sul (Gal, Sph)	O. d. E Zabaikalie, RF - dep. Solonechnoe	
Alkaline granite	TR*	M	Sk (Cask ? Act, Chl)	Bas-Mt-Gar,Px*	Dep. Båstnäs, Sweden	
	Nb	Dis	Ab	Pych-Col + Cas, Zir	Jos Plateau, Nigeria – dep. Bukuru	
Agpaite	Nb, Zr*	Dis	Fen	Zir-Pych*	Dep. Vishnevogorskoe, Ural, RF	
Miaskite	Be, Nb, Th, TR*	St	Fen	Pych-Bary + Eud	O. f. Sill Lake, Quebec, Canada	

Explanations

Economic types deposits: correspond to the main economically important component(s). Slashes between second order components with episodic appearance manifest their alternative presence. In case of more than one economic types deposits, connected with certain type magmatic complex the order is from higher to lower temperature of ore-forming. By the same reason aposkarn type deposits are situated before vein type and stockwork. In both cases typomorphic (economically significant) mineral parageneses are formed at similar temperature conditions, but in aposkarn deposits the beginning of ore-forming processes is at higher temperature.

Spreading:

═══ – widely spread (>100 ore fields, or separate deposits)

——— – widespread (30-100 ore fields, or separate deposits)

.... – limited spreading (11-30 ore fields, or separate deposits)

Not underlined – rare (6-10 ore fields, or separate deposits)

* – very rare (<6 ore fields, or separate deposits)

Morphogenetic ore types: **- V** – veins and/or linear stockworks; **- M** – metasomatic replacement bodies; **- St** – stockwork (veinlet-disseminated); **- Dis** – disseminated only.

Wallrock alteration types **–** the types of wallrock alteration (approximately from higher temperature to lower one) are as followed: skarn (magnesium skarn, calcium skarn, manganese skarn), amphibole (mainly actinolite, tremolite), actinolite, fenite, albitite, greisen, tourmaline-quartz ± chlorite, potassium-feldspar-quartz, biotite-potassium-feldspar-quartz, sericite-quartz, serpentine, jasperoid, hematite, carbonatisation, talc-carbonatisation, argillizite-quartz. Minerals are listed in ascending order of quantity. Differentiation is done based on typomorphic (specific) parageneses in pre-ore metasomatic alteration. Pre-ore metasomatic alterations most often are common and comparatively intensive.

Mineral types of deposits **–** differentiation are based on main ore and gangue minerals in the deposits. Minerals with low content, but economically significant (typomorphic) are also taken into account: for an example Au, Cas, Wol, Mol, etc. Mineral types of deposits are distinguished by the same manner as ore formations in sense of Breithaupt, Schneiderhöhn et al. In this case the object of classification is ore field, not separate deposits within them, because not such deposits, but ore field as a whole manifest peculiarities of concrete ore-forming process, including mineral type of ore. That's why in the table ore fields are given, except for individual deposits. Minerals in mineral types are in ascending order of their amount. Comma separates minerals with almost equal quantity. Abbreviations of minerals most often correspond to first letters of mineral names in English (see abbreviations).

Typical examples **–** ore fields with maximum concentration of ores and well studied have been selected. When deposit is individual (separate) – it is specified. For Bulgaria, in cases when economic mineralization is lacking, main ore occurrences are specified.

Abbreviations – ore objects:

Dep. deposit — **O. f.** ore field

O. oc. ore occurrence — **O. d.** ore district

Abbreviations – minerals:

Act	Actinolite	Chl	Chlorite	Hüb	Hübnerite	Ram	Rammelsbergite
Agss	silver sulphosalts	Chlo	Chloanthite	Ilv	Ilvaite	Saf	Safflorite
Amph	Amphibole	Chp	Chalcopyrite	KFs	K Feldspar	Sca	Scapolite
Aniv	Anivite	Chryb	Chrysoberyl	Kot	Kotoite	Ser	Sericite
Ant	Anthophyllite	Chrys	Chrysotile	Lep	Lepidolite	Sma	Smaltite
Ars	arsenides	Cha	Chalcedony	Lud	Ludwigite	Sche	Scheelite
Asb	Asbestos	Chal	Chalcocite	Mag	Magnesite	Sku	Skutterudite
Aspy	Arsenopyrite	Cob	Cobaltite	Mic	Microcline	Sp	Specularite
Ax	Axinite	Col	Columbite	Mol	Molybdenite	Sph	Sphalerite
Bar	Barite	Dan	Danburite	Mt	Magnetite	St	Stibnite
Bary	Barylite	Dat	Datolite	Mu	Muskovite	Sul	sulphides
Bas	Bastnäsite	Di	Diopside	Nic	Nickelline	Tal	Talc
Ber	Beryl	En	Enargite	Or	Orthoclase	Tan	Tantalite
Bert	Bertrandite	Ep	Epidote	Phe	Phenakite	Ten	Tennantite
Berth	Berthierite	Eud	Eudidymite	Phl	Phlogopite	Tet	Tetrahedrite
Bis	Bismuthinite	Fl	Fluorite	Pic	Picrolite	Tre	Tremolite
Biss	Bi sulphosalts	Fo	Forsterite	Pitch	Pitchblende	Tu	Tourmaline
Bt	Biotite	Gal	Galena	Pre	Prehnite	Tür	Türingite
Cal	Calcite	Gar	Garnet	Py	Pyrite	Ves	Vesuvianite
Car	carbonates	Gla	Glaucodote	Pych	Pyrochlor	Wit	Witherite
Cas	Cassiterite	Hel	Helvite	Pyr	Pyrrhotite	Wol	Wolframite
Cham	Chamosite	Hem	Hematite	Px	Pyroxene	Ws	Wollastonite
				Q	Quartz	Zir	Zircon

Abbreviations – wallrock alterations:

Ab	albitite	Car	carbonate (Ank, Sid)	Jas	jasperoid	Tu-Q-(±Chl)	tourmaline-quartz (±chloritisation)
Act	actinolite	Cask	calcium skarn	KFs-Q	K-feldspar-quartz	Ser-Q	sericite-quartz
Arg-Q	argillisite-quartz	Fen	fenite	Mgsk	magnesium skarn	Serp	serpentine
Bt-KFs-Q	biotite-K-feldspar-quartz	Gr	greisen	Mnsk	manganese skarn	Sk	skarn
		Hem	hematitisation	T-Car	talc-carbonate		
				Tre-Act	tremolite-actinolite		

Abbreviations – geographic names:

Au	Australia	C. Rhod.	Central Rhodope mountain	Fr	France	NW Ter.	North West Territories, Canada
Azer	Azerbaijan	C. St. pl.	Central Stara planina mountain	Is.	island	W St. pl.	Western Stara planina mountain
Brit. Col..	British Columbia, Canada	Cz	Czech Republic	M Caucasus	Minor Caucasus	RF	Russian Federation
Can	Canada			Mt.	mountain(s)		

b) Rare deposits: Au (single deposits mainly in Asian sector of Pacific metallogenic belt).

c) Very rare deposits: U (only one ore field – Bouhovo, Bulgaria). This brings up a matter of genuine genetic relationship of ore mineralization and the intrusive complex.

4. Acid[1] complexes:

Acid intrusive complexes should be distinguished to **M**, **I** and **S** granitoids (Chappel and White, 1974). Type **I**, i. e. granitoids with intrusive protolithe could be detached into two subtypes – $\mathbf{I_1}$ и $\mathbf{I_2}$, depending on ore deposits connected with them. The latter subtype according to its ore-bearing features (Mo, W) corresponds to type **I** in classification of mentioned above authors. The former subtype also manifest specific ore-bearing features: Pb-Zn+Ag, Bi. Pb, Ag and Bi are typical crustal elements and their mobility in supergene conditions is very low. Due to this their content in sedimentary rocks (pelites, sandstones) is also low. Therefore $\mathbf{I_1}$ subtype granitoids, analogues to subtype $\mathbf{I_2}$, also originate from intrusive protolithes with crustal character.

4.1. M type granitoid complexes – granodiorite, andesine-bearing trondhjemite (plagiogranite in Russian literature). Sometimes small plutons + a lot of dykes mainly with plagiogranite composition: ore field Muruntau, Uzbekistan – 4 dyke belts with 148 dykes. Subduction zones, collisional orogens (rarely, small and not so rich deposits). Typical for intrusives is low K content (K_2O usually less than 2%). According to petrogenetical classification of Didier *et al*. (1982) they could be referred to **M** type granitoids (mantle and mixed). According to classification of Barbarin (1990) they could be assigned to $\mathbf{H_{LA}}$ type (mixed, Ca-alkaline, low-K, high-Ca, subduction zones) and to $\mathbf{T_{IA}}$ type (tholeitic, subduction zones). It is well seen, that both classifications determine this type of granitoids as formed in subduction zones. It should be mentioned that Au-bearing granitoid complexes are also formed in collisional orogens. Variscan Au-bearing granitoid complexes in Bulgaria (Western Stara planina mountain, Kraishte) are of this type. Ore deposits:

[1] Their petrogenetic classification according Chappel and White (1974) is used in the table.

a) Main deposits

- a_1) Au (with high fineness): vein (main), skarn (second order), jasperoid (rare). Typical mainly for oceanic parts of subduction zones. Regions with high economic significance (500 – 1000 t Au and more): Sierra Nevada, California, USA; Australia, state Victoria, (dep. Bendigo, etc.)

- a_2) Au (with high fineness) ± Sb (stibnite): almost entirely vein. It seems that they are typical for peri-cratonic part of subduction zones (Yakutia, Bolivia).

b) Second order deposits: Sb (stibnite), vein.

c) Rare deposits:

- c_1) Fe (Mt-Sk)

- c_2) Cu (Chp-Sk).

4.2. I_1 type granitoid (crustal) complexes – granodiorite, granite, mixed. Subduction zones and mainly collisional orogens (postcollisional stage). With increasing of K content in the plutons usually ratio Pb/Zn in ores also increase: from ~ 1 in deposits connected with granodiorite intrusives to 2-3 in deposits connected with granite intrusive. Deposits with almost entirely Pb ores also appear (as Linares – La Carolina, Spain). According to classification of Didier *et al*. (1982) discussed granitoids could be assumed as $\mathbf{C_i}$ type (crustal, intrusive). They could be also compared with $\mathbf{H_{LO}}$ type, according the scheme of Barbarin (1990) – potassium Ca-alkaline (high-K, low-Ca). Some discrepancy is observed – there are no ore-studies data proving that discussed granitoids are of mixed origin (mantle-crustal), as it is specified in this classification (Barbarin, 1990). Ore deposits:

a) Main deposits: Pb $^{>}_{<}$ Zn – vein (main), skarn and jasperoid (second order). Typical for subduction zones (most often between ocean and continental margin) and late (post-nappe) stage in development of collisional orogens. Within subduction zones are widespread in Cordillera Mt., USA and Far East, RF. In collisional orogens such deposits are well expressed in Tian-Shan Mt. (Kazakhstan, Uzbekistan, Tajikistan), Erzgebirge, Germany, Rhodope Massif (Osogovo Mt., Central Rhodope Mt.), etc.

b) Rare deposits: Pb, Ag ± Fl – vein, metasomatic replacement with carbonate (ankerite, siderite) metasomatites. Granitoids are with extremely high K content.

c) Very rare deposits:

- c_1) Bi (bismuthinite, Bi sulphosalts)

- c_2) Fl (fluorite+sulphides, mainly galena) – vein, metasomatic replacement in carbonate rocks.

4.3. I_2 type granitoid complexes – crustal granite, granodiorite and mixed. Subduction zones (peri-cratonic parts), collisional orogens (restricted quantity) – postcollisional stage. Ore-bearing intrusives are enriched in K, compared with the former types (**M** and $\mathbf{I_1}$) and ratio K_2O/Na_2O varies from ~ 1.3 to 2.3 and more. According data for Mo and W deposits in Cordillera Mt. (USA, Canada), Eastern Zabaikalie, RF, and NE China K_2O content in ore-bearing granitoids varies from ~ 4.00 % to ~ 6.30 %, while Na_2O – from ~ 3.00 to ~ 4.00 %, rarely to 4.80 % (Pokalov, 1972; Naletov, 1981; Mineral Deposits of China, 1990, etc.). According to classification of Didier *et al.* (1982) discussed granitoids could be also referred to $\mathbf{C_i}$ type (crustal, intrusive). An indication for this is low Re content (typical mantle element) in molybdenite (Popov, 1977) – n.10 ppm in discussed deposits, compared with n.100 ppm in molybdenite from Cu-porphyry deposits with no doubt mantle origin. Ore deposits:

a) Main deposits: Mo ± W and W ± Mo – stockwork and vein (main), skarn (second order). Minerals: Mo – molybdenite; W – wolframite, rarely hübnerite, scheelite (skarn deposits). In subduction zones most often are situated close to the cratonic parts. Two regions of widespread deposits could be pointed: Mo (the Rocky Mt., USA – dep. Climax, et al.); W (Eastern Zabaikalie, RF). Within collisional orogens such deposits are comparatively rare, but in Central Kazakhstan significant accumulation is observed.

b) Second order deposits: W + Py, rarely Aspy – vein and stockwork (main), skarn (second order). No significant accumulation in separate region is observed. Bulgaria – dep. Grantcharitza, Western Rhodope Mt.

c) Very rare deposits:

- c_1) W, Pb, Zn (hübnerite,galena, sphalerite)

- c_2) Fl (vein, metasomatic).

4.4. S type granitoids - crustal granite complexes. Subduction zones (usually close to peri-cratonic parts), collisional orogens (restricted quantity). Compared with $\mathbf{I_2}$ type granitoids these have lower and more stable K and Na content: K_2O from ~ 4.30 to ~ 5.00 %; Na_2O – from ~ 2.80 to ~ 3.30 %. Ratio K_2O/Na_2O varies from ~ 1.3 to ~ 1.8, rarely to 1.9 (data on ore-bearing granitoids from Far East, RF, SE China, SW England, Alaska et al. – Naletov, 1981; Mineral Deposits of China, 1990, etc.). Petrogenetically discussed granitoids are crustal, sediment **S** type, according Chappel and White (1974), $\mathbf{C_s}$ (crustal, sediment) according Didier *et al*. (1982), crustal, oversaturated in Al ($\mathbf{C_{ST}}$, $\mathbf{C_{CA}}$, $\mathbf{C_{CI}}$ – Barbarin, 1990). Ore deposits:

a) Main deposits

- a_1) Sn, Sn $^{>}_{<}$ W – vein and stockwork (main), skarn (rare). Minerals: Sn – cassiterite; W – wolframite, scheelite (skarn deposits). Mainly in subduction zones of Japan type. Maximum accumulation in SE China, Birma, Malaysia, Indonesia. In collisional orogens with restricted distribution (Erzgebirge, Germany, Czech Republic).

- a_2) Sn + sulphides (chalcopyrite, pyrrhotite, etc.) – cassiterite-sulphide deposits. Within subduction zones are comparatively widespread in Yakutia and Sikhote-Alin range, RF, while in orogens – in Cornwall peninsula, England.

b) Second order deposits: U (pitchblende) – vein. Some data prove that U is almost entirely leached from granite. They are typical for orogens and are well expressed in Central Europe

(Massif Central and Armorican Massif, France) – pitchblende; Erzgebirge (Germany, Czech Republic) – pitchblende + Co-Ni arsenides and sulphides, Ag и Bi minerals (5-element formation).

c) Rare deposits: Be + Fl – vein (beryl, bertrandite), apo-skarn (helvite), apo-carbonate-greisen (phenakite); Be + Sn – skarn (chrysoberyl); Be + phlogopite – veins among ultrabasite (beryl).

d) Very rare deposits:

- d_1) Sn + Li ± Ta – vein (cassiterite, lepidolite, tantalite)

- d_2) Fl – vein, metasomatic replacement

- d_3) B – skarn (kotoite, ludwigite, datolite,danburite).

5. Alkali complexes:

5.1. Alkali granite complexes. Cratons, "hot spots". Mantle. Ore deposits: rare – Nb (columbite, pyrochlor) + Zr (zircon), Sn (cassiterite).

5.2. Agpaite complexes. Cratons, "hot spots". Mantle-crustal? Ore deposits – very rare:

a) Be, Nb, Th, TR_{Ce}; only one ore field – Sill Lake, Quebec, Canada. Ore-forming elements are geochemically contrast – Be, typical for deposits, related to **S** type granitoids and Nb, common for deposits, connected with alkali intrusives. Be minerals are specific – barylite, eudimite; as well as Nb ones – pyrochlor enriched in TR_{Ce}, Th.

b) Nb, Zr (pyrochlor); only one small deposit (Vishnevogorskoe, Ural, RF).

5.3. Myaskite complexes. Ore deposits (very rare): Nb, Zr (pyrochlor, zircon).

CONCLUSIONS

1. Metallogenic specialisation of igneous complexes and genetic relationship of ores with intrusives

Metal plutonogenic deposits are connected mainly with intermediate and acid intrusive complexes and partly with basic and alkaline intrusive complexes. Separate petrochemical types of intrusive complexes manifest quite distinct metallogenic specialisation according to main and second order deposits, expressed as follows:

- Ultabasic intrusive complexes: asbestos and talc. It should be mentioned that chrysotile asbestos and talc deposits also are formed at metasomatic replacement of rich in Mg carbonate rocks under the influence of hydrothermal solutions, related with intrusive complexes. Typical examples: chrysotile asbestos – dep. Aspagashskoe, Siberia, RF, talc – dep. Hopfersgrün, Germany.

- Basic intrusive (gabbro) complexes (rare) – Fe.

- Intermediate intrusive complexes: Cu, Fe ± Mo (molybdenite is enriched in Re – n.100 ppm).

- **M** type granitoids: Au, Sb + Au, Sb.

- $\mathbf{I_1}$ type granitoids: Pb, Zn, Ag, Bi (Pb >< Zn + Ag, Bi; Pb+Ag; Ag; Bi).

- $\mathbf{I_2}$ type granitoids: Mo, W (Mo >< W).

- **S** type granitoids: Sn, W, U, Fl, Be, B (Sn >< W, Sn, Sn + Be, Be ± Fl, U, B, Fl). U deposits connected with granitoids have some specific features. In many cases (Massif Central, France – Geffroy, 1971) the presumption that U ores are precipitated by late hydrotherms, alien to the granitoids. From the other side the granitoids themselves represent source for U, mainly isomorphically included in K-feldspar

Barite deposits connected with granitoid complexes are established, although rarely and with uncertain genetic relationship. They contain usually (except barite) also Q, Cal and insignificant amount of sulphides ± Fl. Examples: dep. Badamskoe, Tian-Shan, Kazakhstan (M); dep. Chordskoe, Greater Caucasus, Georgia (V); in Bulgaria: vein deposits in Central Stara planina – Trudovetz, Visok and Kashana.

In some cases among granite plutons mainly lens-like bodies of piezo-optic quartz without sulphides are established. Probably these are allo-hydrothermal formations (leaching of SiO_2 from granitoids and then precipitation). In Bulgaria of this type seems to be quartz mineralization in Sakar granite pluton (dep. Glavanak, Hliabovo, etc. Sakar Mt.).

- Alkaline intrusive complexes: Nb >< Ta, TR, Th. A case apart is ore field Sill Lake, Quebec, Canada, where in ores associate Be, typical for deposits related to **S** type granitoids and Nb, Th, TR_{Ce}, characteristic for deposits connected with alkaline intrusives.

Deposits transitional between mentioned above types most often represent element of zonality in ore fields. As a rule they are small by ore volume. Only in single cases ore fields with Mo, W and Sn ores are significantly enriched in Pb and Zn.

A distinct disperse is outlined for fluorite deposits – they are connected with $\mathbf{I_1}$, $\mathbf{I_2}$ and **S** types intrusive complexes. Different deposits are accompanied by specific second order elements: Pb (galena) – in deposits connected with $\mathbf{I_1}$ type granitoids, Mo (molybdenite) – in deposits with $\mathbf{I_2}$ type granitoids, Sn (cassiterite) – in deposits with **S** type granitoids.

The geological and isotope data obtained, let us distinguish three types of genetical relationship between mineralization and certain intrusives:

a) Mineralization in direct genetic connection with intrusives, in sense that hydrothermal solutions are generated by magma, generating intrusives. Certainly as such type chrysotile asbestos, connected with auto-serpentinisation of ulrabasic rocks could be assumed. These mineralizations are not widespread and rarely economic significant accumulations are formed (dep. Abzakovskoe, Ural, RF). It seems, that direct connection with intrusive complexes have some deposits of Sn, W, Mo, Be, Li, Nb, Ta.

b) Mineralization mainly in indirect (paragenetic) relationship with intrusive complexes. Isotope investigations of H and O prove, that in many cases water in one or another degree is with non-magmatic origin. Lead isotopes in rocks and sulphides (mainly galena) in ores show similarity – a fact, that demonstrates common genesis of ores and intrusives.

c) Mineralization for which intrusives play a role of educt (allo-hydrothermal mineralizations). From this type are asbestos, talc, nephrite and magnesite deposits, which accompany allo-serpentinisation of ultrabasic rocks, or metasomatic alterations overimposed on serpentinites. It is assumed that hydrothermal fluids are connected with late intrusive magmatism. Such hydrothermal fluids always precipitate sulphides, while in deposits discussed, sulphides in practice are lacking. So more considered is an opinion that hydrothermal fluids are squeezed out from rocks during the ultrabasic sheets obduction in orogens. Quite similar is the case with asbestos deposits of non-alkaline amphibole (anthophyllite, partly tremolite and actinolite). They are usually connected with ultrabasic rocks among metamorphites in amphibolite facies. Obviously in this case metamorphic hydrothermal fluids form asbestos mineralization.

Significant influence of host rocks on the volume of ore mineralization is traced out in Fe deposits – when host rocks are mafic ones, the total quantity of Fe in ore strongly increases, well expressed in Mt-Act type deposits. It could be also presumed that Ni and Co in relevant deposits are leached out from deep-seated ulrabasic rocks. This is the only way to explain association Co, Ni, U in 5-element formation. Probably different sources (mantle and crustal magma) lead to the strange geochemical association Be and Nb (+ Th, TR_{Ce}) in mentioned above ore field Sill Lake, Quebec, Canada.

Extracting of metals from older deposits is also possible. Probably this is the way of forming of single ore fields of Mo, W and Sn with significant presence of Pb and Zn. Very well is expressed the influence of host rocks in relation to petrogenetic elements. It is distinct in case of carbonate host rocks – the quantity of carbonate minerals in ores significantly increases. From the host rocks some elements that represent impurities in rock-forming minerals are leached. In Madan ore field for an example altered wallrocks are with lower Co content, than non altered ones. Significant changes in chemical composition of ores are not observed.

2. Spatial connection of ores with intrusives

Ores in most of hydrothermal deposits are situated within the intrusives themselves or/and close to them. Ores of Pb, Zn and Sb represent an exception. In case with Pb and Zn deposition of ores could accomplish at 1 km and even more from the intrusive body, sometimes associating with dykes. Sb ores represent even extreme case – because of their low deposition temperature (less than 220° C) they are precipitated even farther from intrusives. So, if the erosion had outcrop the intrusive, the ores could be entirely destroyed. Controversial, if the ores are outcropped by erosion pluton might not outcrop at the surface. The situation with barite and fluorite deposits is similar.

3. Connection of mineralization with metasomatites

Nephrite: Serp → Tre; Asbestos: Serp → amphibolisation (Act, Tre); Talc: Serp → T-Car; Fe (Mt) deposits: accompanying skarn (in carbonate rocks), Act (in mafites); Cu: in carbonate rock aposkarn, rarely apo-carbonate jasperoids, in silicate rocks Bt-KFs-Q (Cu-Mo-porphyry deposits), Ser-Q (vein deposits); Au: in carbonate rocks aposkarn rocks, rarely apo-carbonate jasperoids, in silicate rocks most often Ser-Q, rarely Tu-Q and KFs-Q; Pb $^{>}_{<}$ Zn: in carbonate rocks aposkarn ores, but also often apo-carbonate jasperoids, in silicate rocks Ser-Q; Pb, Ag ± Fl: in carbonate rocks Car (Ank, Sid), in silicate rocks Arg-Q; Mo: in carbonate rocks aposkarn ores, in silicate rocks Gr, more rare KFs(Or)-Q, rarely Ser-Q; W: in carbonate rocks aposkarn ores, in silicate ores Gr, more rare KFs-Q, very rare Ser-Q; Sn: in carbonate rocks aposkarn ores, in silicate rocks Gr; Sn + S: Tu-Q±Chl, rarely (with Pb-Zn) Ser-Q; Be: in carbonate rocks aposkarn ores, rarely Fl-Mu apo-carbonate Gr, in alumosilicate rocks Gr, in ultrabasites Serp → Phl; B: aposkarn ores; Sb: Ser-Q; U: Ser-Q, Hem; Fl: in carbonate rocks aposkarn ores, in silicate rocks Arg-Q?; Fl + Sul (mainly Gal): Arg-Q; TR: aposkarn ores; Nb: Ab; Nb, Zr: Fen.

4. Geodynamic environments of forming

Plutonogenic hydrothermal de4posits are formed in following types of geodynamic environments:

- Subduction zones – deposits connected with basic and intermediate intrusive complexes.

-Subduction zones and collisional orogens – deposits connected with $\mathbf{I_1}$, $\mathbf{I_2}$ and **S** type granitoid intrusive complexes. Probably the case with deposits connected with **M** type granitoid intrusive complexes is similar, but deposits in subduction zones predominate.

- Orogens – deposits included in allochtonous ultrabasic bodies (mainly peridotite complexes).

- Cratons – “hot spots”: deposits connected with alkaline intrusive complexes.

5. Metallogenic epochs

Hydrothermal deposits, connected with intrusive complexes are almost entirely Phanerozoic. Single pre-Phanerozoic metal deposits are also established, mainly in the Baltic shield: Sn – ore field Pitkiaranta, Carelia, RF; Mo and W±Mo – respectively ore field Knaben and dep. Ersdallen, South Norway. During the Phanerozoic deposits are typical for all metallogenic epochs. At the end of Alpine metallogenic epoch (after Oligocene) they strongly decrease. The only exclusion is Southern part of Pacific metallogenic belt, where Au plutonogenic deposits with age 5 – 10 Ma (Upper Miocene) are formed: dep. Porgera, Papua New Guinea, 7 – 10 Ma (420 t Au); Dep. Masra, Philippines, 4.7 Ma (28 t Au).

Connected with intrusive complexes hydrothermal deposits in Bulgaria are formed in Late Palaeozoic (Variscan epoch – Western Stara planina, Kraishte), Late Mesozoic (mainly Sred-nogorie and Strandja zones) till Oligocene (Rhodope Massif).

6. Economic significance of plutonogenic hydrothermal deposits

1st place: Mo, W, Sn, Cu (equally with copper sandstones), Asb, Tal, nephrite

2nd place: Sb – after stratiform deposits, Nb (Ta) – after carbonatite deposits.

3rd place: Pb, Zn (+ Cd, Ag. Bi) – after stratifiorm and massive sulphide deposits, Au – after gold-bearing conglomerates and massive sulphide deposits, U – after elision-hydrothermal and infiltration deposits, Be – after pegmatite and volcanogenic-hydrothermal deposits.

Without considerable economic significance (as separate deposits): Bar, piezo-optic Q, Co, Ni Li, TR, Zr, Ag, Bi.

7. Economic significance for Bulgaria

1st place: Pb, Zn (+ Cd, Ag, Bi), Cu, Asb, Tal.

2nd place: Fe – after siderite (Kremokovtzi), Au – after massive sulphide (copper-pyrite) deposits.

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BERYLLIUM, SCANDIUM, YTTRIUM AND YTTERBIUM IN SOME BULGARIAN COALS

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ABSTRACT

The occurrence of Be, Sc, Y and Yb in the coals of different rank (ranging from lignite to anthracite) from fourteen Bulgarian basins and deposits were investigated. The concentrations of all elements in the coal and coal ash were higher than the Clarke values from the Sofia Basins and partly from the Karlovo Basin only. The element content in the coal and coal ash from the Maritza-West, Belibreg, Stanyantzy, Oranovo, Katriste, Suhostrel and Balkan basins were lower than the Clarke. In other coals the concentrations of some elements only were high than the Clarke values. These relations were applied and to the coal shale (with exception of Yb from Samokov, Katriste and Balkan Basin). The correlation coefficients between element concentration and ash content were identical in the coal from Maritza-West, Belibreg, Sofia, Karlovo, Samokov, Oranovo and Pernik (negative coefficients) and Katriste and Suhostrel (positive coefficient). For the other coals the correlation between element and ash content was different. The negative correlation coefficients with ash was highest (from -0.7 to -0.8) for Be (Maritza West and Sofia), Y (Kyustendil) and Yb (Karlovo). Beryllium, Sc, Y, Yb were correlated very often. The associations Sc-Y (Sofia, Maritza West, Belibreg), Y-Yb-Be (Pernik, Svoge, Kyustendil), Be-Sc (Samokov, Suhostrel), Yb-Be (Oranovo, Sofia), Be-Sc-Yb-Y (Karlovo) were established in the investigated coals. Beryllium, Sc, Y, Yb were associated with Ge, Ga, Zr, REE, Al, Si, sometimes with Ca, Mg, S also. The occurrence and concentrations of the investigated elements in Bulgarian coals were depend on some factors: 1) occurrence in the rocks from the peat bog feeding province and 2) the pH values in the ancient peat bogs, which control the fixation of elements in the metal-organic compounds or clay minerals. The degree of fissuring of the coal seams and the presence and composition of mineral waters, which precipitate infiltrational minerals into the fissures of the coal beds were not influenced of the occurrence of the studied elements.

Key words: beryllium, scandium, yttrium, ytterbium, coal, occurrence of elements, factors for accumulation.

INTRODUCTION

The concentration and distribution of beryllium, scandium, yttrium and ytterbium in the coal and coal shale from 14 Bulgarian basins and deposits were investigated. The coal age and rank were different. The lignite from eight Neogene basins and deposits (the Sofia, Beli Breg, Maritza-West, Karlovo, Samokov, Kyustendil basins, Gabrovitza and Katrishte deposits) were studied. The studied sub-bituminous coal was from the Oranovo-Simitli Basin with Miocene age and Pernik Basin with Paleogene age. The bituminous coal was from the Suhostrel deposit with Eocene age and Balkan Basin with Cenomanian age. The studied anthracite was from the Svoge Carboniferous Basin. Data for the concentration and distribution of these elements in other Bulgarian coals were published by Ескенази (1965), Eskenazy (1970, 1978, 1987a,b, 1995).

METHODS

Seven hundred and seventy coal and coal shale samples were studied. All samples were ashed at 800°C and analyzed using Instrumental Neutron Activation Analysis (INAA) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis. The results were examined statistically and the correlation coefficients between the ash content and the element concentration were determined.

RESULTS AND DISCUSSION

Beryllium. The Be concentration in the coal ash from the Sofia, Karlovo, Kyustendil basins and Gabrovitza deposit is higher (1.4-7.9 times) than the Clarke values after Юдович и др. (1985) (Table 1). The Be content in the coal from the same basins and the Samokov and Svoge basins is higher than the Clarke values and world-wide averages from Swaine (1990) also (Table 1). The concentration of Be in the coals and coal ashes from the other basins is lower of the Clarke values (Table 1). The Be content is very below the Clark and the world-wide averages from Swaine (1990) in the coal from Beli Breg, Oranovo, Balkan and Suhostrel. The Be concentration in the Maritza-West lignite is about the Clarke values. The concentration of the Be in the coal shale ashes is less than its concentration in the coal ashes, but it is higher than the Clark (Table 2). The Be concentration is lower than the Clark only in the Maritza-West, Beli Breg, Stanyantzi and Oranovo coal shale ashes. Probably the Be concentration in the rock formations from the waterside line of the ancient peat bogs is high because the element content in the coal and coal shale from the Karlovo, Gabrovitza and Kyustendil is higher than the Clarke values.

Many authors report data for beryllium affinity (Table 3). Eskenazy (1970) published data for the Be connection with the organic acids. The Be has negative coefficient of correlation with the ash content in the most studied coals. Its concentration decreases, when the ash content increases, with an exemption of the Katrishte and Suhostrel coal (Fig. 1). The correlation coefficient of the element with the ash content in the

Balkan bituminous coal is below the statistical mean value and the concentration of the element varies in short interval (Fig. 1). Beryllium presents mainly into the low-ash coals. It has positive coefficients of correlation with the S (+0.57), Ca and Mg (+0.45) and negative coefficient with the Si and Al in the Sofia lignite (Kortenski and Sotirov, 2002). Probably one part of Be amount is connected with the sulfides and/or sulphates.

Table 1. Average content of the elements in the coal ash

Basins	Number of the samples	Content in the coal ash of:				Content in the coal of:			
		Be, ppm	Sc, ppm	Y, ppm	Yb, ppm	Be, ppm	Sc, ppm	Y, ppm	Yb, ppm
Maritza-West	38	11.1	4.6	10.1	n.d.	2.0	0.8	1.8	n.d.
Beli Breg	38	2.0	1.0	0.9	n.d.	0.4	0.2	0.2	n.d.
Stanyantzi	39	7.7	n.d.	n.d.	n.d.	1.3	n.d.	n.d.	n.d.
Sofia	59	15.0	42.2	80.1	5.0	4.3	19.4	17.4	2.2
Karlovo	23	54.7	8.0	43.5	6.6	11.0	1.6	8.8	1.3
Samokov	31	8.4	26.0	31.0	1.6	2.9	9.1	10.8	0.6
Gabrovitza	40	86.6	4.1	4.1	5.2	32.6	1.5	1.5	2.0
Kyustendil	39	37.9	15.2	21.2	3.2	11.5	4.6	6.4	1.0
Oranovo	61	3.3	n.d.	0.7	1.8	0.3	n.d.	0.1	0.2
Katrishte	22	5.1	n.d.	n.d.	n.d.	1.5	n.d.	n.d.	n.d.
Pernik	35	7.6	18.7	24.1	2.5	1.8	4.5	5.9	0.6
Suhostrel	17	4.1	6.8	n.d.	n.d.	1.2	2.0	n.d.	n.d.
Balkan	58	5.8	4.8	8.3	6.0	1.6	1.2	2.1	1.5
Svoge	90	7.0	22.8	3.0	6.5	2.9	9.3	1.2	2.7
Clark for lignite and sub-bituminous coal[1]		11.0	15.0	37.0	5.0	2.4	2.0	7.0	0.9
Clark for bituminous coal and anthracite[1]		21.0	20.0	47.0	7.0	2.1	3.0	6.0	0.8
World-wide averages[2]						1.5-2	1-10	2-50	0.3-3

1 – after Юдович и др. (1985); 2 - after Swaine (1990); nd – no data.

Table 2. Average content of the element in the coal shale ashes

Basins	Number samples	Be ppm	Sc ppm	Y ppm	Yb ppm
Maritza-West	9	1.6	2.0	6.5	n.d.
Beli Breg	8	1.1	0.4	0.5	n.d.
Stanyantzi	10	2.0	n.d.	n.d.	n.d.
Sofia	19	7.5	33.5	41.5	3.8
Karlovo	9	13.2	4.3	17.3	1.1
Samokov	10	6.2	24.0	23.0	1.5
Gabrovitza	8	71.7	6.0	5.5	5.6
Kyustendil	9	14.6	14.8	9.2	1.3
Oranovo	19	n.d.	n.d.	n.d.	n.d.
Katrishte	10	10.2	n.d.	3.2	7.1
Pernik	9	4.1	15.8	16.9	1.8
Suhostrel	8	10.1	8.6	n.d.	n.d.
Balkan	31	6.0	16.5	6.5	4.0
Svoge	21	5.7	26.8	7.7	4.4
Clark for shales by (Turekian and Wedepohl, 1961)		4.0	13.0	26.0	2.6

n.d.-no data

Probably Be in the coal is not connected with the plants, because it is only 0.1 ppm into them (Bowen, 1966). The acidity of the environment probably had not been important factor for the Be accumulation. Basins with high Be content in the coal had different acidity (Sofia 3.5-7; Karlovo 3.5-6.5; Gabrovitza 5-7.5) (Kortenski, 1992; Kortenski et al., 1997). The fissures and the epigenetic mineral solutions obviously had not influenced on the accumulation and concentration of Be, because the Be concentration is low in the high-fissured and mineralized Svoge anthracites, Balkan and Suhostrel bituminous coal and the Pernik sub-bituminous coal. Probably, the main reason for the high concentration of the element had been the presence of the Be in the rocks around the basins. For example the relationship between the Be concentration in Sofia lignite and the Cr concentration in the rocks from the waterside line (Vitosha pluton) is established. The Cr content in the andesites from Vitosha pluton is 13.2 ppm (Kortenski, 1986).

Scandium. The concentration of Sc in the most of the studied coals is lower than the Clark by Юдович и др. (1985) (Table 1). The Sc concentration is about 3 times higher than the Clark in the ash of the Sofia lignite and it is little higher than the Clark in the ash from the Samokov, Pernik and Svoge coal. The Sc is approximately to the Clark value in the ash of the Kyustendil lignite (Table 1). The Sc concentration is higher than the Clark by Юдович и др. (1985) in the coal of the Sofia, Svoge, Samokov, Kyustendil and Pernik basins. Only the Sofia lignite contains Sc more than the maximum level of the interval by Swaine (1990) (Table 1). The scandium concentration in the coal shale ashes from the Sofia, Samokov, Kyustendil, Pernik, Balkan and Svoge basins is higher than the Clark (Table 2).

The Sc has positive coefficient of correlation with the ash content in the coals from Gabrovitza, Suhostrel, Balkan and Svoge basins. The element concentration increases with ash content increasing (Fig. 1). The Sc has positive correlation with the aluminum-silicate part of the inorganic matter in the Sofia lignite (Kortenski, Sotirov, 2000). The Sc has negative correlation with the coal ash from the West-Maritza, Beli Breg, Sofia, Pernik and Karlovo basins and Figure 1 shows that with the increasing of the ash content; the Sc concentration is decreasing. The correlation coefficient with the ash is lower than the statistical mean value in the coal from Samokov and Kyustendil. The Sc concentration nearly not changes many with the ash contents change (Fig. 1). Many authors report data for affinity of the Sc (Table 3). Querol et al. (1997a,b) established positive correlation of the element with the sulphur and the aluminum-silicate content of the coal.

Table 3. Reference data of the Be, Sc, Y and Yb affinities

Element	Reference data of the element affinities		
	Organic	Intermediate	Inorganic
Be	Юровский (1960); Смирнов (1968); Gluskoter et al. (1977); Kuhn et al. (1980); Perrek and Bardhan (1985); Miller and Given (1987); Querol et al. (1992, 1997a); Warwick et al. (1997).	Kojima and Kurusawa (1986); Querol et al. (1996).	Минчев и Ескенази (1972); Beaton et al. (1991); Querol et al. (1997b).
Sc	Минчев и Ескенази (1965); Юдович и Шасткевич (1965); Смирнов (1966); Parrek and Bardhan (1985)	Юровский (1960); Kojima and Kurusawa (1986); Beaton et al. (1991); Warwick et al. (1997); Crowley et al. (1997).	Pippiringos (1966), Минчев и Ескенази (1972), Ескенази и Минчева (1994); Querol et al. (1997a,b)
Y	Gluskoter et al. (1977); Минчев и Ескенази (1965, 1972); Ескенази и Минчева (1983, 1994); Юдович и др. (1985); Miller and Given (1987); Querol et al. (1997a).	Kojima and Kurusawa (1986), Crowley et al. (1997), Warwick et al. (1997).	Юровский (1960); Pippiringos (1966); Spears, Martinez-Tarazona (1993); Querol et al., (1996); Querol et al. (1997b).
Yb	Ершов (1961); Miller and Given (1987); Eskenazy (1995).	Querol et al. (1992); Crowley et al. (1997); Warwick et al. (1997).	Beaton et al. (1991); Ескенази и Минчева (1994); Querol et al. (1997a,b).

The concentration of the Sc in the plants is 0.008 ppm (Bowen, 1966) and it is not important for the accumulation of the element in the coal. But the presence of the element in the rock formations, which build the coal basin waterside, is important. The concentration of the element is higher in the coal and coal ashes from Sofia, Samokov, Pernik and Svoge basins, but it is not so high in the coal from the Maritza-West and Beli Breg basins. It depends from the Sc concentration in the rock formations. Юдович и др. (1985) suggest that if the concentration of the Sc is higher than 50 ppm the element has organic affinity. It has mainly inorganic affinity when the Sc concentration is high, but less than 50 ppm. The environmental acidity of the peat bogs of the Sofia, Samokov, Pernik and Svoge basins had been very different (Kortenski, 1992), but the acidity had been optimal for connection of the Sc with the clay minerals. Юровский (1960) was established that Sc frequently presents in the carbonate minerals. The higher Sc concentration in the Pernik and Svoge coals probably is a result of the high fissuring and presence of the epigenetic carbonate mineralization.

Yttrium. The concentration of the element in the most of the studied coal is low. Only the ash from the Sofia and Karlovo lignite contains Y higher than the Clark value (Table 1). The concentration of Y is below the interval determined by Swaine (1990) in the coal from Maritza-West, Beli Breg, Gabrovitza, Oranovo and Svoge. The concentration of the element in all other coals is into that interval (Table 1). The concentration of the element in the coal shale is much lower than the Clark with an exemption of the Karlovo and Samokov basins (Table 2). It is established that the concentration of the element is high in the coal and the coal shale from the Sofia, Karlovo and Samokov basins, which is probably a result of the presence of Y in the rock formations around the basin.

The reference data for prevailing affinities of Y is shows by Table 3. The Y has positive coefficient of correlation with the ash content only in the coal from Gabrovitza, Svoge and Katrishte, but it has negative coefficient in all other coals. The concentration of Y significantly decreases, when the ash content increases in the coal from Kyustendil, Oranovo, Karlovo and Sofia (Fig. 2). The Y concentration decreases insignificantly, when the ash content increases in all other coals with negative correlation between Y and ash content. The Y content increases when the ash content increases in the coal from Gabrovitza, Katrishte and Svoge.

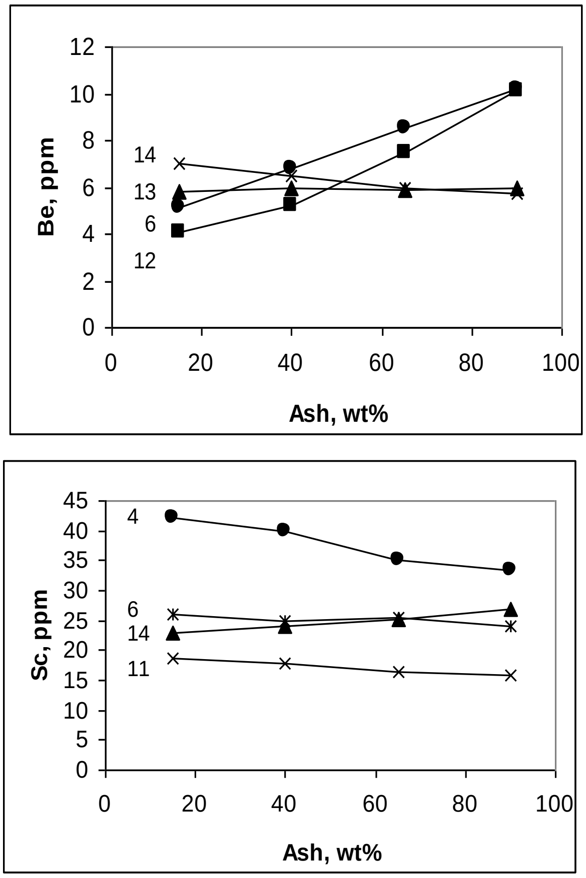

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Figure 1. Distribution of average Be and Sc content versus ash content:
4-Sofia; 6-Samokov; 11-Pernik; 12-Suhostrel; 13-Balkan; 14-Svoge.

The yttrium concentration in the plants is insignificant, about 0.03 ppm (Bowen 1966) and it had not been important factor for the concentration of the element in the coal. The presence of the element in the rock formations, around the basin had been important. The conditions of the peat bogs had not been appropriate for the accumulation of the element. The acidity of the peat bogs for studied basins had been between 3.5 and 7 (Kortenski, 1992). The fissuring and the epigenetic mineralization had not influenced on the Y accumulation also. For an example the coal seams from the Balkan and Svoge basins have high fissuring and epigenetic mineralization, but the concentration of the Y is 8-12 times lower than the Clark (Table 1).

Ytterbium. The concentration of the element is higher than the Clark only in the coal ash from Karlovo. It is about the Clark in the ashes from the Sofia, Gabrovitza, Balkan and Svoge basins (Table 1). The concentration of the element is into the interval of the average rank by Swaine (1990) with an exemption of the Oranovo and Katrishte coal. Some coal shale ashes (from the above-mentioned four basins - Sofia, Balkan, Svoge and Gabrovitza) contain more Yb than the Clark (Table 2). The content of Yb is higher from the Clarke values in the coal shale from the Katrishte deposit, but the element is not established in the coal from that deposit (Table 1, 2).

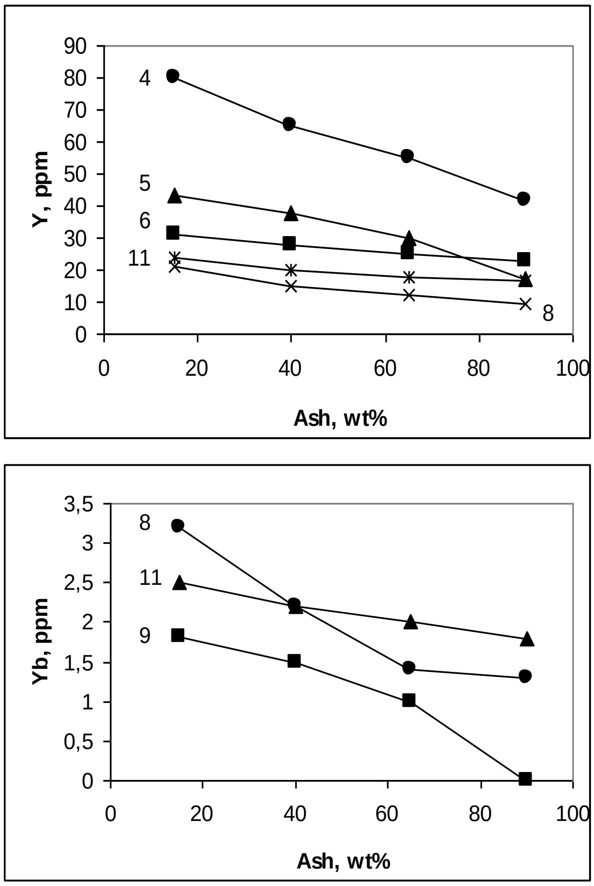

Figure 2. Distribution of average Y and Yb content versus ash content:
4-Sofia; 5-Karlovo; 6-Samokov; 8-Kyustendil; 9-Oranovo; 11-Pernik

The coefficient of correlation of the Yb concentration with the ash content in the Katrishte coal has high positive value. The Yb concentration increases, when the ash content increases. Probably the Yb into that coal has inorganic affinity and it is connected mainly with the clay minerals. The Yb has negative correlation coefficient with the ash content for all studied coals with an exemption of the coal from the Katriste and Gabrovitza. The concentration of the Yb decreases significantly with the increasing of the ash content, especially in the coal with high negative coefficient of correlation (Karlovo, Oranovo and Kyustendil) (Fig. 2). The correlation coefficients between the element and the ash content have values below the statistical mean value and the concentration of the element changes insignificantly with the changing of the ash content in the coal from Samokov and Gabrovitza. The reference data for prevailing affinities of Yb is shows by Table 3.

The concentration of the Yb is low in the studied coals. The major probable reason is the low content of the element in the rock formations from ancient waterside line or inappropriate conditions for Yb accumulation in the ancient peat bogs. For example the rocks from waterside line of Sofia basin contain from 0.7 to 1.5 ppm Yb (Кортенски, 1986).

CONCLUSIONS

Berilium, Sc, Y, Yb concentrations are higher than the Clarke values in the Sofia lignite and coal ash. This is valid and for the Karlovo coal (with exception of Sc). The contents of the four studied elements are below that the Clark and the interval of World-wide averages by Swaine (1990) in the coals from the Maritza-West, Beli Breg, Stanyantzy, Oranovo, Katrishte, Suhostrel and Balkan. The concentrations of the four elements are higher or lower than the Clark in the other coal. The same is valid for the coal shale, with an exemption of Yb concentration in the Samokov, Katrishte and Balkan coal shale.

The elements have similar coefficients of correlation with the ash content in the coal from Maritza-West, Beli Breg, Sofia, Karlovo, Samokov, Oranovo and Pernik (negative) and Katrishte and Suhostrel (positive), but the coefficients are different for all other coals. The negative correlation coefficients are highest (from -0.7 to -0.8) for the Be (Maritza-West and Sofia), for the Y (Kyustendil) and for the Yb (Karlovo). The organic affinity of these elements is high. The elements, which have negative correlation coefficients with the ash content, are with prevailing organic affinity. All studied elements show the inorganic affinity in the coal from Katriste, Suhostrel and Gabrovitza (with exception of Be), Sc has inorganic affinity in the Balkan and Svoge coal and Y – in the Svoge, because its correlation coefficients with the ash content are positive. Be (in Balkan coal), Sc (in Samokov and Kyustendil coal) and Yb (in Samokov and Gabrovitza coal) has the intermediate affinity, because its correlation coefficients with the ash content are below the statistical mean value (positive or negative).

The four elements frequently associate between one with another. The frequently established associations are Sc-Y (Sofia, Maritza-West, Beli Breg), Y-Yb-Be (Pernik, Svoge, Kyustendil), Be-Sc (Samokov, Suhostrel), Yb-Be (Oranovo, Sofia) and Be-Yb-Sc-Y (Karlovo). The elements frequently associate with Ge, Ga, Zn, Al, and Si and sometimes with Ca, Mg and S.

The presence of the elements in the plants is insignificant. Probably the rock formations from the ancient waterside line of the basins had been the main source of the Be, Sc, Y and Y. The clay minerals and sometimes the organic matter had been the main concentrator of the elements, when the conditions had been appropriate. The fissures and the epigenetic mineralization had not been much important for the presence and the accumulation of the studied elements.

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DETERMINATION OF THE INDICES OF THE COAL FACIES IN THE SVOGE ANTHRACITE BASIN, BULGARIA

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ABSTRACT
Thirty samples from V and VII coal seam were studied. The maceral, mineral and chemical composition of the coal ash were established. The indices of the coal facies were determined. Groundwater Influence Index (GWI) was 0.02 and Vegetation Index (VI) was 92.46. This had been determined the ancient peat bog as "ombrotrophic bog forest". According Tissue Preservation Index (TPI) (92.46) and Gelification Index (GI) (97.97) the coal seams of the Svoge anthracite basin had been originated in a forested peatland. The SAL factor (68.7) was deternined the bog also as fen with forest vegetation. The environmental acidity was determined on the diagram of the acidity. The pH value was from 3.5 to 6.2 (average 4.8). The Supply Index (SI) was determined. The supply of the peat bog was prevailing clastic according SI=3.7 and peatdeposit was realized in the limnic bog. Only three macerals from the Vitrinite group and two macerals from the Inertinite group were established in the coal. On the basis of the Vitrinite reflectance, the coal was determined as "Anthracite and Meta-Anthracite".
Key words: anthracite, indices, macerals, chemical composition, type of the peat bog, environment conditions, Svoge basin.

INTRODUCTION

The Svoge basin is situated about 30 km North from the city of Sofia. The basement of the coal-bearing sediments is composed of Ordovician, Silurian, Devonian and Lower Carboniferous rocks. Triassic and Quaternary sediments cover the coal-bearing deposits. Six lithostratigraphic formations in the Carboniferous sediments was separated by Тенчов (1962, 1966). The Tsarichinska Formation (Namurian A, B) is composed of conglomerate, sandstone, siltstone, mudstone and thin coal seams (thickness 150-200 m). The Svidnenska Formation (Namurian C) includes alternation of brecia-conglomerate, sandstone, siltstone, mudstone and coal layers, with summary thickness about 260m. The Dramshanska formation (Lower Westphalian A) is composed of sandstone, siltstone and mudtstone (thickness about 200 m). The Svoge formation (Westphalian A) (conglomerate, sandstone, siltstone, mudtstone and coal) is thick 510 m. The Berovdolska formation (Westphalian AB) is composed of sandstone, siltstone, mudtstone, coal shale and coal. Its thickness is 220 m. The Chibaovska formation (unspecified Westphalian) contains conglomerate, sandstone, siltstone, mudtstone and coal seam with summary thickness 250m. Русанов, Попов (1987), Русанов и др. (1997) determine the same boundaries of the Tsarichinska and Chibaovska formations. These authors are defined the Dramshanska formation as a second formation in the low Namurian A sediments. Русанов, Попов (1987) are separated a new formation (Drenovska formation with Namurian C–Westphalian B age), which includes the sediments from the second to the fifth formations determined by Тенчов (1966). Русанов и др. (1997) are separated three members in the Drenovska formation and one more (Radoglavski Member) into the Chibaovska formation. The Svoge basin is located in the Svoge synclinorium with East-West orientation. A number anticlines and synclines with south spreading are established. After Тенчов (1966), Tenchov (1977) and Русанов и др. (1997) are established two systems of faults in the Svoge basin: Northeast-Southwest and Northwest-Southeast. Petrographic investigations of the Svoge anthracite are reported from Константинова (1962), Пешева (1971) and Майхерчик (1975). The main purpose of the study is to be determined on the basis of the petrographic and chemical composition of the coal, the type of the peat bog, the type of supplying and the environment acidity during the peat genesis.

MATERIAL AND METHODS

The present study is based on 20 samples from V and VII coal seam of the Svoger basin. As a first step, the samples were crushed to a maximum grain size of 3 mm. For petrographical investigations, a representative part of the sample was mounted in epoxy resin, ground and polished. At least 400 points were counted on a Leitz microscope using reflected white (λ=546 nm) and fluorescent light to provide data for maceral analyses. The oil immersion objectives 50x/0.85 and 100x/0.25 and the automatic counter "Prior-G" were used also. For each sample the relative amounts of maceral groups and their subgroups were calculated. The vitrinite reflectance were measured in fifty points in each sample. Yttrium-alluminium-granat with reflectance 0.899% was used as standard. The chemical composition of the ash is determined through ICP analysis.

RESULTS AND DISCUSSION

Average Vitrinite reflectance was measured Ro=4.89%, (Rmin= 4.50% and Rmax=5.64%) with standard deviation ±0.2756. According to the Vitrinite reflectance the coal was determined as "Anthracite" and "Meta-Anthracite A".

Petrographic composition

Vitrinite group. The submaceral telinite 1 have amount 10.14% (10.30% from the organic matter). The submaceral telocollinite predominate (81.32% from the organic matter). The third observed maceral is Vitrodetrinite with amount 5.51% (7.68% from the organic matter).

Inertinite group. Fusinite and inertodetrinite were established in some samples with amount below 1%.

The macerals from the *Liptinite group* were not established because of the very high rank of the coal.

Minerals. Euhedral pyrite, framboidal pyrite and massive pyrite (~1%), clay minerals (1.74%) and calcite (0.29%) were observed in the samples.

Indices of coal facies.

On the basis of the macerals content, the indices of the coal facies were calculated. For that purpose the maceral contents on the basis of all matter were used.

Groundwater Influence Index by Calder et al. (1991):

GWI = gelocollinite+corpocollinite+mineral matter / tellinite+ telocollinite+desmocollinite = 0.02

Vegetation Index by Calder et al. (1991):

VI = tellinite+telocollinite+fusinite+semipyrofusinite+suberinite+ resinite / desmocollinite+inertodetrinite+alginite+liptodetrinite+ sporinite+cutinite = 92.46

According to above-mentioned indices the peat bog was determined as "limnic ombrotrophic forest swamp". Calder et al. (1991) determined the conditions in the peat bog, which are characterized with low ground supplying, low values of the pH, higher degree of tissue preservation (tellinite/telocollinite), lower value of the ratio biological matter/time, lower amount of the sulphur.

Tissue Preservation Index by Diessel (1992):

TPI = tellinite+telocollinite+semipyrofusinite+fusinite+ rootletvitrinite+phylovitrinite / desmocollinite+macrinite+ inertodetrinite = 92.46

Gelification Index by Diessel (1992):

GI = vitrinite+macrinite / semifusinite+fusinite+ inertodetrinite = 97.97

According to the TPI and GI, the peat bog is originated in a "forested peatland". Two types of origin, according to the conditions are possible: 1) in forested peatland (telmatic swamps), when the coal ash is high and/or there are epiclastic bounds. 2) in forested, wet raised bog, when low in ash. The humification is mild and gelification of plant tissues is strong. In present study the peat bog have the second type of origin, because of the low ash and inertinite content. This type of origin corresponds with the determined type (limnic) of the peat bog by Calder et al. (1991).

Silica-aluminum (SAL) factor after Diessel (1992):

SAL=SiO_2x100/SiO_2+Al_2O_3

The SAL factor was calculated with value 68.7, which supposes that the peat bog was "fen" with limited forest plants (Diessel, 1992).

Acidity of the environment (pH).

The environmental acidity in the ancient peat bog is determined through the chemical composition of the coal ash on the diagram of the acidity after Kortenski (1986). It was established that the samples are located in the interval of acidity from 3.5 to 6.2. Most of the samples are located in the interval from 4 to 6. The average value of pH is 4.8. The established pH corresponds very well with the already established TPI as suggests well-preserved plant tissue and the data of Calder et al. (1991) for low values of pH.

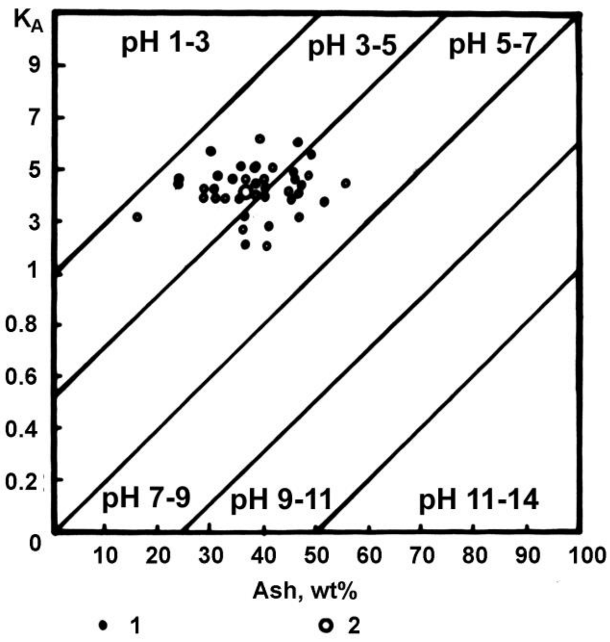

Figure 1. Diagram of environment acidity in the ancient peat bog (after Кортенски, 1985).
KA – coefficient of acidity;
KA = (SiO_2+Al_2O_3+SO_3+P_2O_5)/ (CaO+MgO+Fe_2O_3+K_2O+Na_2O+MnO+TiO_2);
1 – sample from the coal seam; 2 – average sample

Supplying Index (SI)

This index is determined on the basis of the chemical composition of the coal ash:

SI = SiO_2+Al_2O_3+TiO_2 / CaO+MgO+Fe_2O_3+SO_3+MnO+K_2O+ Na_2O+P_2O_5=3.7

Six type of supplying may be divided, according to the supplying index:

- **SI below 0.1** shows marine facies. The rocks from the coastal zone are mainly carbonates. The ground water supplying is predominated. The surface water supplying with clastic matter from the carbonate rocks is very slight. SiO_2+Al_2O_3+TiO_2 is up to 10%. The presence of

SiO_2 is a result of the slight surface water supplying, when the epigenetic quartz is not established in the coal.

- **SI from 0.1 to 0.25.** The marine or calcium-rich facies are typical. The groundwater supplying is prevailing with participation of surface water supplying with clastic matter. SiO_2+Al_2O_3+TiO_2 is from 10 to 20%. The coastal zone is composed of different rocks. It is possible the marine transgression bring one part of the clastic matter. Possible the surface water supplying is very slight if the epigenetic quartz (a part from SiO_2) present. The presence of epigenetic carbonate and pyrite show, that the clastic matter amount is relatively big, because a part from CaO, MgO, Fe_2O_3 and SO_3 is connected with this mineralization.

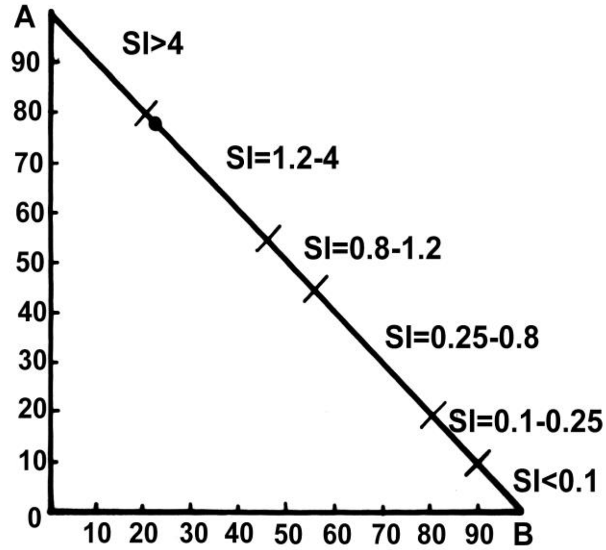

Figure 2. Diagram of the Supplying Index (SI) of the peat bog. The point of the diagram is the SI value in the studied coal. A=SiO_2+Al_2O_3+ TiO_2, %; B=CaO+MgO+Fe_2O_3+ SO_3+K_2O+Na_2O+MnO+P_2O_5, %.

- **SI from 0.25 to 0.8** is a sigh for mixed supplying, but the groundwater is prevailing. SiO_2+Al_2O_3+TiO_2 is from 20 to 45% and it is a result of clastic supplying through surface water. The coastal zone is composed of different types of rocks. Very high ground water supplying (low ash content) or marine transgression (high ash content) is possible when the carbonate rocks absence. The surface supplying is low when the high SiO_2 content as a result from epigenetic quartz mineralization. If the presence of carbonate or/and sulphide epigenetic mineralization in the coal is a reason of the high CaO, MgO, Fe_2O_3, SO_3 and MnO content, ground water supplying is not very high. The peat bog is telmatic, limnic-telmatic, or with Ca-reach facies.
- **SI from 0.8 to 1.2.** The surface supplying is equal to the groundwater supplying. The coastal zone is composed of different type rocks. Very high ground water supplying (low ash content) or marine transgression (high ash content) is possible when the carbonate rocks absence. The presence in the coal of epigenetic quartz mineralization indicate higher fround water supplying and the presence in the coal of epigetic carbonates and/or sulphides indicate higher surface water supplying. The peat bog is limnic-telmatic or limnic or with Ca-reach facies.
- **SI from 1.2 to 4.** The surface water supplying is prevailing and the groundwater supplying is low and insignificant. CaO+MgO+Fe2O3+SO3+MnO+K2O+Na2O+P2O5 is from 20 to 45% and it is a result mainly of groundwater supplying and one part of the elements is transported with the clastic material. Probably some rocks from the coastal zone are carbonates. It is possible marine transgression if the carbonate rocks absence. The presence of the epigenetic quartz mineralization show than the ground water supplying is not so low. The increasing of the CaO, MgO, Fe_2O_3 and SO_3 content is a result of the presence of epigenetic carbotes and/or sulphides and testify to the ground water supplying is lower. The peat bog is limnic, possible telmatic-limnic.
- **SI more than 4.** The supplying is mainly surface water, which transport clastic material. In the coastal zone CaO+MgO+Fe2O3+SO3+MnO+K2O+Na2O+P2O5 is up to 20%, but it is a result of participation of these element in the igneous rocks from the coastal zone of the peat bog. The very low ground water supplying (low ash coal) is possible if the carbonate rocks (limestone, dolomite, marble etc.) in the coastal zone absence or the epigenetic quartz present in the coal. The peat bog is limnic.

The calculated index of supplying with value 3.7 determine prevailing supplying of the peat bog with clastic material as the carbonate rocks from the coastal zone are almost absent. The peat bog is limnic. That conclusion correlates with the determined above acidity of the environment. The value of the pH from 4.8 supposes limited groundwater supplying and relatively well preserved plant tissues. Everything corresponds well with the results for GWI and GI after Calder et al. (1991). The received values for the SI corresponds well with the data of Diessel (1991) for low gelification.

CONCLUSION

As a result of the present investigations was established that the prevailing maceral is telocollinite, followed by telnet and vitrodetrinite. The coal ash is reach of SiO_2 and Al_2O_3. The acidity of the environment is from 3.5 to 6.2 (average 4.8), SAL factor = 68.7, GWI = 0.02, VI = 12.06, TPI = 92.46 and GI = 97.97. The chemical data was used for the calculations of the supplying index (SI), which determines the type of supplying and the facies. The value of the SI=3.7.

Summary data of indices, petrography and chemical composition of the coal determine type of the peat bog, where the plant tissues created the coal seams number V and VII of the Svoge basin, as limnic with prevailing forest plants and prevailing ombrotrophic character. The environment at the time of pet-genesis is characterize by wetness of the peat bog (probably low values of the Eh), pH of the environment from 3.5 to 6.2, relatively low humification, high penetrating of the clastic material, limited groundwater supplying with limited presentation of carbonate rocks in the ancient coastal zone. The plant tissues are well preserved, but the Vitrinite macerals are prevailing and the Inertinite macerals are insignificant.

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THE MINERALOGICAL KNOWLEDGE OF THE ANCIENT BULGARIANS ACCORDING TO SOME MEDIEVAL SOURCES

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ABSTRACT
According to the numerous publications about the origin and distribution of the ancient Bulgarians throughout the centuries (see Dobrev, 1991, 1998; 2003; Tabakov, 1999), they have migrated from their primal native land located around the Pamir region in direction to the Caucases, and later on two major states have been founded, known as Volga's Bulgaria and Asparukh's Bulgaria. In the mineralogical treatise of the Medieval encyclopaedic scholar al-Biruni (XI century) are listed data, pointing out that the inhabitants of Balkh (Balkhara, Bolor, Bulur) and Volga's Bulgaria have extracted, ore-dressed and traded gem minerals and precious metals. The name *balas* for red spinel from Badakhshan has its origin in the ancient name of the region Balaxian (Balkh). According to data of the Armenian scholar Arakel Davrizhetzi (1669) one of the ruby varieties has been called *balkhi* (from Balkh – in analogy to the the colour of spinel). The coincidence of the names *bulhor* (Bulgarians) in the Tadjik and *bullur* (rock crystal) in the Persian and Arabic languages probably can illustrate forgotten traditions of population, which has been engaged exclusively from the most ancient times with exploitation and trade of gem minerals and of metals as copper, gold and iron both.

INTRODUCTION

According to the existing Byzantine and Syrian Medieval sources the most ancient Bulgarian land has been located at Mount Imeon, a name including the high mountain regions in Central Asia enclosing southern Tadjikistan and the northern parts of Afghanistan, Pakistan and India – Hindukush, Pamir, Karakorum and the Kashmir Hymalayas. In this region the name of the ancient kingdon Balkh (Balkhara) has been mentioned according to Indian sources, and the main city has also been known as Balkh (Dobrev, 1991; 1998; 2002). These lands, according to Armenian and Persian sources, have been inhabited by people, known as *Bulkh* or *Bulgkhar*, and in Europe during Greek and Roman times these lands are known as Bactria (Bactrian kingdom). The founded in northern India state Balkhara (Bolo) has been ruled by a king known as *balkhar*a (Dobrev, 1991; cit. after Biruni; comp. Masson and Romodin, 1964, p. 166-167). Another district in the mountains south of Samarkand with the name Burgar has been reported by the Arab scholar Ibn Haukal – now in the territory of contemporary Tadjikistan not far from the Zeravshan river with the local name Falhar (Dobrev, 1991, p. 29; 2002; c. 99-100). The cited by De Groot and Dimitar Suselov early, probably Bulgarian state Bulur (Bolor) fully corresponds to the name of the Tadjik name for Bulgarians – *Bulkhor*, and in the toponymy of the region there is a ridge, khown as Wakhan, related to the *Wakhan* people in resemblance to the Bulgarian branch *Wkhndur*, mentioned in the history of Moses Horenatzi in the V century (Dobrev, 1998, p. 229).

POPULATION AND REGIONS

The root *Bulg-* (*Bulgkh* or *Balgkh;* in the interpretation of Dovrev – a big town or kingdom, and for the Bulgarians – people from the Big town or the Big kingdom correspondingly) is specific with the characteristic Bulgarian sound ъ, which has been pronounced or changed in different languages during the centuries. According to linguistic research two small tribes with similar linguistic peculiarities have been found in the discussed region of Hindukush – *munjan and iidga (bregeio)* (Dobrev, 2002; comp. Litvinsky, 1972, p. 165-168). The contemporary inhabitation of the Tadjiks in Afghanistan displays their localization mainly in the provinces of Badakhshan, Balkh, in both Parvan and Kapisa provinces north of Kabul and in the mountain regions around the town of Herat. In most cases the Tadjiks and the so called Near-Pamir Tadjiks occupy high mountain regions related to some of the most important industrial mineral and ore deposits, some of which have been exploited since Antiquity and Medieval times. This correspondance of certain ethnic groups to definite mountain regions on the background of the whole Hindukush or its surroundings shows a tendency for linking of tribe groups with the culture of more ancient people, which are known to have acted as miners exploiting gem minerals and metals.

In the work of the Arab geographer Yakut ar-Rumi (~1179–1229) the districts Bolor and Burdjan have been mentioned between Kashmir and Badakhshan, suggested as the first mentioning of names of Bulgarian states in Arab geographic literature in Centarl Asia (Tabakov, 1999; p. 204). The statetement that the land Burdjan corresponds to Badakhshan, as well as that Bolor corresponds to the whole Hindukush, is not precise, as the second name has been cited separetely by the Arab author. The more reliable explanation is the land Burdjan to be localized west of the land Bolor, corresponding approximately to parts of the contemporary Northwest Border Province of Pakistan. The land Bulur (Bolor) has been identified in the commentary to the mineralogical work of al-Biruni with Kafiristan (Nuristan), where also a ridge with the name Bolor-tagh is known (Biruni, 1963b, p. 438). The Bolor region has been mentioned by Marco Polo, but as a land probably in the southeastern Fore-Pamir. (Polo, 1986, p. 102; see Tabakov, 1999, p. 249). The Bolor region (Bular, Bulgar, in Chinese sources – Bolo, Po-lu-lo) is localized north of Kashmir and south of the Wakhan ridge (Dobrev, 1991, p. 56; Tabakov, 1999, p. 249; comp. Voinikov, 2001). From a geographical point of view these lands correspond to the most northerrn part of Pakistan and India (in different times and in different range designated as Boloristan, Baltistan, Dardistan, Nuristan and up to Eastern Pamir and Kashmir). Examples for cities and lands Bolo (Bolule, Bolu, Bolyui, Bulu) in this region have been listed in the works of Nikolai Bichurin (1777–1853) (Bichurin, 1950, p. 264, 270, 318-320, 324-325).

THE EVIDENCES OF AL-BIRUNI

The encyclopaedic scholar Abu Rayhan Mohamed ibn Ahmad al-Biruni (973–~1050) is one of the most outstanding Central Asia scientist with a lot of works in astronomy, geodesy, geography, history and botany, written in Arabic language. In one of his last works, devoted to gem minerals and metals '*A Collection of Knowledge on Gemstones'* al-Biruni mentiones several times the names Balkh and Bulur (Bolor) or related to them characteristics. This treatise is an unique in volume and quality of information book about the distribution, production, physical properties, utilization, prices and trade, lore and real stories of gem and decorative minerals, including their varieties, as well as the most important metals.

1.The district Balkh has been discussed in the chapter about the corundum (*yakut*): "Abu Hanifa ad-Dinavri says in his 'Book of Plants' that *ranf* is a species of mountain tree. It is known with the name *hilaf balkhi*… The leaves of *hilaf balkhi*, known in Balkh as *sirishk* by the juice, which they sqeeze from it and purify by boiling, are smaller than the leaves of the lilly" (Biruni, 1963b; p. 37). In this case the Arab name has been underlined with an adiitional name, pointing to the connection of the plant with the Balkh area. This fact indicates that its area of distribution are more likely the mountain regions of Hindukush of the contemporary province Badakhshan, and not the plaines of Balkh. These plants are analysed in the context of the statement, that one of the best colours of the *yakut* (ruby) resembles that of the wild crocus.

2. In another case, al-Biruni tells the story of the rich emir of Gasni, Yamin ad-Daul (998–1030) in Balkh, who during hunting in the mountain met a beggar from Bukhara, who annoyed him. The emir waved with his hand and did not see that a ruby flew away from his ring, found by the beggar. Later on the emir came back to seek for his gemstone and saw once again the beggar, who on the tread to be killed, gave him back the stone being gifted with 300 dinars by the emir (Biruni, 1963; p. 60). In this story once again the idea for the name Balkh as a part of the mountain Hindukush, where red gem minerals (possibly red spinel) can be traced.

3. In the chapter on garnet (*bidjazi*), some garnet deposits have been described as well as the difference between garnet and red spinel (*lal*): "This garnet which comes to Kashmir (from the north) has its origin in the Shikinan pits. From the mountain region with capital Hablik to Shikinan the distance is two days travel, and to Kadkad (Gilgit) – the place of the shah of Bulur – seven days, acounting from the boundary between the Kashmir valley and the capital Adastan (Srinagar]" (Biruni, 1963b; p. 78). According to the comment to the work of al-Biruni the name Bulur (Bolor) can be identified with the mountain region Kafiristan or contemporary Nuristan, but most likely – with regions in the most northern parts of Pakistan. Bulur (Bulul, Bolol) has been described as a kingdom ruiled by a shah. Shikanan has been viewed as a district surrounding the district of Badakhshan, and in its other end is the district of Wakhan.

4. In the chapter on gold, a story about the richness of the river Sind (Indus) has been told, which when "reaching the place against the Shamir idol in the district of Kashmir, towards the district of Bulul, receives its name Sind" (Biruni, 1963b; p. 221). In his work "India" al-Biruni describes, that leaving the mountain pass into the valley, on the left side during two days of travel are the mountains Bolor and Shamilan (Biruni, 1963a, p. 203; comp. Bulur and Shamishan – Biruni, 1963b, p. 479). In the same chapter he tells that the Indians from Kashmir knew the neighbouring country Dardar (Gilgit valley), whose inhabitants have been called *bakhtawaran* (Biruni, 1963b; c. 222; comp. *bhattawarsan* with a king Bhatta-shah and towns Gilgit, Asvira nd Shiltas – Biruni, 1963a, c. 203). In the same chapter as goldbearing has been pointed also the valley of the district Wakhan.

5. In his pharmacological work "Saidan", describing the amber (*kakhrubai ua karuba*) al-Biruni writes: "They say that amber is a dew, [which petrifies on the trees] in the mountains of Bulgar(ia). Later on, it drops (from the mountains) into the sea and it has been (cast) ashore, and there is where they gather it" (Biruni, 1974, p. 776-777; comp. Biruni, 1950; 1963b, c. 472). In the comments on the mineralogical work of al-Biruni it has been asumed that during the VIII–X c. amber appears from the Baltic region with the help of the Bulgarians from the Volga's Bulgaria in the East – at Khoresm and in the Central Asia region. Such data have been confirmed by other sources as al-Masudi and al-Makrisi. In the cited part al-Biruni accepts the district (state) Bulgaria as a mountain region.

6. The trade functions of the Volga's Bulgarians has been confirmed directly by al-Biruni in the chapter for the use of the highly estimated material *hutu*, interpreted in the comments as rhinoceras horn: "It resembles the core of the bone of a fish [walrus ivory, known in ancient Russia as "fish's tooth"], which has been brought by the Bulgarians in Khoresm from the North Sea" (Biruni, 1963b, p. 195). In other interpretations *hutu* is supposed to be fossil mamooth ivory, known from the northern regions (Dobrev, 1998, p. 61). According to the Arab traveller Abu Hamid al-Garnati al-Andalesi (1080–1170), who has visited Volga's Bulgaria "the Bulgarians sell in Khoresm at a great cost similar to ivory teeth of giant animals, which they dig out of the ground", and the trade with mamooth ivory has been mentioned also during the travel of Ibn Fadlan (Akhmerov, 2002, p. 35; the ivory has been exploited from the lands of Volga's Bulgaria and traded to Khoresm, where they used to make hard handles for knives or boxes, but it is not excluded the so called "fish's teeth" to be walrus ivory from the northern regions; Ibid., p. 76). Ancient artifacts made of paleoivory (mamooth tusks) have been found on the territory of Volga's

Bulgaria during archaeological excavations. They are known from the Paleolithic sites Krasnaya Glinka in the Tetyush region and the village Deukovo of the Menzelin region, and thousand mammooth tusk beads have been found from Sungir at Vladimir (Chervonnaya, 1987, p. 14-15). Thus it is possible that *hutu* has been bone material found in local regions, and not from the polar regions.

7. In the chapter on metals, in the story about lead, the following evidence has been listed: "They have told me, but I almost do not believe, that a person in Balkh made mercury from lead and he produced from five parts (of lead) one part (of mercury), and he supplied (the whole) region with it. That is why after him (his death) they asked about it his family, but they did not receive any information, with the exception that he bought lead, which has been molten and that he supplied with mercury a gold mine" (Biruni, 1963b, p. 242-243). The amalgamization with mercury has been one of the main methods for gold extraction, and direct evidence for such a process has been mentioned by al-Biruni in the chapter on mercury.

8. In the chapter on diamond [*almas*] al-Biruni mentions the best sort of diamonds as *bulluri* [that is crystalline or transparent), which are followed by the red diamonds (Biruni, 1963b; p. 86). Thus it is understood, that in Medieval times with the definition *bulluri* (coincidence with the name of the people and state Bulur or Bolor) are named transparent crystals (minerals) as something extremely precious. In the chapter on iron al-Biruni mentions crystal borax (*at-tincar al-bulluri*) once again with the definition of *billuri* – crystalline or transparent (Biruni, 1963b, p. 485).

THE EVIDENCE OF DAVRIZHETZI

In his "Book of Histories" the Armenian historian Arakel Davrizhetzi (1595–1669/1670) describes in a separate chapter the gem minerals used during the Medieval centuries according to data of the priest Sargis of Beria and anonimous sources. Introducing the deposits and properties of noble corundum he mentions that "the red [corundum – ruby] has seven hues: purple, pomegranate [similar in colour with the pomegranate fruit], lilac, residual [probably pale rose], with colour of wine must, with colour of vinegar and balkhi" (Davrizhetzi, 1973, p. 456). Such colour hue as *balkhi* for ruby lacks in the works of al-Kindi and al-Biruni, supposed to be the most voluminous and detailed mineralogical books in Medieval Arab literature. Probably these corundum varieties have been mentioned in some later sources as that of the Arab author at-Tifaschi (1184–1254) (*Arab Roots…*, 1997). Davrizhetzi describes in a next chapter the spinel (*lal*) from Badakhshan, with the popular story how this gem mineral apeared in the mountain after a strong earthquake.

METALLIC AND NON-METALLIC MINERALS

The most ancient Bulgarians (who have been identified as the Ideltzians according to the history 'Dzhagfar Tarikh') have been declared as the first miners in the world (Yarullina, 2002, p. 10), but such a statement has to be supported by evidences of the material culture. A lot of ancient sources confirm that they have exploited not only ores, but also industrial minerals, including gem and decorative minerals (for example rock crystal and lazurite). On the territory of contemporary Afghanistan chalcolithic objects are known since the IV mill. B.C., the copper sources not being clearly identified. Copper artefacts dominate thoughout the III-II mill. B.C., (early agrarian culture Sistan; culture Kandakhara), for which evidence has been found in slags and it has been suggested that the copper has been exported into neighbouring countries (Masson, Rommodin, 1964, p. 37 и 39). Gold mining in the Pre-Pamir region has been known since the II mill. B.C. (Baratov, 1984, p. 40). During the V c. B.C. the lands of Balkh (Bactria) have been conquered by the Ahamenide dynasty, for which is known to take possession of an annual tax of 300 golden talants (21 000 kg gold) (Dobrev, 2001; p. 91). In the same epoch, iron has been allready exploited, its sources however not been identified. The most important gold deposit, known from Medieval times is Zarkashan (al-Biruni mentions the deposts Sarginak and Sangzariz in Zaruban), and the largest copper deposit is Aynak. Gold deposits are known also from the province of Badakhshan (al-Biruni mentions the mountain Shikanan and Rasht, as well as Hutal – Wakhan). In the same region al-Biruni mentions the metal *harsini* (*khadid sini* – "Chinese iron"; from Persian *har chini*), interpreted as arsenic, but the description can suite antimony also. In contemporary Badakhshan are known deposits of copper, gold and iron, as well as a few occurrences of tin (cassiterite).

From the industrial minerals in the Balkh region of specific importance in the past have been the salt (Namakab near the town of Talukan) and sulphur (Chimtal). The salt deposits at Talukan have been described in detail by Marko Polo (Polo, 1986, p. 43). Al-Biruni in his pharmacological work mentions yellow sulphur (*kibrit*) from Balkh, which has been distinguished from the white sulphur from Persia (Biruni, 1974, p. 741), as well as salt (*milkh*) from the districts Darabdjirt and Hutal (Wakhan) (Ibid., p. 823). Halite and gypsum are known from the big deposit Hodjamumin near the town of Kulyab in southern Tadjikistan. Other nonmetallic raw materials with a definite use in the past are talk ("rock powder" – *tashupa*) and graphite from the region around Ishkashim (Baratov, 1984, p. 43).

LAZURITE

The dark blue decorative lazurite has been a sacred mineral to the people of the Mesopotamia and along the trade routes it has reached Ancient Egypt, India and China. The mineral has been used in the material culture, and has been mentioned in literary sources of Sumer and Acad, Assyria and Babylon, in the most ancient period of Egypt (IV mill. B.C.). All these evidences point to intensive trade links in the past and to the extremely importance of lazurite as a highly estimated sacred mineral (Kostov, 1993). Since the IV mill. B.C. lazurite objects are known from the territory of contemporaray Turkmenia and Iran (Sialk; there has been a suggestion, that this settlement has been taken over at the end of the same millennium because of its strategic position on the lazurite trade route) (Sarianidi, 1984, p. 87). In the area of development of the civilizations of Mesopotamia lazurite has been found from archeological excavations in sites dated to the second half of the IV mill. B.C. – in Elam during the reign of Suza I, in

Mesopotamia – in Uruk and Djemdet Nasr (Masson, Rommodin, 1964, p. 35; the authors are inaware who has exploited the mineral in the remote mountains). In a Sumerian text there is evidence for exchange of grain for lazurite, obtained by the tribes in the mountains on the east. The wide spread area of lazurite (dominated by beads) in southwestern Asia allows a suggestion for the beginning of its exploitation to have been started even in the V mill. B.C.

The main source of this mineral is Hindukush with its Sar-e Sang deposit, which has been exploited from Antiquity to contemporary times. The deposit is located at about 3700-4300 m 70 km south of the town of Fayzabad in the valley of the river Sar-e Sang, tributary of the river Kokcha (Brückl, 1937; Blaise and Cesbron, 1966; Efimov and Suderkin, 1967; Rossovsky, 1980). This large lazurite region is located in the range of the Fayzabad metamorphic massif. Al-Biruni mentions two lazurite (*lazaward*, *lazward*, *lazuward*, *alazward* in Persian and Arabic) deposits – at the Karan mountains (probably the Tirgaran ridge) after the steep valley of the river Pandjkhir (Pyandj) and at Tus-Bunak near Zaruban (southern Afghanistan). He writes correctly that in Byzantine times it has been known as *arminakun* (*Armenian stone* – turquoise), as it is similar in colour to turquoise (Biruni, 1963b, p. 182). In a lot of Medieval sources lazurite from Armenia has been mentioned uncorrectly. Probably in such cases, the local or traded from Persia turquoise has been pointed out, which is sky blue and not a dark blue mineral. Lapis lazuri (lapis lasuli) is a name from Medieval treatises, used as a synonym for the mineral lazurite or for lazurite-bearing rock. The Sar-e Sang deposits have been visited and described by an European researcher in 1838 (Wood, 1841, p. 246-245). They have been known in the past with the name of the near-by village of Firgamu (Wood, 1941, p. 261; Fersman, 1961, p. 36). It is possible that this name can be a derivative of Birgamu (with root *bilg-*, *bulg-*). The suffix *-ar* (*-or*; *-ur*) and the deposit (village) with a root *Birg-* (*Bulg-*) can constituate the ethnonym *Bilgar* (*Bulgar*). In Sogdian language lazurite has been known as *r'zβwrt*, *r'zwrt* or *r'cβrt*, from where origins the new Persian and Tadjik name of the mineral, and in Indian sources – as *lājavarta*, *rājavarta* и *rājapatta* (Litvinsky, 1972, p. 79). In the last case the translation would be "the king of the stones" – lazurite as a sacred and royal precious stone.

SPINEL (*BALAS*)

In the province of Badakhshan gem spinel *(lal*) has been exploited. The discovery of spinel in the region has been determined about VII–VIII c., al-Biruni giving the first detailed desciption of the mineral and its deposits. During the X c. this mineral has been mentioned by other Arab authors as Istrakhri (mentions also the deposits of lazurite), Ibn Haukal and Madrisi (Laemmlein, 1963, p. 347). In the same region between Shikanan and Wakhan garnet deposit have been also localized (*bidjada*, *bidjazi*). The Venician traveller Marko Polo (1254–1324) describes in his Asiatic routes and adventures during the XIII c. beside the exploit of lazurite (*lazure*) also the extraction under the king's order of *balas* (spinel) from the Balaxan (Badakhshan) region in the Shighanan mountain. It has been forbidden unauthorized gathering of precious stones even under the threat of death penalty (Polo, 1986, p. 44). Badakhshan can be found in the same and other sources written as Balascian, Balahkshan, Balakhsen, Balaxia or Baldasia. According to the Arab traveller and writer Ibn Batuta (1304–1377) the *badakhshan ruby* has received its name from the name of the corresponding mountains, and has been commonly called *al balakhsh* (comp. *al-lal al-badakhshi* by al-Biruni, but *balakhshi* by al Tifaschi; *Arab Roots…*, 1997). The name *balas* (balas-ruby, bale-ruby) for the spinel as a mineral species (undistinguished in the past from the ruby) or for its variety is attributed to the ancient name of Badakhshan, accepted to be Balkh (Ball, 1893; Hughes, 1994; cit. after Prinsep and Kalikishen, 1832; Wood, 1841, p. 293). The first official record from an European about "ruby" deposits is related to an ambasador (1403–1406) in the court of Timur, who writes about the meeting in Samarkand with the ruler of Balaxia (Badakhshan), around whose grand city in the mountains "rubies'' (spinels) have been found (Ball, 1893; Hughes, 1994; cit. after Markham, 1859). Therefore, the ancient name of spinel – *balas* (from Balaxia – Balkh) denotes an "ancient Bulgarian" gemstone (Kostov, 2003). The contemporary gem spinel deposit Kuhilal in Tadjikistan, as well as the spinel from the regions around have been described in a lot of mineralogical works (Kolesnikova, 1980; Rossovsky, 1980).

OTHER MINERALS

Other gem minerals as green tourmaline, kunzite, beryl and rock crystal are exploited from the pegmatites in the Afghan provinces of Kunar and Laghman (Geruvol et al., 1980; Rossovsky, 1980; Rossovsky and Konovalenko, 1980; Bowersox, 1985). Similar mineralization is known in the neighbouring mountain regions of Pakistan, where aquamarine, yellow-brown topaz and coloured tourmalines are found. The precious minerals have been traded for gold and silver (Biruni, 1963b, p. 64; Laemmlein, 1963, p. 395 and 436).

Before the V c. Chinese sources mention migrations from Balkh (Bolo), connected with the new kingdom in southwestern direction, and during the year "424 some masters went from the town of Balkh in China, and from them the Chinese learned a rare occupation – the making of colour glasses" (Bichurin, 1950, p. 264-265; Dobrev, 1991, p. 44; 2002, p. 106). From the chapter of enamel of al-Biruni it is clear, that during Medieval times the production of crimson-red glass with dispersed gold has been known (now-a-days known as "ruby" glass). According to the data of ad-Dimishki mainly blue glass or enamel has been manifactured, used as a substitute of lazurite (for example "Egyptian azure"; comp. Kostov, 1998, p. 38).

In the Armenian geography "Ashkaratzyuitz", in listing the regions, peoples and tribes, after the Bulgarians (Bulgh) on the west are mentioned the Khoresmians (from Khoresm), where in the district of Tur has been obtained the kholosmian (khoresmian) stone and the best carnelian (Dobrev, 1998, p. 36-37; it is not correct *serdolic* to be interpreted as sardonix, and the *khoresmian stone* as lazurite – cit. in Dobrev, 1991, p. 29; Stamatov, 2002, p. 23). The *serdolic* is a Russian name for carnelian. The *khoresmian stone* is most probably turquoise, known in the past from the mountain ridges on the west (Sultanizdagh), as well as from the central parts of Kuzulkum (Bukamtau and Tamditau), where numerous old mining pits for this gem mineral have been discovered (Menchinskaya, 1989, p. 20-24; comp. Pruger, 1971). Al-Biruni, who has been born in the region, describes in his treatise only histories about rubies, but not as an object of exploit, but of trade.

ON THE NAME *BULLUR*

In the Persian and Arab mineralogical treatises rock crystal (quartz) is denoted with the name *bullur (ballur; billawr; bilawri)*. It is possible that the name is of an Acadian origin – *burallu*. The origin of the Greek word *βήρύλλος* (beryl) is not yet clear in mineralogy and the note of Laemmlein (1963, p. 459) seems to be accepted as logical and correct – this name has been used primary for denoting of rock crystal. It must be remarked that the morphology of quartz and beryl both includes the hexagonal prism of the crystals. Because of the poor mineralogical knowledge up till a definite period, all of the prismatic or transparerent crystals probably have been denoted as "beryl" (mainly rock crystal because of its broader distribution; for the role of quartz comp. Kostov, 1998).

In the monograph on beryl and its varieties, the following derivative names for beryl have been listed (according to the understanding in a broader sense – rock crystal or crystal): *ballur*, *billaur*, *bulur*, *berulin* – in Persian and Arabic language; *besady* – in Persian; *belur*, *belura* – in Hebrew, Pahlevi; *berula*, *berulo*, *brulo*, *burlo* – in Siryan; *berel* – in Ethiopic; *birla*, *birula* – in Chaldeic; *biurey*, *buregh* – in Armenian; *byvrili*, *byvrioni* – in Georgian; *billurin* – in Arameic; *beryllion* – in Coptic; *beruj* – in India (Sinkankas, 1981, p. 616-617). From this name through the Greek *berilos* (*βήρύλλος*) and the Latin *berylus* (*Berillus*; *Beryllus*) has been derived the contemporary "beryl" (whritten in a different manner in European treatises – for example *Berill*, *Beriillis*, *Berillo*, *Berial*, *Beril*, *Berille*, *Berillus*, *Berolus*, *Berre*, *Beryall*, *Birillus*, *Byral*, *Byralle*, *Byrillus*). The name "emerald" is with a supposed Sanskrit origin, and in ancient India the green mineral has been known as *asmagarba* or *marakata*. In the "Simeon's Sbornik" (according to the copy "Izbornik" from 1073), Epiphanius of Cyprus (~315–403) has been cited with the list of the twelve minerals on the pectoral of the Hebrew high priest, among them a pigeon blue *viroulion (βηρύλλιον)* being mentioned from the mountain Taurus (*Old Bulgarian Literature*, 1992, p. 101; comp. different writing in the Hexameron of John the Exarkh fron the XI c. – *virulii*, in the Vilnen copy of the "Simeon's Sbornik" from the XVI c. – *virulion*, Ibid., p. 394; Epiphanius of Cyprus – *virillion*). The name of the Taurus mountains in the past may have been perceived as the whole mountain region on the northeast of Mesopotamia, including Hindukush.

In the understanding of al-Biruni the rock crystal owns its value related to two natural primal essences – water and air. "From Kashmir *bullur* [rock crystal] has been exported either as pieces of rough material, either as manifactured from it vessels, cups, chess figures, pawns for nard [draughts] and beads with the size of a hazelnut. …They find it as pieces in the mountains; its in abundance in the area of Wakhan and Badakhshan, but it is not exported there from" (Biruni, 1963b, p. 172). The regions of Wakhan and Badakhshan are defined as a place, where there is supposed to be "probably, a huge quantity of rock crystal for trade as cut and raw material both" (Laemmlein, 1963, p. 347). The evidence of al-Biruni proves directly the exploit and trade with quartz varieties – mostly rock crystal.

THE TRADITION IN VOLGA'S BULGARIA

Confirmation for preserved traditions in jewellery and trade with gem minerals and noble metals can be found in a lot of the objects of material culture in the Bulgarian settlements in the Volga region. From about 900 mineral objects as dominantly have been described carnelian (48%), amber (20%) and rock crystal (10%), and rarely turquoise (5%), amethyst (5%), chalcedony (agate), lazurite and nephrite or other gemmological materials (Poluboyarinova, 1991, p. 98-99). Lazurite artefacts have been excavated at the settlements of Bolgara and Saraya, where local workshops for cutting gem minerals have been found (Ibid., p. 101). At a later stage the successors of the Volga's Bulgarians are engaged in trade of metallic and non-metallic raw materials from the Ural's mountains towards Europe.

CONCLUSION

In the mineralogical treatise of the Medieval encyclopaedic scholar al-Biruni (XI century) are listed data, pointing out that the inhabitants of Balkh (Balkhara, Bolor, Bulur) and Volga's Bulgaria have extracted, ore-dressed and traded with gem minerals and precious metals.

According to the Armenian historian Arakel Davrizhetzi (1669) one of the ruby varieties has been known as *balkhi* (from Balkh; in analogy with the colour of spinel).

The name *balas* for red spinel from Badakhshan can be drown out from the ancient name of the province (Balaxan from Balkh).

The coincidence of the names *bulhor* (Bulgarians) in the Tadjik and *bullur* (rock crystal) in the Persian and Arabic languages probably can illustrate forgotten traditions of a population, which has been engaged exclusively from most ancient times with exploitation and trade of gem minerals and of metals as copper, gold and iron both. The discussed coincidence in the name of transparent non-coloured crystals (rock crystal) and the ethnonym Bulur (Bolor) as well as the overlapping of the regions occupied with ancient Bulgarian population (mixed throughout the centuries and inherited by the migration of other tribes and people) and regions with distribution of quartz and other gem crystals allows a search for mutual influence in both directions. Thus the ancient Bulgarians can be expressed also as the people of a transparent (clear) nature, who have exploited, treated and traded gem minerals.

Beside medieval sources, the preserved traditions in working and trading gem minerals and noble metals have been demonstrated from data in medieval Volga's Bulgaria.

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GOLD OCCURRENCES IN POREČ-STARA PLANINA METALLOGENETIC ZONE

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ABSTRACT

One of the most prominent tectonic units in Europe, Karpathian-Balkan region, runs in form of "bended chain" from east end of Alps up to Black Sea. The area of Eastern Serbia is a part of Karpathian-Balkan metallogenetic province which from Romania extends into Bulgaria through Serbia. Within it in Serbia four metallogenetic zones are identified with characteristic geological development and mineral associations: Ridanj-Krepoljin zone (A), Neresnica-Beljanica zone (B), Bor zone (C) and Poreč-Stara Planina zone(D), Fig. 1).

Within the Poreč-Stara Planina zone (the subject of this paper) several gold occurrences and deposits are identified.

Main metallogenetic features of this area rocks of diabase-phyllitoid formation which are metamorphosed to the greenschists facies, as well as the rocks that intruded them: Gornjan granitic rocks, Deli Jovan gabbro in the north as well as Zaglavak gabbro and granitic rocks on Stara Planina.

BASIC GEOLOGY OF POREČ-STARA PLANINA METALLOGENETIC ZONE

In the area covered by Poreč-Stara Planina metallogenetic zone there are several formations and associations of formations that range from Proterozoic to Quarternary (Fig. 2).

Gneiss and crystalline schist, of amphibole facies, association of formations belong to **Proterozoic**. Here are also volcanogenic-sedimentary rocks that are metamorphosed to the facie of green schists.

The rocks of **Riphean-Cambrian** are represented by an association of formations of green schists, crystalline schists of amphibole facies and gabbro-diabase formation (crystalline schists of Poreč and Stara Planina). Part of green schists and crystalline schists of amphibole facies originates from felsic metavolcanics and metamorphosed volcanogenic-sedimentary rocks.

Lower Palaeozoic is represented by aspid formation, an association of terrigene-carbonaceous and volcanogenic-sedimentary formations.

The **Upper Palaeozoic** is much more wide spread. Carboniferous is represented by terrigene-calcareous formations (Poreč area), volcanogene-sedimentary rocks on Stara planina and Hercynian granitic intrusions that are found in Plavna and Gornjani in the north and Suvodol, Ravno bučje and Janja on Stara planina. Permian is represented by terrigene sediments, red sandstones with rare conglomerates and siltstones, as well as by smaller masses of vein magmatic rocks.

The rocks of **Mesozoic** are also wide spread in Poreč-Stara planina metallogenetic zone. In the lowest part (Triassic) sandstones, siltstones and limestones are deposited that transition upwards into sandy limestones and dolomites. The volcanic activity during the Triassic was not registered. The Jurassic sediments are represented by sandstones, conglomerates, siltstones and limestones. Significant widespread have volcanogene-sedimentary rocks composed of basic volcanics with occurrences of pyroclastic material. The Cretaceous sediments are mostly limestones and rarely sandstones and conglomerates.

The **Tertiary** formations are found in form of proluvial and limnic-river sediments with coal occurrences.

The **Quarternary** is represented by alluvial sediments.

GOLD OCCURRENCES IN POREČ-STARA PLANINA METALLOGENETIC ZONE

As a consequence of the process of concentration of gold and structural-lithologic features where these processes took place, in Poreč-Stara planina metallogenetic zone there are various morphogenetic types. The main metallogenetic feature of this zone are magmatic complexes (gabbro and granite massives) as well as the rocks that were intruded by magmatic activity (schists).

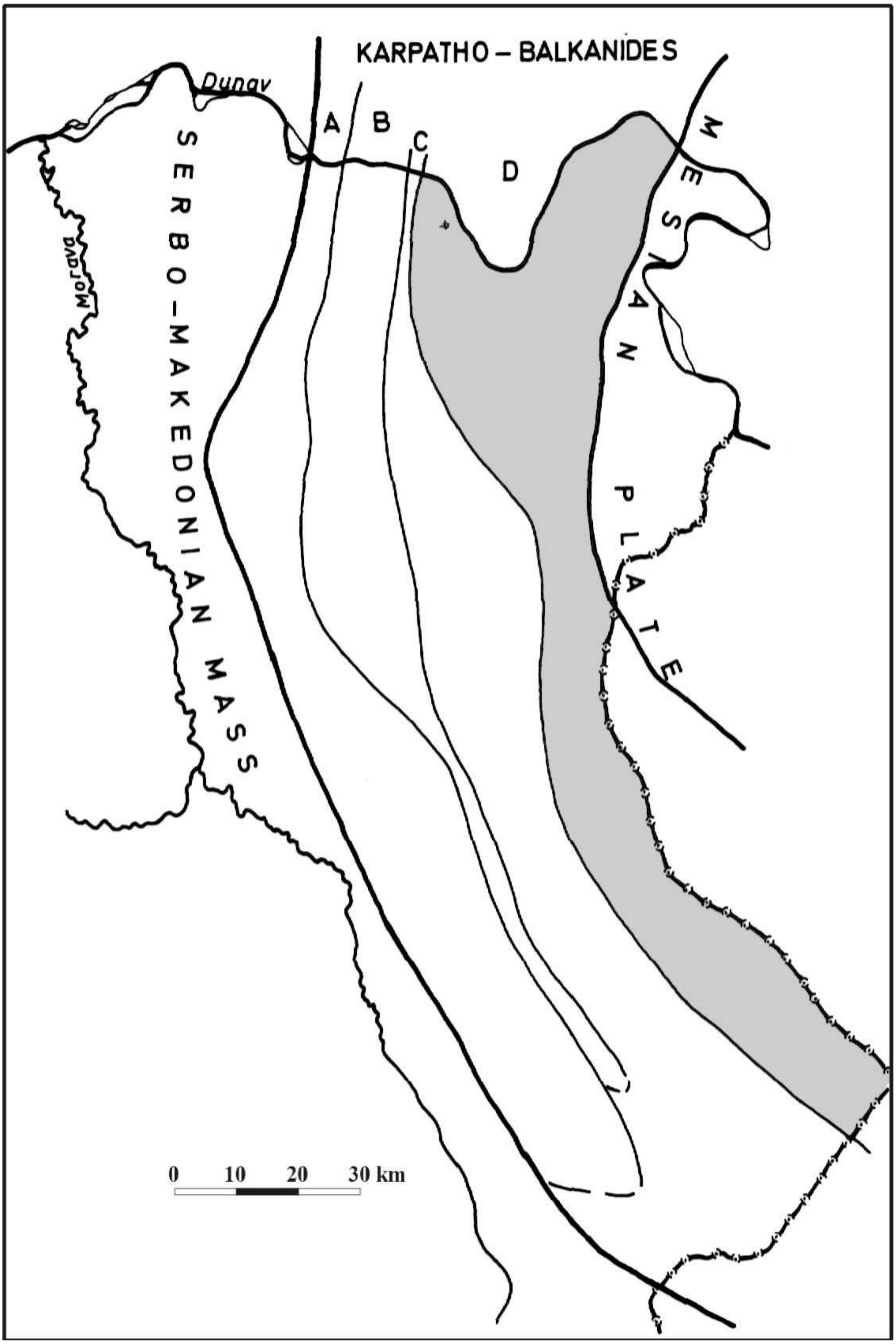

Figure 1. Metallogenetic zones in Karpatho-Balkanides of East Serbia

According to mineral composition, the condition of formation and the manner of distribution of mineralization there are several morphogenetic types of deposits and gold occurrences identified. The most significant occurrences are shown in table 1, and their position is shown in Fig. 2.

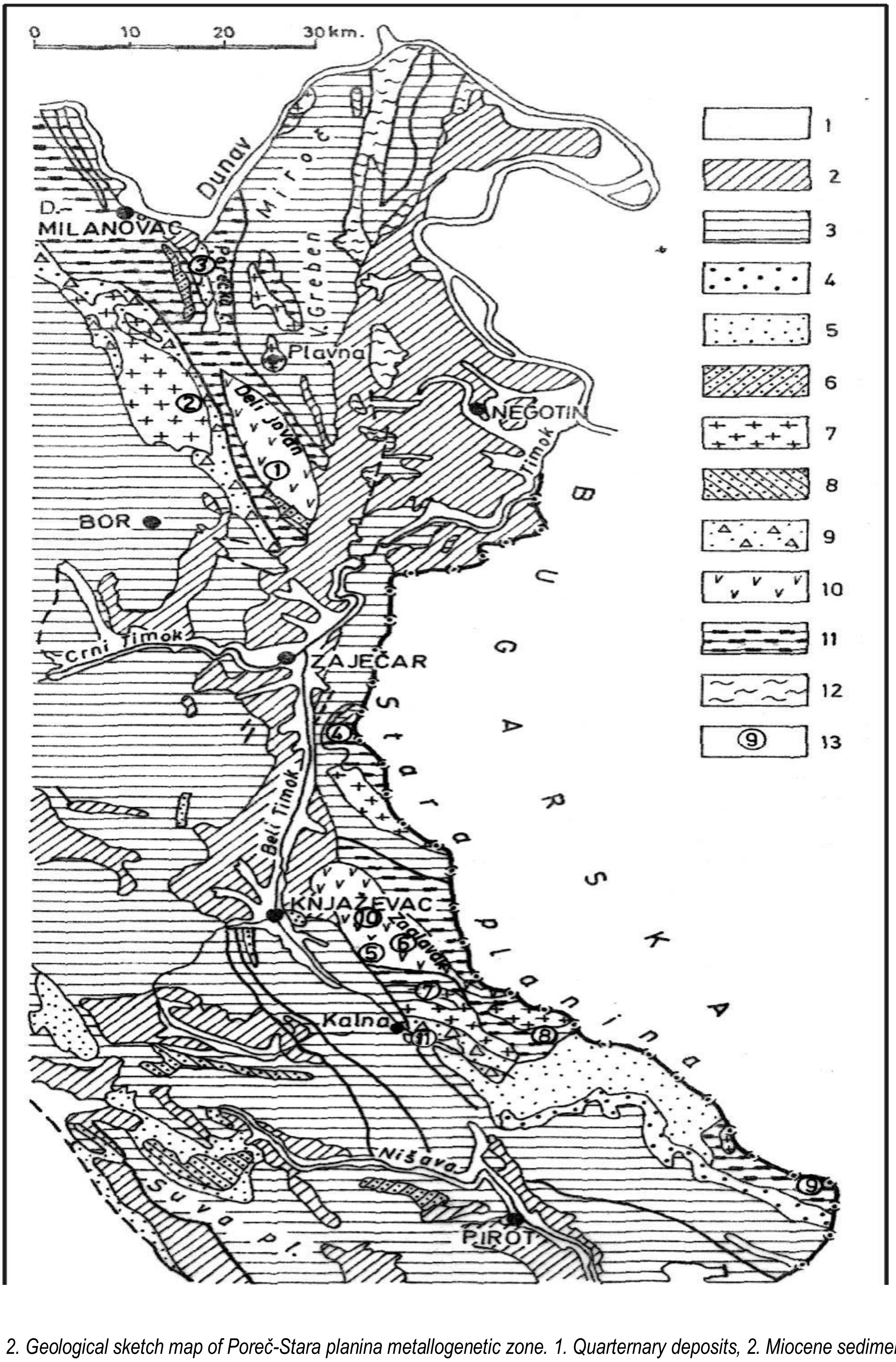

Figure 2. Geological sketch map of Poreč-Stara planina metallogenetic zone. 1. Quarternary deposits, 2. Miocene sediments, 3. Mesozoic sediments, 4. Triassic sediments, 5. Permian sediments, 6. Pyroclastics, 7. Granites, 8. Devonian limestones, 9. Metasediments, 10. Gabbro, 11. Schists, 12. Gneisses

Table 1. Morphogenetic types and occurrences

Genetic type	Morphologic al type	Host rocks	Type of mineralization	Locality
hydrothermal	veins	gabbro	Au, Ag	Glogovica(Deli Jovan)
hydrothermal	veins	granite	Au, Cu, Ag	Mali gabar
placer	lenses	sand and clay	Au	Porečka reka
volcanogene-sedimentary	veins and dissemination	schists and diabase	Au, Pb, Zn, Ag	Mijin kladenac
hydrothermal	veins, lenses	gabbro, granodiorite	Au, Bi, Cu, Pb, Zn, Ag	Gradište
hydrothermal	veins	gabbro, granodiorite	Au, Fe, Cu	Aldinac-Repušnica
hydrothermal	veins	granite	Au	Janja
metamorphogene	lenses	pyritic schists	Au, V	Crnovrška reka
hydrothermal	lenses, veins	schists, diabase	Au, Pb, Zn, Ag	Srebrna glava
placer	lenses	sand and clay	Au	Staro korito
placer	lenses	sand and clay	Au	Kalna

Deli Jovan ore field

Within Deli Jovan ore field in gabbro-peridotitic complex, and partly in Gornjan granitic complex, several quartz veins with gold were discovered, that are accompanied by polymetal sulphides. This area was well known in Roman times, with minor excavations.

Numerous quartz veins with variable content of gold are grouped in three large fault zones with a general strike of NW-SE. The most significant zone is Rusman-Ginduša where mining operations were carried out up to 100 m in depth.

The dimensions of quartz veins are variable. Along the strike they are most often up to 100 m long, rarely up to 700 m. The thickness of these veins varies from few centimeters to 3 m, usually from 0.5 to 1 m.

The quartz veins contain pyrite and gold, locally with concentrations of chalcopyrite and galena. The gold content is highly variable, from traces to over 150 ppm. (Janković, *et al.*, 1990).

In Mali gabar locality several quartz veins with gold were registered, accompanied by increased copper content. This occurrence was not investigated in detail. The gold content in these veins varies from 0.1 to 2 ppm, with silver ranging from 2 to 100 ppm. The thickness of these veins is under 1 m.

Gradište ore field is found in the southern part of Zaglavak gabbro massif. Polymetallic mineralizations are found by the granitic and diabase intrusions in gabbros.

This area is promissing for further investigations for gold.

Stara planina region

In the area of Stara planina gold does not form its deposits but is found in association with other elements (Cu, Bi, Fe, W etc.), so that its investigations were neglected up to recently.

Within Stara planina region several ore fields and ore zones were identified that can be significant in relation to discovery of gold mineralizations.

Vratarnica ore field is found in the northern part of Stara planina. The mineralization in Mijin kladenac locality is found in intensely altered schists, within a zone that can be followed several hundred meters, while mineralization occurs in intervals in form of complex, mutually parallel, veins. This polymetallic mineralization mainly contains pyrite, markasite, galena, sphalerite and arsenopyrite, with significant gold and silver content. Although previous investigations report mean content of 7.2 ppm of gold and around 400 ppm of silver (Buković, *et al.*, 1985), these results are in question and probably the grades are much lower.The dimensions of mineralized veins are still unknown.Although the genesis and age of the mineralization that has characteristics of stratiform type is still not confirmed, its supposed volcanogene-sedimentary origin is acceptable. Thus, the mineralization was formed in the process together with host rocks and with them undergone all changes induced by regional metamorphism.

Within this ore field several mineralized millonitic zones of various dimensions were found. Mostly they can be traced along strike for several hundred meters, with thickness from 1 to over 10 m. These zones were not investigated below surface. In all of them gold is present, mostly accompanying chalcopyrite, pyrite, and arsenopyrite, locally sphalerite and complex bismuth mineralizations. The gold content in mineralized zones range from 1 to over 100 ppm, 7 ppm in average. The copper and silver content in these zones is also significant (Ag cca 20 ppm, Cu cca 1%) (Kovačević, 2002).

Aldinac-Repušnica ore zone is situated in southeast part of Zaglavak gabbro massive along contacts with granodioriteporphyrite intrusions.

In this locality a large mineralized zone was discovered, traceable over 1.5 km in length, with a variable width of 10-60 m. This zone was not explored under surface. The mineral composition, as well as quantity of ore minerals in this zone is variable. The most common ore minerals are pyrite, chalcopyrite, magnetite, and hematite with sporadic galena, tetraedrite, arsenopyrite, molybdenite, scheelite, wolframite, cassiterite, psylomelan, pyroluzite, as well as elementary copper, silver and gold.

The gold content in this ore zone ranges from 0.4 to 30 ppm, 1 ppm in average (Kovačević). The presence of copper and iron is characteristic for this ore zone, and higher contents of gold are related to quartz-hematitic mineralizations. The compilation of all available data suggests that mineralizations in Aldinac-Repušnica ore zone are epigenetic and are promissing as gold potential.

Janja ore field is found in central part of Stara planina within Janja granitic massif.

Within this ore field small pyritized quartz veins, 0.1 to 0.5 m thick, with gold content of 0.1 to 2 ppm have been registered. As these veins are also short (few tenths of meters) they are not particularly interesting. As an exception is a mineralized zone above Gabrovnica village that can be traced for 1 km, with a thickness of 10 to 50 m. It is a millonite zone placed in gneisses near the contact with granite and gabbro. Besides the gold content of 0.1 to 0.3 ppm there is also an increased content of copper and molybdenum.

Crni vrh ore field is composed of rocks of diabase-phyllitoid formation-green complex with marble lenses. Within this ore field a large zone of black pyritized shales was found that can be followed for over 300 m, with visible thickness over 15 m. This zone was little explored and scarce samples show that the content of gold in the black shales is 0.13 to 1 ppm, with 8 ppm of silver, 300 to 2300 ppm of copper and up to 3000 ppm of vanadium, and slightly increased values of lead and zinc. This ore field deserves more attention than it got so far.

Srebrna glava ore field is in the southeasternmost part of Stara planina that is in Serbia.

Within this ore field composed of diabase-phyllitoid formation (green schists and diabases) several occurrences of mineralized quartz veins were discovered, mostly along contacts of diabases and schists. The quartz veins have a strike of NE-SW. The size of the veins is highly variable, few to over 100 m in length with width rarely over 2 m. Besides gold (0.3 to 5 ppm) the mineralization is accompanied by 70 ppm of silver and minor quantities of lead, zinc and rare copper.

PLACER GOLD

In Poreč-Stara planina metallogenetic zone there are several occurrences of gold in alluvial deposits. As most significant the alluvial deposits of Porečka reka, Trgoviški Timok and its tributaries on Stara planina and Koritska reka should be pointed out. The common feature of these alluvial deposits is large alluvial mass over large surface. The exploitation of placer gold took place so far in Porečka reka and Trgoviški Timok near Kalna. The volume of these alluvial deposits is cca 20,000,000 m^3 with the following mean content of gold: Porečka reka-0.16 g/m^3, Trgoviški Timok(Kalna)-0.3 g/m^3, Koritska reka (smaller alluvial volume)-0.4 g/m^3.

The conclusion for above mentioned is that so far geological explorations were limited but enough to point out to the potential for gold in Poreč-Stara planina metallogenetic zone.

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PRINCIPLE OF THE NORMALITY IN THE ENVIRONMENTAL GEOCHEMISTRY

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ABSTRACT
The propounded by the author (2002) principle of the normality is a new specific paradigm of the environmental geochemistry. It reads: The optimum living conditions of the environment are determined by the normal values of its geochemical characteristics – elements content level, physical-chemical and thermodynamic parameters. There are six aspects and consequences of the principle: (1) the clarke contents of the elements serve as an ecological-geochemical standard of the conditions for living organisms habitat, incl. man, in the biosphere; (2) an important goal of the environmental geochemistry is the determination of minimum and maximum threshold values of the variation intervals of the normal (clarke or background) element contents; (3) all the chemical elements are indispensable for the normal existence of the living organisms, incl. man – there are not "useful" and "injurious" or "useless" elements; (4) the background content of the elements is a cardinal geochemical standard for the quality of the environment; (5) the complex assessment of the state of the environment includes the investigation also of its physical-chemical and thermodynamic parameters; (6) the geochemical approach gains an advantage over the ecotoxicological one at the assessment of the quality of the environment components and of the degree of pollution.
Key words: environmental geochemistry, principle of the normality, clarke contents, geochemical background, geochemical standards.

INTRODUCTION

A new interdiscipline science – *the environmental geochemistry* was born in the 70ties of the 20th century in reply to the high sharpening of the problems connected with the contamination of the nature. It develops in the field of interface of the geochemistry with a number of other natural sciences, first of all – ecology, geology, physical geography, chemistry, mineralogy, soil science, hygiene (geohygiene), etc. At the present time the environment geochemistry has its clearly defined philosophy and object of investigation. As a separate branch of the geochemistry it studies the regularities of the distribution and the migration of the chemical elements and their anthropogenic transformations in the man's natural environment. The latter includes the part of the Earth exospheres (the anthroposphere), which is being inhabited or visited by man: the land surface, the low part of the atmosphere, the hydrosphere and the upper part of the lithosphere. The distinctive feature of the environmental geochemistry is the investigation of the interaction between the substances of the "technogenesis" (Ферсман, 1955 – p. 704) and of the natural geochemical systems, and the reply of the latter ones in the case they undergo an anthropogenic impact. Its strategic object – "geochemical ideal", in accordance with the term of L. G. Bondarev (Бондарев, 1976 – p. 48) – is the preservation of optimum natural living conditions for the man and the other organisms on Earth. As far as the anthropogenic pollutions of the environment are presented by different kinds of substances, the studies for their identification and their effects on the nature systems turns the environmental geochemistry into a fundamental and immutable element of the struggle for the survival of the human society, for balanced ("sustainable") relations between it and the environment. Thus it strengthens its position as a science of the 21st century – one of the most modish and priority directions of the investigations in the Earth sciences.

A brief analysis of the development of the environmental geochemistry and its theoretical bases is done in previous publications of the author (Kuikin, 2002; Куйкин, 2002). The aim of this article is to present more fully the principle of the normality, which has been developed further after the two above cited works.

REASONS FOR THE FORMULATION OF THE PRINCIPLE OF THE NORMALITY

As J. Fortescue (Фортескью, 1985 – p. 308, 309) notices, during the 60 – 70ties of 20th century, when the geochemistry as a scientific discipline proved not to be ready to face the problems on the contamination of the environment, research workers without any geological education and knowledge of the principles of the geochemistry began studying the behavior of the elements (mostly of the toxic substances) in the environment. This contradiction caused an evident confusion, and in particular – spending of great funds for investigation without using the available information and knowledge (Such a process happened later on in Bulgaria during the 90ties – see: Куйкин, 2002). A gradual return to the holistic approach in the environmental geochemistry was observed in the advances countries toward the end of the 70ties and a contribution of importance for this have the works of E. Kothny (1973), J. Fortescue (1980 – Фортескью, 1985) and others. It was clarified that a good knowledge of the state and the processes within the nature geochemical systems and their transformations under an anthropogenic influence is necessary for the preservation, and according to some authors – for "the creating" (Перельман, 1973; Бондарев, 1976), of optimum living conditions on Earth. A proper choice of a complex of nature protective measures is possible only under such circumstances. Regardless of this, the cases of substantial misunderstandings are still not rare in the practice of this field. They are manifested in relation to such matters as: lack of understanding of the importance of the geochemical background; not giving an account or underestimation of "the weak" geochemical anomalies; neglecting of the physical-chemical and the thermodynamic parameters of the environment; formalistic attitude to the hygiene norms – maximum allowable concentrations (MAC), etc.; overestimation of the results of the laboratory ecotoxicological examinations irrespective of their relation to the geochemical characteristics of the nature environment; giving absolute meaning of the terms "toxicity" of some elements (e. g. arsenic, cadmium, mercury, selenium, etc.) and the "usefulness" of other ones (e. g. the "nutrients" nitrogen, phosphorus, etc.). The clash with such ones and similar to them misunderstandings brought about the author to the idea of the necessity of the formulation of a new paradigm of the environmental geochemistry, that would reveal the essence of such basic terms as: optimum living environment, pollution of the environment, geochemical standards and so on. The term ***"paradigm"*** (from Greek ***"paradeigma"*** – pattern, example) is introduced in the Wissenshaftslehre by T. Kuhn and means a generally acknowledged scientific achievement (a law, a theory, an application, instruments), which gives models of problems and of their solutions to a practising scientific community for a space ot time (Кун, 1996 – p. 12). The paradigm determines the way of thinking (the ideology) and the directions of the studies in a given scientific field.

The environmental geochemistry builds up its theoretical concepts upon the *fundamental paradigms of the general ("classic") geochemistry* (Kuikin, 2002; Куйкин, 2002) and three specific new paradigms: (1) principle of the normality; (2) ecological geochemistry (or "ecological approach"), and (3) landscape geochemistry (or "landscape-geochemical approach"). The second and the third of the specific paradigms are considered as such ones by J. Fortescue (Фортескью, 1985). The principle of the normality is formulated for the first time by the author in 2000 (I. Atanassov, S. Kuikin *et al*.: "Investigation and elaboration of precautionary values for heavy metals and metalloids in soils", Sofia, 2000, MEW – report № 874-2324) and is presented publicly in 2002 (Kuikin, 2002). The concrete motives to that are the coming across in the practice mistakes of deriving as hygiene norms (thresholds) for increased contents of injurious substances in the environment components – maximum acceptable/permitable concentrations (MAC or MPC, etc.). For example, values for maximum acceptable risk levels (MAR) and negligible risk levels (NRL) of heavy metal concentrations in soil, equal and even lower than their referent background values were derived through laboratory ecotoxicological investigations in the Netherlands (Meent, Aldenberg, *et al*., 1990). Such results are unacceptable for a geochemist. A doubt arises that "something is wrong" – the researchers' "paradigm" is wrong (after T. Kuhn – Кун, 1996)? According to the paradigms of the geochemistry, such thresholds should be above the upper variation limits of the normal ("background") contents of the polluting substances. Moreover, obviously it hasn't been given an account of the fact, that the substances in the nature are usually met in "inert" (immobile) forms, and only a part of them – in "mobile" (soluble) forms, easily consumable by the living organisms (the concept of the total and partial element contents). The authors of the cited study themselves, notwithstanding the derived values, recommend the background contents to be accepted as "desirable levels" for the naturally occurring substances.

FORMULATION OF THE PRINCIPLE OF THE NORMALITY; ARGUMENTATION

The propounded principle, with slight modification of the formulation in Kuikin (2002), could be defined in the next way: ***The optimum living conditions of the environment are determined by the normal values of its geochemical characteristics – elements content level, physical-chemical and thermodynamic parameters***. This principle as a paradigm is closely connected with the other two "specific" paradigms – the ecological and the landscape-geochemical (the three ones are parts of a whole and they function together), but its separate formulation ensure a more clear and deeper vision (outlook) on the essence of the nature phenomena and a model of solving of the problems connected with the environment quality.

The principle of the normality is a manifestation of two fundamental theses: (1) the V. I. Vernadskiy's (Вернадский, 1954) law of the ubiquitous distribution and the uniform dispersion of the elements, and (2) the unity of the inorganic and the animate nature. Life on Earth has originated and evolved in the course of several milliards of years under the conditions, determined by the presence of all the chemical elements and the respective physical-chemical and thermodynamic parameters of the outer spheres of the earth crust. The living organisms build their bodies from the substances of their habitat, and these substances, due to their ubiquitous distribution, enter into the organisms' composition and, in accordance to their different properties and abundance, exercise their specific functions in the structure of their tissues and in the exchange processes of matter, energy and information. On the other hand, under the influence of the living organisms, the Earth exospheres change their composition too – the biosphere is formed. A dynamic equilibrium is established between its components, which is kept through the biogeochemical circle of the elements. The present-day biogeocoenoses and ecosystems are formed in the course of hundred thousands to millions of years (the Quaternary period). The adaptation of the organisms to the geochemical conditions has a global nature, owing to that the normal, wide-spread characteristics of the environment are optimum for them.

SOME ASPECTS AND CONSEQUENCES OF THE PRINCIPLE OF THE NORMALITY

Being aware of the difficulties to put all aspects and consequences of the considered principle in a nutshell, we will dwell on six statements of paramount importance.

First*: The clarke contents* of the chemical elements serve as an ecological-geochemical standard of the conditions for living organisms habitat, incl. man, in the biosphere. YU. E. Saet, B. A. Revich et all. (Сает, Ревич *и др.*, 1990 – p. 58) formulate this maxim particularly about man, but it has obviously a wider ecological significance. The clarkes, calculated as mean element contents totally for the earth crust, for its individual layers and environment components, are objective reference values – geochemical standards for the element concentrations, in which presence the life on Earth exists. At the regional assessments, the element contents are being categorized as normal (nearly equal to their clarkes), deficit or insufficient (bellow the clarkes) and surplus or excessive (above the clarkes). The ecological effects (endemic diseases of plants, animals and man) within the regions of deficit or surplus concentrations of some elements – "the biogeochemical zones and provinces" (Ковальский, 1974) – are an object of study for the geoepidemiology.

Second: An important goal of the environmental geochemistry is the determination of ***minimum and maximum threshold values*** of the variation intervals of the normal (clarke or background) element contents in the environment components, that limit the conditions of an optimum development of the organisms (Ковальский, 1974; Сает, Ревич *и др*., 1990; Алексеенко, 2000). So far the accent in the geochemistry was put mainly on the mean values, or only on the upper thresholds of the normal contents with a view of the geochemical typification of the objects of study or the identification of the ore-genic anomalies and the anthropogenic pollutions.

By the adoption of the new rule, the principle of the normality proves to be in accordance with the two known fundamental laws of the ecology: (1) the law of the tolerance: each one of the living organisms has its determinate, evolutionary inherited upper and low limit of tolerance to every ecological factor; the going out of the factor level even beyond one of those limits is adequate to an incompatibility of the surroundings with the life, i.e. leads to death; (2) the law of the limiting factor: each one of the living organisms has such limits of stability (endurance, tolerance) to whichever of the ecological factors, at the going out beyond that this factor causes reversible and irreversible functional aberrations (disturbances) both of some organs and of some physiological processes, without leading directly to a lethal exit (Стадницкий, 2002). The considered principle deals namely with the geochemical factors of the environment. A. I. Perelman (Перельман, 1975 – p. 131) proposes the notion of an optimum content of the chemical elements in the environment – such a content of theirs in the foodstuffs, water and air, which supplies the man's needs in the best way. He pleads for a creating of optimum geochemical conditions in the different landscape zones (Перельман, 1973).

Third*:* ***All the chemical elements are indispensable*** for the normal existence of the living organisms, incl. man – there are not "useful" and "injurious" or "useless" elements. "A question could stand only about their necessary and injurious concentrations" (Алексеенко, 2000 – p. 162 and 525). The compounds of all chemical elements could be both useful and toxic for the man (Бъчварова и Петров, 1977 – p. 12). From this follows the notion of the conventionality of such terms as "nutrient" and "toxic" elements. In this respect we find a forerunner of our paradigm in the maxims of the Swish physician and naturalist from the 16th century Paracelz (Philip Theofrast Bombast von Hohencheim, 1493 – 1541): "Everything is poison and anything is not devoid of poisonousness" and "The dose makes the poison". The concentration is the thing that specifies a particular substance as a medicine or a poison. At that not the quantities only, but the forms of state of the elements are of importance as well.

It is not difficult to illustrate the thesis that even "the most toxic" elements in low concentrations are a necessary food for the organisms, and "the most nutritious" elements in high concentrations become a poison for them. Arsenic occupies the position of "a king of the poisons" and selenium – of "a cardinal of the poisons" on the top of "the poisonous hierarchy of the chemical elements and their compounds" (Бъчварова и Петров, 1997 – scheme 1). However their compounds are being used as medicines as well. The optimum concentrations of selenium compounds in the human organism are necessary for the realization of the functions of some organs (the retina of the eyes, the skeleton muscles, the heart, the liver, etc.). In the regions of selenium insufficiency it is provided to the organisms in the forms of food supplements or medicines. On the other hand, the "nutritious" elements ("the nutrients") carbon and nitrogen, together with hydrogen and oxygen, are constructive components of the toxins – ones of the most dangerous poisons, many times stronger than the classic poisons of the arsenic and cyanic compounds. Or another example – with the vital necessary for the man oxygen: both the oxygen hunger (the suffocation) and the oxygen satiating (the oxygen overdose) are varieties of a poisoning (Бъчварова и Петров, 1997 – p. 18 – 23). A man needs (his organism is adapted to) an optimum oxygen concentration. The rule of "the golden mean" is active in the cases considered.

Fourth*:* ***The background content*** of the elements is a cardinal geochemical standard for the quality of the environment at the ecological-geochemical assessments. The regional geochemical background is a basis for the elaboration of hygiene norms for quality of the environment components, and the local geochemical background – for the assessment of the concrete geochemical anomalies (natural or anthropogenic ones). The level of concentrations and the forms of element state, generally speaking, are determined by the geological history, the geological structure and the climatic, or in a broader sense – by the physical-geographical conditions (by "the geological past" and "the climatic present" – Ферсман, 1954, p. 555) of the individual regions or "biospheric structures"(Алексеенко, 2000 – p. 527). In the stage of "the noosphere" an increase of the geochemical background for the components of the Earth exospheres (soil, water, air, etc.) is observed in some regions, as a result of the ubiquitous regional diffuse dispersion and input of substances from anthropogenic sources (Terytze, 2001 – p. 76; Kuikin, Atanassov *et al*., 2001 – p. 129).

Fifth: The complex assessment of the state of the environment includes the study also of its ***physical-chemical and thermodynamic parameters*** – power of hydrogen (pH), oxidation-reduction potential (Eh), temperature (T), pressure (P), humidity, etc. They are factors for the forms of the element state, the migration or the accumulation of the natural and the anthropogenic substances, and at the same time they are a part of the direct ecological factors. As it is well-known, each one of the ecological factors is dynamic and changeable in the time and in the space. That's why the contemporary environmental-geochemical investigations must be carried out on a landscape-geochemical basis, with giving an account of the development history of the landscapes.

Sixth: ***The geochemical approach*** gains an advantage over the ***ecotoxicological one*** at the assessment of the quality of the environment components, in particular – at the assessment of the degree of pollution. Many critical notes are given in the literature about the developed in the recent decades hygiene norms for the maximum acceptable or permissible levels (MAC or MPC, etc.) of increased concentrations of the pollutants

(Сает, Ревич *и др.*, 1990; Алексеенко, 2000, *and others*). It is concluded that MAC should be applied in the practice only as previous indicators–reference points, necessary probably in the countries of low ecological culture and during the initial stages of investigations in new regions (Алексеенко, 2000 – p. 521). The quality norms/standards must give an account of the geochemical characteristics of the concrete biosphere (or landscape-geochemical) structures.

"The weak pollutions" also must be controlled carefully – a thing that is already brought as obligatory into action by means of the soil protection legislation in some countries, for instance The Netherlands (Swartjes, 1999) and Germany (Teritze, 2001). The adoption in the Germany's legislation of differentiated precautionary soil values – indicators of the arising of a hazardous soil change is indicative in this respect. It is required the ecotoxicologically founded effect thresholds to be checked against the actual soil background values (Terytze, 2001 – p. 74 and 76). Incompetent are the expert's interpretations, often coming across in the reports about the assessment of the influence on the environment – AIE (Bulg. "ОВОС"), that the values below MAC are an indicator of an absence of pollution, without juxtaposing the date to the upper background thresholds. "Weak" pollutions are possible to be available in such cases, which could be a cause to find out the sources and the mechanisms of the anthropogenic pollution in order of its further elimination or restriction. At the same time, we must have in mind that the prolonged influence of the "weak" pollutions also leads to negative ecological effects, similar to that ones of the short-term "intensive" pollutions.

CONCLUSION

The considerable experience from the practical activities and the theoretical developments in the course of more than three decades created favourable prerequisites for the formulation of the principle of the normality as an important specific new paradigm of the environmental geochemistry, an essential component of its philosophy. The literary quotations in connection with the considered six aspects and consequences of the principle show that recently the last ones have been realized and traced out to a great extent by the leading specialists in this scientific discipline. Their systematization within the scope of a general paradigm and the formulation of the principle of the normality is expected, on the other part, to stimulate the progress in the further solution of the problems in the environmental geochemistry, for the preservation of optimum natural conditions for the life and the activity of the human society on Earth.

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METHODICAL APROACH FOR SANDSTONES GAS-POTENTIAL ESTIMATION IN DOBROUDJA COAL BASIN

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РЕЗЮМЕ
В настоящата работа, на базата на характерни сондажни разрези, е разработена методика за оценка на газовия потенциал на горнокарбонските пясъчници от Добруджанския въглищен басейн и на перспективите за извличане на природен газ от тях. Оценката на газовия потенциал се основава на интерпретацията на резултатите от електрометричните, радиоактивните и акустичните изследвания в сондажните разрези. В резултат на това са определени петрофизични показатели на пясъчниците, на базата на които е оценена тяхната порестост, водонаситеност и газонаситеност. За целта са построени палетки за конкретната апаратура и за специфичните особености на пясъчниците в изучавания район. Предложен е количествен показател – “газ-капацитивен обемен фактор”, който характеризира газовия потенциал. Филтрационният потенциал на пясъчниците, на този етап на изследванията, се характеризира с показателя проницаемост.

INTRODUCTION

Dobroudja Coal Basin (DCB) contains natural gas in coal beds as well as in the Upper Carboniferous sandstones. The sandstones are from different type - lititic, volcanomictic, grauvacs and volcanic and reach up to 40% from the section. They are cemented by shale, shaly carbonate or anhydrite.

The estimation of the gas potential of sandstones is connected with examination of their reservoir and filtration properties and their gas saturation as well. Such estimation was not run till now because the carried out during the period of survey in DCB geophysical investigations in the well have directed to the coal, physics and mechanical studding. The newly received information contains basic petrophysical parameters obtained by well log interpretations.

The goal of the present paper is on the basis of the typical of well logging sections from DCB to develop a method for evaluation of petrophysical properties of UCS and to offer some principles for complex generalization and estimation of their gas potential and the possibility of natural gas extraction.

METHODS FOR ESTIMATION OF PERTOPHYSICAL PARAMETERS USING WELL LOGGING

Petrophysical parameters of the sandstones from DCB are estimated on the basis of well logging survey. The existing information includes: resistivity methods – Lateral logs with length from 0,2 m to 4 m, Self Potential (SP), Neutron-gamma method (NGR|), Gamma ray (GR), Sonic log (ΔT), Caliper and Resistivitymeter. In the interpretation of the well geophysical data the following sandstone parameters are defined: shale volume (V_{sh}) and relative shale content (η_{sh}); porosity (ϕ); residual water saturation (S_{rw}); water saturation (S_w) and gas saturation (S_g).

The lithologic characteristics of the examined sandstones is too complicated because of the wide variety of shale content, the presence of carbonate cement and in some beds the presence of coal. These conditions led out the necessity to elaborate specific methods for log analysis determination of the shale content by the GR and porosity by the sonic and neutron-gamma methods (Larionov, 1969; Nikolova, 1974;Nikolova, 1978a;Nikolova, 1978b; Nikolova, 1981). For the purposes of the petrophysical characteristics is also used data from the core analysis: porosity, permeability, shale content, silicate and grain-size. The content of U, Th, Ra, K^{40} is studied as well. On the base of the estimating characteristics and well logging data for the conditions of Carboniferous in DCB are updated some charts for log interpretation as follows: $\Delta J_{GR}=f(V_{sh})$, $\phi_{sh}=f(\Phi_{NG(S)},V_{sh})$, $\Delta T_{sh}=f(\phi_{sh})$, $\eta_{sh}=f(S_{rw})$, $I_g=f(S_g)$- all examined below. Using this charts (fig.1,2,3,4,5 and 6) is ensured the improvement of the well log interpretation.

Shale volume (V_{sh}) is determined by the natural gamma-ray and the relationship between gamma-ray index (ΔJ_{GR}) and shale volume $\Delta J_{GR} = f(V_{sh})$ (fig.1):

$$\Delta J_{GR} = \frac{GR - GR_{\min}}{GR_{\max} - GR_{\min}} \quad (1)$$

where GR, GR_{min} and GR_{max} are as follows: the intensity of the natural gamma radiation in the bed, in nonshaly bed and in shales.

***Porosity** (ϕ)* is defined by complex interpretation of neutron gamma log (NGL), gamma log (GL) and sonic log (ΔT) by the methods described by J.B. Nikolova (Nikolova, 1974;Nikolova, 1978a; Nikolova, 1981), and shortly exposed down below.

Sonic porosity. In the common occasion the porosity by the sonic method is defined by the average travel time equation:

$$\phi_{S(NG)} = \frac{(\Delta T - \Delta T_{ma}) - V_{sh}(\Delta T_{sh} - \Delta T_{ma})}{\Delta T_w - \Delta T_{ma}} \qquad (2)$$

where: ΔT is the travel time in the bed; ΔT_w - into the water (Dahnov, 1972); ΔT_{ma} - is the matrix travel time and ΔT_{sh} – the shale travel time. The parameter ΔT_{ma} is defined by the chart $\Delta T = f(\phi_{NG,limest}, \Delta T_{ma})$ (fig. 2) and ΔT_{sh} – by chart $\Delta T_{sh} = f(\phi_{sh})$ (fig. 3).

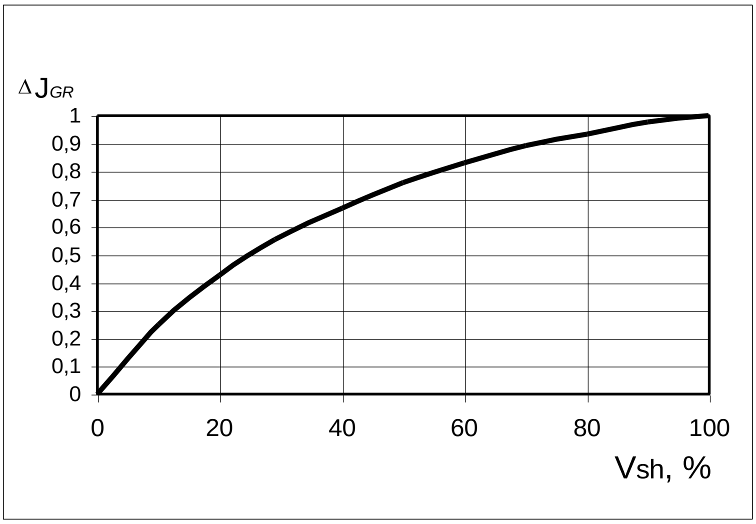

Figure 1. Relationship between natural gamma-ray index (ΔJ_{GR}) in sandstones and shale content (V_{sh}).

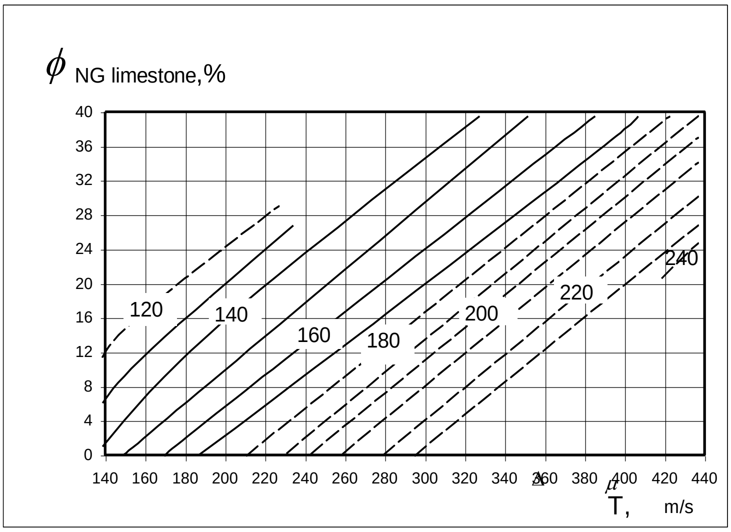

Figure 2. Relationship between travel time (ΔT) and neutron porosity ($\phi_{NG\ limestone}$) (cipher of curves – matrix travel time, ΔT_{ma}).

Neutron porosity. Neutron porosity in shaly sandstones ($\phi_{NG(S)C}$) corrected for the shale content is defined as follows (Larionov, 1969):

$$\phi_{NG(S)C} = \phi_{NG(S)} - V_{Sh}\phi_{Sh} \qquad (3)$$

where: ϕ_{Sh} – shale porosity. It is defined by the equation $\phi_{Sh} = f(\phi_{NG(S)}, V_{sh})$ (fig. 4); $\phi_{NG(S)}$ is defined by the chart $\Delta J_{NG} = f(\phi_{NG}, \Delta T_{ma})$ (fig. 5) (Nikolova, 1978a;Nikolova, 1978b; Nikolova, 1981; Tenchov, et al., 1988).

$$\Delta J_{NG} = \frac{NG - NG_{min}}{NG_{max} - NG_{min}} \qquad (4)$$

where: NG is the NGR tool response in the bed , NG_{min} is NGR in water and NG_{max} – NGR in the bed with porosity close to zero.

Average porosity ϕ_{ol} is defined as follows:

$$\phi_{ol} = \frac{\phi_{NG(S)C} + \phi_{S(NG)}}{2} \quad (5)$$

Porosity by the resistivity methods. In 100% water saturated beds, porosity (ϕ_R), derived by the resistivity of the flushed zone (R_{xo}) and by the resistivity of the noninvaded zone (R_o) is equal to the neutron and sonic porosity.

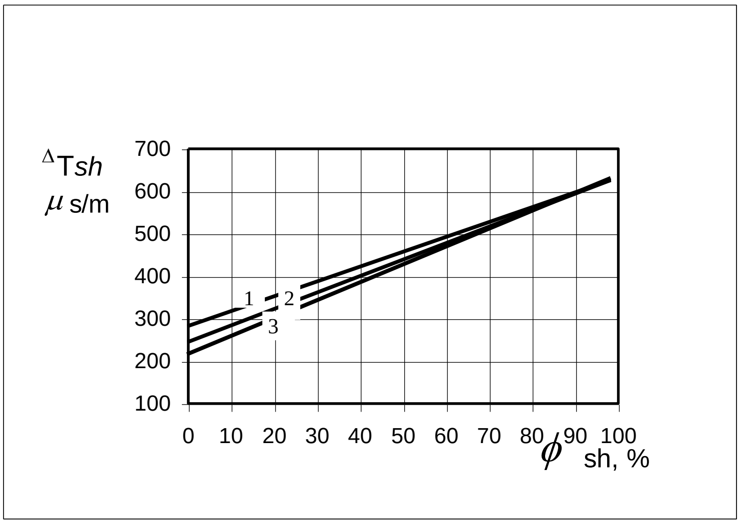

Figure 3. Relationship between shale travel time (ΔT_{sh}) and shale porosity (ϕ_{sh}) cipher of curves 1, 2, 3 – for different type sandstones.

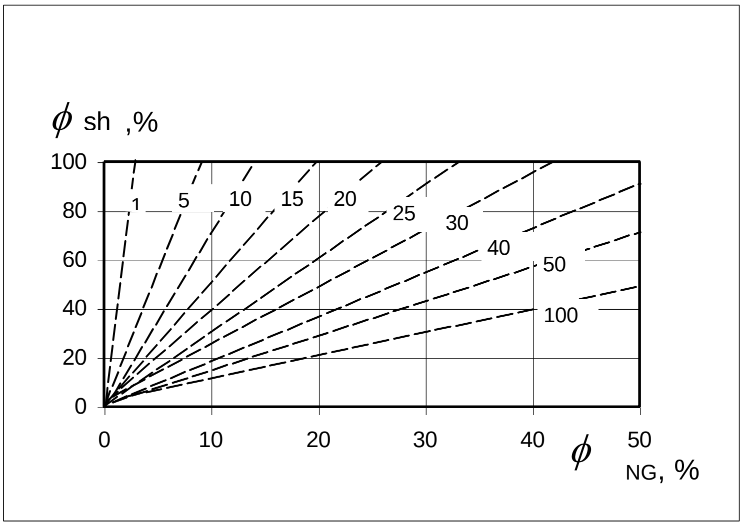

Figure 4. Relationship between shale porosity (ϕ_{sh}) and neutron porosity (ϕ_{NG}) cipher of curves – shale content, V_{sh}.

In shaly sandstones porosity is derived using the following equations:

$$F_{xo} = \frac{R_{xo}}{R_{mf}\,(R_{mix})} = \frac{0.55}{\phi_{Rxo}{}^{2}} \quad (6)$$

$$F_o = \frac{R_o}{R_w} = \frac{0.34}{\phi_{Ro}^{2.2}} \quad (7)$$

where: R_{mf} - the mud filtrate resistivity; R_{mix} - the resistivity of mixture of the mud filtrate and bed water; R_w - the resistivity of the bed water. Equations 6 and Eq.7 are obtained by laboratory data.

Hydrocarbon saturation. Gas saturation in the invaded zone is defined as follows:

$$S_{gxo} = \frac{\phi_{ol} - \phi_{Rxo}}{\phi_{ol}} \quad (8).$$

Gas saturation in noninvaded zone (S_g) is derived as follows:

$$S_g = \frac{\phi_{ol} - \phi_{Ro}}{\phi_{ol}} \tag{9}$$

Gas (Sg) and water saturation (S_w) are derived as follows:

$$I_g = \frac{R_t}{R_o} = \frac{1.4}{S_w^2} = \frac{1,4}{(1-S_g)^2} \tag{10a}$$

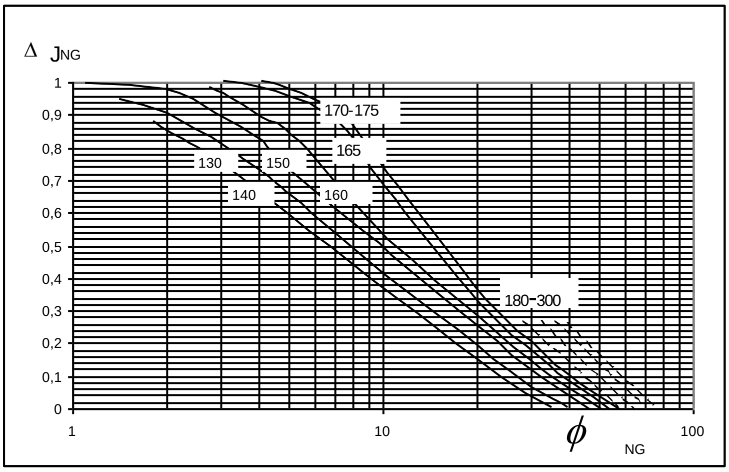

Figure 5. Relationship between neutron gamma-ray index (ΔJ_{NG}) and neutron porosity (ϕ_{NG}) (cipher of curves – matrix interval time, ΔT_{ma}).

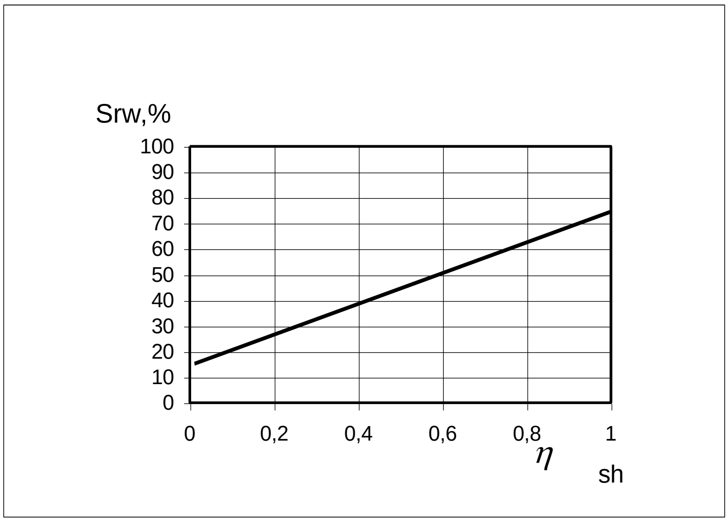

Figure 6. Relationship between relative shale content (η_{sh}) and residual water saturation (S_{rw}).

where: R_t is resistivity of the gas saturated bed;

$$S_g = \frac{1,4}{\phi_{ol}} \sqrt{\frac{R_w}{R_t}} \tag{10b}$$

Both equations are derived using laboratory data.

Residual water saturation (S_{rw}) depends on the relative shale content (η_{sh}) and is defined by the chart $\eta_{sh}=f(S_{rw})$ (fig.6). Relative shale content is defined as follows:

$$\eta_{sh} = \frac{V_{sh}}{V_{sh} + \phi_{ol}} = f(S_{rw}) \tag{11}$$

Permeability. Sandstone permeability (K) was obtained on the basis of 70 core samples laboratory data of K, porosity (ϕ) and residual water saturation (S_{rw}). The following relationship with coefficient of correlation R=0,76, is obtained:

$$K = 0,07\ \exp(0,4119\ \phi\ (1 - S_{rw})) \tag{12}$$

Bed permeability is obtained by Eq.12 where porosity and the residual water saturation are obtained by the log analyses.

PRINCIPLES OF THE COMPLEX GENERALIZATIONS

On the base of the obtained petrophysical parameters are proposed 2 groups qualitative criteria for the estimation of prospective intervals: a) by the filtration possibility and b) by the gas capacity.

Permeability parameter (K) is used as a criterion for filtration possibility. Now is not possible to use of another more appropriate criterion for estimation of the potential productivity of the beds.

The complex parameter ϕ.Sg/100 (gas capacity factor) is used as criterion for gas capacity estimation of the intervals. It characterizes the relative gas content of the pores per unit of rock volume.

Table 1.Classification scale for prospective Upper Carboniferous gas saturated sandstones of Dobroudja Coal Basin

	Qualitative estimation	Estimated parameters and classes					
		by permeability		by gas capacity			
		Permeability (K),md	Class	Porosity (ϕ), %	Gas saturation (Sg),%	ϕ.Sg/100	Class
1	non-conditional	< 0,1	N	< 5	< 20	< 1	n
2	very low	0,1-1,0	A	5-10	20-30	1-3	a
3	low	1-10	B	10-15	30-40	3-6	b
4	middle	10-100	C	15-20	40-60	6-12	c
5	high	100-1000	D	20-25	60-80	12-20	d
6	very high	> 1000	E	> 25	> 80	> 20	e

For comparative estimation of the prospective examined intervals is worked out classification scale (table 1). It is accepted a gradation of the estimating quantitative parameters and criteria. With letter marks were indicated classes by the accepted estimating criteria: by the permeability and by the capacity.

CONCLUSION

The available petrophysical information for the Upper Carboniferous sandstones from the DCB, that contain coal beds, is not sufficient to characterize their reservoir characteristics. There is no information about their gas saturation. It is not possible to estimate the last one on the base of laboratory analyses This specific situation laid out the necessity to develop the specific methods adapted to the DCB conditions.

Using an integrated analyses of petrophysical parameters derived by laboratory analyses and by the well logging are obtained and used charts and relationships that are unique for the sands in the DCB.

It is proposed quantitative criteria for estimation the gas potential of the sandstones and the possibility to extract the natural gas from them. It is offered a classification scale for comparative estimation of prospectivity of the investigated sections and their lithostratigraphical units.

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CALCITE MINERALIZATION NEAR SVETOULKA VILLAGE, ARDINO REGION

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ABSTRACT
The authors visited and took samples from the Island spar mineralization near the village of Svetulka, Ardino region. The calcite mineralization is mainly in the form of irregular net of zones and elongated nests (stockwork type) among the marbles of the Chepelare pastra?? unit. The report represents the results from the selective sampling and the crystalomorphologic studies.

INTRODUCTION

Subject of the present paper is the calcite locality situated among the villages Byal Izvor and Svetulka, which is about 5 km to the west of the town of Ardino and about 32 km west of the town of Kurdzhali (Fig. 1).

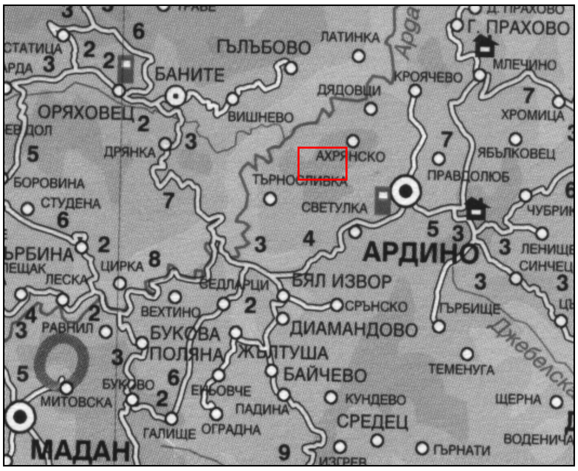

Figure 1. Map of the region, M 1:500 000

The geology of the region includes highly metamorphic rock complexes, referred to the Rhodopes nadgrupa by Kozhuharov et al. (1995), Roupchoska group (Kozhiharov, 1984). South of the locality is outcropped Chepelare mottled formation, consisting mainly of finely grained biotite gneisses as well as some amphibole-biotite gneisses, marbles, amphibolites, which alternate irregularly. The marbles are white, middle to finely grained. Serpentinized ultrabasites of dunite, peridotite and pyroxenite composition are outcropped in the region. They are characterized by a very high level of premetamorphic serpentinization (80-100%) up to serpentinites of antigorite and chrysotile composition. The serpentinite bodies have the form of boudine – concordant with the imbedding metamorphites.

The north border of the Chepelare unit in the region is presented by a detachment surface, which is discordant to the migmatized and granitized gneisses, gneiss-schists and amphibolites of the Vishnevska unit (Kozhuharov, 1984).
The hydrothermal activity led to the formation of listvenites, which form a body like a halo to the north of the outcropped ultrabasites. Listwaenites are of varying composition – from over 90% of SiO_2 to over 90% of carbonate minerals. Right next to the listwaenites are the marbles, among which is imbedded the calcite mineralization (Fig. 2).

Figure 2. General view of part of the zone with calcite mineralization

Morphology of the bodies with calcite mineralization

The calcite mineralization is presented in the form of elongated nests and irregular net of stockwork type zones among the marbles (Fig. 3).

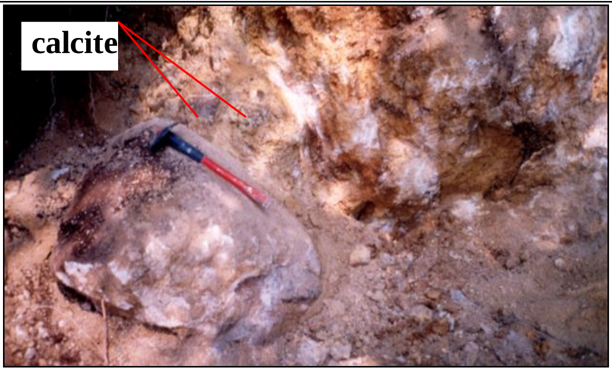

Figure 3. The zone of calcite mineralization (two calcite crystals can be seen above the chisel)

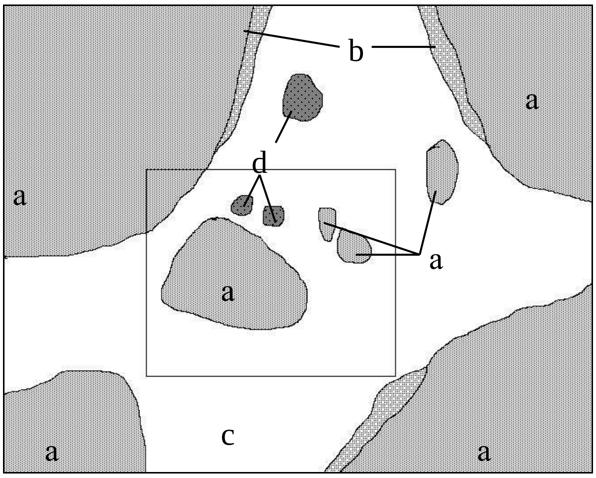

Figure 4. Sketch map of the calcite mineralization zone
(a – blocks of unaltered marbles; **b** – zone of dense opaque calcite crystals; **c –** host rock of calcite crystals; **d -** calcite crystals) ▭ contour of the photo in Fig. 3.

The monolithic blocks of tectonically unaltered marbles are in the size of tens of centimetres to several cubic meters (Fig. 4). They are of rounded irregular shape and consist of finely grained to middle grained white to grayish-white marbles.

Druse-shaped crust of thickly crowded white opaque calcite crystals is formed at some places in the rim of the blocks. The crust is from 1-2 up to 8-10 cm wide.

The host rock (media) presents a loose, slightly bonded sand-like rock consisting mainly of calcite – fine to coarse grained.

The calcite crystals are unevenly distributed as single pieces of irregular shape, elongated as a rule. Their size is from several centimetres up to 30 centimetres .

The collected calcite differs noticeably in its size, colour, and morphology, including twins, poly-twins, various primary or secondary defects.

The calcite is colourless or tinted in different intensity of yellow to brown. Some crystals are evenly coloured or colourless all over, while others, usually the big ones, reveal clear zonality (in the rim or in the whole volume) with yellowish to brown and reddish-brown to red due to iron oxides and hydroxides. This led to phantom crystal formations (fig. 5).

The pigmentation differs in the different zones of growth and is concentrated mainly in the rim. The transparency could be from opaque to transparent.

As a rule the crystals are cracked along the cleavage planes. On the periphery they are often covered by an opaque carbonate crust (Fig 6).

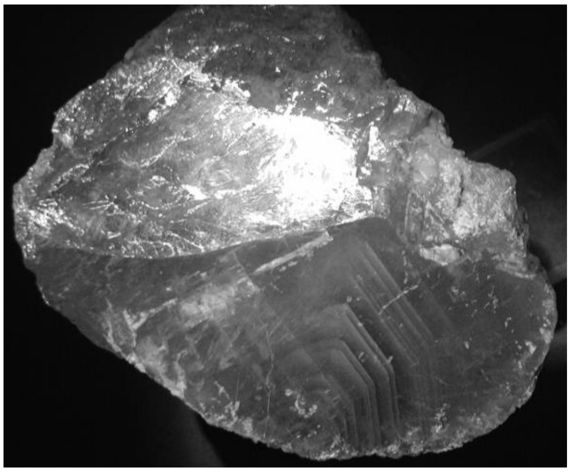

Figure 5. Zonality of colouring leading to phantom crystal formation. The specimen is a part of a twin crystal.

Large number of crystal individuals and aggregates has been studied macroscopically. Because of the dull and uneven surfaces of the crystal faces and the relatively large size of the crystals reflective and photogoniometry were not used. Most of them are characterized by clearly defined crystalomorphology. All the studied samples show polar development of the form. Half of the crystal has well developed crystal faces, while the other half is by rule with no morphology. Besides, the faces belonging to the one and the same simple form are asymmetric and differ in size. They are not smooth and "shiny", but rough and with complex microsculpture, the type of surface that would be formed if growing was not in a free space.

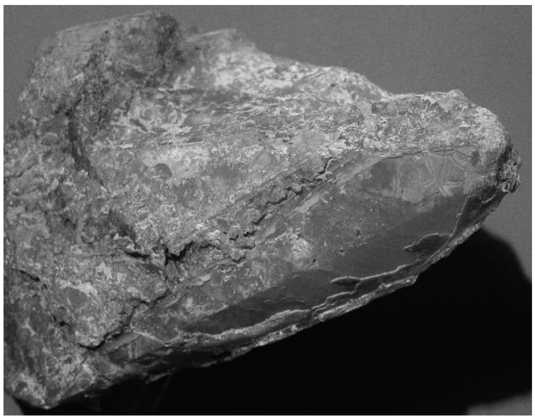

Figure 6. Calcite crust in the rim of the crystal faces, coloured by iron oxides and hydroxides

Large number of crystal individuals and aggregates has been studied macroscopically. Because of the dull and uneven surfaces of the crystal faces and the relatively large size of the crystals reflective and photogoniometry were not used. Most

of them are characterized by clearly defined crystalomorphology. All the studied samples show polar development of the form. Half of the crystal has well developed crystal faces, while the other half is by rule with no morphology. Besides, the faces belonging to the one and the same simple form are asymmetric and differ in size. They are not smooth and "shiny", but rough and with complex microsculpture, the type of surface that would be formed if growing was not in a free space.

Several types combination forms were established depending on the development and the prevalence of a certain simple form.

***Scalenohedral-prismatic* –** This type of calcite crystals usually form scalenohedrons in combination with a hexagonal prism. In most of the cases the scalenohedron predominates, as a result of which every other face of the prism is presented and only three of them are observed in the morphologically developed part of the crystals. (Fig. 6 and Fig. 7)

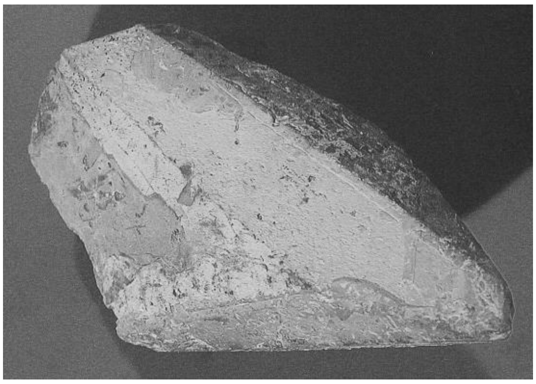

Figure 7. A calcite crystal with a scalenohedron and a hexagonal prism.

Generally no sharp tip is formed or the tip is frayed, dull with rudiments of a pinacoid and/or rhombohedron. In some of the studied crystals, besides the faces of the prism and the positive scalenohedron , there are scarcely revealed faces of a negative scalenohedron and a negative rhombohedron. In this case the crystals are frayed (in direction perpendicular to "c" axis) (Fig. 8)

Figure 8. Calcite crystal, combination of scalenohedron (+) and (-), hexagonal prism and rhombohedron.

Rhombohedral – Crystals of this type reveal exlusive combinations of one main sharp rhombohedron and one or two derivative rhombohedrons (fig. 9). Crystals of this type grow in a free space – opened cracks. The cracks have no specific orientation and vary from sub-horizontal to sub-vertical. The maximum width of the cracks is up to 10 cm. They can be observed in a vertical slope of the old quarry, 200 m east of the zone described above.

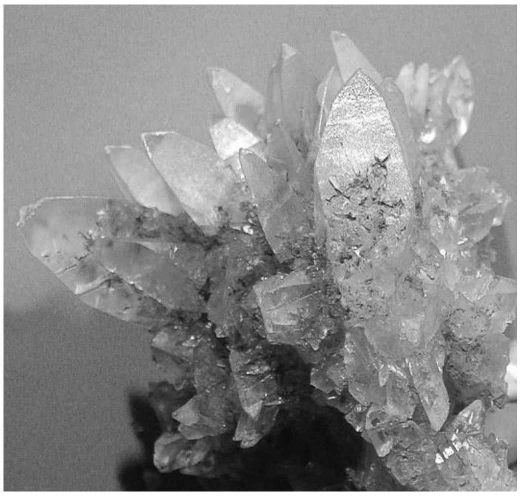

Figure 9. Druse-like aggregate of rhombohedral crystals

Aggregates and twins

Many of the studied samples are presented by various aggregates and twins. Thick druse-like aggregates predominate along the rims of the marble pieces in the zones of calcite mineralization. Aggregates as well as parallel twins and triplets are common (Fig. 10).

Twins are characteristic for the bigger part of the samples. Mainly these are twins of a simultaneous growth or mechanical twins. There are some twins by basic pinacoid (Fig. 11) and by a hexagonal prism.

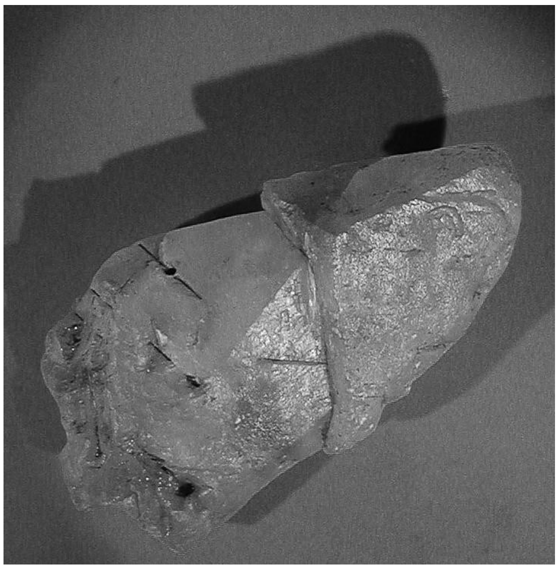

Figure 11. Paralel twin (scalenohedron)

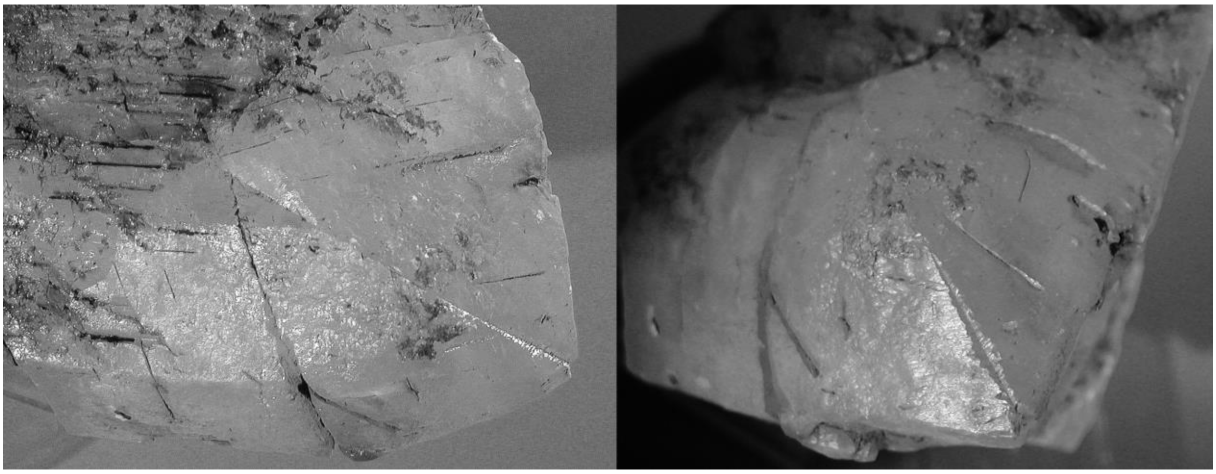

Figure 10. Twin crystal, shown in two views

Forms of superficial dissolution - As the samples are taken from the superficial weathered part of the zone, the sculptures of dissolution are common. There are two main types: single negative strokes parallel to the cleavage planes and a series of fine parallel grooves. In the second case the direction of the negative strokes is not parallel to the cleavage planes. They are along the edge of a rhombohedron (10–12) in the direction, which coincides with the direction of translation, while forming dynamogenic twins (Fig. 12).

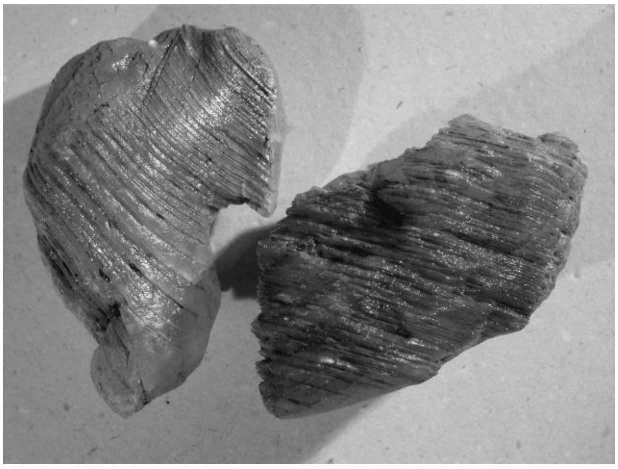

Figure 12. Superficial forms of dissolving along the planes of translation with dinamogenic twins

CONCLUSION

The presented results from macroscopic studies of calcites from Svetoulka region are preliminary. Field investigations have been conducted and the morphology of bodies with calcite mineralization near the surface has been studied. Several morphologic types of crystals and aggregates have been established. The collected data and the research completed so far do not provide enough evidence to formulate a reliable hypothesis for the genesis of the mineralization.

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3D GEOSTATISTICAL MODEL OF THE ORE BODY IN ELATSITE PORPHYRY COPPER DEPOSIT, PANAGYURISHTE ORE REGION

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ABSTRACT

The results of three-dimensional geostatistical modeling of copper ore body in Elatsite porphyry copper deposit are present in this work. The deposit is located in NNW part of Elatsite-Chelopech Ore Field from Panagyurishte Ore Region, Bulgaria. Paleozoic granodioritic rocks are developed in northern part of the deposit and Pre-Cambrian metamorphites are located in south. Upper Cretaceous granodioritic to quartzdioritic or monzodioritic porphyrites are intruded near and along the contact between granodiorites and metamorphites.

Drillhole data from the open pit area, collected during preliminary and detail exploration of deposit and located between levels 1390 and 1045 are used for the model development. Copper contents in composite samples from each drill for each level represent primary data. Three dimensional variogram analysis, based on spherical model is used for determination of properties of spatial variability in data. Automatic routines of Least Squares method are applied for approximation of experimental variogram values, which aims precise determination of variogram models. Cross-validation for the variogram model effectivity is done and it shows that chosen model represent adequately natural variability of source data.

Smooth variation of copper content differences is typical for the Elatsite deposit, which is premise for precise determination and interpretation of variogram model. Derived ore body anisotropy is oriented along fault structures, dykes and host rock contacts, confirming their main ore-controlling role in deposit.

Three-dimensional model of ore body is designed on basis of variogram analysis results, as ordinary block kriging interpolation is used. The deposit is modeled with discrete blocks with dimension 15x15x15 m. The ore body is stockwork type, prolonged in NE direction. Digital terrain model is constructed for the modeling purposes and it is used as boundary to exclude eroded part. The constructed 3D model is proximal and generalized as the ore body development is not studied in depth and spatial characteristics of rock types are not separately analyzed.

GEOLOGICAL NOTES

The Elatsite porphyry copper deposit is located at the northern slope of Chelopeshka Baba pick, about 55-60 km east from Sofia City and about 6 km from Etropole town. It is formed within the frame of Elatsite-Chelopech Ore Field, as it is located about 6 km NW from the center of Chelopech volcano (Popov *et al*, 2001). 114.78 M.t. ore with 0.37 % copper content were extracted during the period from 1981 to 1995. Calculated in 01.01.2001 reserves are 139.57 M.t. ore with contents of 0.32 % Cu, 0.108 g/t Au, 0.004 % Mo, as well as the resources are 425.98 M.t. with 0.28 % copper content.

The Lower Paleozoic metamorphic rocks, Lower Carboniferous rocks of the Vejen pluton and Late Cretaceous rocks of Elatsite dyke-like intrusion with the associated dykes are spread across the region of deposit (fig. 1). The Lower Paleozoic metamorphic rocks are found along the southern deposit’s boundary and phyllite, chlorit-sericitic schist and quartz-sericitic schist represent them. Various interpretations about their lithostratigraphic affiliation exist (Angelov *et al.*, 1995; Cheshitev *et al.*, 1995; Antonov *and* Jelev, 2002). They are alterated into hornfelse and knotted schist along the contact zone with the rocks of the Vejen pluton. Their main orientation is from 90 to 110° with 15-45° dip to south.

The Vejen pluton is developed in northern part of the deposit, mainly represent by granodiorite and granite. Von Quadt *et al.* (2002) determine its absolute age as 314$\pm$4 Ma by $^{206}Pb/^{238}U$ zircon method. The strike in the contact between the granodiorite and the horfelse is about 100° in the westernmost part of the deposit. The contact turns to the southeast (140°) and then rapidly turns to the northeast (60°) as shown in fig.1. The strike of the contact in easternmost part is about 80°. The general dip is 20-25° to the south near the surface, up to 45-55° in depth. Tectonic brecciation is observed along the contact as a result of younger tectonic deformations.

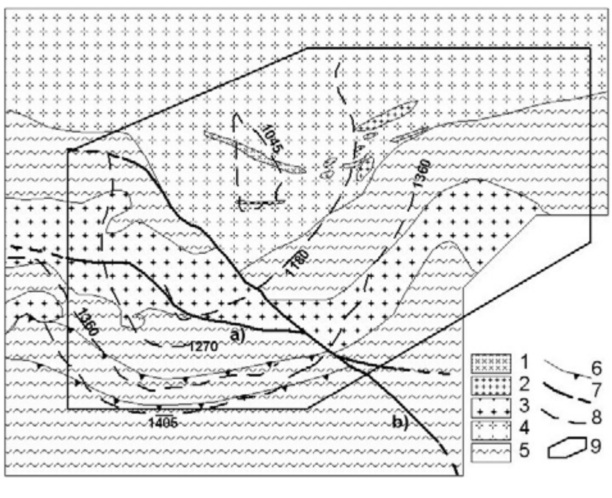

*Figure 1.Geological map of the Elatsite deposit deposit (by G. Georgiev, unpubl.)
1 - microdiorite, micro-gabbro-diorite, microgabbro, 2 – granodiorite porphyrite, granite porphyrite, 3 - quartz-monzodiorite porphyrite, quartz-diorite porphyrite, 4 – Vejen pluton - granodiorite, granite, quartz-diorite, aplite, 5 - hornfelse, knotted schist, schist, 6 – Kashana reverse slip - overthrust, 7 - faults: a) Elatsite, b) Murgana, 8 – open pit horizons, 9 – boundary of designed 3D model*

The Elatsite intrusion (The big dyke) consists of quartz-monzonitie intruded in the contact zone between metamorphites and Vejen pluton. The wide fracturing zone of the Kashana reverse slip - overthrust obviously defines its position. This intrusion is represented by a long plate-like body with over 3.3 km length, as its width varying from several meters up to 200-400 m. In the western part of the deposit the strike of that body is about 90°, in the central part - 110-120°, than it turns sharply to the northeast (50°), and finally turns to the southeast. The intrusion's dip is 20-45° to the south in upper parts, while in depth it's probably increasing up to 55°-70°.

A great number of dykes represent by quartz-monzodiorite porphyrite, granodiorite porphyrite, granite-porphyries and aplite associate with Elatsite intrusive. Microdioritic, micromonzonitic, diorite porphyritic and quartz-diorite porphyritic dykes are also observed (Trashliev *and* Trashlieva, 1964; Von Quadt *et al*., 2002).

The U/Pb zircon method dating determines the age of igneous rock bodies between 92.1±0.3 Ma – 91.84±0.31 Ma (Von Quadt *et a*l., 2002), which is very close to the Cenomanian – Turonian boundary. Velichkova *et al.* (2001) determines 88-90 Ma age of the subvolcanic bodies near Elatsite and Chelopech villages by $^{40}Ar/^{39}Ar$ analysis on biotite. Besides, these intrusions are most probably formed by the end of Turonian or in the beginning of Coniasian ages, according to geological data (Popov *et al*., 2001).

Examining the structure of Elatsite deposit, Kalaydjiev *et al*. (1984) suggest the development of a dense net of rectilinear faults with E-SE, N-NW and NE direction. The recent study (Georgiev, *unpubl.*) does not confirm this assumption. Practically, there are three main fault structures, traced across the deposit: Elatsite fault, Murgana fault and Kashana reverse slip - overthrust (fig. 1). The Elatsite fault posses a strike, varying from 85° to 125°. It lengthwisely crosses Elatsite intrusion in the western part of the deposit, while to the east it passes along the intrusion's southern contact. Its dip is 70-85° to the south. Movements, typical for right normal-slip fault are accomplished. This fault basicly coincides "The first Elatsite fault", defined by Kalaydjiev *et al*. (1984). The Murgana fault possesses a strike about 125-150°. It diagonally intersects the deposit as it's dip is subvertical 80-90° to SW mainly. It is nominated by Kalaydjiev *et al*. (1984) as "Central Elatsite fault". Right-slip movements with amplitude about 200-250 m and collaps of 50-200 m are accomplished. It is turning in southeastern part, where it is noted by Popov *et al*. (2001), as the strike is 150-155°. The Kashana fault is registered for the first time by Trashliev (1961), and later it is traced out and described by Kouykin *and* Milanov (1970) and Kouykin *et al*. (1971). These authors determine its age as Austrian in first mentioned paper, while in second paper they assign Laramian (or Post-Turonian) age to it. A thrust fault zone with width of 80-150 m, composed by anastomosing subordinate fault surfaces is observed in southwestern part of the Elatsite deposit, within the Late Paleozoic metamorphic rocks. It passes along the contact between the Early Paleozoic and Triassic rocks to the west. The zone probably represents the appearance of Kashana thrust in this part of the deposit. The partial intrusion within this zone of Elatsite intrusive, as well as the intrusion at Kashana and some other smaller bodies, point to its Austrian age. Younger post-ore movements most probably with Laramian age are established as well. It should be mentioned that Georgiev (*unpubl*.) determines radial-concentric development of the jointing and small faults within the deposit.

The Elatsite deposit is spatially and genetically related to the Upper Cretaceous Elatsite intrusion and associated dykes (Hadjyiski *et al*., 1970; Kalaydjiev *et al*., 1984; Dimitrov, 1988; Popov *et al*., 2001). This is determined according to circumstance that it is intensively affected together with the Paleozoic rocks by the post-ore hydrothermal alterations and by the ore mineralisation. The hydrothermal alterations are represented mainly by K-silicate (*Ksp+bi+qtz+il+pl+calc* or *Ksp+chl+qtz+il+ab*), propyllitic (*Ep+act+ab+bi+qtz+calc* or *Ep+chl+ab+bi+qtz*) and sericitic (Il+qtz+py) alterations (Strashimirov *et al*., 2002). The copper is primary economic element in the Elatsite deposit and the Au is secondary one. The molybdenite concentrate was extracted during some exploitation periods as well. Several consecutively formed mineral associations represent the ore mineralization: magnetite-bornite-chalcopyrite, quartz-pyrite-chalcopyrite, quartz-molybdenite, quartz-pyrite, quartz-galena-sphalerite and quartz-calcite-zeolitic associations (Strashimirov *et al*., 2002). The development of the magnetite-bornite-chalcopyrite mineralisation is quite irregular, as it includes native gold and some minerals, containing elements from the PGE (Dragov *and* Petrunov, 1996). The major economic interest takes the quartz-pyrite-chalcopyrite association, which comprises the main content of copper, gold (electrum) and molybdenum. The quartz-pyrite and quartz-galena-sphalerite associations are developed mainly in outlying parts of the deposit.

The ore mineralisation forms a big stockwork, which is developed within intensively jointed Paleozoic granodiorite and hornfelse, as well as within the rocks from Elatsite intrusive and associated dykes (fig. 1). This ore body posses an ellipse-like shape in plan, elongated to the northwest. Its length is about 1200 m and the width varies from 200 to 750 m. The area of its horizontal projection is about 0.616 km^2 (Hadjyiski *et al*., 1970). The stockwork is outcropped by the erosion on level 1400 m (before the beginning of exploitation), as the ore mineralisation reaches level 550 m in depth. Its main axis posses a general strike of 40-50° to south, as in general it follows the contact between Lower Paleozoic rocks and granodiorite of the Vejen pluton. The ore stockwork is not outlined in depth, as most of drills do not reach its boundaries. It has continuous strike and dip. The ore body boundary within host rocks is gradual and it is defined by copper content of 0.18 %. The transition is more sharply-outlined within metamorphites, along their contact with granodiorite. The ore mineralisation is represented by multiple veinlets and impregnations within intrusive rocks, while veinlets predominate in metamorphites. Small quartz-pyrite veins are rarely observed.

DATA USED

Drillhole data from preliminary and detail exploration of Elatsite deposit (Hadjyiski *et. al*., 1970), between horizons 1390 and 1045, are used in this study. The preliminary exploration is realised on 100x100 m grid, down to level 805. The drill grid is chessmate condensed up to 71x71 m in the central parts and up to 50x100 m in the periphery during detail exploration. Outlining boreholes placed at 200 to 300 m from the base exploration network are drilled around ore body. This exploration network geometry is preserved down to level 1000, as in deeper levels it is destored due to borehole inclination. The deposit is studied in deep below level 802 with 12 drills, located in central part at intervals of 200 m. The drill core is sampled by section samples with average length of 2.38 m and the copper content is determined by chemical analyses. Composite core samples are used for the developing of geostatistical model, where every composite sample represent the copper content, which is averaged from section samples of

$$\gamma(\vec{h}) = \frac{\sum_{i=1}^{n_h} (x_i - x_{i+h})^2}{2n_h},$$

where x_i-x_{i+h} are n_h of number differences between values (e.g. element's contents), measured in samples at average distance h between samples and situated along given direction. The main advantage of variogram analysis is average estimation of different natural features, as anisotropy, character and degree of correlation between neighbor samples at different distances, value of general variability, continuity, etc., which are typical for the object studied. After calculation of

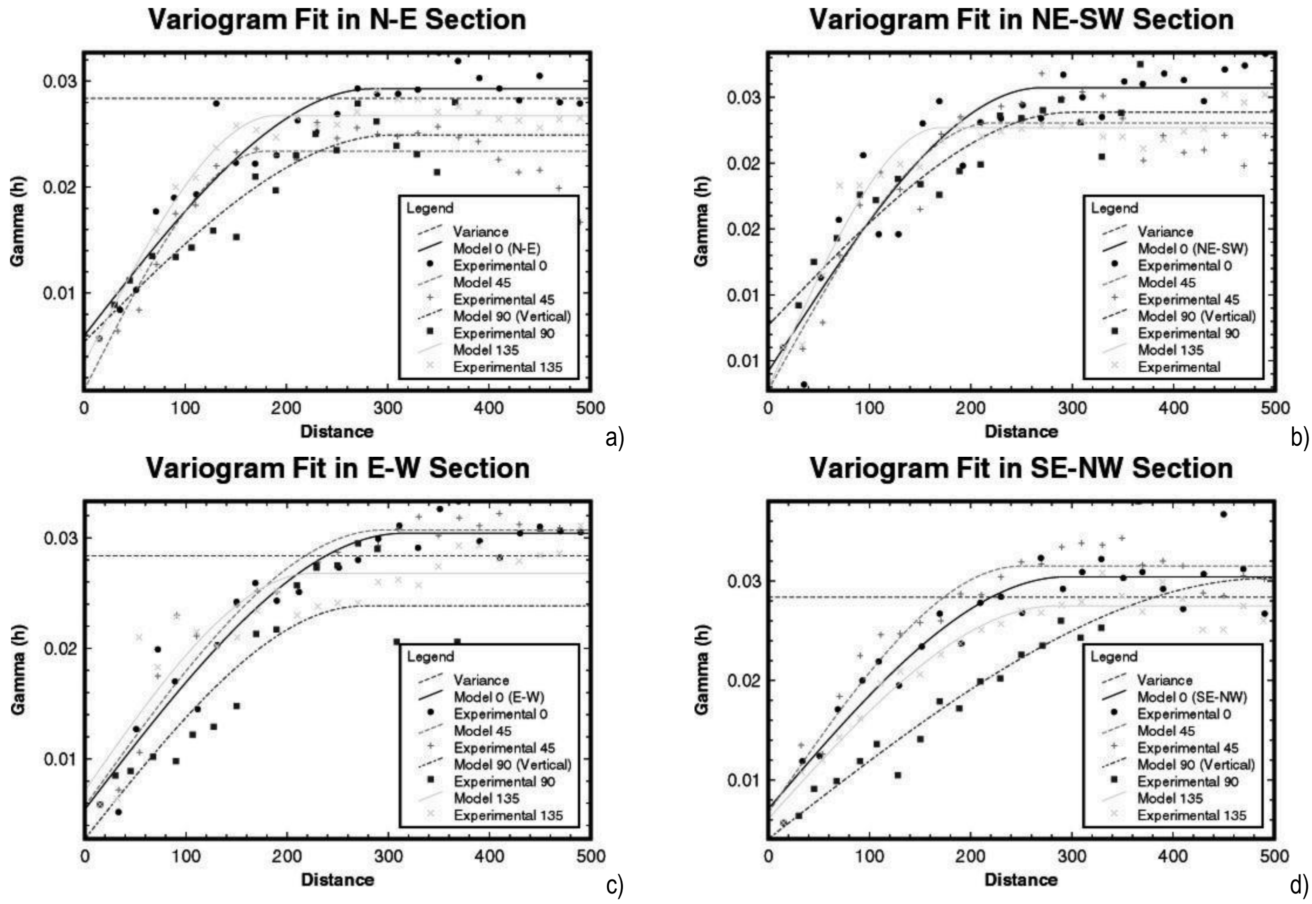

Figure 3. Experimental variograms and respective spherical models, determined for vertical sections in directions 0° (a), 45° (b), 90° (c) and 135° (d). Four variograms, calculated at dips 0°, 45°, 90° and 135°, are shown for every direction.

every drill at current level. Total number of 2819 composite samples from 24 horizons is used. Copper contents in these samples posses asymmetric statistical distribution shown on figure 2, as the statistical parameters describing their distribution low are represented below in table 2.

VARIOGRAM ANALYSIS

The variogram analysis is an essential part from the geostatistical modeling of deposits. Its aim is a determination of the spatial variability nature for studied geological feature (Matheron, 1967; Rendu, 1981). The variogram function is defined as the relation of average differences between measured values towards distances between samples:

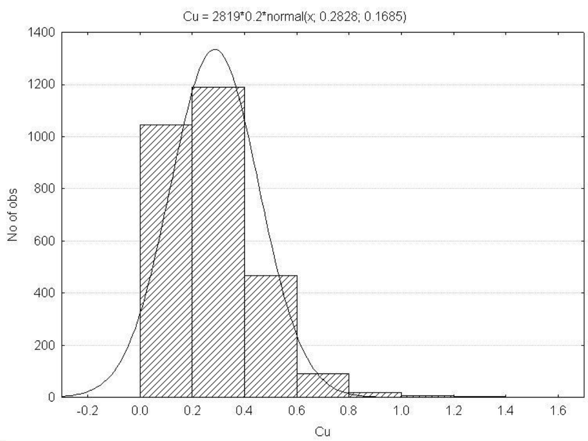

Figure 2.Histogram presenting copper distribution in used composite core samples.

average differences in separate directions, represented by experimental variograms, it is very important to select an appropriate theoretical model, to describe adequately natural structure in variability of data used.

The experimental variograms in plane and in four vertical directions with azimuth 0°, 45°, 90° and 135° are calculated in this variogram modeling of Elatsite deposit. Sixteen experimental variograms are calculated in general – four variograms at 0°, 45°, 90° and 135° directions in plane, as well as at four variograms with 0°, 45°, 90° and 135° slopes in every vertical direction. Variograms are calculated by three-dimensional searching of neighbor samples, in following conditions: from 20 to 500 m distance between samples with lag 20 m, horizontal and vertical bandwidth 200 m, horizontal and vertical angle tolerance 22.5°.

Experimental variograms are approximated with spherical model, represented in general form as:

$$\gamma(h) = C\left(\frac{3h}{2a} - \frac{h^3}{2a^3}\right) \quad \text{for } h \le a,$$

$$\gamma(h) = C \quad \text{for } h > a,$$

where C and a are variogram's sill and range respectively, while h is distance between samples.

The variogram analysis is completely done by UNCERT software (Wingle, *et al.*, 1997), as the approximation of theoretical spherical model is automatically calculated by least squares method. Resulting variogram models and parameters are presented in table 1 and figure 3, which illustrate existing anisotropy of copper ore body. Geometrical anisotropy representing elongated ore morphology is examined, as well as zonal anisotropy, which is determined by ore body location around the contact between granodiorites and metamorphic rocks. 18 variograms with angular lag 20° (half-angle solution) are used for anisotropy analysis in horizontal direction with aim to describe the structure of copper spatial variability (fig. 4). The variogram surface shows that smoothest changes of copper contents are examined in NE-SW direction, along the prolongation of ore body, while highest values of copper contents dispersion are examined in NW-SE direction. Interesting fact is that major anisotropy axis is oriented either in NE-SW or NW-SE direction due to chosen automatic approximation method, which can be explained with the strike variation of host rocks contact as well as orientation of major faults and dykes.

Cross-validation routine is performed for estimation of averaged variogram model significance, which is applied later in kriging interpolation modeling. This validation compares true copper contents measured in composite samples with their kriging estimations by neighbor samples. Popular geostatistical modeling software GSLIB (Deutsch *and* Journel, 1998) is used. The results are shown on table 2 and figure 5, where a high similarity between true values and estimates, with correlation of 0.86, is illustrated. Similarity between real and estimated values confirms the good representation of natural copper variability by variogram model, which is obvious condition for precise reserve calculation trough kriging method. Smoothing effect of kriging interpolation, espatialy for samples with higher contents, is illustrated on figure 5.

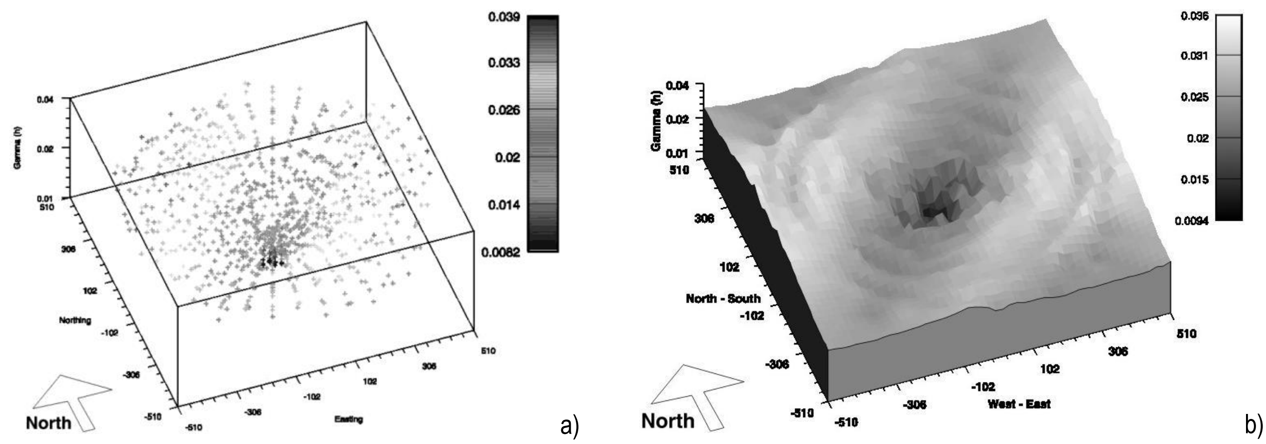

Figure 4. Variogram structure in horizontal direction, determined by 18 variograms (half-angle solution), shown as experimental variograms (a) and variogram surface (b).

Table 1. Spherical variogram model parameters, calculated for individual directions and vertical angles.

Azimuth	Dip	Nugget effect	Sill	Range
0	0	0.00592432	0.0233568	285
0	45	0.000786367	0.0226083	180
0	90	0.00535023	0.0195682	305
0	135	0.00332431	0.0234292	190
45	0	0.00415641	0.0215626	270
45	45	0.00273686	0.0203063	220
45	90	0.00765853	0.0161969	300
45	135	0.0028656	0.0198173	170
90	0	0.00543918	0.0249688	315
90	45	0.00573138	0.0249761	295
90	90	0.00277493	0.0210528	275
90	135	0.00713603	0.0196509	225
135	0	0.00709468	0.0233214	295
135	45	0.00673393	0.0247538	250
135	90	0.00408765	0.026182	495
135	135	0.00609529	0.0213959	285
	Average:	0.00487	0.0221	

Table 2. Statistical parameters from cross-validation, describing distribution lows of copper contents in composite core samples (Cu), their kriging estimations (Cu*), estimation variance (S_{Cu^*}) and the differences between estimations and true contents (Cu* - Cu).

	Cu	Cu*	S_{Cu^*}	Cu* - Cu
Mean.	0.282811	0.283932	0.002157	0.001121
Median	0.26	0.27	0.002	0.009
Minimum	0.007	0.01	0.001	-0.818
Maximum	1.37	0.788	0.024	0.324
Variance	0.028384	0.019908	4.16E-07	0.007325
Std. Deviation	0.168476	0.141096	0.000645	0.085585
Skewness	1.163632	0.568922	14.986	-1.5891
Kurtosis	2.70775	0.283673	469.9832	9.997335

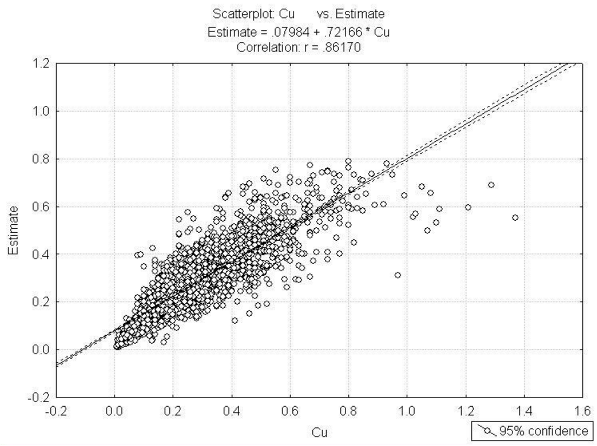

Figure 5. Correlation between true copper contents in core samples (Cu) and their kriging estimations (Estimate).

KRIGING BLOCK MODEL

The geostatistical block model of copper ore body is constructed for the volume with dimensions 1560x1080 m in plan and 345 m in depth, between horizons 1390 and 1045. Outline areas with lack of data are cutted, as the contour in which the copper ore body is designed is shown on figure 1. Digital elevation model is constructed by topographic map and it is used to remove eroded parts. The studied volume is disintegrated to small blocks with dimension 15x15x15 m, which are estimated by block kriging method with 4x4x4 discretization points for every block. Kriging modeling is performed with kt3d program from GSLIB software (Deutsch *and* Journel, 1998), where 4 to 10 neighbor samples are used. Octant type searching within maximum radius is performed for declustering of drill data. Applied average variogram model, determined by variogram analysis (tabl. 1) posses nugget effect 0.00487 and sill 0.01723, as the anisotropy is described with maximum, minimum and vertical range respectively 315 (azimuth 110°), 270 and 300 m. The resulting digital model represents central co-ordinates, estimated copper contents and the kriging estimation variance for each block. Detailed analysis of variability and reserves calculation conditions for separate host rocks and ore types is presented by Todorov *et al.* (2002).

Specialized module to visualize three-dimensional model of copper ore body is developed in OpenDX software, which is based on IBM Visualization Data Explorer software (IBM, 1997). The ore body morphology is illustrated by individual isosurfaces on figure 6, as the relief surface is also shown for higher reality. Constructed model could be used for reserves calculation for separate horizons as well, if the geological-economic and mining-technical conditions in the deposit would be taken into account.

CONCLUSIONS

Designed three-dimensional model describes the spatial features of copper contents distribution and ore body morphology in Elatsite deposit. The variogram analysis shows smooth copper contents variance, which is precondition for the precise model design. Invoked anisotropy posses a complicated morphology due to complex geological setting and different fault directions, as well as the variation of host rock contacts. The major anisotropy axis is oriented either in northeast or northwest direction, parallel or orthogonal to ore body length respectively, in depends of applied method for automated approximation of variogram model. Both geometric and zonal components are observed in invoked anisotropy, as the second is most obviously manifested in W-E direction. The geometrical anisotropy component reflects the differences in ore-forming process intensity at central and outern parts of stockwork and it is main controlling factor for ore body morphology. The zonal component is caused by rapid changes in lithological features of host rocks. It could be concluded that copper content variances are smoothest in NE-SW direction generally, while highest variance values are observed in NW-SE direction.

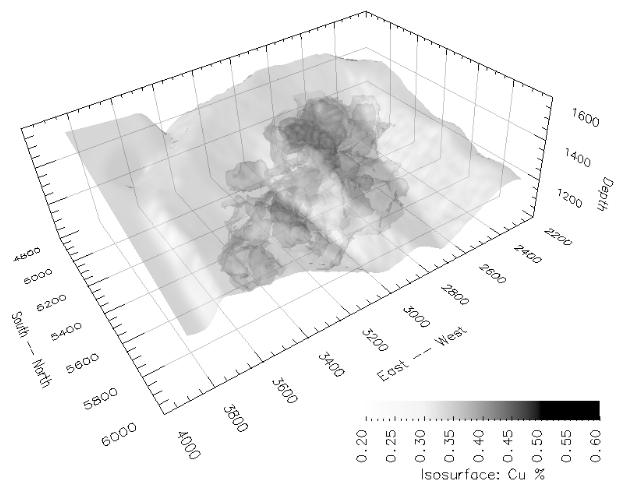

Figure 6. 3D model of copper ore body represented by isosurfaces on 0.25, 0.4 and 0.55 % Cu contents. Relief model is overlaid as transparent light-gray surface. View from Northeast.

The contact between Vejen pluton and Lower Paleozoic metamorphites as well as the sub-parallel to contact Kashana reverse slip – overthrust posses main magma-controlling and ore-controlling role within Elatsite deposit area. The intersection area of this contact, Elatsite intrusive and Elatsite and Murgana faults defines particular ore stockwork location. The last two faults obviously posses an ore-conducting role within studied depth interval. The area of intersection between separate structures is characterized by the highest permeability, which is marked by the highest copper concentration in ore body. The ore stockwork stretch in northeastern direction is obviously determined by orientation of the contact between Paleozoic granodiorites and metamorphites in this area. This contact controls the development of higher metal contents as well. It should be mentioned that the ore mineralisation within Paleozoic metamorphites is developed mainly within the zone, where they are alterated into hornfelse. The knotted schist and phyllite located out of this zone posses screening role during the ore forming, due to their plastic features.

Designed model describes in general the upper levels of deposit, as the highest contents are observed between horizons 1400 and 1200. The cross-validation performed on variogram model shows a high correlation between estimated and true contents, which represents adequate describing of real geological situation by the created model.

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MAIN FEATURES IN GEOLOGY AND METALLOGENY OF THE PANAGYURISHTE ORE REGION

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ABSTRACT
The Panagyurishte ore district is located in the Central Sredna Gora and partly in the Stara Planina mountains. It is an element of the Upper Cretaceous Apyseni-Banat-Timok-Srednogorie Magmatic and Metallogenic Belt. Forming of this ore region is determined by the development of intensive Upper Cretaceous volcanic and magmatic activity. Magmatic rocks belong to two petrochemical series: calc-alkaline and subalkaline ones. Magma generation took place in enriched upper mantle with variegating participation of crustal component. It is established following well expressed volcano-intrusive complexes: Elatsite-Chelopech, Krassen-Petelovo, Vrankamik, Assarel-Medet, Svoboda-Ovchihulm, Elshitsa and Pesovetz. Magmatic activity is realised during Conniasian-Santonnian and the distinct migration from north to south is established. Ore fields include Elatsite-Chelopech, Krassen-Petelovo, Assarel-Medet, Radka and Elshitsa. Metallogenic specialisation of the region is determined by numerous Cu, Cu-Mo and Cu-Au porphyry deposits associating with high to intermediate sulphidation epi- to mesothermal massive sulphgide Cu-Au, Cu-Pyr-Au and Cu-Pyr deposits. Intermediate to low sulphidation Cu, Pb-Zn-(+ Au), Cu-Pb-Zn--(+ Au), Au и Ba deposits related to brittle faulting are developed in the marginal parts of the ore fields. Mn ore occurrences type "silicified umbra" are found in volcano-sediment rocks in the region.

INTRODUCTION

The Panagyurishte ore region is located 55 – 95 km east from Sofia. Its territory involves parts from the Central Srednogorie and the Stara Planina Mountain between towns of Pazardzhik and Etropole with total area of 1500 km^2. Its geological position is determined by the area of development of an intensive Upper Cretaceous magmatic activity and related to it mineral deposits (Georgiev, 1939; Konstantinov, 1952; Dimitrov, 1960; Bogdanov, 1987; Popov & Popov, 1997).

The Panagyurishte ore region is an element of the Apuseni-Banat-Timok-Srednogorie Magmatic and Metallogenic Belt as it was determined the last years (Popov et al., 2000). The belt is commented by different authors as "Banat-Srednogorie zone", "Banatite belt" or a part of Carpathian-Balcanides. This belt is formed as a result of extentional processes in relation to the manifestation of the post-subductional and intra-collision mantle diapirism in the zone of transformation of subducted fragments from the oceanic crust. (Popov, 1981, 1987, 1996; Berza et al., 1998)

Over 150 ore deposits, ore occurrences and mineral indications are found in the Panagyurishte ore region. It is characterized mainly by presence of porphyry copper and massive sulphide copper deposits. Small gold, gold-polymetallic, baryte lead-zinc and manganese deposits are established as well. 489 555 400 t ore and respectively 3 946 092 t copper (in ore), 665 185 t sulphur (in pyrite concentrate), 46 507 kg gold (in ore), about 13 000 t Mo (in ore)and about 195 900 t baryte re extracted from the district within 1942 and 1995 years. Current mining activity is on going in Elatsite, Assarel and Chelopech deposits.

GEOLOGY

The main features in the geology of the Panagyurishte ore region that control development of the metallogenic processes in the space and time are determined by the characteristics and evolution of the Upper Cretaceous magmatic complexes. The effusive rocks united in the Panagyurishte volcano-sedimentary group (K. Popov, 2001a) overlay on Turonian sediments and in the most southern part on the rocks from Pre-Mesozoic basement. They are overlapped by post-volcanic Upper Santonian-Maastrichtian carbonate and flish sediments.

Petrochemical data show that Upper Cretaceous magmatic rocks belong to two petrochemical series: calc-alkaline and subalkaline (Popov, 1981; Popov & Popov, 1997). Calc-alkaline rocks have dominant distribution. The volcanic rocks are mainly with andesitic and less dacitic composition, while hypabyssal and subvolcanic hypabyssal varieties are mainly granodiorite and granodiorite porphyrites. Calc-alkaline rocks are of high potassic type (Ignatovski & Bayraktarov, 1996) and in some complexes the content of alkaline oxides is increased which suggest transition to subalkaline ones. Subalkaline rocks are presented mainly by latite and trachyandesitebasalt rarely trachybasalt, trachyriolite and trachite. The different petrochemical type of the rocks lead to conclusion that magma generating take place in different depths. The last studies or ratio $^{87}Sr/^{86}S$ for some representatives of the calc-alkaline serie was determined as following: for the effusive rocks from the Chelopech volcano the ratio is between 0.7049 и 0.7054 (Stoykov et al., 2003)., for the intrusive rocks from Elatsite - between 0.70492 и 0.70571 (Von Quadt et al., 2002) and for the intrusive rocks at Elshitsa – between 0.70514 и 0.70583 (Peytcheva et al., 2003). These data show for enriched mantle source, mixed in varying proportions with crustal material. It could be presumed that subalkaline magma are entirely a product of the upper mantle.

Detail structural-volcanic studies in the district establish that the volcanic activity is dominantly central type. Following volcanoes are determined in the region: Elshitsa (Bogdanov et al., 1970, 1974), Chelopech (Popov & Moutafchiev, 1980; Popov et al., 1983), Assarel (Angelkov & Parvanov, 1980; Popov & Petkov, 1994; Popov et al., 1996), Pesovetz (Bogdanov et al., 1974), Ovchihulm and Svoboda (Popov & Popov, 1997, 2000), Vrankamik (Ignatovski & Bayraktarov, 1996), as well as Tangur, Petelovo and Smilets (Popov & Popov,1997, 2000). Slavov et al. (1978), Angelkov & Staikov [1980] and Ignatovski & Bayraktarov (1996) suggest a little bit different interpretations for some parts of the district which are not confirmed.

On the base of the studies provided and analysis of data obtain in could be concluded that as a result of the Upper Cretaceous magmatic activity an unit of well individualised volcano-intrusive complexes is formed on the territory of the Panagyurishte ore region (Popov & Popov, 1997, 2000). Recent studies established following volcano-intrusive complexes: Ealtsite-Chelopech, Krassen-Petelovo, Vrankamik, Assarel-Medet, Svoboda-Ovchihalm, Elshitsa and Pesovetz (Fig. 1). These magmatic complexes are set up by accumulative volcanic structures formed during the effusive processes and also by the associating comagmatic subvolcanic to hypabissal intrusive bodies and dykes. The intrusives cut effusive rocks and the rocks from the basement. In some of the complexes on the daylight surface intrusives are presented only by subvolcanic bodies they could be determined as volcanic-subvalcanic. Accumulative parts of the described complexes usually are characterised as well individualised stratovolcanoes of central type often elongated along the magma channel faults. In some cases volcanoes are located closely to each other in space and time and they formed complicated accumulative structures from the volcanogenic "brachianticlines" type. Presence of some smaller separated or satellite volcanoes is not excluded. Differentiation of the volcanoes is based on the spatial development of magmatic rocks from different facieses, lateral relations of the effusive rocks with sediments and volcano-sediment depositions, their position in the Upper Cretaceous column and the specific features in petrological and chemical composition of their rocks.

Characteristic feature in the evolution in the different magmatic complexes and the whole volcanic activity is the intensive volcano-tectonic faulting. This process takes place during the entire period of magmatic activity and it is most effective after the end of effusive activity in separate magmatic complex and before introduction of subvolcanic intrusives. This faulting determines block separation of the volcanic structures and movement of rocks formed at different depths to one and the same level. As a result effusive rocks that are products of later formed volcanoes lay over different levels of the older effusive units. These Intra-Santonian fault movement are demonstrated as well as by the fact that Upper Santonian-Maastrichtian postvolcanic depositions overlay on eroded in different grade volcanic structures formed during different stages.

Intrusive bodies as a rule are present by two sequentially formed groups: subvolcanic and subvolcanic-hypabissal to hypabissal. They are intruded the most often after volcano-tectonic faulting and block separation of the volcanic cones. The Elshitsa pluton is an exception that is formed after effusive activity but before volcano-tectonic faulting. Small intrusive bodies formed before the effusive activity are known as well in the Elatsite-Chelopech complex.

The forming of volcano-magmatic complexes could be divided into four stages (Popov & Popov, 1997, 2000; K. Popov, 2001a). Distinct migration of the magmatic activity from north to south is established.

Elatsite-Chelopech volcano-intrusive complex is formed during the first stage in the most northern part of the regiont. Krassen—Petelovo volcano-intrusive complex formed by several interfingering volcanoes (Petelovo, Tangur, Smiletz) is formed during almost the same time between Panagyurishte and the villages of Smiletz and Ovchepolzi. The Vrankamic volcano-intrusive complex is formed northwest from Panagyurishte during the same stage..

Assarel-Medet volcano-intrusive complex which partly overlays on Vrankamic and Krassen-Petelovo volcanoes could be divided as second stage. Forming of Ovchihalm and Svobodinski volcanoes that overlay on the rocks of Petelovo and Smiletz volcanoes also could be nominated as a part of the second stage.

Third stage is marked by forming of the Elshitsa volcano-intrusive complex which includes Elshitsa volcano, Elshitsa intrusive and numerous subvolcanic bodies. It overlays on the Ovchehalmski volcano to the north and on the rocks from the basement to the south.

The forming of Pesovetz volcano marks the fourth stage. It overlays on different levels of the Krassen-Petelovo, Svobodino and Slshitsa complexes.

Paleonthological data conclusively prove that magmatic activity took place almost entirely during the Coniacian and Santonian (88 –83 Ma). It is confirmed also by the fact that effusive rocks overlay on Turonian and they are overlapped by Upper Santonian-Maastrichtean sediments (Vrublyanski et al., 1961; Karagjuleva et al., 1974; Moev & Antonov, 1978; Dimitrova et al., 1984; Jelev et al., 1999). The last few years were realised determinations of the absolute age of the magmatic rocks. The age of the Elatsite intrusive is determined as 91.72$\pm$0.70 - 90.78$\pm$0.44 -90.78$\pm$0.44 Ma based on $^{40}Ar/^{39}Ar$ method, Vosdol neck (north from Chelopech) – 89.95$\pm$0.45 Ma, Medet intrusive is aged as 85.70$\pm$0.35 Ma and andesites from St. Nikola Hill (south from Panagyurishte) 80.21$\pm$0.45 Ma (Hander et al., 2002). Based on $^{206}Pb/^{238}U$ zircone method the age of the intrusive rocks in Elatsite is determined as 92.1$\pm$0.3 - 91.84$\pm$0.31 Ma (Von Quadt 2002), The Elshitsa granite is aged 86.62+0.02 Ma and Elshitsa subvolcanic dacites- 86.11+0.23 Ma (Peycheva et al., 2003). Data from the absolute age determinations show increasing of the results compared to the paleothological data but they confirm the known fact that the migration of the magmatic activity is developing from north to south.

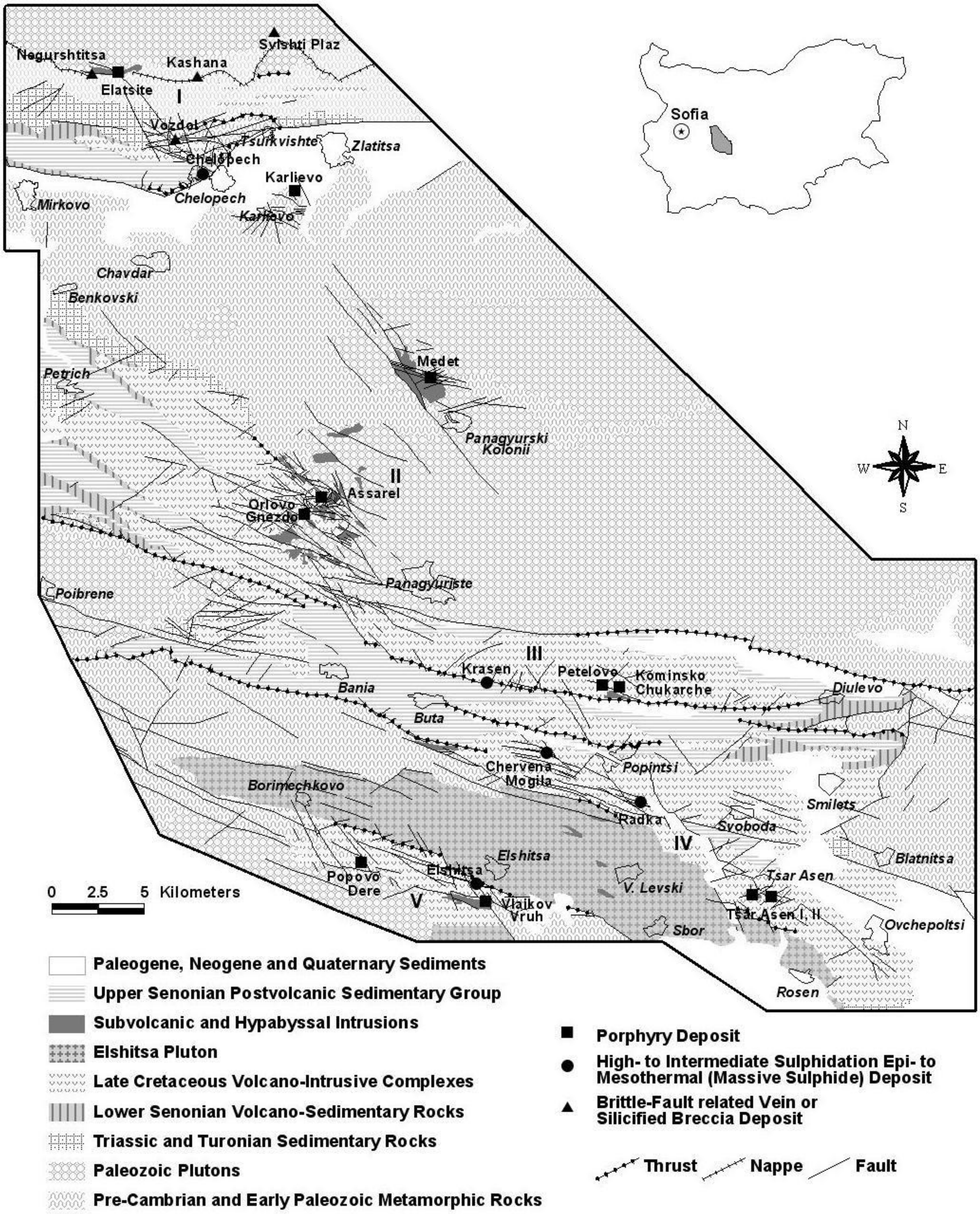

Figure 1. Geological Map of Panagyurishte Ore Region (compilated by K. Popov)
Ore Fields: I - Elatsite-Chelopech; II - Assarel-Medet; III - Krasen-Petelovo; IV - Radka; V - Elshitsa

METALLOGENY

Metallogenic characteristics of the Panagyurishte ore region is determined mainly by development of numerous porphyry copper and massive sulphide copper deposits. Smaller copper, gold, gold-lead-zinc and gold-copper-lead-zinc deposits and ore occurrences of vein type associate very often with them. Several manganese ore occurrences are also established in the region. Forming and spatial distribution of these mineral deposits is controlled by the position, evolution and structural features of the Upper Cretaceous volcano-intrusive complexes. The ore fields are localised within the frames or parts of these complexes (Fig. 1). The boundaries of the ore fields are determined by the area of development of the late subvolcanic and subvolcano-hypabyssal intrusions and large dykes. Five ore fields (districts) are established in the region: Elatsite-Chelopech, Assarel-Medet, Krassen-Petelovo, Radka and Elshitsa ore fields, involving unified ore-magmatic systems. Porphyry copper, massive sulphide and vein deposits and ore occurrences which are a result of the evolution of one and the same ore magmatic system within the frames of each ore fields are developed.

The Elatsite-Chelopech ore field is located in the most northern part of the region within the frames of the volcano-plutonic complex with the same name. It is set up by Early small intrusives, the Chelopech volcano (including the Vosdol monovolcano) and Later small intrusives. Ore deposits Elatsite, Chelopech, Negarshtitsa, Kashana, Dolna Kamenitsa, Vosdol, Karlievo and probably Svishti plaz are developed in this ore field.

The Assarel-Medet ore field is located northwest from the town of Panagyurishte within the area of the Assarel-Medet volcano-intrusive complex. It includes Assarel volcano, Medet, Assarel, Lisa Mogila and numerous smaller intrusives. Porphyry copper deposits Medet, Assarel, Orlovo Gnesdo as well as numerous ore occurrences are found in this ore field.

The Krassen-Petelovo ore field is located south-east from the town of Panagyurishte in the central part of the volcano-plutonic complex with the same name. It is set up by Petelovo and Tangur volcanoes and Petelovo intrusive. Ore deposits in it are Krassen, Petelovo and Kominsko Chukarche.

In the most southern part of the ore region is located the Elshitsa volcano-intrusive complex which includes Radka ore field in its northern part and Elshitsa ore field in its southern part. Their spatial development is controlled by two sheaves of linear subvolcanic bodies cutting respectively southern and northern slopes of the Elshitsa stratovolcano. Ore deposits Radka, Tzar Assen and Chervena Mogila belong to the Radka ore field and Elshitsa, Vlaykov Vruh and Popovo Dere are within the frame of Elshitsa ore field.

Porphyry copper ores are found in Medet, Assarel, Elatsite, Vlaykov Vruh, Tzar Assen deposits as well as in subeconomical deposits Orlovo Gnesdo, Karlievo, Popovo Dere, Kominsko Chukarche, Petelovo and numerous ore occurrences The lateral distribution of porphyry copper deposits is controled by Upper Cretaceous hipabyssal to subvolcanic-hipabyssal porphyritic intrusives and dyke sheaves. They are usually members of the different volcano-intrusive complexes described above. The porphyry copper deposits are located in some cases in the central parts of the volcanoes and in the rocks from the basement in other cases. The ore bodies are present by column-like ore cone-like inclining, rarely linear elongated stockwerks formed by disseminated ore mineralisation.

Porphyry copper deposits in the region could be divided into two groups on the base of their specific features. The first group includes ore mineralisations and hydrothermal alterations developed mainly in the apical parts of intrusive bodies and partly in the rocks from the frame (Medet, Elatsite). The second group includes deposits in which ore mineralisation and hydrothermal alterations affect not only the upper part of the small porphyritic intrusives but the largest part of it is developed in the effusive rocks and volcanic neck of the complexes (Assarel, Tzar Assen). The development of the hydrothermal systems in the first group is characterised by relatively limited participation of meteoric waters and higher temperatures of the ore-forming processes. The early stages of the evolution of the systems is determined by the large forming of K-silicate alterations of the host rocks mainly in the central parts of the deposits gradually changed to propilitisation in the marginal parts. Fluids separated in the initial stage of the hydrothermal process are characterized by high salinity (up to 50 wt. % NaCl equiv.) and temperatures above 450^{o} C (Strashimirov et al. 2002) which suggest their mostly magmatic origin The next stages of the evolution of the systems are characterised by gradually dicreasing of the temperature and salinity of brunes due to the removement of the generating source in depth and large participation of meteoric waters in the systems. Hydrothermal alterations of the host rocks that accompanied ore precipitation are mainly of sericitic type.

The second group of porphyry cooper deposits are characterised by hydrothermal processes developed relatively closer to the daylight surface and the ore-bearing small porphyritic bodies are intruded in volcanic accumulative cones. K-silicate alterations are developed in significantly limited scale compared to the first group deposits. Dominating hydrothermal alterations are present by sericitic to propylitic types. These alterations are developed much intensively in the upper parts of the deposits in lower temperature conditions. Such alterations in the Assarel deposit are overlapped on earlier acid-silphate alterations formed during the effusive activity (Arnaudova et al., 1991).

Specific conditions of mineralisation in different porphyry systems in the region reflect to the composition of precipitated ore associations. The first group of porphyry copper deposits mentioned above is characterised by larger presence of Fe-Ti oxide association formed in the initial stage of the ore forming, distinct presence of quartz-molybdenite association, presence of Co-Ni mineral assemblages and relatively higher content of gold as trace element in ores (Strashimirov et al., 2002). Particular interest represents minerals from PGE established in the Elatsite deposit (Petrunov & Dragov,1993) that suggest for deeper source of the brines probably with many basic geochemical characteristics.

Data from fluid inclusions studies in quartz determine the evolution of hydrothermal systems from type H_2O-NaCl $\pm FeCl_2$ to types H_2O-NaCl-KCl and H_2O-NaCl and gradually decreasing of salinity about 10 wt.% NaCl equiv. The precipitation of the main economic association quartz-pyrite-chalcopyrite in all deposits practically takes place within temperature range 350 – 250^{o} C. Later well-shaped veins of quartz-pyrite are formed in the intermediate and upper part of the deposits. Quartz-sphalerite-galena associations developed as short veins in the most upper and marginal parts of deposits are typical for the later stages of the hydrothermal systems evolution.

Final of the hydrothermal activity is marked by precipitation of carbonates and zeolites as vein and veinlets that cut all formed before mineral associations.

Differences in mineral composition of deposits located in the apical parts of intrusive bodies and those located mainly in effusive rocks from paleovolcanic structures is underlined by appearance of polyelement associations including enargite (Assarel, Petelovo), goldfildite, colusite, aikinite, hessite and other sulphosalt minerals typical for high sulphidation style of mineralisation (Assarel, Petrunov et. al. 1993). Forming of well expressed cementation zone of secondary copper sulphide enrichment (Assarel, Orlovo gnesdo, Kominsko Chukarche) a result of intensive development of exogenic processes, which realisation is stimulated by the high grade of tectonic rework of the host rocks during the processes of volcano-tectonic faulting is another significant difference between both groups of porphyry copper deposits in the region.

Massive sulphide ores are found in Chelopech, Krassen, Elshitsa, Radka, Chervena Mogila deposits as well as in numerous ore occurrences such as Stiptsata, Varnichka Chukara, Isgorelia Vruh, Kaleto and others. These are epigenetic mineralisations which spatial distribution is controlled by the position of subvolcanic intrusives cutting the central parts or scopes of volcanic structures, as well as by the volcano-tectonic faults. Massive sulphide ores are located the most often in tectonic breccia or zones with intensive fracturing. They are developed mainly along the exocontact zones of linear or arc-like subvolcanic bodies, also in and around volcanic necks rarely in the explosion pipe. Ore bodies are with column-like, stock-like, lense-like or nest-like shape. Almost all of them are discordant to the layering in the effusive units. Typical are massive texture ores formed generally by metasomatic replacement of hydrothermal altered fractured and brecciated volcanic rocks. Low grade disseminated ores present as hallo around the massive ores. Tendency of precipitation of later formed and low temperature mineralisations in marginal and upper part of the ore bodies is established.

Massive sulphide ore deposits in the district could be divided into two groups according the type of ore mineralisation and hydrothermal alterations of the host rocks. The first group is represented by typical high sulphidation epithermal copper-gold deposits. Chelopech deposit is one remarkable example for this group with its mineral composition including large scale of sulphosalt minerals and advanced argillic alteration of the host rocks. Hydrothermal mineral forming process is preceding by limited in volume hydrothermal-sedimentary precipitation of pyrite-marcasite association. Typical for the high sulphidation deposits ore associations including enargite, lusonite, famatinite, goldfildite, colusite, native gold, tellurium, bismuth and numerous minerals in Cu-Pb-Bi-S-Se, Pb-Bi-Hg-Te-Se and Cu-Au-Ag-Te systems are formed during the main ore forming process. Precipitation of large crystals of enargite marks the temperature conditions (280 – 300^{o} C) within the range typical for the high sulphidation systems (Bonev et. al., 2000). Hydrothermal alterations include forming of zones of propylitic, sericitic, sericitic-advanced argillic, advanced argillic, propylitic-sericitic as well as representatives of the secondary quartzite formation – quartz-dickitic and quartz-alunite facieses.

The second group is represented by intermediate sulphidation epi- to mesothermal copper-pyrite and copper-pyrite-gold deposits. The first variety includes Elshitsa and Radka deposits and the second one includes Krassen and Chervena Mogila deposits. The evolution of ore forming processes is similar in both subtypes – initial stages are marked by precipitation of iron-sulphide associations followed by copper sulphide and polymetallic associations. The final of hydrothermal activity includes forming of significant quantity of gypsum and anhydrite. Temperature range of mineralisation is a broad one. Hydrothermal alterations start at about 400^{o} C and the end of hydrothermal activity is probably about 160^{o} C (Strashimirov & Kovachev, 1992). Kouzmanov et al. (2002) determined through infrared microthermometry of pyrite from Radka deposit temperature of its precipitation 360 – 320^{o} C and low bulk salinity 3.5 – 4.6 wt. % NaCl equiv. Sulphosalt minerals found in these deposits are not so various like those established in the first group, the quantity of enargite is significantly low. Distinct differences are also found in the hydrothermal alterations of the host rocks. Typical for the group discussed are propylitic, propylitic-sericitic and sericitic alterations while the advanced argillic type is not developed except as minor occurrence in Chervena Mogila deposit. All these differences give a reason for differentiation of both groups in epithermal deposits from the district.

Vein type ore deposits are developed in the marginal parts of porphyry and massive sulphide deposits and they could be accepted as integral part of ore magmatic systems. They could be determined as brittle-fault related veins and silicified breccia ore deposits. Based on the type of are mineral associations and hydrothermal alterations presented in them they could be classified as intermediate to low sulphidation epi- to mesothermal mineralisations. Their composition is different – copper, lead-zinc ($\pm$ Au) (Dolna Kamenitza deposit), copper-lead-zinc ($\pm$ Au) (Vosdol deposit), gold (Negarshtitsa) or baryte (Kashana).

An other specific feature of the Panagyurishte ore region is a development of manganese mineralisations type "silicified umbra". This type is presented by ore occurrences Momin Skok, Toplika, Milkova Chesma, Dulgi Rid (Oborishte) and other.They are banded-like or lense-like ore bodies localized concordant to layering along the contact between andesite and argillic rocks that cover it. Their composition includes pyrolusite, psilomelane, manganite and braunite with which associate chalcedony, quartz, baryte, calcite and zeolites (Dimitrov & Kostov, 1954).

CONCLUSIONS

Combined lateral distribution of described above two types copper deposits and associating with them vein deposits within the frames of distinct expressed ore fields is one remarkable feature of the Panagyurishte ore region suggesting unified source and well established sequence in evolution of ore bearing systems from which mineralisations are precipitated in the different ore fields. Isotopic studies of fluid systems in

Radka, Elshitsa and Vlaykov Vruh deposits provides strong evidences for existing of unified ore-magmatic systems within the frames of single ore fields (respectively volcano-intrusive complexes) (Kouzmanov et al., 2001). Within the frame of these systems forming of porphyry copper and epithermal deposits is established as a result of consecutively developed processes. The migration of magmatic activity in general from north to south in different ore-bearing volcano-intrusive complexes it is established larger participation of crustal material in magma which mark much shallow levels of magma generation. Significant content of gold and presence of PGE minerals in the most northern part of the district (Elatsite-Chelopech ore field) is probably connected to the deeper generating of the magma chambers that are related to the ore mineralisations. The gold content decreases and PGE minerals are not found in the ore fields from the southern part of the region.

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PETROLOGICAL AND STRUCTURAL CHARACTERISTICS OF THE LOW GRADE METAMORPHIC ROCKS FROM THE VALLEY OF GABROVNITSA RIVER, WESTERN STARA PLANINA

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ABSTRACT
New data of the petrologic features and structures of the low-grade metamorphic Lower Paleozoic rocks from the Gabrovnitsa river between the villages of Ossenovlak and Elenovdol are discussed in the present paper. These rocks are referred to the Diabase-phyllitoid Complex. The metasedimentary sequence is represented by irregular alternation of siltstones, siltshales, mudshale, sandstones and conglomerates metamorphosed in the condition of green schist facies. Four formations and four mark levels are divided in the studied rocks as well as three fold generations as a result of polyphase deformation

INTRODUCTION

Dimitrov (1930) made the first and the most detailed petrographic and stratigraphic study of the low grade metamorphic Lower Paleozoic rocks from the Gabrovnitsa river between the villages of Ossenovlak and Elenovdol. He divided one arkose-graywacke complex and another one of grey-greenish schist situated above it that are separated by "discordance between them" or "secondary discordance". In the same work he emphasized that in the Iskar Gorge their position is opposite. Later for these metamirphic rocks, referred to the so called Diabase-phylitoid Formation or Diabase-phylitoid Complex (DPhC), are proposed various startigraphical schemes by Chunev, Kozhouharov (1968), Ivanov (1970; 1972), Gorshkov, Dzhelepov (1970) and Dzhelepov (1983). Only two of them by Ivanov (1970; 1972) and Dzhelepov (1983) could be compared with the complexes, divided by Dimitrov because they are accompanied by correlation tables and geological maps. After Ivanov (1970, 1972) the Lower Paleozoic section is discontinuous and includes three superpositionally disposed formations – volcano-terrigenous (later characterized by Ivanov, 1983 as olistostrome), aleurolite-quartzitic and clayey. Dzhelepov(1983) detached three formations – sandstone-argillitic, conglomerate-qurtzitic and volcano-argillitic. He supposes, that the rocks from the two upper formations are "deposited in the condition of a new sedimentary cycle, because in the base of the second formation "basal polygenous conglomerates" are situated with angular or parallel discordance above various levels of the sandstone-argillitic formation. The author correlates the low and the medium formations respectively to Dimitrov's schist and arcose-greywacke complex and the upper one with the clay formation (Ivanov, 1972). The Dzhelepov's scheme is accepted by Haydoutov (1991) who used it with slight changes in the preparing of the Bulgarian Geological Map on scale 1:100 000 (Angelov et al., 1992; 1992a; Tzankov et al., 1991; Yanev et al., 1992). In the map the sandstone-argillitic formation is referred to the Berkovitsa Group and the two upper formations to the Dalgidel Group.

During the clarifying of the structures connected to the rare-earth mineralisation in the Iskar Gorge region one of the authors (M.A.) carried out geological and structural investigations in the region of the Gabrovnitsa river and the results were partly published (Antonov, 1989).

In the present paper on the base of additional field works and laboratory studies, more detailed characteristic of the petrologic and structural features and metamorphism of the low-grade metamorphic rocks is made.

GEOLOGICAL SETTING

The Lower Paleozoic low-grade metamorphic rocks with the cross cutting Upper Paleozoic intrusive bodies and dykes built up the basement of the so-called Berkovitsa unit, according to the Alpine structure setting (Angelov et al., 1992; Tzankov et al., 1995)

During the present study it was found out that the Lower Paleozoic section in the valley of the river Gabrovnitsa is continuous but differs from those of the Iskar Gorge. It could be subdivided into four formations and a few mark levels. The surface distribution, vertical and lateral interrelations between the lithostratigraphic units are presented in fig. 1, 2, 3. The names of these units correspond to the protolith composition. The lowest sandstone-siltstone-argillite formation is set up of rhythmic alternation of fine to medium bedded low metamorphosed fine-grained sandstone, siltstones, mud stones, mudshales and argillites. It comprises fast wedging out fine packets of fine-grained polygenic conglomerates, gravelites, coarse-grained sandstones, marls and limestones.

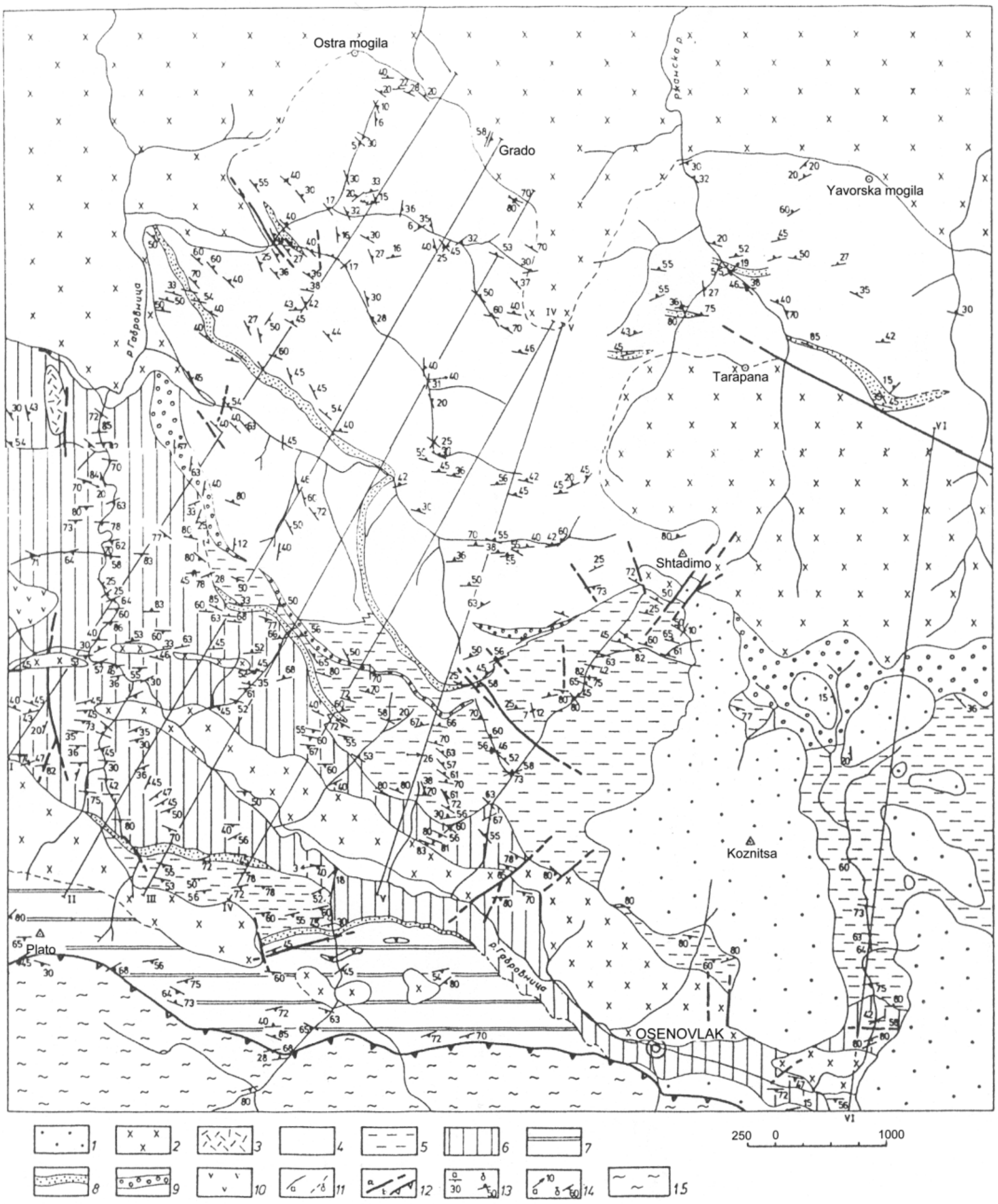

Figure 1. Geological map of the studied area
1 – Mezozoic cover; 2 – untrusive granitoide bodies; 3 – bodies and dykes of granite porphyre; 4 – siltstone –argillite formation; 5 – argillite formation; 6 – sandstone-siltstone –argillite formation; 7 – contact metamorphosed rocks of the DPhC; 8 – sandstone-quartzite and quartzite marl level; 9 – conglomerate mark level; 10 – diorite porphyrites; 11 – geological boundaries: a – established; б – probable; 12a- fault of unclear character 12б – reverse-slip fault; 13 – bedding strike and dip: a – normal; б – overturned; 14a – fold hinge direction and plunge ; 14б – foliation strike and dip; 15 – Grohoten Formation.

Argillite formation is built up of mudstones and mudshales with singular fine interbeds of siltstones. Its lower boundary is gradual transition and to the NW direction it laterally joins with sandstone-siltstone-argillite and siltstone-argillite formations. *Siltstone-argillite formation* consists mainly of siltstones and mudstones building up packets of various thicknesses. Single beds and thin packets of fine-grained conglomerates, sandstones and quartzites are presented there. *Conglomerate formation* mainly includes conglomerates and small quantity sandstones, siltstones and argillites. The low boundary with the argillitic formation is a sharp lithological contact and to the NNW direction it laterally joins probably with the siltstone-argillite formation. Single fragments of metagabbro-diabase, metadiabase and its tuffs are common in the three formations. The mark levels (*sandstone, sandstone-conglomerate and quartzite*) are situated often between formations and partly are included in them.

The above-described lithostratigraphic units take part in the formation of a relatively large anticlinal fold, known as Gabrovnitsa anticline (Maljakov, Cholakov, 1971; Gorshkov, Dzhelepov, 1980).

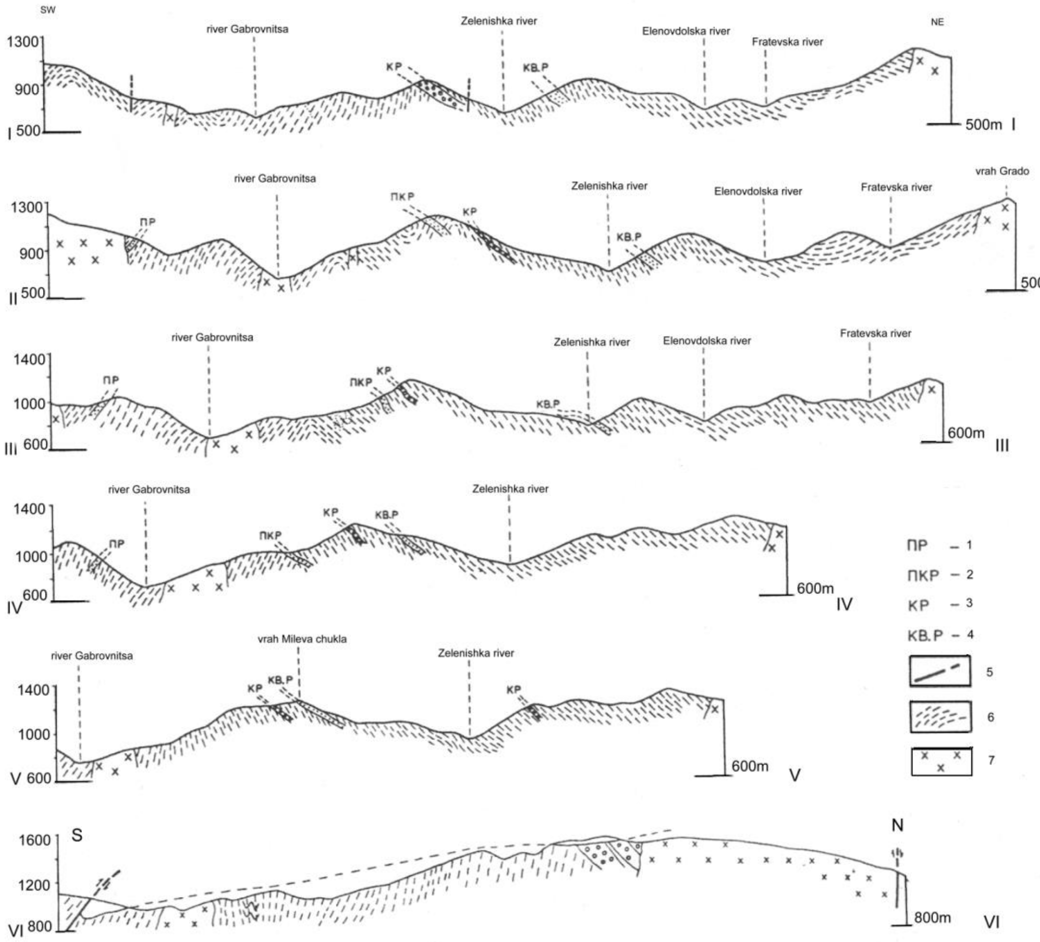

Figure 2 Geological cross-sections
1 – sandstone mark level; 2 - sandstone-quartzite mark level; 3 – conglomerate mark level; 4 - quartzite mark level; 5 – fault; 6 – axial foliation; igneous rocks

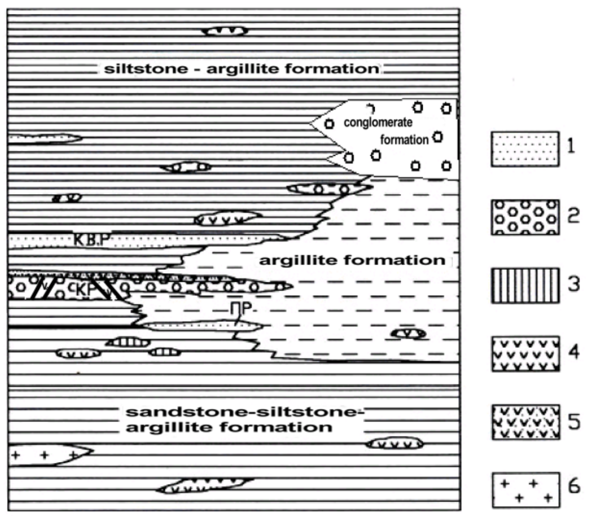

Figure 3 Scheme of the interrelations between the lithostratigraphic units: 1 – sandstones and quartzites; 2 – conglomerates; 3 – calc-silicate rocks and marbles; 4 – diabase and diabase tuffs; 5 – dykes of diabase; 6 – gabbro, gabbrodiabase; ПР – sandstone mark level; КР – conglomerate mark level; КР – quartzite mark level

PETROLOGIC CHARACTERISTIC

The rock spectrum of DPhC in the studied area includes chiefly metasedimentary rocks with protoliths: argillites, mudstones and mudshales, siltstones, sandstones – arcose wackes and lithic greywackes; conglomerates, single thin interbeds of limestones and a small quantity of metagabbro-diabases, metadiabases and their tuffs.

The classification scheme by Potter at al. (1980) was used for fine-grained terrigenous rocks (Table 1). Determination of the psammitic rocks was made according to the classification scheme by Pettijohn et al.(1976) (after Dott, 1964).

Siltstones and argillites are the dominant fine-grained rocks in the studied section. Pure silty and clayey rocks are absent – mudstones and mudshales are the most abundant rock types. About ¼ of the fine-grained clastic rocks are set up of alternation of silty and argillitic laminae (varves) with thickness 0,5-3,0 mm. Argillites show microflaked texture and oriented microstructure. They consist of 70-95% clay minerals altered to chlorite and sericite and 5-30% quartz, feldspars and single flakes of terrigenous muscovite of fine to medium silty size. Siltstones have similar composition with domination of quartz and feldspars. They are fine to medium grained with irregular grained texture. The transitional varieties (mudshales and mudstones) are the most common. Laminated argillites (varves) comprise an alternation of mudshales and mudstones varying in their silt composition. *Sandstones* are presented mainly of arkose wackes and lithic greywackes and insignificant amount of arkose arenites. Wackes and greywackes consist of about 65-75% clastic component and 35-40 % matrix. Arkose waskes are fine-grained with relict irregular graned texture. Clastic grains are semi-rounded to rounded and contacts between them are loose and pointed. The matrix type is pore-filling and basal. The composition of clastic part is mainly of quartz, less feldspar. The primary matrix was probably clayey later altered of chlorite and sericite. Numerous newly formed ore products (sphene – leucoxene) are present too. Lithic greywackes are fine grained with relict irregular graned texture. Clastic grains have irregular distribution and are represented of quartz, less feldspars and rock fragments. The matrix is of clay minerals altered of the chlorite and sericite. Ilmenite and leucoxene grains are common. *Conglomerates* from the lens-like structure consist of clasts with sizes from 4.0 – 8.0 mm up to a few cm. There are also conglomerates with abundance of clasts with sizes 2.0 – 4.0 mm transitional to the gravelites. The clasts shape is semi-rounded to rounded, corroded by the matrix. Their composition is mainly of rock fragments - micro to fine grained quartz, metadiabases, metaultramaphites(?), argillites and siltstones. The matrix was originally clayey-sandy altered of the chlorite-sericite mass with quartz and feldspar grains. The conglomerates from the conglomerate mark level accepted by Dzhelepov (1983) as “basal” are specific without analog in the studied section. Macroscopically they are grey-greenish to gray-pinkish, medium to thick bedded. They are significantly different from the above mention along to their clast composition and the presence of numerous dykes of diabase. The last ones cut conglomerates and they are not observed in the another rocks from the section (Table I, a, b). The clasts show semi-rounded to rounded shape and sizes from 1.5 – 3.0 mm up to 8 – 10 cm. The clasts are composed of arkoses, greywackes, lydites, quartz grains, two types diabases (grained and variolitic-like) in the most abounded and in a small quantity metasilstones, metagravelites, chlorite schist (table I, c, d). The matrix is sandy to gravel consisting quartz, plagioclase, K-feldspar, epidote – terrigenous component and chlorite-sericite cement enriched of iron-titan dusty products. Diabase dykes, which are observed only in the conglomerate mark level have various thickness from 1 – 2 cm to a few dm. They are grey-greenish in color, dense with massive texture. Two generations of dykes could be described, here. The first one (probably earlier) is represented by fine-grained metadiabases with micro-diabase structure – chaotic situated long prismatic plagioclase crystals (up to 0.3 – 0.4 mm along long axis), patchy albitized, with fine grano-lepidoblastic mass of chlorite (mainly), sericite, epidote, sphene, quartz, calcite and ore minerals in their angular spaces (table I, e). This type of dykes are the thickest ones. The second generation of diabase dykes is represented by meta-hyalodiabases with thickness up to 5.0 cm that cut both the conglomerates and the previous dykes. They are composed of very fine plagioclase microlites (traces) among chlorite - epidote - amphibole (?) - albite cryptocrystalline ground mass (table I, f). Porphyritic generation of plagioclase and fully altered mafites is rarely observed.

Carbonate rocks are represented by marbles, built up of about 95% calcite and 5% terrigenous component - quartz, plagioclase and clay minerals. Calcite is irregularly recrystallised to fine- medium grained. Texture is granoblastic. Clay minerals are completely altered to chlorite and sericite.

Diabases and their tuffs have limited distribution in the studied section as conforming to the parametamorphite lenses and boudinage structures. They are intensively metamorphosed and the most part of them are presented as green schists and actinolite schists

Table 1. Classification of shales (Potter et al., 1980)

Persentage of clay-size constituents			**0-32**	**33-65**	**66-100**
INDURATED	BEDS	> 10 mm	BEDDED SILTSTONE	MUDSTONE	CLAYSTONE
	LAMINAE	< 10 mm	LAMINATED SILTSHALE	MUDSHALE	CLAYSHALE
METAMORPHOSED	DEGREE OF METAMORPHISM	LOW	low grade metamorphosed QUARTZ ARGILLITE	low grade metamorphosed ARGILLITE	
			QUARTZ SLATE	SLATE	
		HIGHT	PHILLITE AND/OR MICA SHISTS		

Metamorphism. All rocks from the studied area are metamorphosed in conditions of low-grade regional metamorphism in the limit of green schist facies. Depending on the type of protoliths they form different low-grade metamorphic rocks. The grade of metamorphic change is assessed according to the following criteria: 1) mineralogical – processes of dissolution and regeneration, recrystallisation, degree of the matrix alteration in the clastic rocks; processes of mineral formation; 2) structure changes – conform-regeneration, lens-like, segregation and strip structures of oriented corrosion and recrystallisation under stress and 3) textural changes.

Depending on the intensity of the metamorphic alteration, the following parametamorphites are described: *low grade metamorphic argillites and siltstones, slates, quartz-slates, phyllites, quartz-sericite schists* (protoliths – argillites and siltstones); *metaarkoses and metagreywackes* (protoliths – psammites); *metaconglomerates* (protoliths – psephites); *green schists, actinolite schists, metadiabases, metagabbro-diabases* (protoliths – diabases and their tuffs, gabbro-diabases). The mentioned above variety of the parametamorphites is a result of the intensity of the metamorphic recrystallisation in the terrigenous rocks and the degree of alteration according to the protolith’s composition. Any differences in the grade of metamorphism are not observed in the different levels of the studied section. The anisotropy of the metamorphic alterations in the conditions of the low-grade metamorphism (green schist facies) is a result of two main factors – the protolith's composition and irregular distribution of the synmetamorphic deformations. Argillites and siltstones are the most intensively metamorphosed rocks with end metamorphic members – phyllites (table II, c, e) and quartz-sericite schist, respectively. Lower metamorphosed their analogues are low metamorphosed siltstones and argillites, slates and quartz slates. The rocks enriched in the terrigenous components (siltstones) are more resistant to the low-grade metamorphism and they show better-preserved relicts of sedimentary structures and minerals (table II, a, b). It is very clear in the frame of the thin-sections where alternation between above described laminae is observed (table II, b). The low-grade metamorphic quartz slates and phillites are the most widespread in the investigated area. (fig. 4). The psammitic rocks are affected by low-grade of metamorphic alteration and the clastic grains are well preserved and the matrix is intensively metamorphosed with formation of sericite and chlorite (table II, d). The metamorphic changes in the conglomerates are only in the matrix analogous to the psammites. The intensity of the metamorphic alteration in the different protoliths and their quantity are generalized in fig. 4.

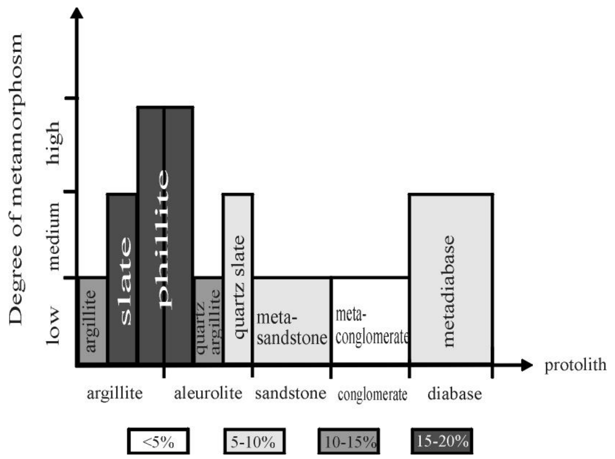

Figure 4. Scheme about intensity of the metamorphic alteration in the different protoliths and their quantity

The most intensively metamorphosed rocks: phyllites, quartz-sericite schist (parametamorphites) and green schists and actinolite schists (metadiabase and their tuffs) are typical members of the low-grade metamorphic rocks in green schist facies which are the main elements of the DPhC. Relict structures and minerals in these tocks are not present. The last ones are characteristic features for all the rest para- and ortometamorphites in the region.

The described rocks have clear polymetamorphic character in locally expressed zones. They are affected by contact metamorphic alterations close to the contacts with Paleozoic granite bodies and dykes and are changed in spotted and knotted schists. In the narrow shear zones they are turn to typical mylonites and blastomylonites. These types of metamorphic alterations are not a subject of the present study.

STRUCTURAL CHARACTERISTIC

Geometrical and age relationships between the different types of planar and linear structural elements indicate that their formation was accomplished during the four deformational stages, designated conditionally as D_1, D_2, D_3, and D_4.

D_1 structures. Early folds F_1 on the primary bedding, axial plane foliation S_1 and few morphological types of lineations are developed during the earliest stage in the conditions of low-grade metamorphism. The spatial position of the mark levels, the orientation and the asymmetry of the mesoscopic folds on the bedding show that the hinge of the Gabrovnitsa anticline has a direction 100-110° and plunges about 15° to ESE. Its northeastern limb has average dip 45-55° and the southwestern - 30-40°. Mesoscopic folds F_1 are isoclinal and tight with centimeter and meter sizes. The shape of the folded bed surfaces is parabolic or hyperbolic and folds are most of the classes 1C and 3. Diagrams about the orientation of bedding, fold hinges and the lineation $L_{ss/ss1}$ (Antonov, 1989, fig. 1c) evidence for the general subequatorial orientation of the fold hinges with the dominating plunge about 25° to ESE. The axial plane-foliation S_1 is a dominating structure in the silty and pellitic rocks where it almost obliterates primary bedding. The different morphological types and mechanism of the axial plane foliation are published by Antonov (1989). According to their morphological features, the secondary lineations formed during the earliest deformational stage are mineral lineation, lineation along to the axes of mullions and rodes, elongated conglomeratic clasts, crenulation and intersection lineation. The last two types are widespread.

D_2 structures. The formation of a new superposed fold generation F2 and synchronic to it crenulation lineation are connected to the second regional deformation. The folds of the second generation are formed on the surfaces of the axial plane foliation S_1. The notion about their morphology and dimensions could be obtained from the cross-sections (fig. 2). They are imposed coaxially upon F_1 folds, determining in mesoscopic scale the presence of the interference pattern of type 3 after Ramsay (1967). The second crenulation lineation is expressed as fine undulation on the folded cleavage surfaces S_1. Its orientation is subparallel to the orientation of the fold hinges.

D3 structures. The third deformational stage is characteristic by the development of the locally expressed ductile-brittle shear zones thick 40-50 m and up to few hundred meters long. Small asymmetrical kink-folds and kink-zones with disjunctive cleavage S_2 parallel to their axial planes are superimposed on the structures of the previous stages. The dominating zone orientation is in SE direction and rarely in EW or NE direction.

D_4 structures. The numerous local faults with insignificant amplitudes as well as a few larger faults (fig. 1) that cut crosswise or oblique the three fold generations are connected with the fourth stage.

CONCLUSIONS

The results of the present study could be resumed as follows:

1) the diabase-phylitoid complex from the valley of the Gabrovnitsa river is built up of terrigenous sedimentary rocks - manly siltstone and agrillite and in less quantity sandstone and conglomerates ;

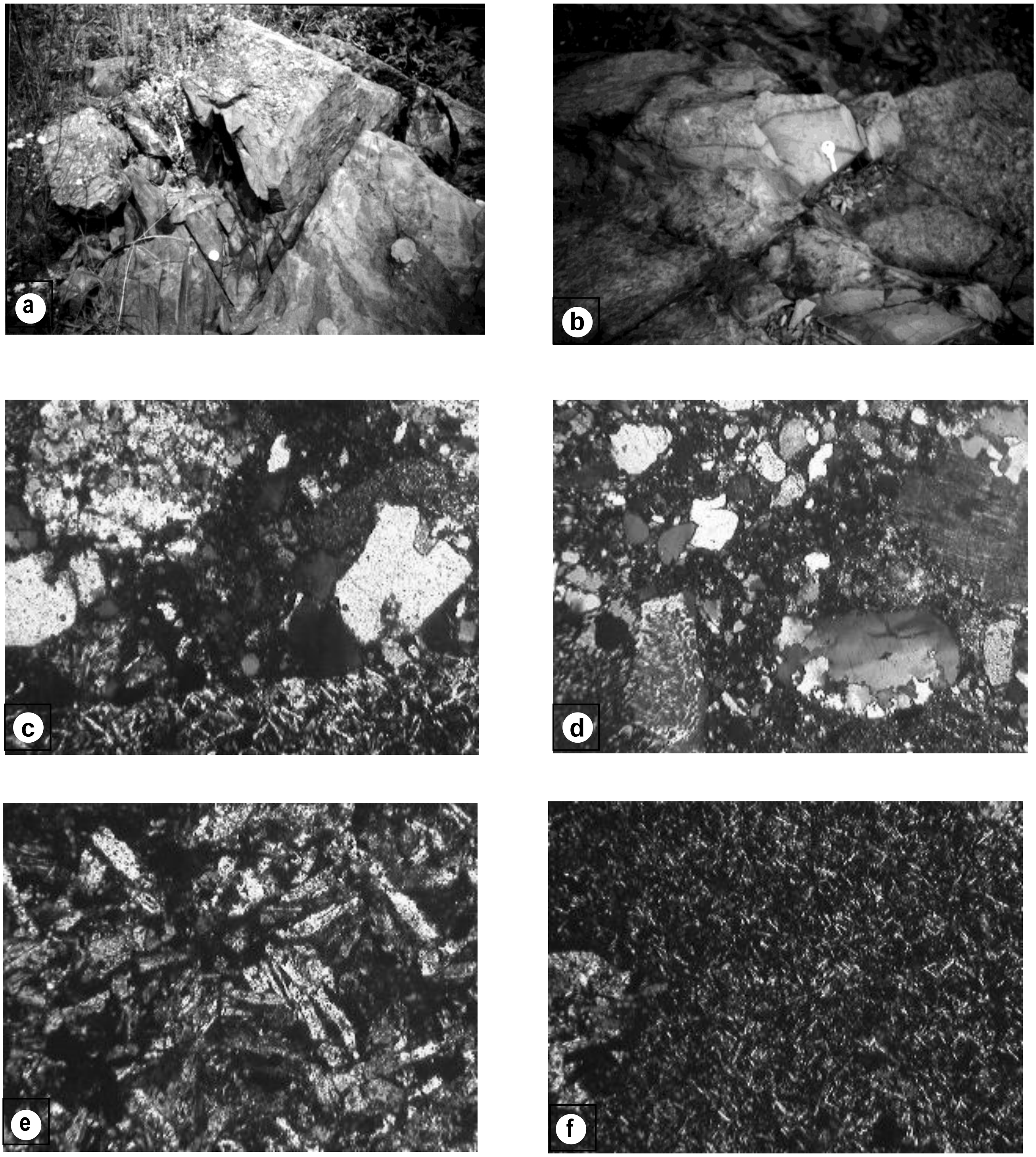

TABLE I

***a**– field's photos of the rocks from the conglomerate mark level;*
***b** – field's photos of the diabase dykes cross cut the conglomerate mark level;*
***c** – micro-photo of the conglomerates from the mark level. X 50; N +;*
***d** – micro-photo of the conglomerates from the mark level. X 50; N +;*
***e** – daibase texture in the fine grained diabase dyke. X e 100; N +;*
***f** – graund mass and plagioclase microlites in the hyalodiabase dayke. X 50; N +.*

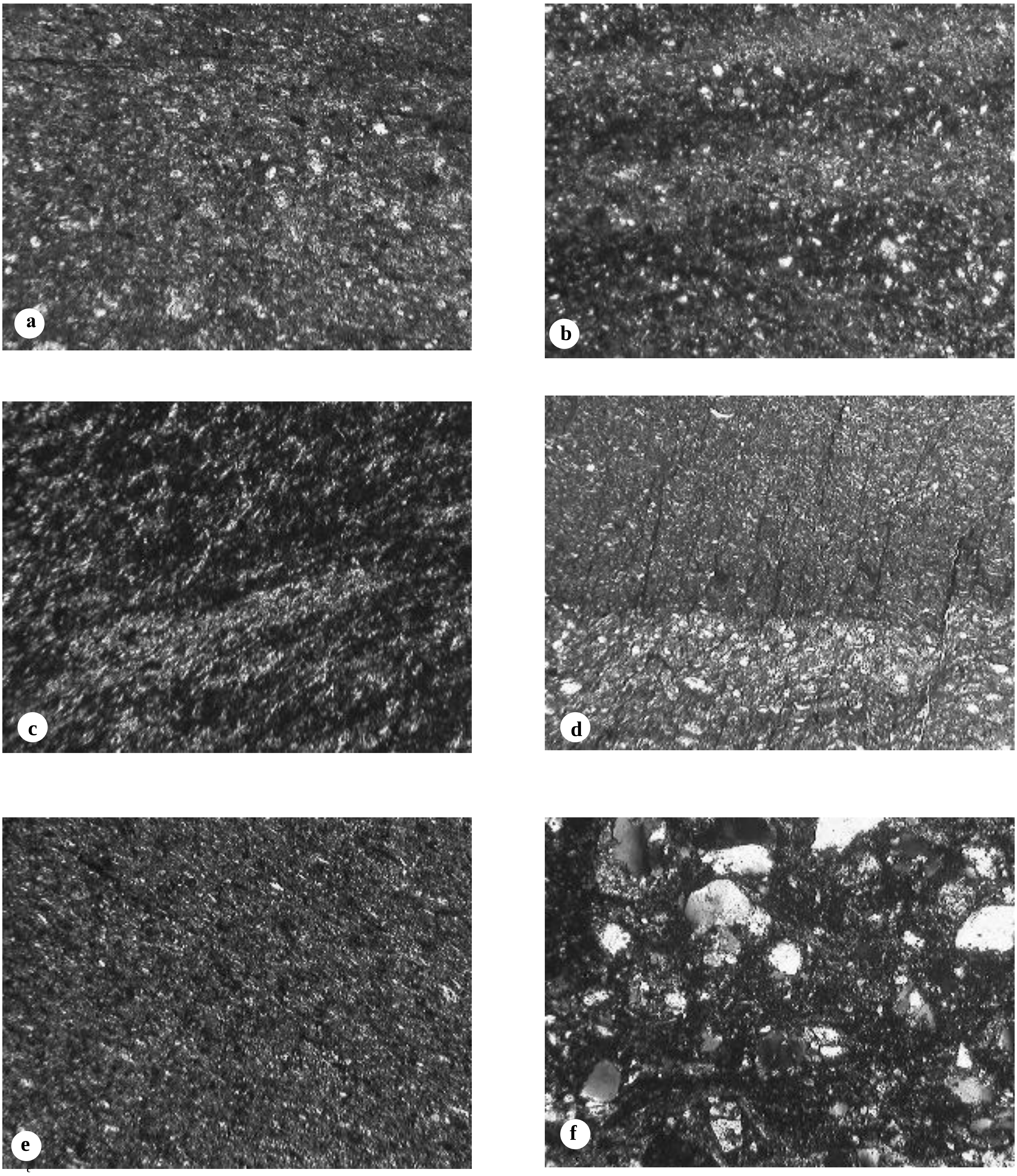

TABLE II

***a** – low metamorphosed argillite. X 100; N +;*
***b** – alternation of laminae of low metamorphosed quartz argillite and arhillites. X 100; N +;*
***c** – phyllite with two crystallisation cleavages. X 100; N +;*
***d** – crenulation cleavage in the argillite laminae. X 100; N +;*
***e** – phyllite. X 100; N +;*
***f** – arkose wacke. X 50; N +.*

2) on the basis of specific features of the protoliths a new scheme for lithostratigraphic subdivision of the complex is proposed. The vertical and lateral interrelations between the separated mark levels and formations as well as structural data give reason for the continuity of the section. This result requires a new point of view on the proposed correlations to the Berkovitsa and Dalgidel Groups.

3) the fragments of the basic igneous rocks among sediments from the all formations obviously are with allochtone genesis and the biggest ones are probably olistotrimes. The conglomerate mark level is probably allochtonous (olistoplake) as well;

4) the structure evolution includes four deformation stages and three fold generations are formed during them;

5) the variety of the low grade parametamorphic rocks from the studied region is a result of two factors – different resistance of the protoliths in the conditions of the low-grade metamorphism (green schist facies) and different intensity of synmetamorphic deformations.

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DEPOSITS AND OCCURRENCES OF MOLYBDENUM IN SURDULICA ERUPTIVE MASSIVE AREA IN SOUTHEAST SERBIA

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ABSTRACT

In the area of Surdulica eruptive massive and its margin several deposits and occurrences of molybdenum are known. Mačkatica molybdenum deposit, within this complex, according to the number of its ore bodies, belongs to significant deposits, not only in Serbia and Europe, but in the world also. In the geotectonic sense this area belongs to Serbian-Macedonian mass, and in metallogenetic view it is a part of Besna Kobila-Osogove zone.

Metallogeny of this zone is connected with the processes on Neo-Alpine tectonomagmatic activity, actually Tertiary (Oligocene-Miocene) magmatism of granodioritic composition, featured by the presence of Mo, Cu, W, Zn, Pb mineralizations, with significant ore reserves, especially molybdenum, lead and zinc.

Mo-mineralizations are spatially found in dacites and schists or in their contact, and rarely in granodiorites. Concentrations of molybdenum as a rule increase in hydrothermaly altered rocks, meaning that the altered rocks are geochemicaly most favorable environment for the deposition of molybdenum. From the aspect of genetic features and morphostructural types of mineralizations, the occurrences and deposits in Surdulica eruptive massive area belong to: hydrothermal stockwork-impregnation, vein and porphyry type of mineralizations.

INTRODUCTION

The rim of Surdulica eruptive massive represents an interesting area in view of molybdenum deposits. It covers a surface of approximately 220 km^2 in southeast Serbia, stretched about 25 km along its longer axis that strikes almost north-south. In places its width is up to 12 km. The massive continuously extends from Vrla river in the north to Novi Glog in the south (Fig. 1). Geotectonically the massive belongs to Serbian-Macedonian mass, while metallogenetically it belongs to BesnaKobila-Osogovo zone. This ore zone begins near Ruplje village and Bistrica and Vlasina river in the north, and extends over Mačkatica, Besna Kobila and Osogovo to Thasos in Greece where it disappears in Aegean sea. (Janković, 1967, 1990; Jelenković, *et al*., 1997; Serafimovski, 1993; Simić, 2001). It is featured by numerous metal deposits, especially lead, zinc and molybdenum.

Surdulica massive was intruded during Neoalpine cycle, unconformably into crystalline schists of Vlasina complex. It is mostly composed of medium to coarse grained granodiorites and monconite granites that make up the basis of the massive. In places they are intruded by granodioriteporpyrites and quartzdioriteporphyrites, the vein varieties of granodioritic magma. Weakly eroded granites of Crnook in the vicinity of Na area is also composed of crystalline schists of Vlasina complex, granitic rocks of Božica and Doganica, as well as Tertiary volcanics, mainly of dacitic composition. In the east part remnants of Devonian, Permian and Triassic sediments, and in the valley of Pčinja and Morava, deposits of Senonian (Fig. 1). of the area, towards Bulgarian border, there are erosional remnants of Devonian, Permian and Triassic sediments, and in the valley of Pčinja and Morava, deposits of Senonian (Fig. 1).

Erosional remnants of Devonian, Permian and Triassic zarica and Dukat villages are similar in age and partly petrologically to granodiorites of Surdulica (Babović, *et al*., 1977; Petrović, *et al*., 1973).

Besides the Surdulica granodiorites and Crnook granites, the Granodiorites of Surdulica, as well as crystalline schists of Vlasina complex are intruded by numerous veins and smaller masses of dacites and quartzlatites, rarely by andezite and latite, that hardened in subvolcanic to hypoabyssal levels. Dacites mostly occur in the northern part, while quartzlatite is situated in the middle and southern part of this ore zone.

The deposits and occurrences of molybdenum in this ore zone are genetically connected to dacitic-andezitic rocks. The Mo-mineralization is deposited in hydrothermally altered (silicified, sericitised, K-feldspar) dacites and schysts and their contact, rarely in granodiorites. The general occurrence of mineralization in rocks, that compose this area, is conditioned by pre ore tectonics, mainly by length and width of faults and fault zones. In places where they are dense and intersected, stockwork bodies are formed with dissemination between the veins. In places where fractures are scarce or wide apart from each other ore veins are developed, smaller or larger in size (Milovanović, Ilić, 1953/54; Simić, 1993).

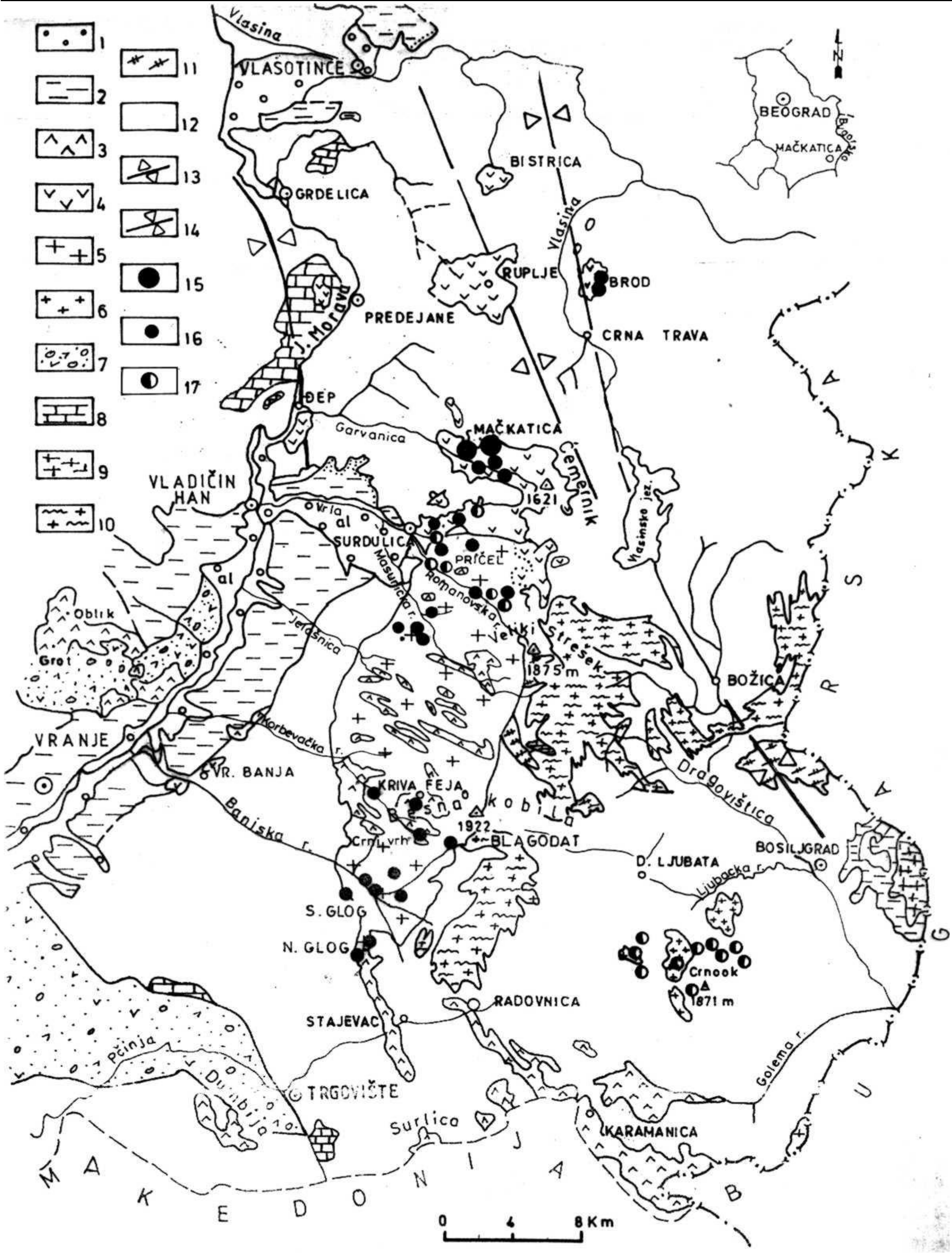

Figure 1. Geological sketch map of the Surdulica granodioritic massif with Mo – occurrences
1. Alluvium, 2. Miocene-Pliocene sediments, 3. Quartzlatites and latites, 4. Dacites and andezites, 5. Surdulica granodiorites, 6. Crnook granites, 7. Eocene sediments, 8. Cretaceous sediments, 9.Triassic sediments, 10. Doganica and Božica granitoides, 11. Gabbros, 12.Metamorphites of Vlasina complex, 13. Anticlinorium, 14. Synclinorium, 15. Mo-deposits, 16. Mo-occurrences, 17. W-occurrences

From the aspect of genetic features and morphostructural types of mineralizations, the deposits and occurrences of molybdenum in the Surdulica eruptive masive can be divided into three groups: hydrothermal stockwork-disseminated type of mineralization that is characterized by extensive mineralization and low grade of molybdenum ore (usually under 0.1 % of Mo). Mačkatica and Borovik deposits belong to this type of mineralization. The second type of mineralization are hydrothermal quartz-molybdenite veins of small size and thickness under 0.5 m (Stari Glog, partly Masurička and Romanovska rivers). The third is porphyry type of mineralization discovered in Novi Glog and Kriva Feja in exocontact part of granodiorites and quartzmonconiteporphyrite, with low Mo and Cu content and small reserves.

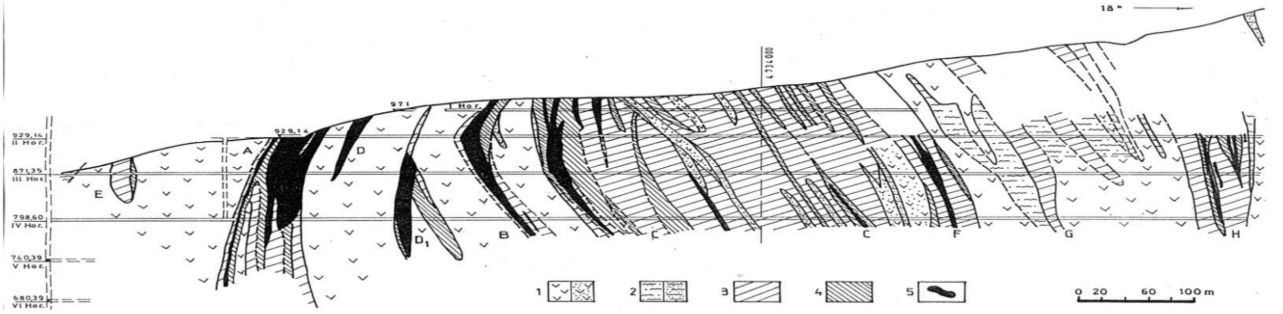

Figure 2. Cross section – Mačkatica
1. Fresh, locally slightly mineralized dacite (<0.04%Mo), 2. Fresh, locally poorly mineralized micaschists (<0.04%Mo), 3. Ore with Mo contents less than 0.08%, 4. Ore with Mo contents less than 0.14%, 5. Ore with Mo contents more than 0.14%.

MOLYBDENUM OCCURRENCES AND DEPOSITS

In Surdulica eruptive area and its rim, in Besna Kobila metallogenetic zone, there are several economically interesting deposits and occurrences. The Mo-mineralizations occur beginning from Brod, north of Crna Trava, and extend towards the south over Mačkatica, Surdulica, Kriva Feja up to Stari Glog and NoviGlog (Fig. 1).

The occurrences of molybdenum in **Brod area** are found in Belčinski potok, in the zone of intensively silicified and kaolinised dacites in form of rare quartz veins up to 5-10 cm thick. The quartz veins are composed of coarse quartz crystals, pyrite, flaky molybdenite and chalcopyrite. The molybdenum content in quartz veins, widely ranges from 0.02-0.8 %, while copper content in the same veins ranges from 0.01-0.1 % (Simić, 1994, 2001).

Mačkatica molybdenum ore field is situated about 7 km southeast of Surdulica in Čemernik mountain complex. The deposit of the same name is found within this ore field in the region of Popova dolina as well as Borovik deposit on Borovik. Besides Mačkatica and Borovik deposits, molybdenum mineralizations are known in other localities of this ore field: Kučišnjak, Pavlova dolina, Meča dolina, Groznatova dolina, Troskački potok, Đokanov potok, Malikina dolina, Garvanica and other (Simić, 1993, 1994, 1994a, 1995, 1996, 2001; Milovanović, Ilić 1953/54).

This ore field is composed of crystalline schists of Vlasina complex in Serbian-Macedonian mass and Tertiary magmatic rocks, among which dacites are predominant. Muscovite and albite-muscovite schists of Riphean-Cambrian age are most frequent metamorphic rocks (Petrović, *et al*., 1973).

The molybdenum mineralization is deposited in lithologicaly various environments, and mineral assemblages. It belongs to stockwork-disseminated type and is closely connected with silicification, K-feldspar and sericitization. Hydrothermally altered zones, actually the mineralized zones, are featured by low content of N_2O and an increased content of K_2O with a high ratio of K_2O/N_2O.

The Mo-mineralization in Mačkatica ore field occurrs in all ore bodies and mineral zones in more or less the same way. Dense network of veins and veinlets of quartz with pyrite and molybdenum are deposited in tectonically determined zones of east-west strike. The more the pre-ore tectonics fractured the area the more it was favorable for ore deposition. The boundaries of ore bodies towards the surrounding rocks is not sharp but transitional, drawn on the basis of geochemical analyses.

The molybdenite ore bodies are usually elongated, lenticular shape with a strike E-W to WNW-ESE, rarely irregular and isometric, with mild tendency of dipping towards the N and NNE. The length of some ore bodies amounts to 100-350 m, with a thickness up to 250 m (Fig. 2).

The mineral composition of Mo-ore in Mačkatica ore field is simple. Quartz, pyrite and molybdenite are basic mineral components which occur either as joined or complex, or they form monomineral veins. Pure molybdenite veins are rare, while quartz ones are the most frequent. The mentioned minerals are accompanied by insignificant quantities of chalcopyrite, haematite, scheelite, sphalerite, galena and rarely wolframite. Scheelite is fairly extensive in Mo-mineralizations in Mačkatica ore field but with a low content.

The content of Mo in Mačkatica ore field varies from on to another deposit and occurrence. In Mačkatica deposit the Mo content is 0.091% in 25,000,000 t of ore, while in Borovik deposit its content is 0.05% in 70,000,000 t of ore. In other localities the MO content varies from 0.03-0.1%, rarely over 0.4%. In the ore concentrate of Mačkatica deposit there is also about 150 g/t of rhenium. In Mo-ore in Mačkatica and Borovik copper is either absent or is present in small quantities (40-70 ppm). The content of tungsten is also low, up to 0.026% WO_3 (Vujanović, 1959; Simić 1993, 2001a).

In the area of **Surdulica-Masurička reka** several molybdenum and tungsten occurrences have been registered in the vicinity of Ćurkovica-Studenički potok, Masurička reka and Romanovska reka. The Mo-mineralization mostly occurrs in hydrothermaly altered granodiorites in the vicinity of small dacite intrusions. The Mo as well as W-mineralizations are related to tectonic zones, sometimes fairly large (100-200 m), with ENE-WSW strike. They are usually vein type quartz-molybdenite and vein-disseminated type of mineralizations of small dimensions and mineral content of Mo and W (Simić, 1994a, 1996a, 2001a).

In the Ćurkovica-Studenički potok area, in one tectonic zone 100-200 m wide and almost E-W strike, extensive vein-disseminated type of mineralization was found, where 10 intervals were identified, 0.5-1.7 m wide with Mo content of 0.02-0.13%. The tungsten occurrences in Studenički potok that are found in form of individual scheelite veins or zones up to 7 m wide have WO_3 content of 0.05-0.15%.

W is much more frequent than Mo in the valley of Romanovska reka. Larger mineralizations of W and Mo are found in the area of Donji Romanovci, Lokvanjski potok, Pričel and mid part of Romanovska reka. The mineralizations occur along fault zones with a strike WNW-ESE to NW-SE in hydrothermaly altered, limonitized, silicified and pyritic zones in granodiorites with a thickness of up to 10 m. The Mo-content is up to 0.1%, while W-content is up to 0.07% of WO_3.

In Opalenički rid and Koštinjak, in the vicinity of Masurička reka, the Mo-mineralizations have similar occurrences as in previous localities. Molybdenite is found in form of veinlets and disseminations near small dacite intrusions in granodiorite that is silicified, partly pyritized. The Mo-content ranges from 0.03-0.1%, with Cu-content that ranges from 0.02-0.1% (Simić, 1994a).

The **Mo-Cu mineralizations on Kriva Feja**, found in the vicinity of Crnovrška reka and Gornja reka, belong to porphyry type related to hydrothermaly altered porphyroid varieties of granitic magma (granodioriteporphyrite, quartzmonconiteporphyrite and other). The Mo-Cu mineralizations of vein-disseminated type on Kriva Feja are composed of pyrite, magnetite, chalcopyrite, molybdenite, quartz and rarely calcite.

The mean content of Cu ranges from 0.04-0.08%, with Mo content of 20-80 ppm. The contents of Au and Ag, elements characteristic for this type of mineralization, range from 0.02-1.31 g/t of Au and 0.6-6 g/t of Ag (Simić, 1992).

In **Crni vrh, near Stari Glog and Prvonek**, there are several occurrences of molybdenum. Molybdenite occurs in quartz veins whose thickness varies from 5 to 10 cm, maximally 40 cm. The edges of quartz veins are coated with thin films of molybdenite. These veins are rare and therefore although with high Mo-content, they are of little economic interest. Mo-mineralization is genetically connected with the dacites that intrude crystalline schists, and partly granodiorites. Small adits were excavated within these ore occurrences before World War II. The data from these investigations reveal that the content of Mo ranges from 1-4%, rarely from 0.65%. Besides Mo in some localities (Tanka Rtina) high content of 3 g/t of Au was found with 11.9 g/t of Ag (Simić, 2001).

Little more south of Stari Glog in the area of **Novi Glog**, in the left tributary of Mala reka, and uppermost part of Petrogorski potok there are several occurrences of Mo and Cu. The Mo-Cu occur in exocontact part of granodiorites, in dacites and schysts that are intensely hydrothermaly altered, fractured and brecciated. The Mo-Cu mineralization is accompanyed by silification, pyritization, K-feldspar and rarely biotitization and sericitization. Molybdenite and chalcopyrite, together with quartz and pyrite, are mostly found in form of veins and films along fractures and fissures of diverse strike and dip, and rarely as individual grains and aggregates.

The best results of Mo and Cu were obtained from Mala reka where low grade, vein, dissemination, and porphyry mineralization was found with contents of Mo that ranges from 0.025-0.07% and Cu content that ranges from 0.047-0.15%. The similar are Mo-Cu mineralizations in the uppermost part of Petrogorski potok (Simić, 1991).

In **Crnook** area several scheelite occurrences are found, while Mo is absent. The most interesting are scarn type of scheelite mineralizations in Bresnica and Blenski del, in the gneiss serie intruded by pegmatitic veins. These are ore bodies of small dimensions, but with high content of WO_3. In Bresnica the average content of W is 3% (ranging from 2-19%), while in Blenski del the average content is 4.7% (Marić, *et al*., 1959: Simić, 2001, 2001a). The occurrences of W of hydrothermal type that are also found in Crook ore field are of lesser importance (Dukatska reka, Crnoštica). In whole this ore field is poorly investigated, so that it is hard to asses its potential in relation to mineral raw materials.

CONCLUSION

In Surdulica eruptive massive and its rim there are numerous occurrences and deposits of molybdenum. In the first place these are hydrothermal deposits represented by vein, stockwork-disseminated and porphyry, as well as vein-disseminated types of mineralizations. Geotectonically they belong to eastern part of Serbian-Macedonian mass and metallogenetically they are a part of Besna Kobila-Osogovo zone.

The metallogeny of this zone is related to the processes of neo-Alpine tectonomagmatic activity, actually Tertiary (Oligocene-Miocene) magmatism of granodiorite composition, featured by Mo, Cu, W, Zn, Pb, Sb mineralizations with significant ore reserves, especially molybdenum, lead and zinc.

According to the number of occurrences and deposits in Surdulica eruptive massive outstanding is Mačkatica ore field. This ore field belongs to the largest ones according to the number of ore bodies and their dimensions. Regarding the numerous occurrences found, in Mačkatica ore field as well as in other parts of this ore zone, it is certain that the reserves of molybdenum are much larger than the calculated ones.

Taking into account the rising demand for molybdenum as a metal that has wide application in modern industry, it is only a question of time when will this mineral raw material be utilized from this area in future.

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FIVE PROTECTED OUTCROPS OF THE CRETACEOUS/TERTIARY BOUNDARY IN BULGARIA

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ABSTRACT
According to the famous 'impact theory', 65 million years ago a great meteorite caused explosion exceeding 10 000 times the present day nuclear weapon potential. This impact is considered to be one of the major disasters in the Phanerozoic history of the Earth. As a result, great quantity of ash material rose up into the atmosphere and covered the Earth for months. The subsequent fallout produced thin, globally traceable layer, enriched in iridium and other rare elements, oxides, minerals, shocked quartz and microtectites. This catastrophic event is probably responsible for disappearance of many typical Mesozoic animals and plants - dinosaurs, marine reptiles, ammonites, belemnites, over 90% of calcareous nannoplankton and planktonic foraminifera, 60% of angiosperm species, etc. In the present study geoconservation characteristics of five nominated for protection outcrops of this geological phenomenon in Bulgaria are proposed: geosite "Belite skali" in limestone-marl periodites near Byala Town, Varna District; geosite "Kozya reka" in cyclic limestone near Asparoukhovo village, Varna District; geosite "Kozichino" in turbidite sequence near Kozichino village, Bourgas District; geosite "Kamenitsa" in limestone sequence near Mezdra town and geosite "Kladorub" in marl-silty sequence near Kladorub village, Vidin district.

INTRODUCTION

During the recent 20 years the Cretaceous/Tertiary boundary has been examined in the light of the 'impact theory' (Alvarez et al., 1980), proclaiming a giant impact of Earth with a great meteorite (the Chicxulub Crater) 65 million years ago. It caused explosion exceeding 10 000 times all the present day nuclear weapon potential. As a consequence great quantity of ash material rose up into the atmosphere and covered the Earth for months.

The fallout after the impact produced thin layer, enriched in Ir and other rare elements, shocked quartz, microtektites, and rare minerals. This event is considered to be one of the major disasters in the Phanerozoic history of the Earth that caused catastrophic changes in the organic world. This level marks the final extinction of many typical Mesozoic animal groups like dinosaurs, marine reptiles, ammonites, belemnites, rudistid and inoceramid bivalves, actaeonellid gastropods. Deep taxonomic reduction underwent many other groups of molluscs, planktonic foraminifers, echinoids, corals, and primitive mammals. The change of atmospheric and water parameters caused disappearing of nearly 100% unicellular calcareous nannoplankton and 60% of angiosperm species.

This geological phenomenon of global scientific value has been established in several places on the territory of Bulgaria. Due to its unique character, some of them are proposed for protected geosites. Geoconservation assessment and protection measures are proposed in this study for five of the outcrops, described in different facial types and environments: geosite "Belite skali" in limestone-marl periodites near Byala town, Varna District; geosite "Kozya reka" in cyclic limestone near Asparoukhovo village, Varna District; geosite "Kozichino" in turbidite sequence near Kozichino village, Bourgas District; geosite "Kamenitsa" in limestone sequence near Mezdra town and geosite "Kladorub" in marl-silty sequence near Kladorub village, Vidin district.

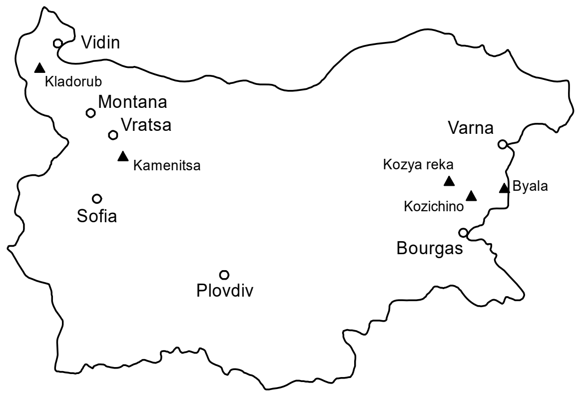

Figure 1. Regional disposition of the geosites representing the K/T boundary in Bulgaria

PREVIOUS WORKS

Data about Maastrichtian-Danian deposits in Bulgaria was first reported during the first half of 20th century, but the boundary itself was not examined since the Danian Stage was considered part of the Cretaceous System. Later was proved that most of these sections contain significant hiatus including the uppermost Maastrichtian and lowermost Paleocene.

Purposeful investigation of the potential transitional sequences through the K/T boundary started during the latest 80s of the last century. Continuous sedimentary sequences through the K/T boundary in Bulgaria have been established in several facial types: limestone-marl periodites near Byala town, Varna District (Stoykova, Ivanov, 1992) and Lyutidol village, Vratsa District (Стойкова и др., 2000; Sinnyovsky, 2001b); turbidite deposits near Emona village, Burgas District (Sinnyovsky, Stoykova, 1995), Kozichino village and Aytos Pass (Sinnyovsky, Vangelov, 1997) and along Marash river S of Kotel town (Stoykova et al., 2000); cyclic limestone sequences near Moravitsa (Синьовски, 1998) and Mezdra town (Стойкова и др., 2000), Kozya river, Razkrachenitsa river and Wonderful Rocks (Вангелов, Синьовски, 2000; Sinnyovsky, 2001a); marl-siltstone sequence near Kladorub village, Vidin District (Sinnyovsky et al., 2002).

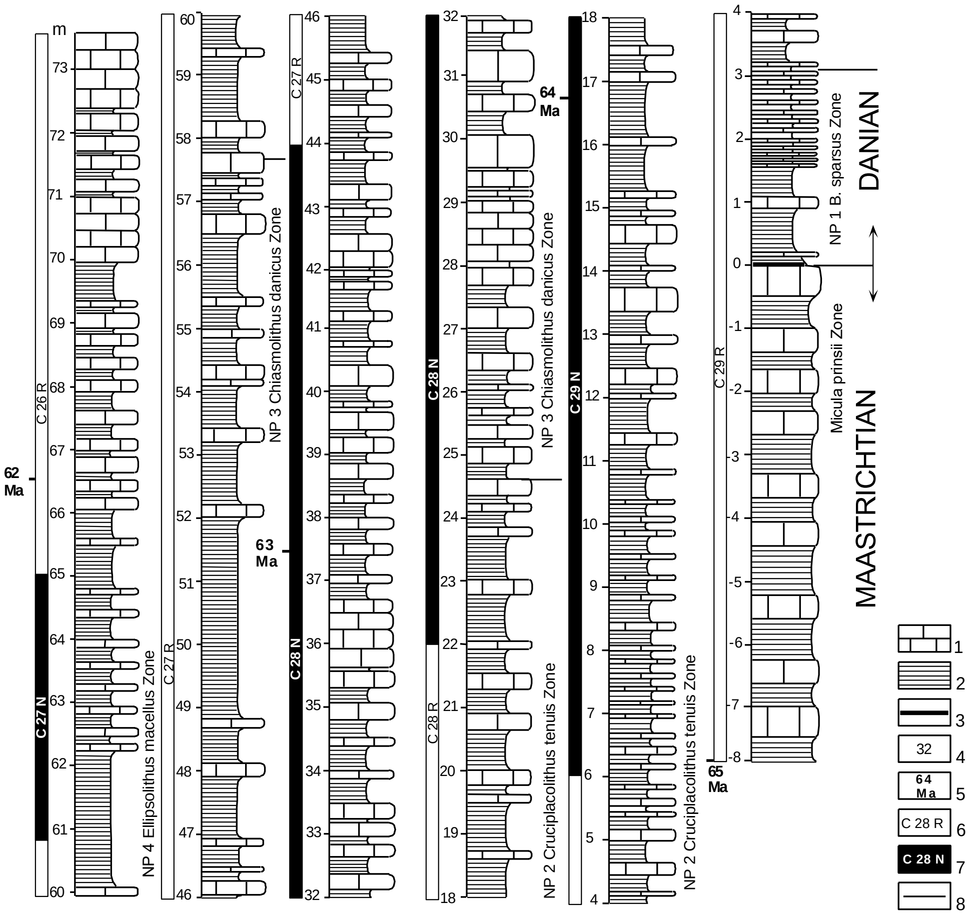

Figure 2. Section of limestone-"marl" periodites near Byala town, with actual thickness of the beds in scale 1:100 (after Preisinger et al., 1993ab and Sinnyovsky, 2001): In different parts of the section are represented cycles of different order: cycles between 32,20 and 48,20 m (mean thickness 0,8 m) are of average duration 28 ka and may be compared with the precessional 21 ka Milankovitch cycles (see Fig. 4); cycles between 3,7 and 10 m (mean thickness 0,315 m) correspond to 11 ka sub-Milankovitch cycles; cycles below K/T boundary from -8 to 0 m (mean thickness less than 1 m) are of duration 33,33 ka and probably correspond to the 41 ka Milankovitch cycles; 1 - robust limestone, 2 - clayey limestones ("marls" in field determination) and marls, 3 - K/T boundary iridium layer, 4 - meters from the K/T boundary (+ above; - below), 5 - correlation to the absolute time scale in million years, 6 - reversal magnetopolarity chron, 7 - normal magnetopolarity chron, 8 - zonal boundary based on calcareous nannoplankton

Figure 3. Iridium layer marking the K/T boundary near Byala town

Figure 4. Limestone-marl couplets (between 32,20 and 48,20 m) with periodicity ~0,8 m, corresponding probably to 21 ka Milankovitch cycles (scale line 30 cm)

Nevertheless, the boundary is proved geochemically only in the outcrops near Byala (Preisinger et al., 1993a,b), Moravitsa (Синьовски, 1998) and Kozya river (Вангелов, Синьовски, 2000; Sinnyovsky, 2001a).

Due to its unique character as geological phenomenon of global value, five of the K/T boundary outcrops are proposed for protected areas in the frame of the Project for Register and Cadastre of the geological phenomena in Bulgaria of the Ministry of Environment and Water. The present study is devoted to the geoconservation characteristics of these five outcrops (Fig. 1), nominated for geosites of scientific value.

PROTECTED GEOSITES

Geosite "Belite skali"

This geosite is situated on the Black Sea coast and is now in procedure for protection. It is developed into the limestone-marl sequence of the Byala Formation (Джуранов, Пимпирев, 1989). The boundary layer near Byala town (Fig. 3) was found for the first time north of the entrance to the beach (Stoykova, Ivanov, 1992) in the frame of Bulgarian-Austrian project, led by Prof. Anton Preisinger. His team proved geochemically the iridium anomaly of 6 ppb at the boundary between the uppermost Cretaceous nannofossil zone Micula prinsii (the uppermost part of the former Micula murus Zone) and the lowermost Paleogene NP 1 Biantholithus sparsus Zone (= Markalius inversus Zone) (Preisinger et al., 1993a,b). They established magnetostratigraphical subdivision of the boundary interval.

Later Preisinger (1996) recognized periodicity of about 100 cm in the Cretaceous part and 50 cm in the Paleocene part of the section. He presumed climatic change at the K/T boundary and correlated the cycles above with 20 ka Milankovitch cycles. However, the thickness of the couplets in different levels of the section shows most likely cycles of different order (Sinnyovsky, 2001a). The interval 32,20-48,20 m (Fig. 2) contains 20 well-expressed couplets of mean thickness 0,8 m with supposed duration 28 ka, corresponding approximately to the precessional 19-23 ka Milankovitch cycles (Fig. 4). The interval 3,7-10 m contains 20 cycles with mean thickness 0,315 m corresponding exactly to 11 ka sub-Milankovitch cycles.

Geosite Belite skali is a wonderful place on the Black Sea Coast. Its geoconservation characteristics, including stratigraphical cycles and events of global scientific value, combined with its tourist significance and easy access, make this place geosite of global significance.

Protection measures according to the protection ordinance may be resumed briefly as follows:

- conservation activities - scientific research; establishment of visitor centre, paths for access to the geosite and placement of information signboards; strengthening the cliff and the beech;
- forbidden activities - any kind of building; geological prospecting and quarry excavation; alpine and deltaplane sports.

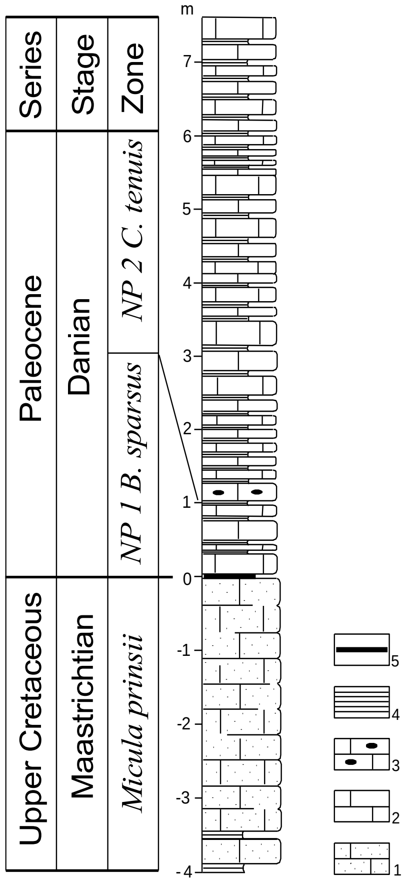

Figure 5. Section of the boundary interval between the Cretaceous and Paleogene along Kozya River: 1 – sandy limestone; 2 – limestone; 3 – limestone with chert; 4 – clayey-silty interbeds; 5 – Ir layer at the K/T boundary

Figure 6. The outcrop of the K/T boundary along Kozya River: the Ir layer between the boundary nannofossil zones Micula prinsii (uppermost Maastrichtian) and NP 1 Biantholithus sparsus (lowermost Paleocene) with 5 ppb Ir content

Geosite "Kozya River"

The geosite is situated along Kozya River, S of Tsonevo dam and 4 km SE of Asparoukhovo village, Varna District. The iridium layer is localized on the basis of the great change in taxonomical composition of the calcareous nannoplankton.

It is situated between two lithostratigraphical units – the Asparoukhovo Formation (Upper Maastrichtian) and the cyclic limestone sequence, which is related to the "Mezdra Formation" (Lower Paleocene).

The boundary layer is 5 cm dark-gray calcareous argillite with 5 ppb Ir content, composed of 35% $CaCO_3$ and 65% insoluble residue (Sinnyovsky, 2001a). It is very well expressed on the background of the more robust limestone below and above (Fig. 6). The stratigraphical interval below the K/T boundary is massive clayey-silty limestone with 63-80% $CaCO_3$ (Figs. 5,6). The nannofossil content is rather poor but along with common Upper Cretaceous forms are encountered typical for the Upper Maastrichtian nannofossils *Lithraphidites quadratus* Bramlette & Martini, *Micula murus* (Martini) and *Micula prinsii* Perch-Nielsen. The latter is the zonal marker of the uppermost Maastrichtian nannofossil zone Micula prinsii.

The nannofossil assemblage above the boundary is extremely poor, but it differs significantly from the Maastrichtian one. In the lowest 0.98 m only survivors are encountered belonging to the genera *Thoracosphaera* and *Braarudosphaera*, as well as small Paleocene forms of *Princiaceae* and *Coccolithus cavus* Hay & Mohler. *Cyclagelosphaera alta* Perch-Nielsen, *Cruciplacolithus primus* Perch-Nielsen and *Cruciplacolithus intermedius* van Heck & Prins are found in a relatively rich sample at +0,98 m. The latter is one of the zonal markers for the next Paleocene nannofossil zone NP 2 Cruciplacolithus tenuis.

The Danian interval is represented by typical bed-scale periodites. Totally 32 couplets with mean thickness 23,60 cm are investigated. The mean thickness of the limestone beds is 19,22 cm with 86-97% $CaCO_3$. The mean thickness of the siliciclastic interbeds is 4,38 cm with 46-81% $CaCO_3$ (Sinnyovsky, 2001a).

The outcrop itself is a place of exceptional beauty. It is named "Skoka" and is located just next to Tsonevo dam, near a forestry house with a high debit karst water source. The access is by narrow, asphalt forest road, 17 km east of the geosite 'Chudnite skali' ('Wonderful rocks'). It is necessary to put signboard near the resthouse 'Chudnite skali' at the branch from the main road Shumen – Aytos.

The iridium layer is located in an outcrop on the left riverside, just after the bridge on the forest road. It needs marking and signboards with information about the geological event that caused formation of this layer and its scientific importance.

Proposed forbidden activities in the area are: quarrying and other activities that change the natural landscape and water regime; building around the geosite except strengthening the bridge; disturbing the rock outcrops.

The place is near the geosite 'Chudnite skali' and it could be included in the routs of organized groups from the Varna resorts. This makes the place a geosite of continental significance.

Geosite "Kozichino"

The section near Kozichino village is the only place in the country where the boundary layer is established in turbidite sequence (top of the Emine Formation). It is situated in the Eastern Balkan and is first described in this paper. This is about 4 cm thick layer (Fig. 7) overlying a hard ground resembling surface, similar to the outcrop near Byala (Fig. 3).

The boundary is localized biostratigraphically on the basis of nannofossils. So far the presence of iridium anomaly has not been proved geochemically.

Micula prinsii and NP 1 Biantholithus sparsus boundary zones are present with their characteristic elements. The change at the boundary is very clear, which is not typical for the turbidite sequences. It is probably due to the short hiatus marked by the presence of *Cyclagelosphaera alta* Perch-Nielsen in the lowermost Paleocene sample. This is one of the first Paleocene species, appearing slightly above the K/T boundary.

Figure 7. The boundary layer in the turbidites of the Emine Formation near Kozichino village (scale line 30 cm)

The outcrop is of rather large dimensions and the layer could be traced in several meters. The turbidites are fine-grained, with rare sandstone beds. Granulometric analysis show that the boundary layer could be classified as silty marl: 47,35% $CaCO_3$, 32,55% clay, 20,05% silt and only 0,055 % psammite.

The close proximity of the geosite to the southern Black Sea resort Sunny Beach is a good prerequisite for popularization among the tourists. It could be included in the tourist route Slanchev Bryag - Kozichino for visiting the ostrich farm. This could be combined with visiting the other geological phenomena in the area – Cape Emine east of Sunny Beach and Dobrovan mushrooms, north of Prosenik village. For this purpose, signboards should be put with information about the geological development of the area and the Cretaceous/Tertiary boundary near Kozichino village and indicative signboards near the road through Dyulino Pass and Bourgas-Varna.

Geosite "Kamenitsa"

The Kamenitsa study interval is situated in the West Fore Balkan, SE of Moravitsa village. It is in a cyclic carbonate sequence of the Mezdra Formation. The K/T boundary in the outcrop south of Moravitsa village is 1-2 cm thin, dark colored, iridium enriched layer containing 7-11 ppb Ir (Синьовски, 1998). It is situated just below a well-developed major bedding plane, representing short hiatus (Fig. 8). The underlying soft interbed contains poor nannofossil assemblage with *Lithraphidites quadratus* Bramlette & Martini, and *Micula murus* (Martini). The uppermost Maastrichtian nannofossil marker *Micula prinsii* Perch-Nielsen has not been found in this assemblage. The interbed located 80 cm above the boundary contains one of the first Paleocene nannofossils *Cyclagelosphaera alta* Perch-Nielsen. The layer is not laterally traceable because of the diagenetic deformation of the interbed below the major bedding plane.

Figure 8. The boundary layer in the limestone sequence of the Mezdra Formation near Moravitsa village (scale line 30 cm)

Comparable results for the mineralogical content of the boundary layers near Byala and Moravitsa are published by Костов и Цанкарска (2000).

Along with the K/T boundary layer, Geosite Kamenitsa represents many stratigraphical cycles and events of scientific value and is classified as geosite of global significance. This place does not need any special protective measurements because the outcrops are of erosion-resistant robust limestones. The only necessary protective activities are to put signboards along the international road E-79 near Mezdra, Vratza and Moravitsa and information signboard in the place with data on the geological history of the region and the geological event, responsible for this layer, and its scientific importance.

Geosite"Kladorub"

This geosite is situated near Kladorub village in the West Fore Balkan in sedimentary rocks belonging to the Kladorub Formation, known as "Sinaya" or "Karpathian type Cretaceous". It was described by Sinnyovsky et al. (2002). Three nannofossil zones are present in the investigated boundary interval – the top of the uppermost Maastrichtian Micula prinsii Zone, the lowermost Paleocene NP 1 Biantholithus sparsus Zone and NP 2 Cruciplacolithus tenuis Zone (Fig. 10). The presence of the two boundary zones allowed finding dark, up to 4 cm thick layer, marking sharp change in the calcareous nannoplankton assemblages (Fig. 9).

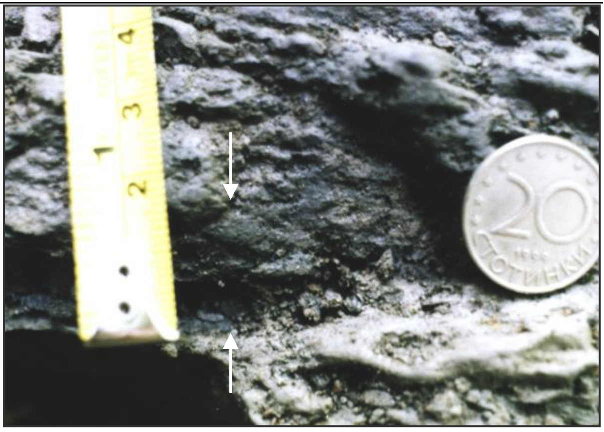

Figure 9. The K/T boundary layer in the marl-siltstone sequence of the Kladorub Formation, 2 km SE of Kladorub village, along Ciganskiya dol (Photo after Boris Valchev)

The samples below this layer contain rich nannofossil association represented by more than 50 Cretaceous species, including the Upper Maastrichtian markers *Lithraphidites quadratus* Bramlette & Martini, *Nephrolithus frequens* Gorka, *Micula murus* (Martini) and *Micula prinsii* (Perch-Nielsen).

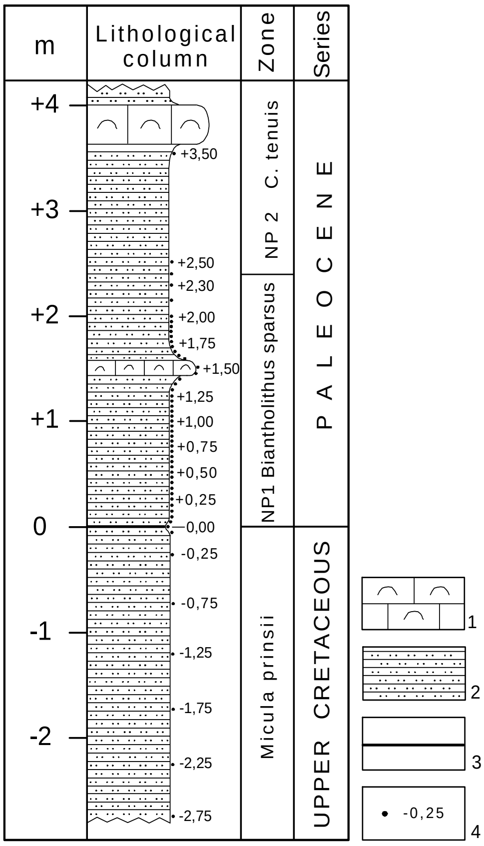

Figure 10. Section of the boundary interval between the Upper Cretaceous and Paleocene in Ciganskiya dol Valley, SE of Kladorub village (after Sinnyovsky et al., 2002): 1 – bioclastic limestone; 2 – siltstones and marls; 3 – boundary layer; 4 - sample

The composition of the Paleocene nannofossil association is entirely different. The taxonomical diversity in the first samples +5 and +10 cm above the boundary is drastically reduced and represented by survivors *Braarudosphaera bigelowi* Gran & Braarud and *Thoracosphaera operculata* Bramlette & Sullivan.

The new Paleocene species *Biantholithus sparsus* (Bramlette & Martini) appears immediately above the boundary layer between +5 and +10 cm. Thus, the lower boundary of NP 1 Biantholithus sparsus is marked by both disappearance of the Cretaceous species and appearance of the zonal marker. *Cyclagelosphaera alta* Perch_Nielsen is another Paleocene species appearing in this interval. The first specimen was found at +0.75 m. The thickness of the NP 1 Biantholithus sparsus Zone is 2.40 m (Fig. 10). The first appearance of *Cruciplacolithus intermedius* (van Heck & Prins) marks the lower boundary of the NP 2 Cruciplacolithus tenuis Zone. The lower level of the zone is characterized by the presence of another cruciplacoliths *Cruciplacolithus primus* Perch_Nielsen, appearing just below the zonal boundary, *Cruciplacolithus tenuis* (Stradner), *Cruciplacolithus asymmetricus* (van Heck & Prins) and *Coccolithus cavus* Hay & Mohler.

This geosite is difficultly accessible even on foot, so it is necessary to cut path or dirt road with suitable markers of the route. At the crossroad to Rabisha village and Magurata Cave in the center of Kladorub village indicative signboard have to be placed with data about the distance and location of the geosite. Such signboards have to be placed also on the highway E-79 near the cross road to Kladorub in Dimovo Town. The outcrop itself needs marking by resistant markers and putting signboard with information of the event, responsible for the layer formation and its scientific significance.

The place is far from the large towns in the district, but it could be popularized along with the other famous geological phenomena in the region - Belogradchik rocks and Magurata Cave. In close proximity to the geosite is situated another interesting geological phenomenon of aesthetic and scientific value – "Chuturite" ("The Mortars"). It is easy accessible from Gramada village and represents "stone forest".

CONCLUSION

Although representing the same event, the proposed geosites are of different geoconservation value, mainly because of their different tourist and educational value and different degree of study. "Belite skali" and "Kamenitsa" are estimated as geosites of global significance because they represent complex geological events rather than K/T boundary only, and have higher degree of study.

The visitor centre in Byala and its position on the Black Sea coast are major premises for high attendance of the place.

The museum in the field campus of the University of Mining and Geology in Ljutibrod village contains all types of rocks that crop out along Kamenitsa River. It is visited every year by tens of students and is of high educational value. As part of the future geopark "Iskar Gorge", this place is very convenient for international practices and workshops. The most interesting geological routes are described in a geological guide in English and Bulgarian including the other geological phenomena in this part of the Iskar Gorge – the rock dolls and "Kamarata" near the villages Kameno pole and Reselets, "Strupanitsa" and "Provartenika" near Karlukovo village, Lakatnik rocks, the rock bridges near Lilyache village, "Ritlite" in Ljutibrod village, Cherepish rocks and Vratsa karst field with Ledenika Cave and "Vratzata" near Vratsa town.

The other outcrops – Kozya River, Kozichino and Kladorub are of continental and regional significance, because of their difficult access and low degree of study.

In making comparative assessment of a type of phenomenon to identify the best example, it is generally appropriate to identify more than a single example. The identification of multiple examples of a class of geological phenomena is known as "replication". This approach is important because a single example could easily become degraded.

The proposed geosites are national treasure, because of the rare exposures of the K/T boundary in global scale. They could be used for popularisation not only of this phenomenon of global significance, but also of the other geological phenomena of Bulgaria.

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CYCLIC UPPER CRETACEOUS-PALEOCENE ROCKS IN THE WESTERN FORE-BALKAN

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ABSTRACT
The Upper Cretaceous – Paleocene rocks in the transitional zone between the Western Fore-Balkan and the Moesian Platform in NW Bulgaria are established mainly in bore holes. The age of the rocks in one of the rare surface outcrops near Vladimirovo village, Montana District, is continuously interpreted as Late Cretaceous. The rocks are represented by robust, dense, highly fractured limestone in which a limestone quarry has been developed for many years. The present study represents paleontological evidence for the age of the rocks and emphasizes their cyclic structure. The dating of the rocks is made on the basis of calcareous nannoplankton. It shows that insignificant part of the limestones is of Late Cretaceous age, but the rest of the section belongs to the Lowest Paleocene nannofossil zones. The main portion of the limestones has clearly expressed cyclic structure. Well traceable flooding surfaces are developed, represented in the section as major bedding surfaces. The hierarchy of the cycles shows that these are most likely climatic cycles from the Milankovitch frequency band of 20 and 100 ka.

INTRODUCTION

Cherty limestones represent one of the widespread Upper Cretaceous - Paleocene lithofacies on the territory of the Fore-Balkan in North Bulgaria. It is related by most authors to the "Mezdra Formation" and is considered Lower Maastrichtian, analogically to the cherty limestones in the Moesian Platform. However, according to recent data, its stratigraphical range in the large territory of the East and West Fore-Balkan is Maastrichtian-Paleocene (Синьовски, Христова-Синьовска, 1993; Sinnyovsky, 1993; Синьовски, 1998; Вангелов, Синьовски, 2001; Стойкова и др., 2001; Sinnyovsky, 2002).

The most western outcrops of this lithofacies are near Vladimirovo village, Montana district, in the northern part of the transitional zone between the Fore-Balkan and the Moesian Platform (Fig. 1). These rocks are not well studied in the area. In the present study wider stratigraphical range and new data for their cyclic structure are proposed.

PREVIOUS WORKS

Degree of study of the surface outcrops

The earliest data for flint containing limestones near Lyuta village (now Vladimirovo) belongs to Златарски (1905). He reported findings of *Echinocorys vulgaris* Breyn., *"in the upper whitish or yellowish limestones"* on the left riverside of Ogosta River and he first accepted Senonian age. In his later overview on the Upper Cretaceous in Bulgaria he persists in his opinion that "*west of Vit River the Senonian Stage has been positively recognized only near Lyuta village on Ogosta"* (Златарски, 1910). The same opinion is supported in his work "The geology of Bulgaria" (Златарски, 1927).

Е. Бончев & Б. Каменов (1934) united the flint limestones in "chert containing horizon with Coraster Vilanovae". They included the studied limestones near Lyuta village into this horizon: *"Chert containing limestones have tangible presence between the rivers Iskar and Ogosta. The most western point, where we found them is Kovachevitsa hillok, west of Ogosta near Lyuta village".* They mention findings of echinoids in the quarry near Lyuta (now Vladimirovo) village but only the ammonite species *Pachydiscus neubergicus* v. Hauer is cited. In this work are published schematic profiles across Lyuta anticline, first named by the authors.

The geological mapping in scale 1:25 000 (Йорданов et al., 1962) did not change the notion about the age of the rocks. It is not changed in the geological map of Bulgaria in scale 1:100 000, map sheet Montana (Филипов et al., 1995a), where these rocks are related to the uppermost Campanian-Lower Maastrichtian. This age is accepted by Филипов (1995), following Йолкичев (1982, 1986).

Interpretation of drilling and geophysical data

Useful data on the subsurface structure of the area was obtained by deep petroleum drilling. Borehole P-8 Vladimirovo penetrated the Upper Cretaceous deposits and reached Albian marls of the Sumer Formation at 1800 m. Borehole P-1 Madan (4382 m) penetrated all rocks, from Quaternary to Lower Triassic, including about 600 m thick "Maastrichtian" limestones (Fig. 1).

The great thickness of the Upper Cretaceous deposits was commented during the 60s. Атанасов (1961) noted that the 550-600 m thickness of the Maastrichtian near Vladimirovo is close to the thickness of the Senonian in the Lom Depression. Later Бончев (1971) assumed that "*a depression was formed here during the Late Cretaceous, approximately at the boundary between the plate and the Fore-Balkan, on which the Fore-Balkan was additionally moved*". The fault, separating the Fore-Balkan from the Moesian Platform, was characterized as steeply inclined to the south thrust on the basis of drilling data from P-8 (Fig. 1). It was named Nivyanino fault (Бончев, 1971), and its eastern part - Lesura fault (Велчева et al., 1970).

Possibility of giving logical explanation about this thickness has been restricted by acceptation of Maastrichtian age as the basis for geological interpretation.

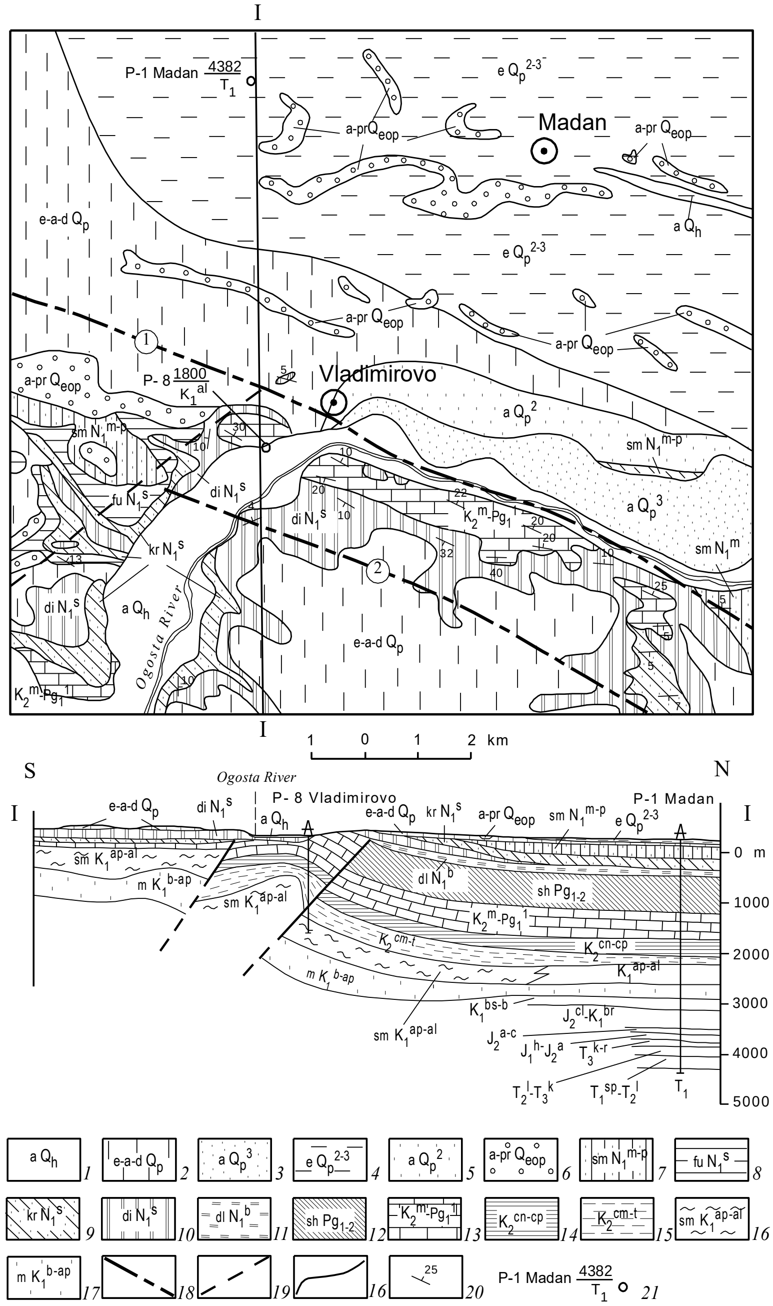

Figure 1. Geological map in scale 1:100 000 (after Филипов et al., 1995, with additional data): 1 – fluvial deposits (Holocene): gravel, sand, clay and reworked loess; 2 – eluvial-fluvial-deluvial deposits (Pleistocene): loess-like clays; 3 – fluvial deposits of the first and second terraces (Upper Pleistocene): gravel, sand and clays; 4 – aeolian deposits (Middle-Upper Pleistocene): loess; 5 – fluvial deposits of the third and fourth terraces (Middle Pleistocene): gravel, sands and clays; 6 – fluvial and fan deposits (Eopleistocene): boulders, gravel and coarse-grained sands; 7 – Smirnenski Formation (Meotian-Pontian):clays and sandstones; 8 – Furen formation (Sarmatian, Upper Bessarabian): detrital, oolitic and sandy limestones, sands and sandstones; 9 – Krivodol Formation (Sarmatian, Upper Volinian – Upper Bessarabian): clays with sandy and marly interbeds; 10 – Dimovo Formation (Sarmatian, Upper Volinian – Lower Bessarabian): sands, sandstones and detrital limestones; 11 – Deleina Formation (Badenian): clays with limestone, sandstone and gypsum interbeds; 12 – Shemshevo Formation (Paleocene - Eocene): clays and silty clays; 13 – "Mezdra Formation" (Maastrichtian - paleocene): Limestones with cherty concretion; 14 – Byalo Bardo + Knezha formations (Coniacian - Campanian): glauconitic sandstones, marls and clayey limestones; 15 – Sanadinovo Formation (Cenomanian - Turonian): marls, clayey limestones and siltstones; 16 – Sumer Formation (Aptian - Albian): marls, clayey limestones, sandstones; 17 – Mramoren Formation (Barremian - Aptian): marls, clayey limestones and siltstones; 18 – fossilized reverse fault: 1 – Nivyanino fault; 2 – boundary fault between 'Devene' and Kutlovitsa' units; 19 – supposed fault; 20 – lithostratigraphical boundary; 21 – borehole with depth in meters and reached stratigraphical unit

If one calculates the sedimentation rate on the basis of about 600 m thickness of the Maastrichtian Stage (Fig. 1, borehole P-1 Madan), it could be about 100 Bubnoff (m/Ma), which is too high for platform deposition.

GEOLOGICAL SETTING

The investigated area is in the northern periphery of the so called "Vladimirovo-Markovo Folded Zone (Йовчев, Балуховски, 1961) or "Vladimirovo-Markovo Transitional Zone" (Bončev, 1966). It is disposed between the real Fore-Balkan and the Moesian Platform (Fig. 1). Бончев (1971) called this zone "folded-blocky strip Vladimirovo-Rakita". Two adjacent folds are described in this area – Lyuta anticline (Бончев, Каменов, 1934), called later Vladimirovo anticline, and southern situated Gradeshnitsa syncline (Богданов, 1971). The former is considered to be a "horst-anticline" by Попов et al. (1960), Атанасов (1961), Бончев (1971).

This zone is interpreted in different ways on the neighbor map sheets of the geological map of Bulgaria in scale 1:100 000, where the investigated outcrops are disposed. On map sheet Byala Slatina the "Vladimirovo-Markovo (Transitional) Zone" is considered as separate tectonic unit of the same rang as the Moesian Platform and the Western Fore-Balkan (Филипов et al., 1995a,b). The Vladimirovo anticline, ranging from Vladimirovo village on map sheet Montana east to Lesura village on map sheet Byala Slatina, is described as a constituent part of this zone. On map sheet Montana the same zone is interpreted as part of the so-called "Devene unit", overthrusted over the "Moesian microcraton" to the north (Цанков, 1995). It is restricted by two faults, fossilized under Neogene deposits – Nivyanino fault from the north and the boundary fault with "Kutlovitsa unit" from the south (Fig. 1). The map sheet is crossed diagonally by the so called "Madan Regional Lineament" constituent of the Tvarditsa System with orientation 30-40º (Филипов и др., 1995b).

PRESENT RESULTS

The limestones near Vladimirovo village are the most western outcrops of the cherty carbonates, commonly related to "Mezdra Formation". The main purpose of this investigation is more precise dating of the rocks and study of their cyclic origin.

The limestone sequence is composed of robust, dense, beige to light-gray or cream limestones with small brown to light-gray cherty concretions. They are well bedded and intensively fractured with bioturbated bed surfaces. On the basis of nannofossil investigation of 59 samples is proved that the carbonate sequence includes both Maastrichtian and Paleocene rocks. Most of the samples contain poor or no nannoflora. Nevertheless Maastrichtian and Paleocene parts of the section are easily recognized due to several marl interbeds below and above Cretaceous/Tertiary boundary, containing rich nannofossil assemblages. These assemblages are composed of characteristic Upper Cretaceous nannofossils below and Paleocene nannofossils above the K/T boundary, differing nearly 100 % in their taxonomic content, due to the great change of the nannofossil taxonomic composition at this boundary.

The outcrops are located mainly on the southern riverside of Ogosta River between Vladimirovo and Gradeshnitsa villages, but the largest outcrop is in the quarry on the left riverside, west of Vladimirovo village. Subject of the present study are the outcrops in three areas: the quarry and its surroundings, the outcrop west of the river in the SW part of the map and the outcrops south of the river between Vladimirovo and Gradeshnitsa.

Figure 2. Bedding surfaces (the arrows) in the Maastrichtian part of the section south of Ogosta River near Vladimirovo village – probable boundaries between 100 ka Milankovitch cycles, composed of 5 layers corresponding probably to 20 ka Milankovitch cycles

Maastrichtian

The Maastrichtian Stage occupies the lower parts of the outcrops on both riversides of Ogosta River. It generally builds up the core of the Lyuta anticline.

Only the lowest few meters of the section north of Ogosta River belong to the Maastrichtian. This is a restricted 3 m high outcrop, west of the western entrance of Vladimirovo village. The samples from the marl interbeds contain poor Upper Cretaceous assemblage with typical Upper Maastrichtian nannofossil markers *Micula murus* (Martini) and *Lithraphidites quadratus* Bramlette & Martini.

Deluvial deposits cover the overlying 10-12 m interval of the section. The above exposed carbonates contain Lower Paleocene nannofossils and the Cretaceous/Tertiary boundary falls into the covered interval.

The beds on the southern riverside are inclined to the SW and the rocks get older from west to east along the river. The cyclic limestones 500 m east of the bridge are of Late Maastrichtian age (Fig. 2). In this outcrop is established well-expressed cyclicity corresponding probably to 20 and 100 ka Milankovitch cycles. The Cretaceous/Tertiary boundary is located some 30 m above the base of the outcrop. The boundary layer, marking this boundary in many outcrops in the country and all over the world, has not been found.

The total thickness of the exposed part of the Maastrichtian Stage is about 30-40 m.

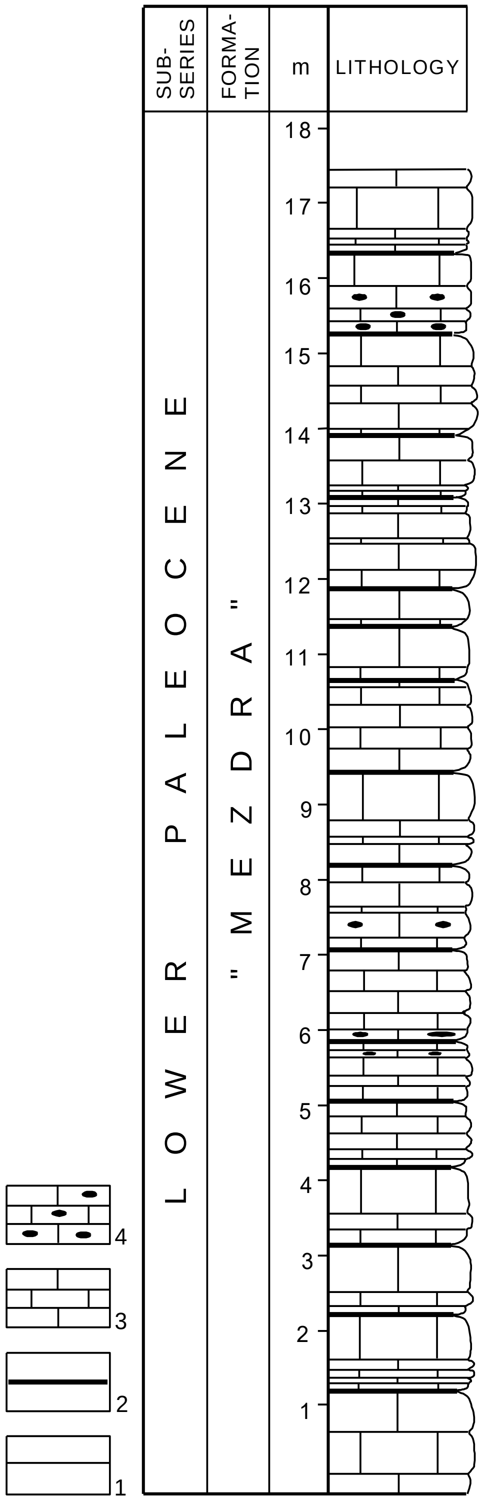

Figure 3. The lowest portion of the Paleocene section shows cyclic structure with major bedding surfaces restricting probably 100 ka Milankovitch cycles, each composed of mean 4,7 layers, probably corresponding to 20 ka Milankovitch cycles

Paleocene

The Paleocene part of the carbonate sequence is well exposed on both riversides of Ogosta River. Its thickness is more than 60 m. In this stratigraphical level is developed the limestone quarry. At the upper western edge of the quarry is exposed the transgressive boundary between the studied carbonate sequence and the Sarmatian limestones of Dimovo Formation.

The Paleocene is represented by robust, light gray to cream limestones with brown to gray cherty concretions. The beds are 20-40 cm thick, separated by well-developed bioturbated bedding surfaces. A well-exposed 18 m section between the lowermost Paleocene beds above the covered K/T boundary interval has been investigated for cyclic elements. The rocks in this interval are naturally weathered with well-developed bedding surfaces (Fig. 3).

Totally 70 limestone beds have been measured with thickness between 8 and 65 cm. The most common thickness is 20, 25 and 30 cm. According to the field methodology of Schwarzacher & Ficher (1982) the bedding surfaces are divided into two groups – common and major. Common bedding surfaces are traceable in the frame of a singular outcrop whereas the major bedding surfaces could be followed between different outcrops. Totally 15 major bedding surfaces are recognized in the studied interval. Statistical processing shows that the mean number of the beds between the major bedding surfaces is 4.7. This allows assumption that the common bedding surfaces separate beds, corresponding to 20 ka Milankovitch cycles. They are grouped into bundles, separated by major bedding surfaces and probably corresponding to 100 ka Milankovitch cycles. This type of cyclicity was recognized in the Paleocene part of the same lithofacies near Mezdra town (Синьовски, 1998).

The outcrop in the SW part of the map is situated near Boychinovtsi town north of the bridge on Ogosta River. It is situated along the abandoned railway to the former Ogosta Enterprise. The outcrop is 10 m high of well-bedded limestones with cherty concretions. The nannofossil content allows dating this interval as Lower Paleocene.

CONCLUSION

Present results show that most of the cherty concretion limestones, representing the widespread lithofacies in the Fore-Balkan, known as “Mezdra Formation”, in their most western outcrops near Vladimirovo village, are of Paleocene age. This outlines a more complete notion about their stratigraphical range in the Fore-Balkan and confirms the version that in large territories this lithofacies is formed for a long period including the whole Maastrichtian age and part of the Paleocene Epoch. These limestones show elements of cyclicity, controlled most probably by the climatic Milankovitch cycles. Their lower distinctness is an evidence for comparatively distal sedimentation in contrast to the Mezdra region, where the clearly cyclic limestones are formed in the shallowest part of the epicontinental Maastrichtian-Paleocene Sea.

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PETROGRAPHY OF THE HELVETIAN LIGNITE FROM THE CHUKUROVO BASIN, BULGARIA

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ABSTRACT
The complicated coal seam (complex) in the south part of the Chukurovo basin was sampled and 25 samples were taken. Polished block samples were prepared and the petrographic composition of the coal was established. There were found macerals from the three maceral groups. Macerals from the Huminite group were textinite, texto-ulminite, eu-ulminite, attrinite, densinite, phlobaphinite, and psudo-phlobaphinite. The following liptinite macerals were observed: cutinite, sporinite, resinite, suberinite, alginite, liptodetrinite, and chlorophillinite (?). Fusinite, sclerotinite, and inertodetrinite presented the inertinite macerals. Their amount was very vow. Minerals found with reflected light were clay minerals, pyrite (euhedral, framboidal and massive) and epigenetic calcite. The peat bog was determined as wet forest bog according the maceral composition. According to the calculated indices of the coal facies (Groundwater Influence Index and Vegetation Index), the type of the peat bog was determined as "limnitic ombrotrophic bog forest". The Tissue Preservation Index (TPI) and Gelification Index (GI) was determined peat bog as "forested peatland", where the water level was increasing continuously or in a forested, continuously wet raised bog. On the basis of the huminite reflectance, the coal was determinate as "Lignite".
Key words: lignite, macerals, indices of the coal facies, type of peat bog, Chukurovo basin.

INTRODUCTION

The Chukurovo lignite basin is located 40km southeast from the city of Sofia. It is situated in the central part of the Sofia coal province. The coal-bearing sediments have Helvetian age Паламарев (1964). They are separated by Бл. Каменов as a *Formation of the clay sandstones and shale with the Chukurovo coal seam* (Кацков, Илиев, 1993). It is composed by shale, sand shale, sandstone layers and coal seams, which number is 12 to 18. Кацков, Илиев (1993), published data that all coal layers make one complicated coal seam thick up to 40 m. The coal-bearing sediments fill Chukurovo graben, which has Northwest-Southeast orientation. They are low banded. The underlying rocks of the basin are diabase phillitoide complex (DFK) with Middle Triassic (Pancharevska formation) and Middle-Upper Jurassic (Ginska formation) (Кацков, Илиев, 1993).

Petrographic investigations of the coal were done by Плачков, Стойнова (1961), Минчев (1963) and Константинова (1969). The main purpose of the study is to determine the maceral composition of the lignite from the complicated coal seam (complex) in the south part of the basin and to update the data for the Liptinite macerals, using fluorescent light. On the basis of the present investigations were calculated the indices of the coal facies and the type of the peat bog, where the plant tissue were accumulated.

METHODS

The complicated coal seam in the South part of the basin was sampled. Twenty polished block samples were studied with a microscope "Leica" with reflected light (λ=546 nm), fluorescent light, and a computer program "Leica mpv_meas". Oil immersion objectives 50x/0.85 and 100x/0.25 were used also. Automatic counter "Prior-G" was used for the counting of the macerals. For determination of maceral percentage four hundred macerals were counted and 50 points for vitrinite reflectance were measured of each sample. Yttrium-alluminium-granat with reflectance 0.899% was used for a standard for determination of the vitrinite reflectance.

RESULTS AND DISCUSSION

Average huminite reflectance was measured as Ro=0.23%, Rmin=0.18%, Rmax=0.25% with standard deviation ±0.0204. According to the huminite reflectance the coal was determined as Lignite.

Macerals from the Huminite group. All amounts of these macerals are 82.23% and 84.82% from the organic matter (Table 1). The macerals from the *subgroup Humotellinite* are prevailing in the studied coal. Textinite is observed as bands and lenses. It associates with the ulminite, attrinite and densinite. Clay minerals, resinite (Fig. 2b) and phlobaphinite fill the textinite lumens. The textinite amount is relatively high (Table 1). The two maceral types present the ulminite. Its amount is highest in the coal (Table 1). The maceral type texto-ulminite is prevailing significantly. It builds thick bands. The texto-ulminite lumens are filled with clay minerals (Fig. 1d) and phlobaphinite (Fig. 1a) or resinite (Fig. 2a). The texto-ulminite associates with eu-ulminite, textinite, attrinite and densinite. The eu-ulminite significantly presents in the samples. It is like bands, which alternates with the texto-ulminite and textinite. These bands make wood annual circles. That maceral is observed as lenses with different sizes also. Resinite (Fig. 2d) and rarely phlobaphinite fills the lumens of the eu-ulminite.

Table 1. Petrographic composition of the Chukurovo lignite.

Macerals	Content,%	Content in organic matter, %
Huminite *group*	82.23	84.82
Textinite	15.50	
Texto-ulminite	31.30	
Eu-ulminite	20.24	
Attrinite	8.33	
Densinite	1.8	
Phlobaphinite	4.79	
pseudo-phlobaphinite	0.27	
Liptinite group:	14.44	14.90
Cutinite	0.13	
Sporinite	0.13	
Resinite	10.38	
Suberinite	1.86	
Alginite	0.13	
Liptodetrinite	1.6	
Chlorophillinite	0.01	
Inertinite group:	0.27	0.28
Fusinite	0.01	
Sclerotinite	0.13	
Inertodetrinite	0.13	
Minerals:	3.06	
pyrite	0.13	
epigenetic calcite	0.53	
clay minerals	2.4	

The amount of the macerals from the *subgroup Humodetrinite* is relatively lows (Table 1). The attrinite is prevailing, as the densinite amount is insignificant (Table 1). These macerals in association with clay minerals consolidate all other macerals (Fig. 1c,e; 2c,f).

Subgroup Humocollinite is presented only by the maceral corpohuminite. The phlobaphinite is prevailed maceral type of the corpohuminite (Table 1). It fills the ulminite lumens (Fig. 1a) and rarely of the textinite. The second maceral type – pseudo-phlobaphinite associates with attrinite and densinite (Fig. 1c). The shape of the both maceral types is oval or circle and they have low relief (Fig. 1a, c).

According to Кортенски et al. (2001), the amount of the macerals from the *Huminite group* increases in the central part of the basin.

Macerals from the Liptinite group. The amount of the macerals from this group, with an exemption of the resinite, is low (Table 1). The cutinite has the lowest amount (Table 1). It was observed as well-shaped and preserved bodies (Fig. 2e) or as single particles with different sizes. Cutinite associates with attrinite and densinite. The sporinite is rarely observed (Table 1) and it is presented mainly from miosporinite. It is probably pollen relicts. The sporinite associates with attrinite, densinite, liptodetrinite (Fig. 2c), sometimes with suberinite (Fig. 2f) and cutinite. The suberinite is frequently observed maceral, which is typical for the coal from Sofia province (Кортенски, 1993), but its amount is low in the studied coal. It was observed as well shaped bands with good structure (Fig. 2b), or bed preserved bands (Fig. 2f) or particles with different sizes (Fig. 2e). It associates with the other Liptinite macerals, attrinite, densinite, textinite and ulminite. The resinite is most spread Liptinite maceral (Table 1) and it is a sign for participation of Conifer plants at the time of peat accumulation. It was observed as spherical, oval or long bodies mainly into the textinite (Fig. 1b), texto-ulminite (Fig. 1a; 2a) and eu-ulminite (Fig. 2d) lumens. The resinite has more weak fluorescent color than the detrial resinite, which was observed also into the studied coal. It is like single bodies among the attrinite and densinite (Fig. 1c) and with associations with other Liptinite macerals. The alginite amount is insignificant (Table 1), which is typical for the forested swamps (Stach et al., 1982). It was observed as small lenses-shaped bodies among attrinite with an association with sporinite and liptodetrinite (Fig. 2c). The liptodetrinite is from 1 to 2.5% in the samples. It associates with the other Liptinite macerals, mainly sporinite and attrinite (Fig. 2c). The maceral chlorophillinite is determined, using fluorescent light. It is like small bloody-reds bodies into the Lipten bands with low Huminite reflectance (Ro=0.21%). It associates with cutinite

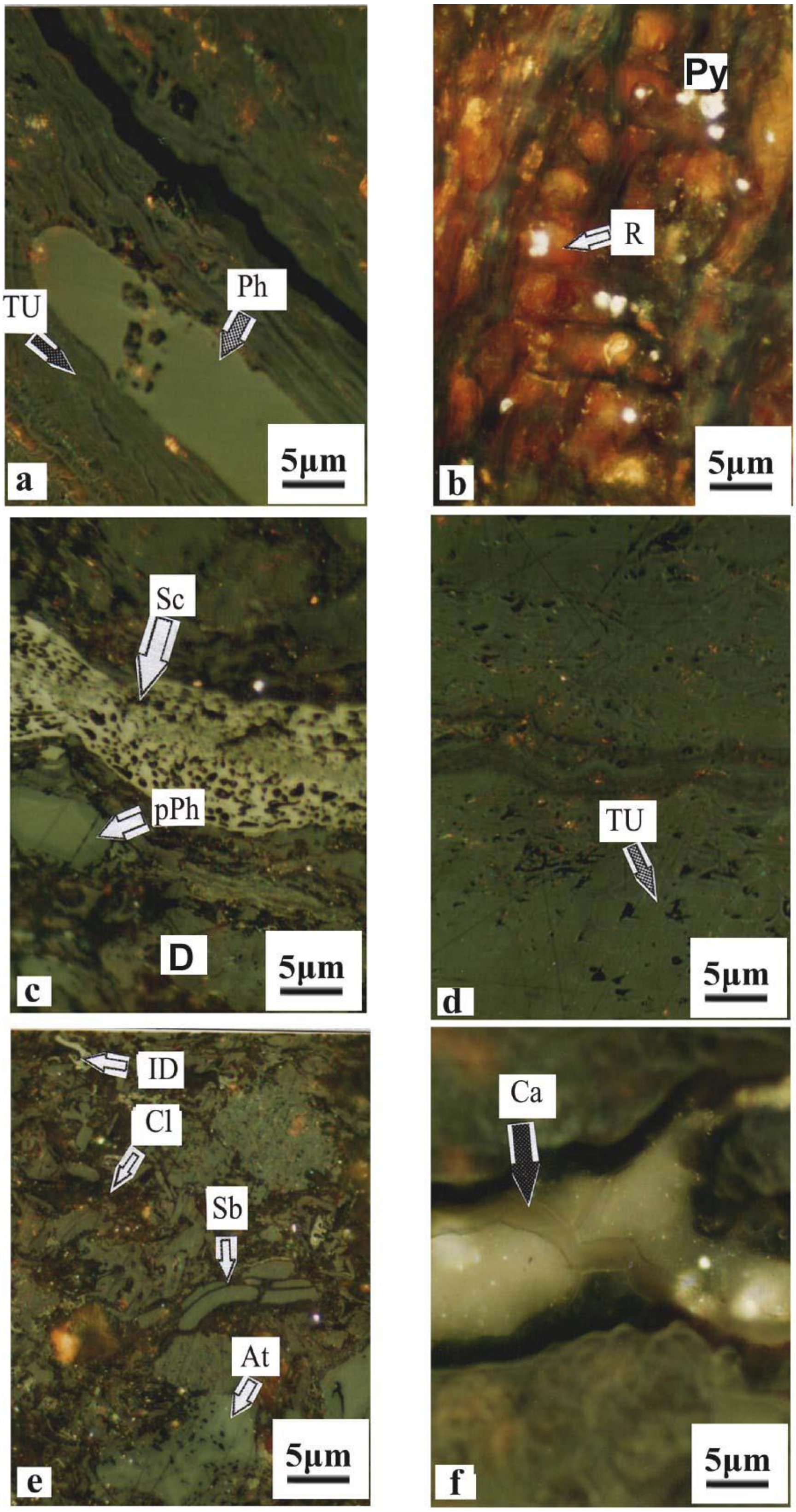

Figure 1 Petrographic composition of the lignite from the Chukurovo basin, reflected light, oil immersion: a)Texto-ulminite, phlobaphinite (Ph); b) Resinite (R) into textinite; c) Sclerotinite (Sc)-plectenhiminite, pseudo-phlobaphinite (pPh), densinite (D); d) Texto-ulminite (TU); e) Inertodetrinite (ID), clay minerals (Sh), suberinite (SB), attrinite (At); f) Epigenetic calcite (Cc).

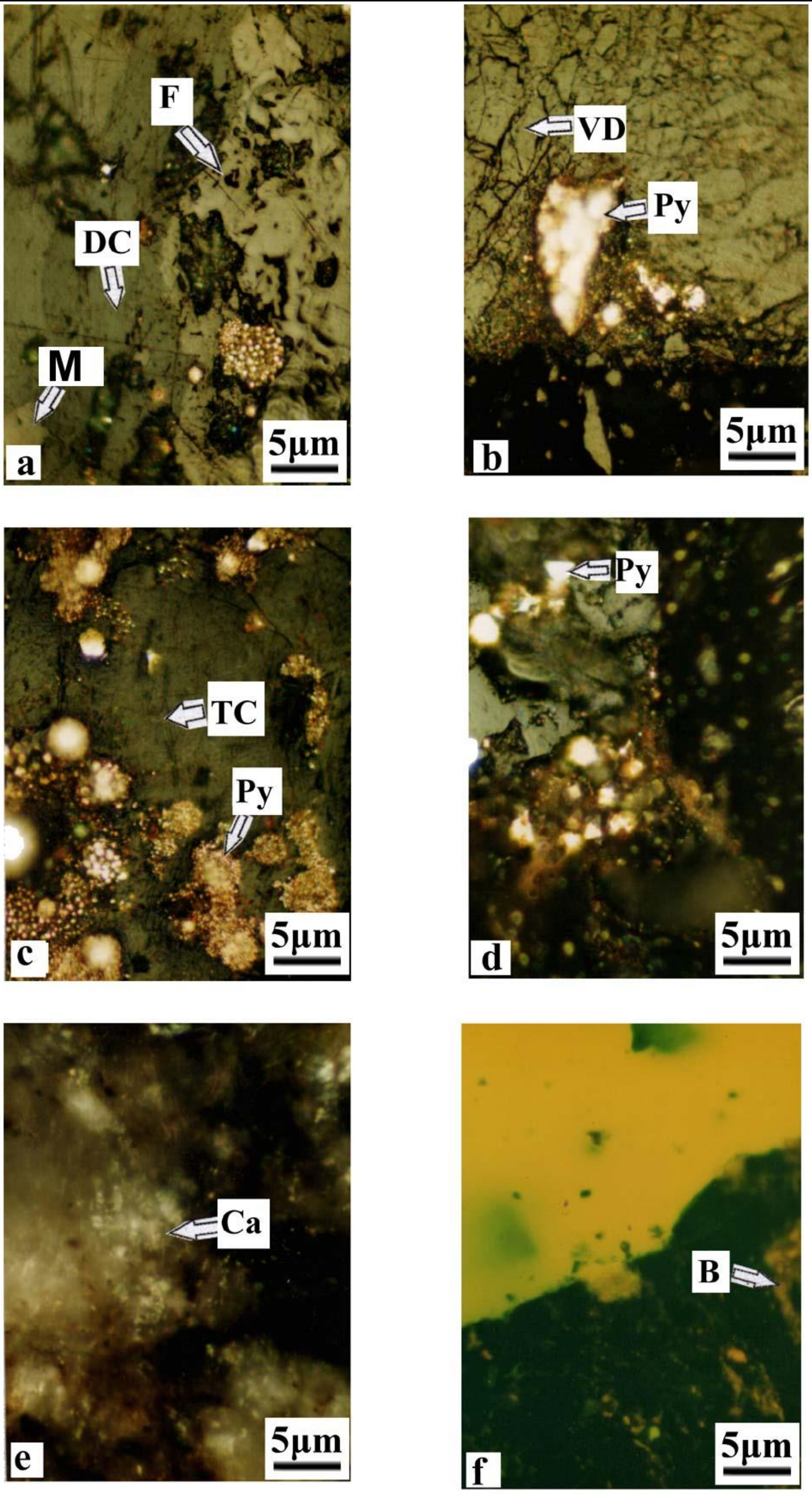

Figure 2 Petrographic composition of the lignite from the Chukurovo basin, fluorescent light, oil immersion: a) Resinite (R) into texto-ulminite; b) Suberinite (Sb); c) Alginite (A), liptodetrinite (LD), sporinite (S), attrinite (At); d) Resinite (R) into eu-ulminite; e) Cutinite (C), chlorophillinite (?) (Ch) attrinite (At); f) Suberinite (Sb), sporinite (S), attrinite (At).

(Fig. 2e). Taylor et al. (1998) wrote that the chlorophillinite is relicts from chlorophill around the cutinite bodies.

The color of the most studied Liptinite macerals is yellow with different intensity (Fig. 2) or orange, because of the low rank of coalification of the coal (Taylor et al., 1998). Only the chlorophillinite has bloody-red color. The Liptinite macerals have similar surface distribution as the Huminite macerals and their amount increases toward the central part of the basin (Кортенски et al., 2001).

Macerals from the Inertinite group. The amount of the Inertinite macerals in the studied coal is lowest, moreover it is below 1% (Table 1). The fusinite has lowest content (Table 1). It is highly destroyed and it was observed as small particles among the attrinite. The fusinite associates with the inertodetrinite. The sclerotinite is presented mainly by plectenhiminite, which was observed as relatively large bodies among the attrinite (Fig. 1c). It was established also one-cell and two-cell fungi-sclerotinite. The inertodetrinite particles associate mainly with attrinite (Fig. 1e) or fusinite. The Inertinite macerals increase their amount toward the periphery of the basin (Кортенски et al., 2001).

Minerals

Clay minerals. They fill the lumens of the textinite, texto-ulminite and fusinite and create small lenses or associate with attrinite (Fig. 1e).

Pyrite. Its amount is low. It is fine-grained and it is presented from framboidal, euhedral and massive pyrite. They were observed as single grains among the attrinite and densinite (Fig. 1c, e). Sometimes pyrite was observed into the lumens of the textinite (Fig. 1b), texto-ulminite (Fig. 1d) or fusinite.

Epigenetic calcite. It was established into single cracks (Fig. 1f). Its amount is low (Table 1).

Indices of the coal facies

On the basis of the petrographic composition the indices of the coal facies were determined. The maceral percentages, calculated on the basis of all matter were used.

Groundwater Influence Index (GWI) by Calder et al. (1991):

GWI=gelinite+corpohuminite+mineral matter / textinite+ ulminite +densinite=0.1

Vegetation Index (VI) by Calder et al. (1991):

VI = textinite+ulminite+fusinite+suberinite+resinite / densinite +inertodetrinite+alginate+liptodetrinite+sporinite+cutinite=22.35

According to these two indices, the type of the peat bog was determined as “limnitic ombrotrophic forested swamp”. Calder et al. (1991) determined the conditions of this type as low groundwater supplying and higher acidity.

Tissue Preservation Index (TPI) by Diessel (1992):

TPI = textinite+ulminite+fusinite / densinite+macrinite+ inertodetrinite=78.76

Gelification Index (GI) by Diessel (1992):

GI=huminite +macrinite / fusinite+inertodetrinite=634.15

According these two indices, the origin of the peat bog was determined in a forested peatland or forested swamp with continuing increasing of the water level. According to Diessel (1992), the plant tissue was suffered of intermittently humification and strong gelification.

CONCLUSION

The Chukurovo lignite is characterized with high content of Huminite macerals and low content of Inertinite macerals. The high amount of textinite and ulminite is a result of accumulation of wood plants and well preservation of the plant tissue. They are low disintegrated and because of this reason the contents of attrinite and densinite is low. The presence of suberinite in the studied coal is related with wood plants and one part of them was coniferous, which is seen from the high content of resinite. According the maceral content, the Chukurovo lignite is located into group C (subgroup C_1), divided by Шишков (1988) with accordance of the type of the coal-generated paleobiotypes. According to the maceral composition, the peat generation was developed in a typical forest swamp. It had been continuously wet, and because of that reason the Inertinite macerals are not many. There were established low contents of minerals – clastic (clay minerals) and singenetic (pyrite). The epigenetic calcite is accumulated into fractures of the coal seam. The calculated indices of the coal facies prove the conclusion for typical forested swamp. The values of Groundwater Index and the Vegetation Index determine the peat bog as limnetic ombrotrophic forested swamp. According to the Tissue preservation Index and Gelification Index the origin of the peat bog was in a continuously wet forested peatland or swamp.

The petrographic composition of the Chukurovo lignite is similar to the coal from Sofia province and they are characterized with high contents of textinite and ulminite, presence of corpohuminite and suberinite, relatively high content of resinite and low content of Inertinite macerals (Кортенски, 1993). But the maceral percentages are different for the Sofia coal. The Chukurovo coal is different than the Sofia province coal, because of the low amount of attrinite, densinite and fusinite and the presence of chlorophillinite. Some conditions of peat forming were different also and especially it relates for the Sofia basin after Kortenski and Sotirov (2001).

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PETROLOGY, SR AND ND ISOTOPE SIGNATURE OF THE LATE CRETACEOUS MAGMATISM IN THE SOUTH-EASTERN PART OF ETROPOLE STARA PLANINA, SREDNOGORIE MAGMATIC ZONE

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ABSTRACT
The Chelopech volcano is the host of one of the largest Au-Cu deposits in Europe. It includes three phases: dome-like bodies (andesites and latites to trachydacites), lava to agglomerate flows (andesites, latites, dacites to trachydacites), a lava breccia neck (andesites to shoshonites and latites) and dykes (andesites to dacites). The age of those magmatic products is probably Turonian. The volcanic rocks are porphyric with plagioclase and amphibole phenocrysts, rarely quartz (in the dome-like bodies and dykes) and biotite. The groundmass is microlitic. The lava flows contain fully crystallized fine-grained inclusions with more basic compositions indicating mingling between two parental magmas. The chemical evolution from more acid to more basic lavas, and the absence of an Eu anomaly probably indicate a chemically zoned magmatic chamber. The trace element content is similar to that of the active continental margin (Andean type). Sr isotopic compositions display a small range between 0.7049 and 0.7054 (corrected for 90 Ma) and Nd rations are from 0.5124 to 0.5125 (corrected for 90 Ma).

INTRODUCTION

The Chelopech volcanics and dykes outcrop in the southeastern part of Etropole Stara planina. They are part of Late Cretaceous Central Srednogorie volcano-intrusive area. The Chelopech volcano is the host of one of the largest Au-Cu deposits in Europe, containing well in excess of 5.5 million ounces of Au and >10 million ounces Au equivalent (Andrew, 1997). It is situated about 65 km east of Sofia at the foot of the Stara Planina Mountain. This deposit has been an object of many investigations connected to its geology and structures (Popov and Mutafchiev, 1980; Popov et al., 2000, 2002), hydrothermal alteration (Mutafchiev and Chipchakova, 1969), mineralogy, stratigraphy of the Upper Cretaceous sequences (Moev and Antonov, 1978a; Dimitrova et al., 1984), structures in the region (Moev and Antonov, 1978b; Popov et al., 2000, 2002), and radiogenic age (Lilov and Chipchakova, 1999; Velichkova et al., 2001), because of its large economical interest. The petrographic and age characteristics of the surrounding area of the Chelopech deposit have received less attention (Mutafchiev and Chipchakova, 1969; Moev and Antonov, 1978a; Stoykov et al, 2002; Stoykov and Pavlishina, 2003). The aim of present paper is to complete this information and to show new data about the geological, petrochemical, Sr and Nd isotope, mineralogical and age characteristics of the magmatic rocks, pert of the Srednogorie magmatic zone.

GEOLOGICAL SETTING OF STUDIED MAGMATIC ROCKS

The region of the Chelopech volcano (Fig. 1) is built up by metamorphic basement rocks and a Late Cretaceous volcanic and sedimentary rock succession. The basement appears in the northeastern part of the region and it is composed by the metamorphic rocks of the Pirdop and the Bercovitza Groups in tectonic contact with each other. The Pirdop Group consists of two-mica migmatites with thin intercalations of amphibolites, hornblende-biotite and biotite gneisses (Dabovski, 1988). The Bercovitza Group is a Late Precambrian-Cambrian sedimentary-volcanic complex of island-arc association (Haydoutov, 2001). It consists of equal parts of sedimentary and volcanic rocks (spilites, keratophyres and their pyroclastic rocks) metamorphosed under greenschist facies conditions. Late Cretaceous (Turonian - Maastrichtian) sedimentary and volcanic rocks, more than 2000 m in thickness transgressively overlie this basement. The metamorphics is also cut by east-west oriented andesitic, latitic, dacitic to trochydacitic dykes.

The Late Cretaceous sedimentation starts with conglomerates and coarse sandstones with coal-bearing interbeds (Coal-bearing formation, according to Moev and Antonov, 1978a) covered by polymictic, argilleous and arcose sandstones to siltstones (Sandstone formation) with up to 500 m thick. Both formations are probably of Turonian age (Nikolaev, 1947; Moev and Antonov, 1978a) as confirmed by the new pollen data of Stoykov and Pavlishina (2003). These sedimentary rocks are cut by volcanic bodies and overlaid by the sedimentary and volçanic rocks of the Chelopech Formation according to Moev and Antonov (1978a) or the Tuff formation according to Dimitrova et al. (1984). The products of the Chelopech volcano form the Vozdol member of this Formation. After the Subhercinian tectonic deformations (Popov et al., 2002) the rocks of this units have been eroded and transgressively covered by the sedimentary rocks of the Mirkovo Formation - reddish limestones and marls (Moev and Antonov, 1978a) or the limestone-marls formation after Dimitrova et al. (1984). They are covered by the flysch of the Chugovo Formation (Moev and Antonov, 1978a) or the flysch formation after Dimitrova et al. (1984). The rocks of the last two Formations build up the Chelopech syncline (Moev and Antonov, 1978b). The size of this structure is 10 × 2 km. The volcanic rocks preserved by erosion form the limbs of this syncline that is cut and covered in the eastern part (Fig. 1) by the Chelopech thrust (Moev and Antonov, 1978b). The last structure is recovered by the Neogene-Quaternary Zlatitsa graben.

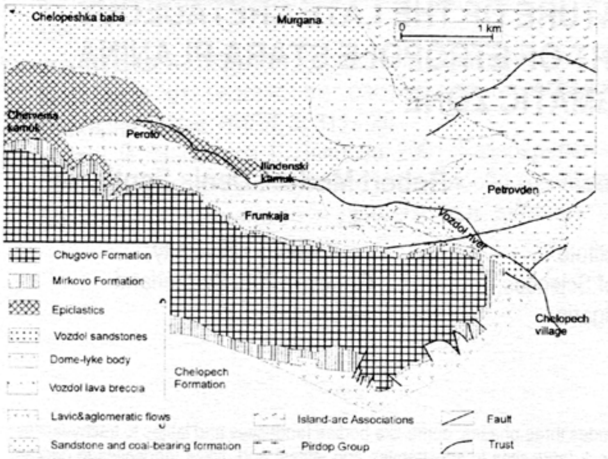

Figure 1. Geological map of the Southeastern part of Etropole Stara planina

The geophysical data show the presence of a positive anomaly 20 km in diameter, which is located between the studied magmatic rocks and the Elatsite pluton in the north (Popov et al., 2002). This magnetic anomaly is interpreted as a large magnetic-active body corresponding to a shallow magmatic chamber. These authors proposed that the Chelopech volcano and the Elatsite pluton are part of the same volcano-plutonic complex and one ore-magmatic system.

GEOLOGICAL STRUCTURE OF THE CHELOPECH VOLCANO

The basement of the Chelopech volcano

It is not exposed on the surface, but is cut by the boreholes in the underground mine of Chelopech. It is composed by the rocks of the Sandstone formation, with a thickness between 300 and 450 m (Moev and Antonov, 1978a). According to Popov et al. (2002), in the northern part of the Vozdol river, the basement of the volcano is built up by an olistrostrome unit with a limited development according to borehole data. These data can be interpreted in terms of blocks of metamorphic basement with a sedimentary rock cover, cut by volcanic bodies.

The Chelopech volcano

It (stratovolcano according to Popov et al., 2002) consists of 3 phases: (i) dome-like volcanic bodies, (ii) lava and agglomerate flows and (iii) a neck, locally known as the Vozdol neck (Popov et al., 2002).

Dome-like volcanic bodies. In the Murgana area (Fig. 1) the dome-like volcanic bodies are exposed on the surface without clear relationships with the products of the next phase. These bodies are intruded in the Turonian sediments where the bedding of the hosting rocks close to their contact is subvertical (e.g. in the Belishka river). The largest body is about 2 × 1 km in size. It has a complicated morphology probably reflecting its composite character. Some parts of the bodies (to the south of the Murgana summit) have a dome-like morphology (according to the data of Moev and Antonov, 1978a), corresponding to their petrographic characteristics (see below). Popov and Mutafchiev (1980) described these bodies as subvolcanic, and later, as subvolcanic intrusion (Popov et al., 2000). These authors distinguished an early and a late group of subvolcanic bodies. Lilov and Chipchakova (1999) attributed a 65-67 Ma age according to K-Ar dating of some of the bodies, which probably reflects a younger, overprinting geological event (see below).

The lava flows grade into agglomerate flows (with fragments up to about 30 cm in size) in the upper levels. Subvertical columnar jointing is observed in the lava flows in some places (e.g. in the Ilindenska river). The total thickness of these volcanic products is up to 1200 m according to the drilling data (Popov et al., 2002). K-Ar data of non-altered andesite indicate a Turonian age (91 Ma according to Lilov and Chipchakova, 1999) and U-Pb zircon dating of andesite overprinted by alteration and mineralization in the mine $^{206}Pb/^{238}U$ age is 91.45 ± 0.15 Ma (Moritz et al., 2003).

The location of the volcanic center is not clear. It is probably situated in the area of the Chelopech deposit (respectively in the area of the Chugovo river) where two boreholes cut a very thick volcanic succession (1700-2000 m). The other boreholes in the deposit cut a 700-800 m thick succession of volcanic rocks only. This difference in thickness is too large to be connected to a caldera subsidence. There are also no geological and geophysical evidences for concentric faults related to caldera subsidence, as proposed by Popov et al. (2000, 2002). There are also volcanic breccia and tuffs in the deposit (Mutafchiev and Chipchakova, 1969; Popov and Mutafchiev, 1980). They are strongly hydrothermally altered rocks and probably more of them are epiclastic rocks.

In the western part of the volcano, nearby the Chervenia Kamak summit the upper levels of the agglomerate flows are intercalated with psephitic and psamitic epiclastic rocks, the latter are interbedded with the sandstones and marls of the Chelopech Formation.

The Vozdol neck. In the eastern part of the Vozdol valley (Fig. 1), to the northeast of the Petrovden fault a volcanic breccia is outcropping with a surface of 1.5 × 0.250 km. It is interpreted as the youngest neck of the Chelopech volcano, and is called Vozdol monovolcano by Popov et al. (2000, 2002). One $^{40}Ar/^{39}Ar$ age of biotite from this breccia gives a Turonian age of about 90 Ma (Velichkova et al., 2001). The former K-Ar age of 65 Ma obtained by Lilov and Chipchakova (1999) for samples from the same locality likely represents the age of a younger overprinting thermal event than the real magmatic crystallization age of the Vozdol volcanics. The Vozdol neck consists of clasts-supported lava-breccia with 20 to about 80 cm-sized fragments in a lavic matrix. In the eastern periphery of the body, sedimentary material occurs in the matrix (sandstones to gravelites), which increases volumetrically to the border of the body, where they form a small lens and layers. These features show sedimentation during the formation of this volcanic body and the beginning of its destruction and redeposition in the younger sandstones of the Vozdol area.

The cover of the Chelopech volcano

It is represented by the Vozdol sandstones (in the eastern part), the muddy limestones of the Mirkovo Formation (in the central part) and the sedimentary rocks of the Chelopech Formation (in the western part).

The Vozdol sandstones, which have not been described as a single litostratigraphic unit in previous contributions, are only locally developed. They are exposed on a surface of about 2.5 × 1 km and are partly covered by the Chelopech syncline. These sandstones have a variable thickness, with the largest one (up to 250 m) being located in the syncline and on the Vozdol river. They are probably of fluvial or coastal origin (Stoykov and Pavlishina, 2003) and of Turonian age (Nikolaev, 1947) confirmed by the new pollen data of Stoykov and Pavlishina (2003). The sandstones are coarse, thick bedded, and they show cross-bedding. Small coal lenses are present and two conglomerate layers can be recognized (described previously as tuff layers by Moev and Antonov, 1978a, and Popov and Mutafchiev, 1980) with fragments of different volcanic rocks (including from the Vozdol neck) and variable sizes up to 1 m. They can be interpreted as products of mud flows. In comparison to the sandstones of the Chelopech Formation, they also contain muscovite which corresponds to another source of terrigeneous material probably derived from the Pirdop Group to the north.

The partly eroded Chelopech volcano (in the central part of the region) and the Vozdol sandstones (in the eastern part of the region) are transgressively covered by reddish clayey limestones of the Mirkovo Formation (Moev and Antonov, 1978a). These limestones, with a thickness up to 30-40 m, comprise fragments up to 25 cm in size of different volcanic rocks and the Vozdol sandstones. Calcareous nannofossils from the limestones, mostly in the base of this sedimentary unit, indicate a Latest Santonian to Campanian age (unpublished data of K. Stoykova, Geological Institute). They are concordantly covered by flysch sedimentary rocks of the Chugovo Formation (Late Campanian - Early Maastrichtian according to K. Stoykova). The latter consist of an interbedding of calcareous sandstone, siltstone and argillite with a thickness up to 500 m. Volcanoclastic layers are not present in the region of the Chelopech volcano, which is in contrast with other parts of the Central Srednogorie area (Velichkova et al., 2002). The sedimentary rocks of these two formations form the Chelopech syncline.

The dykes

They have predominately east-west direction and are intruded into pre-upper Cretaceous basement rocks of the Bercovitza and the Pirdop Group without clear relationships with the products of the Chelopech volcano are not clear. The largest one is more than 7 km in length.

PETROLOGY OF THE STUDIED MAGMATIC ROCKS

Methods

The major and trace elements were analyzed by X-ray fluorescence (XRF) at the University of Lausanne (Switzerland). The rare earth elements (REE) were analysed by ICP-atomic emission spectrometry following the procedure of Voldet (1993). The representative analyses of the compositional variation of the rock recovered from the Chelopech volcanics are given in Tables 1 and 2. Trace elements (Table 2) were analyzed also by XRF at the University of Geneva. The petrological study was carried out on fresh samples. Mineral analyses on 10 samples of the different phases were carried out at University of Lausanne (Switzerland) on a CAMEBAX SX-50 electron microprobe.

Petrography

The volcanic rocks are shoshonites, andesites, latites to dacites and trachydacites (Fig. 2).

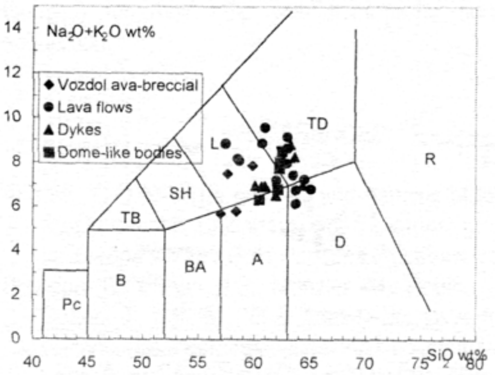

Figure 2. TAS diagram after Le Maitre (1989) for representative magmatic rocks from the studied region (B, basalt; BA, basaltic andesite; A, andesite; D, dacite; SH, shoshonite; L, latite; TD, trachidacyte)

In the Chelopech volcano the magma evolved from more acid volcanic rocks with 61-64 wt% SiO_2 of the earlier products (lava and agglomerate flows and dome-like bodies) to the more basic ones with 55.5-58 wt% SiO_2 of the Vozdol volcanic rocks (Table 1).

Table 1. Major element composition of the representative volcanic samples

Oxides wt. %	Dome-like body	Lava flows	Vozdol breccias	Dykes
SiO_2	61.22	63.01	57.11	60.07
TiO_2	0.54	0.51	0.65	0.47
Al_2O_3	17.98	16.36	18.35	16.46
Fe_2O_3	5.01	4.94	7.03	4.04
MnO	0.14	0.12	0.12	0.2
MgO	1.44	1.63	1.75	1.61
CaO	3.38	4.91	4.87	5.34
Na_2O	5.32	3.39	4.19	3.69
K_2O	2.70	2.74	3.27	3.2
P_2O_5	0.25	0.23	0.26	0.2
LOI	1.73	1.16	1.55	3.71
Total	99.71	99.00	99.15	98.99

The dome-like bodies are porphyric with a microlitic groundmass and an andesitic, latitic to trachydacitic chemistry. These volcanic rocks consist of plagioclase, zoned amphibole, minor biotite, quartz and titanite as phenocrysts, and microlites are presented by the same minerals.

The composition of the lava flows is mostly latitic. Subsidiary andesites, dacites and trachydacites are also present in minor amount too. These volcanic rocks are highly porphyric with microlitic groundmass. The phenocrysts (> 40 volume %) consist of plagioclase, zoned amphibole, minor biotite, and titanite; whereas the microlites consist of plagioclase and amphibole only. The accessory minerals are apatite, zircon, and Ti-magnetite. The lava flows contain fine-grained, fully crystallized inclusions consisting of the same minerals (plagioclase, amphibole and minor biotite), which comprise phenocrysts of different chemistry. The margins of the inclusions are marked by fine-grained quartz zone, which is interpreted as evidence of magma mingling.

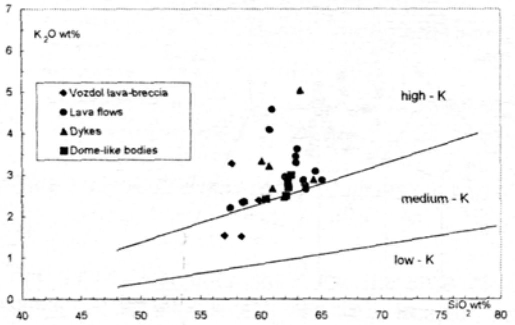

Figure 3. SiO_2 vs. K_2O diagram after Le Maitre (1989) for representative Chelopech volcanic rocks

The Vozdol andesites and latites to shoshonites display similar petrographic characteristics but their phenocrysts (plagioclase, amphibole, minor biotite, and titanite) are less abundant compared to the other magmatic rocks of the Chelopech volcano. The groundmass is composed of the microlites of the same minerals. K-feldspar is present as microlites only in the Vozdol andesitic rocks.

The composition of the dykes is andesitic, latitic to dacitic and trachydacitic. Plagioclase, amphibole, minor biotite, and titanite present phenocrysts of these rocks.

Mineral chemistry

The composition of plagioclase phenocrysts of the Murgana dome-like body $An_{38.5-42.2}$ (core) to $An_{38.7-46.2}$ (rim); those of the lava flows varies from $An_{42.5-48.2}$ (core) to $An_{30.1-53.9}$ (rim); for the Vozdol volcanic rocks phenocrysts display range from center $An_{50.8}$ to $An_{36.2}$ in the periphery; and for dykes $An_{44.1-46.2}$ (core) to $An_{40.7-44.2}$ (rim). The rims are variable in composition and substantially overlap the field of the phenocryst cores, the compositions of plagioclase microlites vary from An_{31} to An_{48}. K-feldspar microlites (Or_{86-93}) where only analyzed in the Vozdol volcanic rocks. The amphiboles for all volcanic rocks display $Mg^{\#}$ between 0.48 and 0.67. The contents of Si p.f.u. range between 6.40 and 6.55 and they plot on the limit of the magnesiohastingsite, pargasite, ferropargasite, hastingsite and Fe-edenite field of Leake et al. (1997). The composition of the amphibole crystals of the inclusions is different to the one of the volcanic rocks. It displays higher values of Mg# between 0.70 and 0.83 and is classified as magnesiohastingsite. The contents of Si p.f.u. of the amphiboles from the inclusions range between 5.90 and 6.10.

Trace elements

The MORB normalized patterns for the described magmatic rocks indicate enrichment of LILE and in lesser degree of some HFSE (Ce, Zr, P and Hf) with a strong negative Nb anomaly and a depletion of the Fe-Mg elements (Table 2). All these features are typical for subduction-related magmatic sequences due to the melting of sedimentary material in the subducted slab. In comparison to the volcanic rocks of an Andean-type active continental margin, the studied magmatic rocks show small K_2O, Ba and Hf enrichments and depletions of Nb, TiO_2, Zr and P_2O_5.

Table 2. Trace element composition of the representative volcanic samples

Elements (in ppm)	Dome-like body	Lava flows	Vozdol breccia	Dykes
Nb	7	7	6	9
Zr	121	98	127	123
Y	23	20	18	22
Sr	1430	781	871	641
Rb	72	63	46	102
Th	4	3	3	4
Pb	17	16	15	13
Ga	18	19	18	19
Zn	46	72	137	49
Cu	25	26	35	7
Ni	3	2	4	2
Co	50	10	13	7
Cr	10	14	15	13
V	96	127	139	89
Ba	870	1441	768	726
S	12	113	29	11
Hf	7	6	6	6
Sc	6	10	9	10
As	11	6	3	7
La		22.9	21	25.2
Ce		49.3	44.7	53.3
Pr		5.3	5.2	6.4
Nd		24	22.8	24.8
Sm		4.9	4.6	4.9
Eu		1.26	1.27	1.23
Gd		3.3	3	3.6
Dy		3.1	3	3.2
Ho		0.66	0.64	0.67
Er		1.8	1.7	1.8
Tm		0.26	0.24	0.26
Yb		1.5	1.4	1.6
Lu		0.22	0.18	0.25

All rocks have fractionated LREE and relatively flat HREE patterns (Stoykov et al., 2002), as typically found in subduction related volcanic rocks. The LREE enrichment ranges from 33 to 105 times chondritic, whereas La_n/Yb_n ratios vary from 10 to 13. Middle and heavy REE show relatively flat patterns, generally within 5-30 times that of chondritic ones. An Eu anomaly is not observed, which suggests that there was no plagioclase fractionation involved in genesis of the studied andesitic rocks. The data can be interpreted in terms of a chemically zoned magmatic chamber (according to the model of Hildreth, 1981). The rocks from the Murgana dome-like body show slightly enriched values of the LREE compared to the lava flows and the Vozdol volcanic rocks.

Sr and Nd isotopes

The Sr isotope ratios of the magmatic rocks from the Chelopech volcano and dykes display a small range between 0.7049 and 0.7055 after a 90 Ma correction (Stoykov et at., 2002). Generally $^{87}Sr/^{86}Sr$ ratios fall within the field previously defined by Kouzmanov et al. (2001) values from 0.7046 to 0.7061 (after 80 Ma correction) for the volcanic (andesite and dacite) and plutonic (granodiorite and granite) rocks from the southern part of the Central Srednogorie volcano-intrusive area.

Table 3. Sr and Nd Isotope composition

	$^{87}Sr/^{86}Sr_{90Ma}$	$^{143}Nd/^{144}Nd_{90Ma}$
Murgana dome-like bodies	0.7054	0.5125
Lava flows	0.7050	0.5125
Vozdol lava-breccia	0.7049	0.5124
Dykes	0.7055	0.5125

The Nd isotope ratios of the magmatic rock from the Chelopech volcano and dykes display a small range 0.5123 to 0.5125 after a 90 Ma correction.

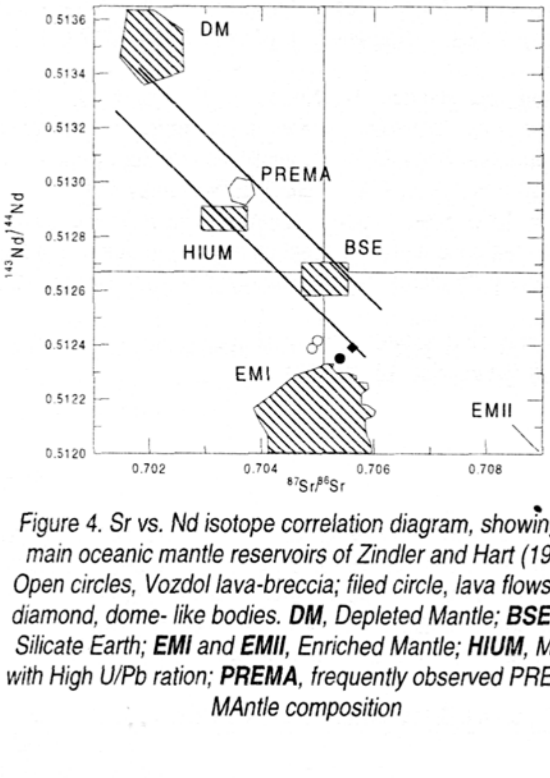

Figure 4. Sr vs. Nd isotope correlation diagram, showing the main oceanic mantle reservoirs of Zindler and Hart (1986). Open circles, Vozdol lava-breccia; filed circle, lava flows; filed diamond, dome- like bodies. ***DM****, Depleted Mantle;* ***BSE****, Bulk Silicate Earth;* ***EMI*** *and* ***EMII****, Enriched Mantle;* ***HIUM****, Mantle with High U/Pb ration;* ***PREMA****, frequently observed PREvalent MAntle composition*

CONCLUSIONS

The Upper Cretaceous volcanic rocks of the southeastern part of Etropole Stara planina are located in the central part of the Srednogorie zone. The magmatic products display Ca-alkaline to shoshonitic affinity. They are probably of Turonian age. The magma evolved from more acid volcanic rocks with 61-64 wt% SiO_2 of the earlier products (dome-like bodies, lava and agglomerate flows) to the to more basic ones with 55.5-58 wt% SiO_2 of the letters (Vozdol lava breccia neck). This chemical evolution and the absence of an Eu anomaly probably indicate a chemically zoned magmatic chamber. Magma mingling was a ubiquitous process and together with fractional crystallization controlled the evolution of the andesitic magmas of the Chelopech volcano. The behavior of the trace elements is similar to the andesitic rocks formed an active continental margin. The Sr and Nd isotope signature suggests derivation of melts generated in a mantle source modified by the addition of crustal material.

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MINERAL OCCURRENCES IN THE BADIA REGION/NE JORDAN

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ABSTRACT
The Cenozoic continental basaltic rocks exposed in northeast Jordan are the northern extension of the North Arabian Province, which covers a total of more than 46,000 km2, of which 12000 km2 are only in Jordan. The mineral resources of the Badia region in northeast Jordan are very important to the national economy of Jordan, due to the fact that unlimited reserves of industrial commodities are widely distributed in the region. Therefore, one of this research aims of this map is to indicate the occurrences and distribution of the mineral resources in the northern Badia Region. To facilitate study, evaluate and exploit these resources for the investors in this sector. The idea was to shed light the location of the previously indicated mineral resources and to indicate the location and distribution of the newly discovered localities during this mapping project. The paper summarizes the available data published on the mineral commodity and the results of the analysis, which were carried out as part of this work.

1. Introduction

The mineral resources of the Badia region are very important to the national economy of Jordan, due to the fact that unlimited reserves of industrial commodities are widely distributed in the region. Therefore, one of the main aims of this paper is to indicate the occurrences and distribution of the mineral resources in the northern Badia Region. To facilitate study, evaluate and exploit these resources for the investors in this sector. The idea was to show on the map the location of the previously indicated mineral resources and to indicate the location and distribution of the newly discovered localities during this mapping project. Therefore, each mineral resource was given a different symbol shown on the map. The paper summarizes the available data published on the mineral commodity and the results of the analysis, which were carried out as part of this work.

2. Basalt

(a) Occurrences. it is the most widespread mineral resources in the mapped area, covering more than 70%. Two quarries were indicated in the map, one is less than 3km to the north of Tell Hassan and the second is about 22km to the east of Safawi. Several potential areas are present in the area, mainly the extensive exposed Abed Olivine Phyric Basalt Formation, which can be considered as suitable occurrences for future exploitation programs.

(b) Reserves and Production. The area holds unlimited reserves of basalt and because of its wide availability, it was formerly used for construction purposes. During the Nabatian, Roman Byzantine and early Arabic periods, basalt was extensively used in Northeast Jordan. It is evidenced from the ancient castles (Qasr) in the area such as Qasr Al Azraq, Qasr Usaykhim, Qasr Uaynid, Qasr al Huwaynit Deir el Kahf and Umm el Jimal, which are built completely from the basalt. The old buildings of Al Azraq town and the BRDP center at Safawi (an abandoned oil pumping station, H5) were also built of basalt. In the present time, basalt is not used anymore as a building stone in the area with few exceptions.

(c) Physical and Technical Properties. The physical characteristics of basalt as resistance to weathering and corrosive chemicals, durability and strength with a low porosity and permeability makes it a potential source as a decorative stone (Table 1).

Table 1. Physical properties of the basalt of NE Jordan, (from Nawasreh, 1993)

Density (g/cm^3)		2.50-2.77
Unconfined compressive strength (kg/cm^2)		225.5-5437
Specific gravity (g/cm^3)	bulk	2.66-2.80
	saturated surface	2.70-2.85
	apparent	2.82-2.92
Water absorptipn(%)		1.47-2.28
Abrasion (%)		23.4-28.4
Crushing strength (atm)		1700-2200
Cohesive strength (atm)		320-440
Thermal conductivity for melt at STP* (cal/cm^2)		1-30
Thermal conductivity for rock at STP(cal/cm^2)		4-6
Heat capacity at constant pressure (cal/c/g)		0.2-0.3

*STP *is standard temperature and pressure*

3. Rock Wool and Cast Basalt

(a) Definition. Rock wool (an artificial product) is composed of extremely thin silicate fibers, where basalt forms more than 70% of the raw material with siliceous or argillaceous rock, make up the rest.

(b) Occurrences. As was indicated earlier, basalt is the most widespread mineral resource in the area, however, those areas suitable for rock wool and cast basalt are not indicated in the map, because detailed studies to verify there physical and chemical properties was not carried out. The evaluation of the NE Jordan basalt for cast industry is highly recommended.

(c) Uses. Rock wool is used in insulation and energy conservation. These can be used as loose "wool", but can also be bonded together with resin binders to form rolled mats, rigid panels and pipe sections. Rock wool has the following properties:

- Low coefficient of heat transfer;
- High acoustical insulation;
- Weather, water, & damp proof;
- Light in weight;
- Noncombustible;
- Non corrosive.

(d) Physical and Technical properties. Rock Wool: Basalt suitable for this wool industry needs to have low $Ti0_2$, MgO, FeO contents and high alkali contents. Homogeneity of the raw material, fine-grained texture and low melting point are also important. The basalt exposed in NE Jordan are almost similar to those quarried by the Jordan Rock Wool Company and are of good potential rock wool industry. The standards requirements for rock wool are as follows:

Ma of acidity=($Si0_2$+Al_20_3)/(MgO+CaO) =2.5-3.0

Cast basalt (petrurgy): It requires a raw material similar in composition to that used by rock wool industry. Basalt must be alkaline, undersaturated with respect to silica, homogeneous with a constant composition, fine-grained and not weathered. A raw material with a low melting point is necessary i.e. melting is executed on an industrial scale using 10-30 cm pieces at 1300° C. Table 3 shows the chemical and mineral composition of basalt needed for cast basalt. *Table 3 Chemical and mineralogies! composition for cast basalt, after Ibrahim (1997).*

Table 2. Chemical and mineralogical composition for cast basalt, after Ibrahim (1997)

SiO_2 (%) Al_2O_3 (%) TiO_2 (%) Fe_2O_3(%) FeO (%) MnO (%)	43.5-47.0 11.0-13.0 2.0-3.5 4.0-7.0 5.0-8.0 0.2-0.3	CaO (%) MgO (%) Na_2O (%) K_20(%) P_20_5 (%)	10.0-12.0 8.0-11.0 2.0-3.50 1.0-2.0 0.5-1.0
magnetite pyroxene olivine plagioclase nepheline		4-8 45-60 10-15 15-25 0-10	

The standards requirements for cast basalt are as follows:

- Ma = (SiO+AI203)/(MgO+CaO) = 1.1-3.0;
- Mb = (Ab'+2.3Di' + 1.8Hy') CIPW normative = 123-136.

4. Scoria (Pozzolana)

(a) Occurrences. Scoria (Pozzolana) is widely distributed in the map area, such as Tell Rimah, Tell Hassan, Jibal Zumal al Hashshad (two cones), Jabal Mafarid al Asfar (three cones), Jibal al Aritayn (two cones), Jibal al Manasif al Gharbya (three cones), Jibal al Manasif ash Sharqiyya (six cones), Jabal al Fahem., south and southeast of Jabal al Asfar (six cones), Tulul Ashaqif (six cones), Jabal ed Dhirwa, Tulul el Bassus (three cones) and Tulul el Ghussaun (three cones).

(b) Uses. The scoria deposits from all the above-mentioned cones are of great potential for use in cement industry, in agricultural applications and as lightweight aggregates. In the cement industry, pozzolana is added to the cement for two purposes:

- A corrective material for Fe content in the cement mixture in proportions up to 10% by weight before the reaction in order to produce Portland cement;
- An additive material, to standard Portland cement in proportions from 10-30% by weight at low temperature and then ground finely to produce Portland pozzolanic cement.

(c) Reserves and Production. Exploitation of scoria is a relatively simple, surface mining operation. Expected reserves of pozzolana in the map area are huge, estimates from some of the important volcanic cones are illustrated Table 4.

Pozzolana is currently quarried from Tell Rimah and Tell Hassan for use in cement industry and in agricultural applications, by the Jordan Cement Company and Al-Qawasmeh Company. The total production of pozzolana from the map area in the last four years exceeds 600,000 ton, as shown in Table 5.

Table 4. The estimated reserves of pozzolana in the Badia region. Data from Jordan Cement Company (1985) except * from Al-Malabeh(1993).

Locality	Reserve (x 10^6 ton)
J. Fahem*	10.46
J Aritayn (N)	67
J. Aritayn (S)	102
J. Ufayhimat (N)	25
J. Ufayhimat (S)	21
J. Jilad	68
J. al Manasif al Gharbya	91
J. al Manasif ash Sharqiyya	6
J. Ushayhib	4
Total	394.46

Table 5. Annual production of pozzolana from the map area in thousand ton. * data from Abed and Omari (1994)

Year	1992*	1996	1997	1998	1999
Tell Rimah		91.862	222.621	100.757	199.892
Tell Hassan		3.400	4.509	10.396	11.900
Total	410	95.262	227.130	111.153	211.792

(d) Physical and Technical Properties. Some of the important physical parameters of the pozzolana in the Badia region are given in Tables 6 and 7.

Table 6. Physical parameters of Tell Hassan and Jabal Fahem pozzolana (from Al-Malabeh, 1993). Hco is cone height and Wco is cone basal width

Parameters	Tell Hassan	Jabal Fahem
Water absorption	10.8 %	9.2 %
Main colors	gray, gray to brown	brown, gray, reddish-brown
Abrasive value	35 %	52 %
Unit weight	1010 kg/m^3	980 kg/m^3
Specific gravity	1.801 g/cm^3	1.79g/cm^3
Aspect ratio		Hco = 0.026 Wco

Table 7 Selected physical properties of the pozzolana in the area. Data from Jordan Cement Company (1985).

Locality	Hydraulic Factor	Strength (Nt/cm^2)	Specific Gravity (g/cm^3)	Loss on Ignition (%)
J. Fahem	41	1212	1.4	5.6
J. Aritay n (N)	52.5	1190	*1.57*	6.5
J Aritayn (S)	31	810	1.85	6.6
J. Ufayhimat (N)	39	1112	1.78	5.8
J. Ufayhimat (S)	37.5	729	1.64	9.7
J. Jilad	22	-	1.7	5.8
J. Al Manasif al Gharbya	41	1005	1.59	2.7
J. Al Manasif ash Sharqiyya	19	280	1.58	4.7
J. Ushayhib	28	210	1.64	2.6

For cement industry, the hydraulic factor is an important parameter, the higher is this factor the more suitable is the material. The hydraulic factor of the pozzolana varies from 19 to 52.5. It was reported by the Jordan Cement Company (1985) that the presence of zeolites enhances significantly the hydraulic factor of the pozzolana.

During this mapping project, selected samples from the pozzolanic material of Jabal ed Dhirwa were evaluated. The study revealed that pozzolana is characterized by bad cementing, good sorting and with specific gravity of 1.6 g/cm3. Size classification of Jabal ed Dhirwa pozzolana.

Table 8. Chemical composition of Jabal ed Dhirwa pozzolana

Major Oxide	Wt%	Major Oxide	Wt%
SiO2 (%)	40.24-46.63	MgO (%)	5.00-5.07
CaO (%)	11.88-16.00	TiO2 (%)	1.33-1.45
Fe2O3 (%)	7.66-8.43	K2O (%)	1.03-1.22
Al2O3(%)	12.50-13.86	Na2O(%)	2.68-5.12

5. Zeolites

(a) Definition. Zeolites are a group of hydrated alkali alumino-tektosilicates, which are characterized by their open crystalline structure.

(b) Occurrences. In the mapped area, zeolites were indicated in several areas including Jabal Aritayn (N) and Jabal Aritayn (S), Tell Rimah, Tell Hassan, Tulul Al Ashaqif and Jabal Hannoun. Phillipsite tuff was discovered by Dwairi (1987) in Jabal Aritayn (S), whereas, the economic zeolite deposits in the other localities in the Badia region were discovered by Ibrahim, (1996b) occurring in the Aritayn Volcaniclastic Formation and are restricted to a diagenetic zone with variable thickness from few meters up to 20 m.

(c) Uses. Based on their unique structure zeolites can be used in the following applications:

- Slow release fertilizers and soil amendments;
- Industrial and municipal wastewater treatments;
- Gas and oil purification;
- Animal nutrient, fish and poultry farming;
- Reduce strong odor intensity and ammonia gas concentration from farms.

(d) Reserves and Production. Quantitative determination of zeolites indicate that the mineral content range between 20% to 65% by weight (Ibrahim, 1996b; Ibrahim and Inglethorpe, 1996). Preliminary studies indicate the presence of a huge reserve. Small quantities of the zeolitic tuff is extracted from Jabal Aritayn (N) every year (Table 9) by an American-Jordanian Company (Green Technology) and exported to Israel. The zeolitic tuff product is activated by synthetic fertilizers for agricultural and gardening uses. Unfortunately, zeolite deposits from Tell Rimah area are over exploited as being mined along with pozzolana for the Jordan Cement Company.

Table 9. Annual production of the zeolitic tuff from Jabal Aritayn (N)

Year	1997	1998	1999
Production (Ton)	3193	543	408

(e) Physical and Technical Properties. Using simple mineral processing techniques, zeolite grade could be concentrated to the range between 85% and 96% (Ibrahim, 1996b; Ibrahim and Ingelthorpe, 1996). The identified zeolite minerals are phillipsite, faujasite and chabazite. From the Badia region 8 zeolite concentrates were produced, and were given the symbols: Zeordan 1 - Zeordan 8 (Ibrahim, 1996b). Experimental investigations on the zeolitic tuff emphasized the importance of the Jordanian zeolites for use in wastewater treatment plants and as a soil conditioner and as slow-release fertilizer.

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MINERALOGICAL CHARACTERISTICS OF SUPERGENIC MINERALIZATIONS IN COPPER DEPOSITS OF CENTRAL SREDNOGORIE

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ABSTRACT
82 minerals and their varieties have been established in the composition of the supergenic mineralizations in copper deposits of Central Srednogorie , i.e. 30% of all described for the region, 12 of them being new for our country .The following characteristic supergenic minerals have been found from the comparative mineralogical analysis : hematite, hydrohematite, goethite, lepidocrocite, malachite, azurite, kaolinite, montmorillomite, bornite, chalcococite, covellite, djurleite, digenite, gold. Specifical minerals for copper and pyrite deposits are : melanterite, gypsum, chalcodone, opal, chalotrichite, alum , sulphure, amilite; for copper and porphyritic: hydromica, hydrogoethite, elite, diskite, halloysite, nacrite, maghemite, martite, mushketovite, chrysocolla, chalcanthite, brochantite, thenardite, tenorite, cuprite, copper, antlerite and for copper molybdenum and porphyritic: specularite, hematolite, hydro-goethite, molybdite, chrysocolla, spherosiderite. Supergenic minerals have a different qualitative disribution. Special mineralogical characteristics are a reliable criterion for exploring new copper deposits in the region and for determining the character of hypogenic mineralization. Supergenic mineralizations of copper deposits are a source for production of copper, gold, kaolinite and other mineral reserves.

INTRODUCTION

Mineralogy of supergenic mineralizations is various. Over 25% of all discovered mineral types and varieties have been found in them. 82 minerals and their varieties or 30% of the established up to now in this region have been described in the composition of supergenic mineralizations of copper deposits in Central Srednogorie. 14 of them are completely new for our country. Author has carried long-lived mineralogical investigations of supergenesis of copper and pyrite deposits of Radka, Elshitza, Krassen and Chelopech, of copper and porphyritic deposits of Tzar Assen, Assarel, Vlaikov vruh, Petelevo and Popovo dere and of copper and molybdenum and porphyritic – Elatzite and Medet. Results of these studies are being generalized and added in the present paper. The main target is to establish the characteristics of supergenic mineralizations for three types of genetic deposits by comparable mineralogical analysis. This helps in drawing mineralogical criteria when making an assessment deposits. The zones of supergenesis are a source of mineral raw materials. Studing their mineral composition helps in improving their production and treatment technology.

METHODICS

Terrain observations have been made for a long time not only of ground surface exposures but of the entire depth of the zones of oxydation and of secondary sulphide processing during the entire period of ore production from copper deposits in the regoin. The selected over 2 500 pieces of samples have been observed under a bineye-lense stereomicroscope. These are mineral mixtures forming porous cavernous and spongy aggregates. 320 thin sections have been studied in a suitable and reflected light. Optical properties such as: reflection, bi-reflection, colour, effect of anisotropy, internal reflections, diagnostic fretting and reactions of colouring have been applied. Many of the optical inverstigations have been carried out in cooperation with E. Afanasieva and M. Isaenko and have been compared to the published by them in 1981 determining tables.

Over 160 powderd samples have undergone a semi-quantitative spectral analysis, quantitative chemical analysis of Cu, Au, Ag, Pb, Zn, Fe, Mo and complete silicate analysis. 198 monomineral samples have been studied under bineye- lense stereomicroscope. Powder radiogrammes (96) and radiodi-fractogrammes (56); investigations with intra-red spectroscopia (65); differential and thermal analysis (28) have been made in the laboratories of UMG. 356 electronic and microscopic investigations have been made in MGRI – Moscow by enlargement from 2000 to 8000 times and microdifraction of separate mineral particles. 95 minerals have been studied by microdrilling analysis in Evrotest – Ltd - Sofia and in IGEM-Moscow. Each of the mentioned methods has a different permissing ability. Mineral diagnostics has been done by several methods. Quantitative distribution of supergenic minerals has been studied.

Table 1 shows the quantitative distribution of supergenic mineralizations of the main genetic types of copper deposits in Central Srednogorie in a reductional and oxydational stage. It generalizes the earlier made studies of the author published in 8 publications given in Referances.

RESULTS

Mineralogical characteristics of supergenic mineralizations of copper and pyrite deposits

During the reductional stage of mineral formation in the zones of secondary sulphide processing of copper and pyrite genetic type of deposit considerable quantities of chalcocite, bornite, covellite, anilite and of the non- ore minerals- kaolinite and montmorillonite have been formed. Secondary typical minerals are gold, djurleite, digenite, neodigenite and from the nonore minerals- chalcedone, halloysite and hydromica. Rarely met minerals are elite and hydrobiotite. Hydrogenic minerals are formed in a wide space from waekly acidic to neutral medium according to the scheme of E. Afanasieva and M. Isaenko (1981) using the data of R. Garelse and V. Schebrina. The quantitative storage of copper sulphides determines the industrial signifficance of the zones of secondary sulphide processing for copper, gold and silver production. Typical hypergenic minerals are anilite, neodigenite and bornite. (Table 1).

Cousiderable quantities of hematite, goethite with ferrous oxides and hydroxides in the mineral mixture "limonite", chalcedone, alum, melanterite, yarozite are beeing precipitated in the composition of oxidizing zones of copper and pyrite deposits (fig. 1). Kaolinite, hydromica, montmorillonite, gypsum, chalcanthite, malachite, azurite, lepidocrocite, hydrohematite, elite, diskite, halloysite, halotrichite, sulphure, cuprite are of secondary quantitative deposition. Tenorite, opal and chrysocolla are rarely met. Gold is a typical metal. Gold content in the zones of oxidation of copper and pyrite deposits varies from 1g/t (Radka deposit), 2g/t (Chelopech and Krassen deposits) and 3g/t (Elshitza deposit). That defines the zones of oxidation as a source of gold production (fig. 4).

Mineral formation is realized in an acidic medium as a result of which considerable quantities of sulphate minerals are being deposited. That is a characteristic feature of the zones of oxidation of copper and pyrite type deposits. The deposition of considerable quantities of hematite and "lemonite is typical due to which local population has been using them for ochre since ancient times.

Mineralogical characteristics of supergenic mineralizations of copper and porphyritic deposits and copper and molybdenum and porphyritic deposits

Considerable quantities of chalcocite, covellite, djurleite and digenite are being deposited during the reductional stage of these genetic type deposits. Secondary minerals are martite and specularite. Quantitative deposition of kaolinite, diskite, hydromica, halloysite and montmorillonite is typical for copper and porphyritic deposits. Gold can be rarely found. Copper contents in the zones of secondary sulphide processing vary from 0,2 to 3,5%; gold- from 0,06 to 1g/t; silver- from 5 to 20g/t; molybdenum- from 1 to 10g/t; tellurium- from 0,5 to 20g/t; bismuth- from traces to 0,9g/t. That determines their importance for copper, gold and silver production and from copper-porphyritic type deposits (Assarel) for kaoline mineral raw material as well.

Mineral formation took place in weakly acidic to acidic raw material. Specific minerals for copper and porphyritic deposits are: maghemite, martite, mushketovite, and for copper and molybdenum and porphyritic deposits- specularite.

Considerable quantities of montmorillonite, kaolinite, halloysite (fig. 2) goethite,lepidocrocite and ferrous oxides and hydroxides in the mineral mixture "limonite", cuprite, malachite, azurite, chalcodone, chalcanthite, chrysocolla, brochantite are being deposited in the zones of oxidation of copper and porphyritic deposits. Copper, hematite, tenorite, hydrogoethite, elite, diskite, alunite and alum have secondary quantitative deposition. Typical for these zones minerals are rarely found: nacrite, antlerite, spangolite, thenardite, dioptase and electrum. (Table 1). Mineral content of the zones of oxidation of copper and molybdenum and porphyritic deposits is characteristic for the smaller quantitative deposition of clay minerals (Table 1). Typical supergenic minerals in their composition are: specularite, hematolite, molibdite, (fig. 3), chrysocolla, malachite, azurite, spherosiderite and hydrogoethite. The following minerals can be rarely met: kottigite, libethenite, mimetite, atelestite, chalcophyllite, feromolybdite, goslarite, alunogen, rosenite,linarite,szomolnokite, anglesite, montmozillonite. The only malachite with juwelleric qualities in their content has been found.

Table 1. Quantitative distribution of supergenic minerals in reductional and oxidational stage of genetic type deposits

Class Mineral	Reduc Cu pyrite	tion Cu porphyrite	stage Cu-Mo-porphyrite	Oxida Cu pyrite	tion Cu porphyrite	stage Cu-Mo-porphyrite
1	2	3	4	5	6	7
Elements						
Gold	+++	++	++	+++	+++	++
Copper					++++	++
(Electrum)					++	
Sulphuze				+++	+	+
Sulphides and sim. compounds						
Bornite	++++	+++	+++	++	++	++
Chalcocite	+++++	+++++	++++	++	++	++
Anilite	++++					
Djurleite	+++	++++	+++			
Digenite	+++	++++	+++			
Covellite	++++	+++++	++++			
Wittichenite		++				
Aikinate		++				
Neodigenite	+++					
Oxides and hydroxides						

1	2	3	4	5	6	7
(Maghemite)		++++			++	++
(Martite)		++++	+++		+++	+++
(Mushketovite)		+++				
(Specularite)		++++	++++		++	+++
Hematite				+++++	++++	+++
Hydrochematite				+++	+++	+++
Goethite				+++++	+++++	++++
Chalcotrichite					++	
Hydrogoethite					++++	+++
Lepidocrocite				+++	++++	+++
Srelimonite				+++++	+++++	++++
Tenorite				++	+++	++
Cuprite				+++	++++	++
Fe wad						+
Zincite						+
Claudetite						+
Fluellite						+
Silicates						
Kaolinite	++++	+++++	+++	++++	+++++	+++
(Illite	++	+++		+++	++++	+++
Diskite		+++++		+++	++++	++
Nacrite					++	
Halloysite	+++	+++	++	+++	++++	+++
(Ferrihalloysite)					++	
(Metahalloysite)					++	
Hydromuscovite					++	++

1	2	3	4	5	6	7
Hydromica	+++	+++++	+++	++++	+++++	++++
Ewladonite					++	
Montmorillonite	++++	+++++	++	++++	+++++	+++
Chrysocolla				++	+++	++
Hydrobiotite	++	++	++	+++	+++	++
Dioptase					++	
Edingtonite						
Phosphates, arsenates, vanadates						
Scorodite					+	
Andrusit					+	
Hemalolite					+	++
Kiottilite						+
Libethenite						+
Mimetite						+
Atelestite						+
Chalcophyllite						+
Wolframs and molybdates						
Molybdite						++
Feromolybdite						+
Sulphates						
Alunite				+++	++++	++
Alum				+++++	++++	+++
Barite					++	
Melanterite				+++++	+++	++
Jazorite				++++	+++	++
Gypsum				++++	+++	++
Chalcanthite				++++	+++++	+++
Brochantite					+++++	++
Halotrichite				+++	++	++
Thenardite					++	++
Goslarite						++

1	2	3	4	5	6	7
Antlerit e					++	
Spang olite					++	
Alunog en						++
Roseni te					++	++
Linarite						+
Szomo lnokite						++
Anglesi te						++
Montm orillonit e						+
Carbon ates						
Calcite					++	
(Mn calcite)					++	
Azurite				++++	+++++	++++
Malach ite				++++	+++++	++++
Juvelir en malach ite						++
Sphero siderite					++	++

Note: mineral is: +++++ in considerable quantities
++++ in secondary quantitative deposition but deposition
+++ in small quantities
++ rarely found
+ very rarely found

Cu-copper; Cu- Mo- copper- molybdenum ;sulphides and simular compounds.

Mineral formation took place in acidic and slightly acid medium for copper- porphyritic type depositsand in neutral medium for copper- molybdenum porphyritic type deposits.

CONCLUSION

Industrial minerals for secundary sulphide processing zones for all copper deposits of Central Srednogorie are: chalcocite, covellite, djurleite, digenite, bornite, gold. Industrial minerals for oxidation zones are: gold, alum, hematite- for copper-pyrite deposits, malachite, azurite, molybdite- for copper- molybdenum- porphyritic type deposits. Gold (fig. 4) in greatest quantities is in the content of oxidation zones of copper- pyrite deposits. Pouring on the aggregates with acid brings to gold particles with the dimension of 1 mm (fig. 5).

Figure 1. Zone of oxidation of copper and pyrite deposits: hematite, goethite, yarosite and ferrous oxides replace compact pyrite, plished section, increased 410x.

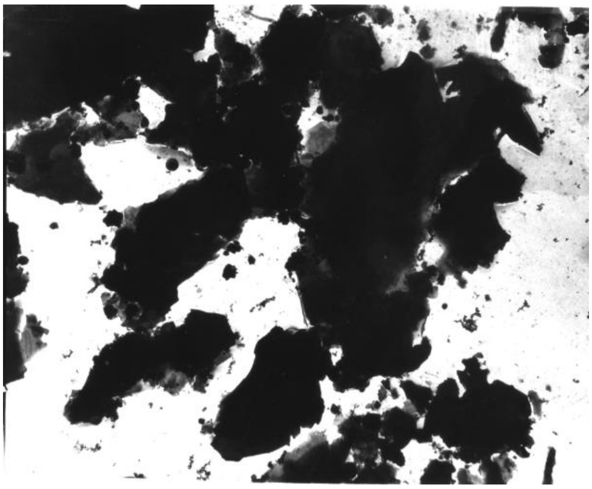

Figure 2. Zone of oxidation of copper and porphyritic deposits: mineral mixture of montmorillonite, kaolinite, halloysite, electronic microphotography, suspension, increased 30 400x

Figure 3. Zone of oxidation of copper and molybdenum and porphyritc deposits: molybdite, electronic microphotography, suspension, increased 30 400x

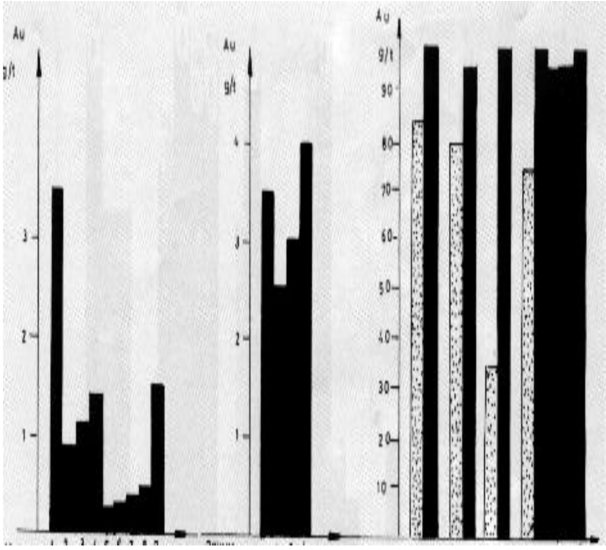

Figure 4. Gold contents in: left – zones of oxidation of copper deposits: Elshitza, Radka, Krassen, Chelopech, Tzar Assen, Assarel, Elatzite, Petelevo (from left to right); middle- terraces of the rivers: Banska Luda Yana, Luda Yana, Topolnitza (Panagiursko), Malak Iskar (Etropolsko) (from left to right); right – gold content (from…to…) of deposits of Radka, Chelopech, Elatzite of river, Banska Luda Yana, Topolnitza, Zlatishka, Malak Iskar (from left to right).

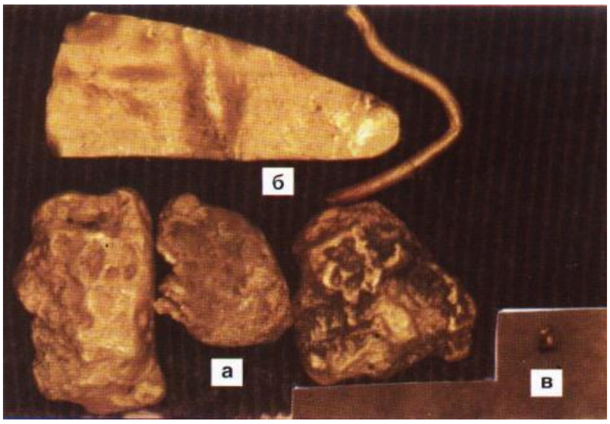

Figure 5. Gold from: a) - terrace of the river of Banska Luda Yana: composition: Au=98,50%; Cu=0,74%;Fe=0,70%; b) - cuttings of juwelleric gold found in the river of Banska Luda Yana, composition: Au=81,40%; Ag=17,11%; Cu=0,79%; Fe=0,70%; c) - zone of oxidation of copper and pyrite deposit "Elshitza", composition: Au=80,40%; Ag=19,60%, increased 5x.

There composition corresponds to gold content from the river terraces in this region (fig. 4). That gives us ground to accept that the main source of deposition of wash gold in the region are infact the zones of oxidation of copper mineralizations. It is of high mill test. The river terrace gold in its composition is close to the gold in the juwelleric cuttings found in the local rivers. Therefore in ancient times gold in the region of Panaguiriste has been extracted from river terraces. Articles of art such as the " Golden treasure of Panaguiriste" have been produced.

Supergenic mineralization are the first geological objects we meet. Comparable mineralogical analysis shows the common features in their mineralogical characteristics. Differences in quantitative deposition of supergenic minerals as well as in their mineral composition have also been established. These mineralogical characteristics are typical for the zones of oxidation found directly on the earth surface. For instance, considerable deposition of hematite, goethite, chalcodone, alum, melanterite, yarosite, gypsum, chalotrichite is typical for copper and pyrite type of deposits. Quantitative deposition of kaolinite, halloysite, hydromica, montmorillonite, mineral mixture "limonite", alunite, chalcanthite, brochantite, secondary staged- copper, malachite, azurite is typical for the zones of oxidation of copper and porphyritic types of deposits. It is rare to find minerals such as: nacrite, ferri and methahalloysite, chalcotrichite, maghemite, scorodite, andrusit, thenardite, antlerite, spangolite. Ferrous hydroxides and oxides, specularite, malachite, azurite are deposits in the zones of oxidation of copper and molybdenum and porphyritic deposits, as well as the typical for them: zincite, claudenite, fluellite, hematolite, libethenite, mimetite, atelestite, chalcophyllite, molybdite, feromolybdite, alunogen, linarite, rosenite, szomolnokite.

The discussed supergenic mineral associations can be considered a reliable critereon in prospecting and exploring new copper deposits in the region. The copper type deposit in depth can be determined by the mineral composition of the earth surface zones of oxidation.

Mineralogical characteristics of supergenic mineralizations give the chance of industrial utilization of these valuable mineral raw materials for copper, gold, kaoline, alum and ochre production. Moreover, present investigations contribute the study of the Central Srednogorie deposits as well as the copper- pyrite and copper- porphyritic and copper-molybdenum- porphyritic genetic types of deposits all over the world.

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CHARACTERIZATION OF THE SULFIDE MINERALIZATION IN METAMORPHOSED SERPENTINITES NEAR ZHIVKOVO VILLAGE, CENTRAL SREDNA GORA, BULGARIA

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ABSTRACT
Sulfide mineralization manifested by monosulfide solid solutions (*mss*) of pentlandite and pyrite is studied. *MSS* include troilite and pyrrhotite (monoclinic and hexagona). The minerals are found in an artificial outcrop in the central part of a small serpentinite body at about 3 km SW of Zhivkovo village (Ihtiman region). The serpentinites are built by antigorite, chrysotile, carbonate, and relics of orthopyroxene and olivine. The widespread minerals, which give the outlook of the ore mineralization are *mss* and pentlandite embedded in serpentinite and observed as intimately interweaved aggregates of elongated (veinlets, lamellae) or irregular form. Their size varies in wide ranges with the length of the former reaching 5 to 6 cm while the irregular ones display 0.6 cm width and up to 1.5 cm length. Pyrite is met more rarely that the other minerals and is represented by individual grains of irregular or crystal (mostly cubic crystals) form. Initial phase of oxidation of pyrite is rarely observed and, if this case, it associates with Fe-oxides (or hydroxides). Other ore minerals are found very rarely represented mainly by spinelides (magnetite and chromite).

INTRODUCTION

On many places in the Precambrian metamorphites of Central Sredna Gora plenty of small ultrabasite bodies (single or groupings) are found the predominant part of them being strongly altered or almost entirely serpentinized. The data about these bodies in the Bulgarian geological literature are scarce and as concerns the sulfide mineralizations only the presence of pentlandite has been discussed (Kozhoukharov et al., 1980). The present study presents data for the mineralogical features of a sulfide mineralization found in a relatively small body cropping out at about 3 km SW of Zhivkovo village (Ihtiman region), quite near to the road Ihtiman-Samokov. Petrographic characterization of the studied metamorphosed serpentinites is also performed. The mineralization is found in an artificial outcrop in the central parts of the body sized some tens of m^2. In the past, many of the serpentinite bodies in the region have been prospected for manual production of small amounts of talc (Zhelyaskova-Panayotova and Bozhinov, 1989). During the last years this production has been stopped. At present, for juvenille-decoration purposes only manual processing of small blocks of relatively fresh serpentinite from separate bodies is performed. Due to the past activity the studied body is with removed cover of weathered mass and in depth fresh metamorphosed serpentinites crop out in which the sulfide mineralization is observed.

GEOLOGICAL SETTING

The serpentinized bodies in Ihtiman Sredna Gora are localized among Precambrian metamorphites in the rims of boudinage structures among gneisses and migmatites (Kozhoukharov et al., 1980). The above authors note that bodies are embedded in the rocks of the Boturche Group (in the frame of the Western Sredna Gora these rocks are related to the Garvanitsa series), which are represented by biotite gneisses, amphibolites, muscovite and two-mica schists, kyanite schists, and gneisses and biotite gneisses. According to the same authors, during the regional metamorphism new mineral association developed in a zonal manner over ultrabasites. The hydration of the primary rock-forming minerals afterwards has caused the formation of chrysotile, antigorite, serpophite, bastite, chlorite, and ore minerals (magnetite, chromite, and pentlandite).

METHODS OF STUDY

The microscopic observations in transmitted light was performed with microscope Amprival. Ore minerals were studied with optical microscope Leitz Orthoplan-Pol and electron microscope Philips SEM-515 in a regime of secondary and back scattered electron emission. The electron microprobe analyses (point and area quantitative scans) were performed on analytical attachment EDAX PV 9100 under the following conditions: U – 20-25 kV, I - 0.5 mA, beam diameter of 5 μm, count time of 80 s; lines and standards: FeKα and SKα (marcasite), NiKα (pentlandite), CoKα (cobaltite). Powder X-ray diffraction (XRD) studies of serpentinites and sulfides were fulfilled on a DRON 3M diffractometer (CoKα radiation; 40 kV, 28 mA). A sample taken from the richest ore part of the body was milled and a trial was made to separate a heavy mineral concentrate but the applied gravitational enrichment did not give any result. Applying electromagnetic separation, a sample was isolated, which contains mainly serpentinite minerals with inclusions of sulfides and magnetite.

PETROGRAPHIC CHARACTERIZATION

The studied body is located among Precambrian metamorphites – two-mica schists, biotite schists, gneisses, and amphibolites.

Mica schists are the prevailing rock varieties, which display a clearly expressed crystallization schistosity and homoblastic (lepidoblastic, granolepido-blastic) textures and are built by a fine-grained aggregate of quartz (30-40 wt.%), which is xenoblastic, isometric, or elongated along the schistosity as well as by preserved, in some cases partially serpentinized, fine-lamellar plagioclase (5-15 wt.%) represented by albite-oligoclase, $An_{8-10} \div An_{12-24}$). Quartz is observed also as monomineral stripes and lenses and displays a wavy, rarely mosaic darkening. Mica (30-35 wt. %) is with a sub-parallel orientation and is localized in bands, which determine the clear crystallization schistosity of the rock. The mica quantity ratio varies but biotite always prevails above muscovite. Chloritoid occurs as sporadic, strongly elongated lens-like aggregates, which are parallel to the schistosity. It is greenish, weakly pleochroic, fresh or partially chloritized along the cleavage surfaces. Kyanite is colorless, prismatic and platy, fresh, but in cases intensively sericitized with only separate relics remaining preserved. It was observed only in some of the mica schists. In cases, when the kyanite quantity increases it is observed that the mica schists go into kyanite schists. Garnet is rare but is always found. It is isometric and sized predominantly in the range 0.1-0.4 mm. The accessory minerals are represented by apatite, zircon, and rutile. Typical feature of the schists is the local manifestation of K-feldspar mineralization expressed in formation of thin bands and lens-like parts of pink K-feldspar.

Rare layers of pegmatite veins (thick from 0.5 to 1.0 m) are observed among the mica schists in the region. They are built by K-feldspar, plagioclase, quartz, muscovite, and accessory apatite.

The gneisses (biotite and two-mica) are schistous and on places display “eye”-like structure. They are composed of rare porphyroblasts of fresh or partially serpentinized plagioclase sized up to 1.5 cm, which determines the “eye”-structure of the rock. A fine-grained aggregate fills the space between porphiroblasts composed of xenoblastic quartz, plagioclase (oligoclase, An_{22-28}), and slightly pelitized K-feldspar. Quartz builds also not well-formed bands and lenses. Mica is represented by elongated biotite scales, which, together with muscovite, surround the plagioclase porphyroblasts. The accessory minerals are apatite and rutile as well as included in biotite zircon, around which there are formed pleochroic courts. The texture is granoblastic (for the stripes built mainly by quartz) and granolepidoblastic (in the places where mica prevails) and also porphyroblastic in respect to plagioclase.

Amphibolites crop out in the region of the studied body but no immediate contact between them and serpentinites is observed. They are dark-green to black with a banded structure and granoblastic and poikiloblastic texture. Composed are mainly of plagioclase (with plenty of zoisite inclusions) and amphibole, subordinate amount of zoisite and garnet as well as of accessory titanite, apatite, and magnetite.

Ultrabasites are intensively but irregularly serpentinized. The outer parts of the bodies are relatively fresher with preserved relics of the primary rock. In their peripheral parts there are developed talc-chlorite, talc-tremolite-chlorite, and talc rocks without clear spatial relations between them. Similar rocks are described by Kozhoukharov et al. (1980). According to the authors the smaller bodies are entirely replaced by tremolite, tremolite-chlorite, talc-tremolite-chlorite, and talc rocks, formed during the regional metamorphism.

The serpentinites from the inner parts of the bodies are built mainly by serpentine (antigorite and chrysotile) with admixtures of talc, chlorite, carbonate (in varying quantities), relics of ortopyroxene and olivine and accessory magnetite. In some cases the quantity of secondary minerals is great. Antigorite is colorless, platy, scaly or is coarse fibrous with a perfect cleavage and is developed on ortopyroxene. Chrysotile occurs in subordinate quantity and forms fibrous (most frequently cross fibrous) veinlets and cryptocrystalline aggregates replacing olivine at the periphery or along the fissures. Talc is scaly with perfect cleavage and high birefringence. Carbonate forms irregular bodies and associates with serpentine and talc. Chlorite is in a subordinate quantity and is colorless, with perfect cleavage and typical anomalous gray-green and yellow-green interfering colors. Along the cleavage surfaces it is partially replaced by talc. XRD analysis defines this phase as clinochlore. The texture is fibrous, cross-fibrous, and unclearly expressed ladder-like.. The mineral composition of serpentinites and the established relics of primary minerals give reason to propose a peridotite composition of the primary rock.

The talc-chlorite rocks are gray-green to dark green and on places with a rusty-brown color caused by the presence of iron hydroxides. They are built mainly by fine- to medium-scaly talc and clinochlore replaced by talc and serpentine along the cleavage surfaces. The secondary minerals are antigorite, lizardite, and tremolite. With the increase of talc content the rocks gradually go into talc ones.

The mineral composition of the talc-tremolite-chlorite rocks (talc, clinochlore, tremolite, antigorite, and lizardite) is determined in a transmitted light and confirmed by XRD phase analyses. Tremolte is colorless, thin-prismatic to needle-like and without clearly expressed contours. Characteristic cleavage below 124^{o} is observed in cross sections. On places along the cleavage surfaces it is replaced by talc.

The chemical composition of the metamorphosed serpentinites is given in Table 1. The content of SiO_2 is between 41.33 and 50.07 % with lowest quantities displayed for the serpentinites in the inner parts of the body and highest ones are typical for the peripheral parts - in the talc-tremolite-chlorite and most of all in the talc rocks. (Table 1). Inverse tendency is observed in respect to MgO content.

Table 1. Chemical composition of metamorphozed serpentinites

Oxides (%)	CS-11	CS-11/1	CS-9	CS-8	CS-10
SiO_2	41.33	41.59	46.90	49.47	50.07
TiO_2	0.02	0.10	0.02	0.06	0.06
Al_2O_3	2.16	2.84	2.04	2.54	2.98
Fe_2O_3	4.26	4.98	5.40	3.45	2.99
FeO	4.30	4.47	3.06	2.45	1.35
MnO	0.12	0.11	0.06	0.04	0.01
MgO	36.35	34.94	32.39	32.92	34.52
CaO	1.64	1.83	1.09	1.94	0.06
Na_2O	0.11	0.18	0.13	0.10	0.12
K_2O	0.08	<0.05	<0.05	0.08	0.08
P_2O_5	<0.03	<0.03	<0.03	<0.03	<0.03
ЗПН	9.57	9.05	9.01	6.67	7.59
Сума	99.94	100.09	100.10	99.72	99.83
(g/t)					
Cr	1880	1840	1940	1790	1920
Ni	1335	1341	1648	684	915
Cu	22.6	29.4	34.2	47.1	18.8
Co	60.6	63	40.3	20	19.9
Ag	<1	<1	<1	<1	<1
Au	<0.03	<0.03	<0.03	<0.03	<0.03

CS-11, CS-11/1 – serpentinites ;
CS-8, CS-9 – talc-tremolite-chlorite rocks;
CS-10 – talc-chlorite rocks.

MINERALOGY OF SULFIDES

The sulfide mineralization in the studied body is represented by monosulfide solid solutions of iron (*mss*), pentlandite, and pyrite and is incorporated in the serpentinite matrix of the rock. Minerals of widest distribution, which give the outlook of the ore mineralization are those of *mss* and pentlandite being in most cases intimately interweaved in complex aggregates, which build veinlets or single grains with irregular form. The latter are with size up to 0.6x1.5 cm, while the veinlets are wide up to 0.8-1.0 cm and long up to 5-6 cm. Dominating in this association are the *mss* minerals. Pyrite is the most rare mineral among sulfides and is represented by single grains of irregular or crystal form. It rarely associates with Fe-oxides (hydroxides).

Mss are represented by troilite and pyrrhotite (monoclinic and hexagonal), which always form complex aggregates of structure type "dissociation of solid solutions" (varieties - plate-like and framework). According to Kostov and Minceva-Stefanova (1984) the phases $Fe_{1-x}S$ are the widely distributed minerals of nickeline-type structure (NiAs) and play the role of an example for sulfides with varying superstructures and non-stoichiometric compositions. They are formed at various conditions and in nature three different pyrrhotites are formed: monoclinic, Fe_7S_8, hexagonal, Fe_9S_{10} - $Fe_{10}S_{11}$ - $Fe_{11}S_{12}$, and finally hexagonal troilite FeS. The similarity in chemical composition and structure results in a significant equality in optical properties of these minerals making them hardly differentiated in optical light (Reference book…). The studied monosulfide aggregates in reflected light are light-yellow in color and with unclear boundaries between the separate phases. The criterions for their differentiation are in the strongly expressed anisotropy of troilite while pyrrhotite is with richer color effects in the region of the yellow-brown and reseda-green nuances. The investigation of polished samples with magnetic suspension for diagnosis of monoclinic pyrrhotite gave a negative result. The XRD data, however, registered its presence in the complex aggregates. The powder XRD pattern in the interval 50 - 52^0 2θ (Fig. 1) displays the diffraction maxima of 1 1 4 peak (2.093 Å) characteristic of troilite, of 1 0 0 peak (2.072 Å) typical of hexagonal) pyrrhotite and of 3 2 2 peak (2.060 Å) - intense peak of monoclinic pyrrhotite. The broadening in the base of diffraction maximum 1 0 0 (of hexagonal pyrrhotite) is caused probably by partial overlapping with the peak 2 0 4 of monoclinic pyrrhotite. Also, in the XRD pattern at about 35^0 2θ there exists another peak, 1 2 2 (2.9710 Å), which belongs to monoclinic pyrrhotite. Despite the low intensity of these peaks they confirm the presence of monoclinic pyrrhotite, which is of less quantity than the other monosulfides in the sulfide aggregates and falls in the detection limits of the method. The obtained d-values for the studied *mss* are given in Table 2.

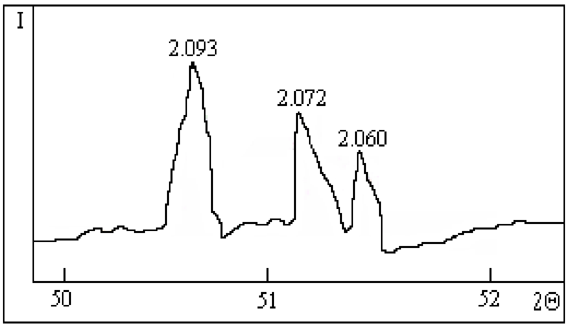

Figure 1. d-values (Å) 2.093 (troilite), 2.072 (hexagonal pyrrhotite) and 2.060 (monoclinic pyrrhotite) in the interval 50 - 52^0 2θ of the XRD pattern of mss from ultrabasites of Central Sredna Gora

Mss are most often intimately intergrown with pentlandite and rarely form single grains and veinlets. The form of the individuals is irregular, almost isometric (Fig. 2a) or profoundly elongated (lamellar) (Fig. 2b, c). The veinlets are composed of separate sub-parallel or oblique oriented fine lamellae with length of up to several mm. The polished surfaces of the separate monosulfides are homogeneous and without optically visible zoning.

Table 2. d-values (Å) of *mss* from ultrabasites of Central Sredna Gora

pyrrhotite				troilite	
monoclinic		*hexagonal*			
d, Å	I	d, Å	I	d, Å	I
2.971	10	2.985	8	4.748	9
2.640	8	2.647	9	2.983	8
2.629	8	2.072	10	2.668	7
2.068	7	1.723	7	2.093	10
2.060	9			1.720	6
2.052	7				

Their composition is simple and includes only the constitutional elements with only small variations in the composition of the separate grains (Table 3). The composition of the studied grains varies from $Fe_{1.01}S_{0.99}$ to $Fe_{0.98}S_{1.02}$. The studied pyrrhotite does

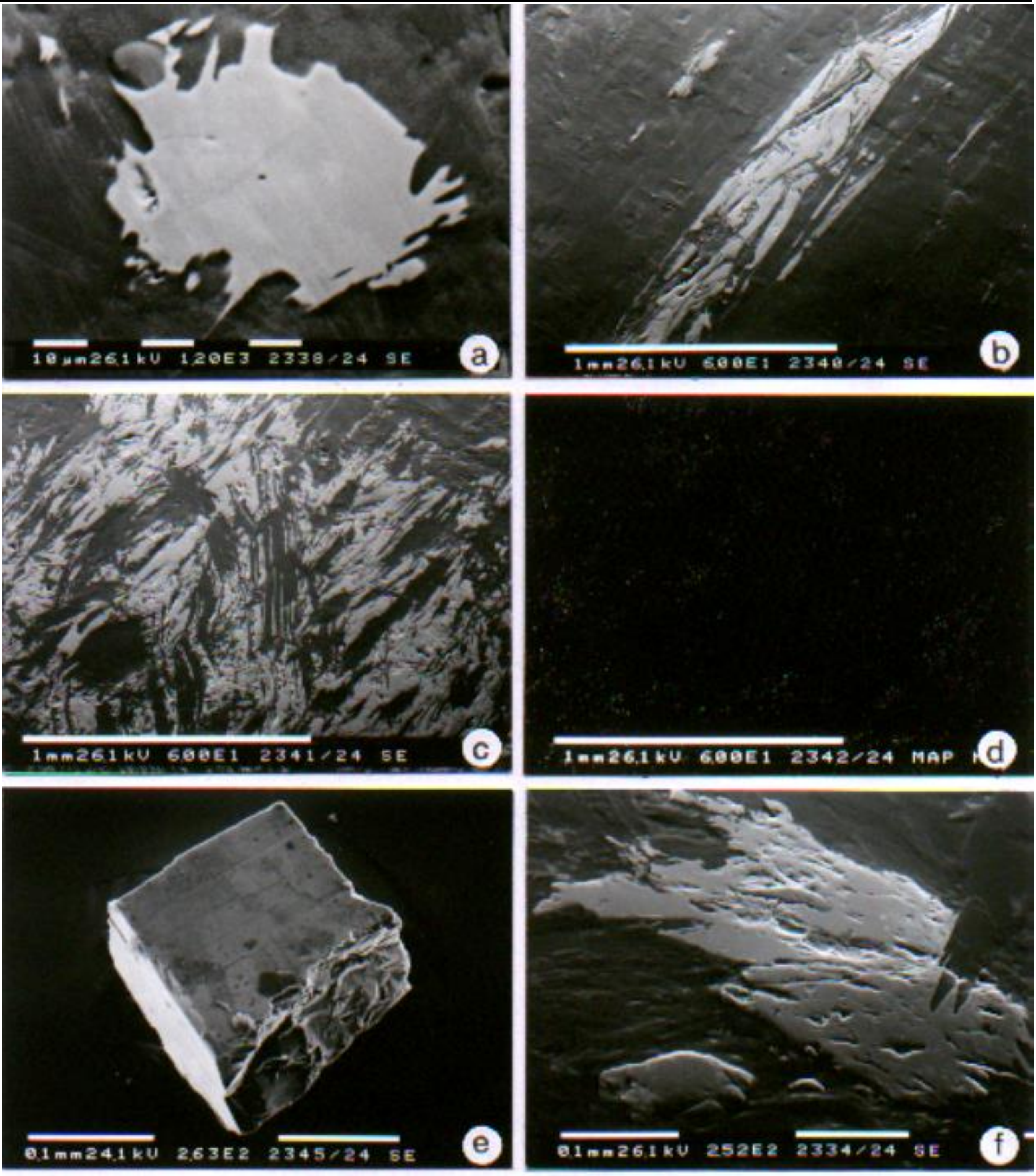

Figure 2. SEM micrographs of sulfides in ultrabasites from Zhivkovo village, Central Sredna Gora. a – irregular grain of mss; b - vein of mss; c – association mss-pentlandite; d – single element scans for Ni; e - cubic crystal of pyrite; f – association pyrite and Fe-oxide/ hydroxides*. Polished sections – a-d, f; native surface – e. Scale bars: 10 μm – a; 100 μm – e, f; 1 mm – b-d.*

not display metasomatic replacements like the one described for Martinovo deposit (Tarassova, 1987). Troilite is found principally in meteorites, while in the rocks of the Earth it is very rarely met - mainly in ultrabasites. The studied troilite is a first find in mother rocks in Bulgaria. Such mineral sample with meteoritic origin has been found in the third specimen of the meteoritic rain "Gumoshnik" (Dimov, 1972).

Pentlandite is found always intergrown with *mss* but in this association the mineral is of a subordinate significance. Most frequently it builds e definite segment of the periphery of the obtained aggregates and more rarely it is found as fine needles among *mss*. The size of the separate individuals varies in wide ranges - their width most often being several microns (in some cases up to 15 μm), while their length reaches several mm. The polished surfaces of the grains are dense (rarely displaying small caverns), uniform and without zoning, which indicates that the system Fe-Ni-S had not been influenced by phase transformations from later metamorphic processes. The composition of pentlandite is constant and the variations in the contents of the elements in different points of the separate individuals are very small and between separate grains these variations are in narrow ranges (Table 3).The atomic ratio Ni/Fe is from 0.99 to 1.05 and the content of Co is from 1.23 to 1.30 at %. According to Kostov et al. (1986) when this ratio is close to 1 (our case) we can define the mineral as low-cobalt normal pentlandite. The stoichiometry of the mineral is from $(Fe_{4.43}Ni_{4.38}Co_{0.22})_{9.03}S_{7.97}$ to $(Ni_{4.53}Fe_{4.31}Co_{0.22})_{9.06}S_{7.94}$.

The *mss*-pentlandite association is characterized by interrelations, which show that the aggregates are formed as a result of a dissociation. Following the nomenclature of Durazzo and Taylor (1982) the resulting structure can be determined as cell or lamellar type.

Table 3. Chemical composition of the sulfide mineralization in ultrabasites from Zhivkovo village, Central Sredna Gora

N	Fe	Co	Ni	S	Total
Monosulfide solid solutions					
1	63.62			35.39	99.01
2	64.85			35.71	100.56
3	62.41			37.45	99.87
4	63.78			35.40	99.18
5	62.97			37.24	100.21
Pentlandite					
6	30.92	1.64	34.17	32.73	99.47
7	31.77	1.67	33.03	32.80	99.27
8	31.23	1.68	34.15	32.86	99.92
9	30.96	1.64	34.12	32.85	99.57
10	31.03	1.58	33.96	32.79	99.36
Pyrite					
11	46.74			53.59	100.33
12	47.26			52.91	100.17
13	46.91			52.78	99.69
14	47.15			52.66	99.81
Formulae coefficients					
Monosulfide solid solutions					
1	1.01			0.99	
2	1.02			0.98	
3	0.98			1.02	
4	1.01			0.99	
5	0.98			1.02	
Pentlandite					
6	4.31	0.22	4.53	7.94	
7	4.43	4.38	0.22	7.97	
8	4.51	4.31	0.22	7.96	
9	4.51	4.31	0.22	7.96	
10	4.51	4.32	0.21	7.96	
Pyrite					
11	1.00			2.00	
12	1.02			1.98	
13	1.01			1.99	
14	1.02			1.98	

Pyrite is the less distributed sulfide and is observed in only one sample. This is probably due to its restricted distribution in the studied body. Morphologically it is represented by cubic crystals or by grains of irregular form (Fig. 2e, f). The surface of the former is uniform, dense, sometimes disrupted by small caverns of predominant ellipse-like form. The color of the crystals is light-yellow. Partial replacement of pyrite by Fe-hydroxides due to oxidation processes is very rarely observed. Also, there are no observations of its association with the other sulfides. The stoichiometry of pyrite is in the range $Fe_{1.00}S_{2.00}$ to $Fe_{1.02}S_{1.98}$.

ISCUDSSION

The interpretation of the ore structures is the most difficult, but at the same time the most important aspect in the study of rocks, which are carriers of Fe-Ni-sulfide mineralization. The intergrowth relations between pyrrhotite and pentlandite give a rich genetic information (Durazzo and Taylor, 1982). Data up to now give reason to consider that only *mss* and pentlandite from the studied sulfide mineralization display a paragenetic relation, while pyrite is formed in other more restricted spatial conditions. The post-magmatic processes impose a very high degree of serpentinization of the primary ultrabasites in the region of Ihtiman Sredna Gora where the low-temperature hydrothermal metamorphism had played a definite role (Kozhoukharova, 1986). The restricted presence of sulfides and magnetite observed in the studied body indicate for local changeable conditions for $f(S_2)$ and $f(O_2)$ during the process of crystallization (Oberthür et al., 1997). The association *mss*-pentlandite had been probably formed in conditions of primary hydrothermal alteration of ultrabasites. Firstly, the mineralization had been widely manifested in the body. The formed structures of dissociation of the solid solutions of the two minerals allow to propose that the processes had started at about 300^{0}C (Durazzo and Taylor, 1982). The lowering of temperature had led to structural changes in the high-temperature hexagonal pyrrhotite, which below 300^{0}C had resulted in the formation of substructures and monoclinic pyrrhotite. Then, at 142^{0}C dissociation between troilite and hexagonal pyrrhotite had taken place in compositions poor in S (Naldrett et al., 2000). Together with those processes an inversion in the conditions had taken place - locally increased $f(S_2)$ had been replaced by high $f(O_2)$ resulting in the formation of magnetite. The later stages in their transformations had led to destruction of a part of these sulfides and to a new increase in $f(S_2)$ in separate parts where pyrite had crystallized. The needed iron for the formation of the sulfide mineralization had been released from the primary rock-forming minerals of ultrabasites being present there in divalent form (Zhelyaskova-Panayotova, 1965). The earlier formed pentlandite and Ni-containing minerals could be considered as a probable sources of Ni (Atanassov and Vitov, 1981; Kostov et al., 1986).

Sulfide mineralization represented by pyrrhotite + pentlandite + chalcopyrite + pyrite has been described as a carrier of platinum-group elements (PGE) for the ores of Great Dyke (Zimbabwe) where among sulfides there have been observed also minerals of the platinum-group element (PGM) represented by sperrylite ($PtAs_2$), cooperite (PtS), moncheite ($PtTe_2$), and merenskyite ($PdTe_2$) (Oberthür et al., 1997). The ultrabasite body Baula Complex (India) is a carrier of analogous Ni-Fe-S association also accompanied by PGM (dominated by sperrylite) and formed in hydrothermal conditions (Augé et al., 2002). On the basis of these data it seems very probable to expect during detailed mineralogical studies on sulfides in the ultrabsites in the region of Ihtiman Sredna Gora the finding of PGM and some other sulfides like chalcopyrite, cubanite, etc. Most probably PGM should be represented by sulfides and related compounds of Pt and Pd, which are very mobile hydrothermal conditions. As a confirmation of this statement can be considered the finds of mineralizations of PGE with a probable hydrothermal origin reported for the placers from the upper parts of Iskar river, region being close to the studied ones (Tsintsov, 2003).

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STRUCTURAL CRITERIA FOR METALLOGENIC ZONATIONNORTH OF MARITSA FAULT

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ABSTRACT
The established allochthonous position of the Paleozoic formations in Central Stara Planina turned out to be of essential importance. Central and East Stara Planina are excluded from the proposed metallogenic zonation as far they lack any magmatic and metallogenic occurrences. The trend of the Cambrian volcano-sedimentary arc turns to SE toward Strandzha. Tthree pulses of linear magmatism – diabase, granitoid and quartz porphyries, mark the Balkan-Strandzha deep fault that controlled the magmatic and metallogenic activity from the Cambrian to the Tertiary. This fault separates the Moesian from the Thracian microplate. During the Late Carboniferous, the Turonian and the Lutetian, the Rhodope allochthounous plate, composed of high grade metamorphics and Paleozoic granites, was thrusted over the Thracian plate. During the Late Cretaceous, upon a basement of diverse structure and stratigraphy, powerful magmatic and metallogenic processes developed and modeled the Srednogorie metallogenic zone. In contrast to the Balkan polygenic and polychronous macmatic activity, the Srednogorie metallogenic zone evolved within a relatively narrow time interval – during the Late Cretaceous. The final stages of thrusting, magmatic and metallogenic activity toward the end of the Lutetian shaped the present structural and metallogenic zones which did not changed until now.;

A new insight into any metallogenic zonation requires re-evaluation of some basic structural elements and concepts. The concept of Vulchanov (1971) for the allochthonous position of the Paleozoic formations in Central Stara Planina shed new light on the problem. The main issues are as follows:

- There are no traces of magmatic and metallogenic activity in Central Stara Planina, East Stara Planina and the Fore-Balkan. For this reason they are excluded from the proposed metallogenic zonation.
- The trend of the West Balkan zone and its back-bone – the diabase-phyllitoid complex (DPC) is re-directed not along Central Stara Planina but deviates toward Sveti Ilya Heights and Strandzha.
- The three pulses of linear magmatism along the zone of DPC – the diabase magmatism during the Cambrian, the Stara Planina granitoids and the Permian extrusives evidently trace a deep fault – the Balkan-Strandzha fault (BSF) – Fig. 1. This fault is marked by a first order gravity gradient that intersects the crust and dies out into the upper mantle.
- The allochthonous position of Karandila (K), Tvarditsa (T) and Shipka (SH) tectonic units is not related to gravity phenomena. These units form structural sandwiches in the area of Sliven and Tvarditsa Stara Planina where they mark the stages of thrusting events (Fig. 3).
- The high-grade metamorphic complex and associated Paleozoic granites are not a median massif. They form an allochthonous plate (RAP) – Fig. 4 that, while moving to the north, detached the K, T and SH units from their root zones and thrusted them over Stara Planina (Fig. 5).

According to morphological features, RAP can be divided into several units: Central Srednogorie (CS), Ihtiman (IH), Sakar (SK), Strandzha (ST) and Rhodope (RD) – Fig. 5. During the thrusting events, RAP behaved as a monolithic body. Neither of its units moved independently – they were transported en block.

Valuable information on the deep structure of the crust, where magmatic and metallogenic process are generated, is provided by the geotraverses along the lines Petrich-Kalenik-Dolni Dabnik and Sliven-Galatz as well as by other geophysical methods.

There is no doubt that the consolidated crust on the territory of Bulgaria is of continental type. Fig. 1 shows that the ratio between the "granitic" layer and the heavier "basaltic" layer in the Moesian platform is 1:3-4. To the south, the granitic layer increases in thickness and in the area of Petrich this ratio is 1:1. The larger thickness of the granitic layer may be explained by cascade piling of thrust sheets as a result of compressional stresses. RAP may have been transported to the north along one of the thrust surfaces. Probably for this reason, the crust there is not so dense as compared to the Srednogorie.

Towards the end of the Riphean, during the Cambrian, the territory of Bulgaria began to break-up along the lines of BSF and the Kraishte fault – possible continental rift zones converging into the Carpathian arc. They divided the territory of Bulgaria into three microplates: Moesian, Thracian and Serbo-Macedonian (Fig. 1). Huge amounts of volcanic products were ejected (DPC) along the fault zones.

The DPC is the oldest structural unit and shows a very complex internal structure. It is widely exposed in the West Balkan tectonic zone, from Serbia to Botev Peak. The present shape of the zone is preserved due to the Stara Planina granitoids intruded along the axis of BSF (Figs. 2, 4). The Kazan, Vezhen, Botevgrad and Petrokhan intrusions form a huge "dike", about 180 km long and 5 to 10 km wide that is locally covered by younger sediments or is not exposed at the present erosional level. The Kazan intrusion may extend to the southeast under RAP, similarly to Tvarditsa pluton, the roots of which are concealed beneath this plate. Between Botev Peak and Stara Zagora, DPC is covered by RAP. Near Stara Zagora and in Sveti Ylya Heights, small outcrops of DPC are exposed

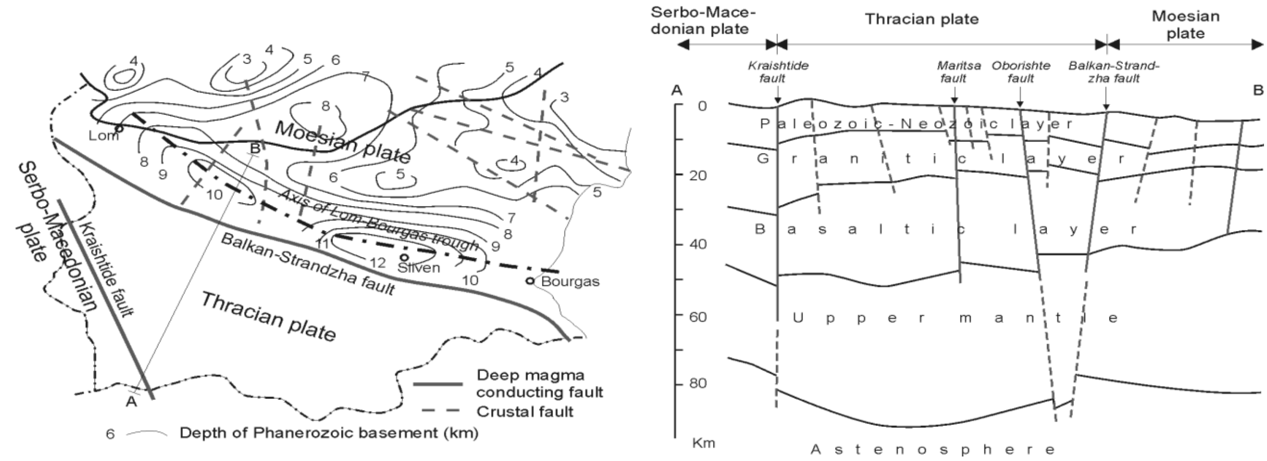

Figure 1. Morphostructural zones in Bulgaria (after Dachev, 1986, midified)

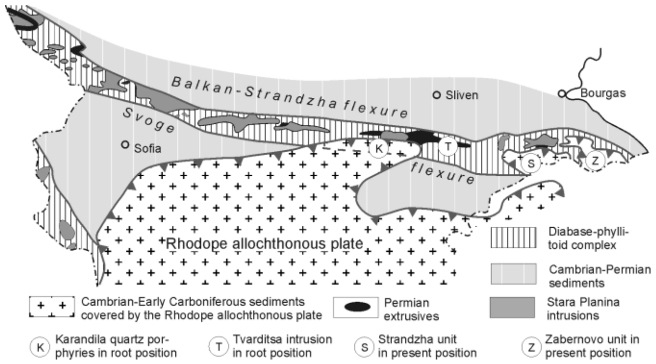

Figure 2. Paleotectonic reconstruction of Bulgaria toward the end of the Permian

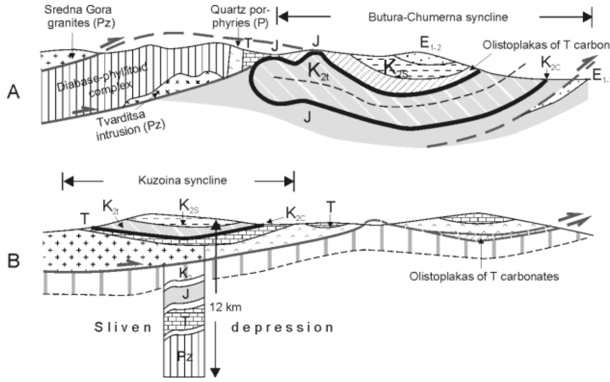

Figure 3. Geological sections across Tvarditsa (A) and Sliven (B) Stara Planina

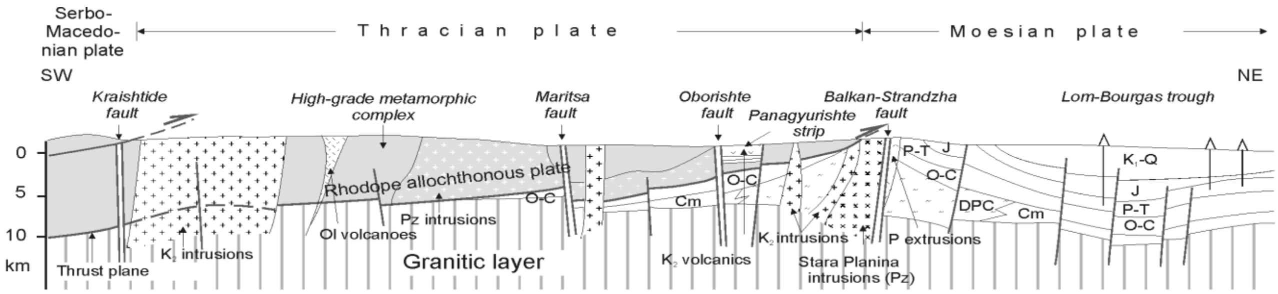

Figure 4. Deep section Petrich-Kalenik-Dolni Dabnik

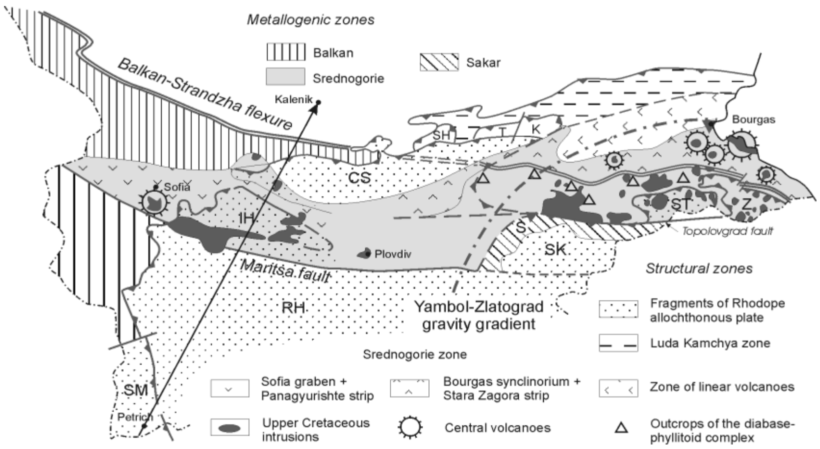

Figure 5. Structural and metallogenic zones north of Maritsa fault

while in Strandzha a minor intrusion of Stara Planina type (Punchevo pluton) is in contact with undivided Paleozoic rocks. So far these small outcrops have not been interpreted as indicating the general trend of a Cambrian volcano-sedimentary arc. This underestimation is related to the incorrect assumption that the West Balkan tectonic zone continues along the ridge of Central Stara Planina forming the autochthonous cores of Alpine anticlines. Those who seek the explanation of Karandila nappe need to know some facts. In the area of Sliven and Sliven Mineral Baths, two 1200 m wells were drilled that terminated in Upper Cretaceous rocks without indications of coastal deposits. It is well known that the area of Sliven is the deepest, about 12 km (Figs. 1, 3) depression on the territory of Bulgaria. There, autochthonous Upper Cretaceous overlies Jurassic and Triassic rocks, the Permian probably buried at a depth of 3 km. Most probably, the roots of Karandila nappe are located about 40 km to the south, in the area of Sveti Ilya Heights and within the zone of BSF.

The Thracian plate – the deformed margin of the Eurasian continent, is bordered by the Balkan-Strandzha and Kraishtide deep faults (Fig. 1). To the southeast it is buried beneath the Aegean Sea and the Sea of Marmora. During the Cambrian-Early Carboniferous the plate developed as a typical platform like the Moesian platform. The northern slope of the Cambrian volcano-sedimentary arc (DPC) was the terrigenous source of the Moesian platform. The lack of clastic components from the high-grade metamorphic complex and related granites in the Cambrian-Lower Carboniferous formations suggests that these complexes were located to the south of the present territory of Bulgaria. There are also no granite intrusions and contact aureoles in these formations. The high-grade metamorphic complex and the Paleozoic granites evidently form an allochthonous unit that was thrusted during the Late Carboniferous – RAP. As a result the realm of the Thracian plate was restructured into three zones: RAP, West Balkan zone and Strandzha zone.

The zone of RAP. In the beginning of the Late Carboniferous, RAP was thrusted over the Cambrian-Lower Carboniferous sediments and possibly related ore mineralizations. RAP was practically sterile in metallogenic respect until the Late Cretaceous. It was the dominating feature in the ancient relief and played the role of a new source of clastic material. It is assumed that the frontal line of RAP was already well outlined during the end of the Permian for the following reasons. A structural assemblage of rocks from DPC, Tvarditsa granitoids and Permian quartz porphyries (K and T units in Fig. 2) is exposed along the northern boundary of RAP within the zone of BSF. This assemblage is transgressively overlain by thick Triassic sediments that mark the front of RAP – parallel to the present boundary of the plate. Uranium polymetallic deposits are related to the contact between the quartz porphyries and the Triassic. During the Cenomanian-Turonian the frontal parts of RAP and the strip from Slivnitsa, Kremikovtsi, Chelopech, Botev Peak and eastward along the northern boundary of Luda Kamcya zone were covered by the Late Cretaceous sea.

Toward the end of the Turonian, RAP experienced a new northward thrusting of about 30-35 km over the Upper Cretaceous sediments. The DPC, Stara Planina granitoids and Permian quartz porphyries were detached from their roots and thrusted over the Luda Kamcya zone – sterile in metallogenic respect. Thus, Karandila (K), Tvarditsa (T) and Shipka (SH) allochthonous units were formed as independent structures both in tectonic and metallogenic respect (Fig. 5).

During the Lutetian RAP was again thrusted to the north by about 5-6 km. The Tvarditsa unit was blocked by the coal-bearing, folded Cenomanian-Turonian sediments in front of the plate. This was the time when the Belene dislocation originated. This fault, interpreted as a deep oblique-slip fault, has been used to invent the so-called “Tvarditsa system”. It is well known that there are no independent strike-slip faults in nature. They mark thrusting events. To the west of this fault, RAP was thrusted over the Tvarditsa unit and partially over deformed Cenomanian-Turonian sediments. East of the fault the thrust assemblage and the Kuzoina syncline on top of it were thrusted at a lower level. Practically, the Belene fault is a shear fault along the frontal line of the thrust association and can not be referred to the category of deep faults. Consequently, the “Tvarditsa system” does not exist.

The displacement of the thrust assemblage was accompanied by powerful shocks. Limestone blocks of different size broke off from the Triassic and were deposited into Turonian sediments. Larger plates (olisthoplakas) were also detached and covered a large part of the coal-bearing Cenomanian-Turonian sediments, preserving them from erosion. Olistoplakas were formed also in the area of Karandila and later overthrusted by the quartz porpyries (Fig. 3, sections A and B). This assemblage is preserved today in Sliven and Tvatditsa Stara planina in the form of structural sandwiches that mark the stages of thrusting. This was the time when erosion of RAP commenced and terrigenous material of gneisses and granites participated in the deposition of the “wild flysch”. The klippen in Tvarditsa and Shipka Stara Planina and Botev Peak are remnants of the destruction of the frontal part of RAP. The Senonian transgression covered the olistoplakas.

The Sakar and Strandzha allochthonous units, along with the transgressively overlying metamorphosed Triassic rocks, were transported to the north synchronously with RAP (Fig. 2, index S). The Strandzha unit is confined between the Balkan-Strandzha flexure and the Topolovgrad fault – a probable continuation of Oborishte deep fault (Fig. 1).

E. Bonchev (1971) has described two large flexures. The first follows the northern slopes of Strandzha Mts. and Svety Ilya Heights. The second runs along the northern slopes of the West Balkan zone. The same author assumed that the flexure turns from Botev Peak to the east on the basis of the incorrect interpretation of the Paleozoic formations in Central Stara Planina as autochthonous units. In fact, this is a single Balkan-Strandzha flexture that, between Botev Peak and Stara Zagora, was overridden by RAP, the latter covering also the root zones of DPC and the Tvarditsa pluton (Fig. 5).

The Yambol-Zlatograd gravity step of Dachev (1988) is still not well explained (Fig. 5). It divides regions of different Triassic successions – a sedimentary succession to the west, overlying transgressively RAP and the allochthonous units K, T, SH, and a metamorphic Triassic to the east, covering unconformably the Sakar and Strandzha units of RAP (Fig. 5, index S).

Northwest of the Yambol-Zlatograd gravity gradient, the Balkan-Strandzha fault coincides with a 1st order gravity gradient. To the southeast this gradient is not so well expressed and the pre-Creaceous magmatic activity is not so intensive. The same concerns the Maritsa fault.

According to Dachev (1988) the Maritsa fault, as a well expressed deep structure, is buried 8-10 km below RAP. In RAP it is expressed as parallel joint systems forming a graben syncline. After the thrusting of RAP, this syncline was transported by about 35-40 km to the north. This is the present Panagyurishte strip. The real Maritsa fault, covered by RAP, was again ruptured by sub-parallel fractures – the secondary faults on the surface.

Towards the end of the Late Cretaceous the seismic, magmatic and metallogenic processes intensified. Intrusive bodies from Plana to Plovdiv were emplaced along the revived fracture system in the zone of Maritsa fault. The magmatic and metallogenic processes were most intensive in Panagyurishte strip. A minor intrusion (Medet pluton and the associated deposit) perforated the thinned western flank of the Central Crednogorie unit of RAP. The deposits at Chelopech and Elatsite were formed within the zone of the Balkan-Strandzha fault. Most probably, these two deposits were covered by RAP but later erosion exposed them on the surface. The Strandzha unit of RAP was intruded by several minor intrusions. The Sakar unit of RAP has a more specific position. It is confined between Topolovgrad and Maritsa faults and is largely covered on the west by Neogene sediments. The metamorphosed Triassic was metallogenically mobilized and as a result the polymetallic deposit at Ustrem (dated 270-240 Ma, i. e Permian) originated. If these results are correct we have to assume that older Pb, from the period before the thrusting of Sakar unit, was re-mobilized. Re-deposition of Pb was probably related to metamorphic processes. The fact that a minor intrusion was emplaced in the western periphery of the Central Srednogorie unit of RAP is not a reason to include the whole unit in the Srednogorie metallogenic zone. The molybdenum and gold mineralizations localized in this unit are probably related to the Early Paleozoic magmatism. The Central Srednogorie unit may be defined as an independent metallogenic unit but within the confines of the Srednogorie metallogenic zone. The mineral associations, the paragenesis and the age of mineralizations both in Sakar and Central Srednogorie are alien to the Srednogorie metallogenic zone.

The West Balkan zone, prior to Late Cretaceous time, was bordered by the Balkan-Strandzha flexture, the Maritsa fault and the western margin of RAP. During the Late Cretaceous, a volcano-sedimentary association developed south of the line Slivnitsa, Kremikovtsi and Chelopech, covering the southern flank of the West Balkan zone and forming the western flank of the Srednogorie metallogenic zone. This was the time when the West Balkan metallogenic zone was finally shaped. There, directly on the surface, all stratigraphic units are exposed in complex structural position, high-style fold and thrust tectonics and polygenous and polychronous magmatic and metallogenic activity. East of Botev Peak, the zone is covered by RAP.

The Stranzha zone is confined between the Balkan-Strandzha flexure and Topolovgrad fault. This zone remains one of the key problems of Bulgarian geology. Different and controversial interpretations have been proposed – from an autochthonous anticlinorium to allochthonous unit that was detached from East Stara Planina. East of Elhovo Neogene basin, the Strandzha unit of RAP and Zabernovo allochthonous unit are thrusted over the Strandzha autochthon (Figs. 2, 5). Both units cover about 80% of the zone. The situation is similar in the western parts of the zone, buried beneath Zagora and Elhovo Neogene basins. The main question is to what extent the Balkan-Strandzha Cambrian volcanic arc (DPC) is preserved in the structure of the autochthon. Its trend is symbolically shown in Fig. 5. The question is: where are the autochthonous sections of the Ordovician to Upper Cretaceous successions if the oldest autochthonous formations are directly exposed on the surface at 250 m above sea level and the highest parts of the mountain (including the allochthonous units) do not exceed 500 m. Entire stratigraphic units are missing while others are symbolically represented. Evidently, positive vertical displacements prevailed. Destructive processes dominated over accumulative ones. Due to the more erosion-resistant units, the region was not covered by Neogene deposits. If we assume that DPC is symbolically present in the structure of Strandzha zone, this means that the consolidated crust was uplifted close to the surface, which is an absurd. There is no doubt that the Cambrian volcano-sedimentary arc extends to the east of Stara Zagora and forms the autochthonous backbone of Strandzha.

During the Late Cretaceous, the territory between the Balkan-Strandzha and Topolovgrad (Oborishte) faults was a domain of intensive intrusive activity and associated ore deposition. The Zabernovo metasedimentary unit, like Sakar unit before the thrusting, was an area of metallogenic mobilization (Gramatikovo ore deposit). After the thrusting, Zabernovo unit was involved into the Late Cretaceous metallogenic and magmatic cycle and was incorporated into the Srednogorie metallogenic zone. Most probably, the Sakar and Zabernovo units are parts of one depositional, metamorphic and metallogenic cycle that is of wide occurrence beneath the Neogene deposits on the territory of Turkey.

The Moesian plate is surrounded in the form of a horseshoe by the Balkan-Stranzha and the Carparthian zone. From the Cambrian to present it developed as a typical platform of dominantly heavy (basalt-type) crust. This explains the dominating subsidence during the geological history of the platform. The contour lines (Dachev, 1988) trace an axis – Lom-Kalenik-Sliven-Burgas along which the Phanerozoic basement progressively deepens from northwest to southeast along a system of sub-parallel normal faults that roughly parallel BSF. This axis marks a continental rift zone with embryonic volcanism during the Triassic, formation of a flysch trough during the Jurassic and volcanogenic activation during the Late Cretaceous within the Burgas synclinorium (Figs. 1, 4). The depth of the trough axis is about 7 km in the northwest, about 10 km at Kalenik and 12 km in the area of Sliven – the deepest depression on the territory of Bulgaria. The through axis is an indication for lack of oil and gas resources.

In the confines of Burgas synclinorium, parallel and north of the Balkan-Strandzha flexture, central volcanoes formed as sources of metal deposits. North of the line Yambol-Burgas, the volcanoes are linear and sterile. The boundary between central and linear volcanoes is enigmatic. Such is the boundary of the Srednogorie metallogenic zone. The domain of linear volcanoes is excluded from the metallogenic zonation. The boundary between linear volcanoes and Luda Kamchya zone is also conventional since there is a mutual penetration and interfingering between the two facial varieties. Luda Kamchya zone is void of metallogenic indications and for this reason is likewise excluded from the metallogenic zonation. If there were any metallogenic indications in this zone, then it could be included into the Srednogorie metallogenic zone but not in the Balkan one.

In contrast to the polygenic and polychronous Balkan metallogenic zone, the Srednogorie metallogenic zone developed within a narrow time interval – the Late Cretaceous, and is confined to the domain of Late Cretaceous magmatism. The Srednogorie metallogenic zone is superimposed upon a basement of diverse structure and stratigraphy. After the end of the magmatic activity and the thrusting events, i. e. toward the end of the Late Cretaceous and during the Lutetian, the restructuring of the tectonic and metallogenic zones north of Maritsa fault came to an end and they did not change to present days (Fig. 5).

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ON THE POTENTIAL OF SMALL BENTHIC FORAMINIFERA AS PALEOECOLOGICAL INDICATORS: RECENT ADVANCES

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ABSTRACT
The present article aims to introduce some of the possible ways of paleoecological interpretation of data obtained from the study of foraminiferal assemblages. Six criteria are first introduced in Bulgaria: diversity index α (*Fisher*-index), triangular plot for the foraminiferal assemblage structure (based on three types wall texture - agglutinated, porcelaneous, hyaline), planktic/benthic ratio, tau-index as bathymetrical indicator, the tolerance of the taxa (mainly at generic level) with respect to some environmental parameters (bathymetry, temperature, salinity levels, calcium carbonate availability, dissolved oxygen levels, substrate conditions, water energy), occurrence of dominant species in relation to species diversity.
Key words: benthic foraminifera, paleoecological interpretation, criteria, parameters.

INTRODUCTION

During the last four decades foraminifers have turned into one of the most useful groups for ancient sea environment interpretation. With the renewal of the foraminiferal fauna during the Paleogene, Tethyan assemblages have closer approximation to modern ones (mainly at generic level), which allows applying the recent distribution patterns for reconstruction of paleoenvironmental parameters from distant time intervals. The interpretations will be more precise if analogues are made between forms at the lower taxonomical level. However, this possibility decreases as the time distance increases because of the decrease of the resemblance between the species composition of modern and fossil assemblages.

The recent advances in paleoecological investigations of foraminiferal assemblages made us reassess the significance of small benthic foraminifera in Bulgarian micropaleontology and direct the investigations in a paleoecological apect, because till now in Bulgaria this group has been used for biostratigraphical and taxonomical purposes only. The present article aims to introduce some of the possible ways of paleoecological interpretation of data obtained from the study of taxonomical composition and structure of small benthic foraminiferal assemblages. Six criteria are first introduced in Bulgaria.

CRITETIA

The following criteria are usually used in the paleoecological interpretations: diversity index α (*Fisher*-index), triangular plot for the foraminiferal assemblage structure, planktic/benthic (P/B) ratio, *tau*-index as bathymetrical indicator, the tolerance of the taxa (mainly at generic level) with respect to some environmental parameters (bathymetry, temperature, salinity levels, calcium carbonate availability, dissolved oxygen levels, substrate conditions, water energy), occurrence of dominant species in relation to species diversity.

Diversity Index α (Fisher-index)

Diversity index was introduced by Fisher et al. (1943, in Murray, 1991). It takes in account the number of species among a certain number of specimens:

$$\alpha = n_1 : x \qquad (1)$$

where x is a constant having values <1, $n_1 = N(1-x)$, N being the number of individuals. To facilitate the calculations the graph shown on Fig. 1 is usually used. Low values of α suggest some deviation from the norm of some of the paleoenvironmental parameters. It has to be borne in mind the fact that the species diversity in fossil assemblages could be influenced by taphonomical factors.

Triangular Plot for the Foraminiferal Assemblage Structure

It is based on three types wall textures: agglutinated, porcellaneous and hyaline, corresponding with three suborders - Textulariina, Miliolina, Rotaliina from the Loeblich&Tappan's (1964) classification. In the revised classification (Loeblich&Tappan, 1988) suborder Rotaliina was divided into four suborders - Spirilinina, Lagenina, Robertinina, Rotaliina (Fig. 2);

Planktic/Benthic Ratio

With the increase of the depth the percent abundance of planktic individuals in the samples increases. However there are exeptions –very wide shelves and enclosed epicontinental seas are characterized by low abundance of planktic forms despite the depth. With the approach of *carbonate compensation depth* (*CCD* – 3500-4000 m) a gradual dissolution of the calcareous tests is observed, and under this level planktic forms are not available.

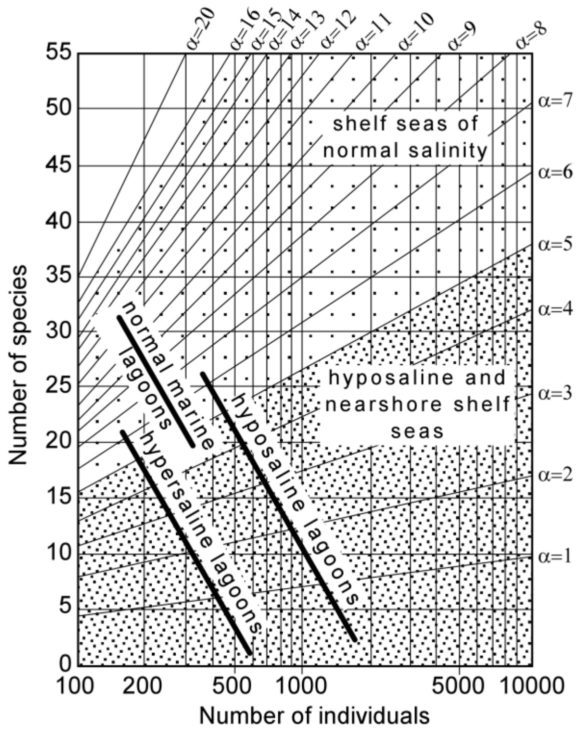

Figure 1. Graph illustrating the calculation of the diversity index α (after Wright, 1972)

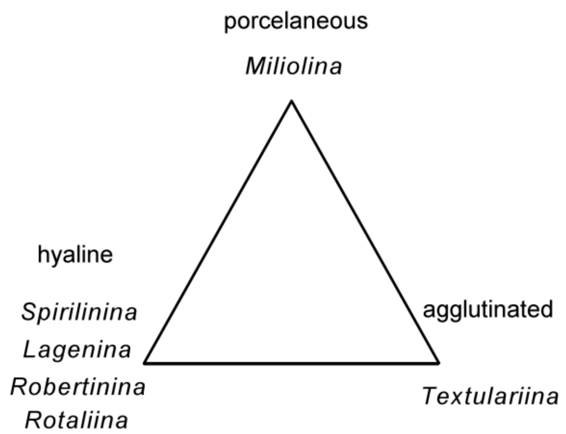

Figure 2. Triangular plot about foraminiferal assemblage structure based on three types wall texture (after Murray, 1991)

Tau-index

It was introduced as bathymetrical indicator by Gibson (1988) based on data obtained from the Gulf of Mexico. It could be calculated using the formula:

$$tau = b \,.\, \%p \qquad (2)$$

where *b* is the number of benthic species, and *p* – the number of planktic individuals in a sample. With the increase of the depth the values of *tau* increase.

Tolerance of the Taxa with Respect to Some Environmental Parameters

Particular taxa demonstrate different tolerance of depth, temperature, salinity, aeration, calcium carbonate and silica availability, water energy, substrate conditions. Of grate importance are taxa with minimal tolerance of changes in the above mentioned parameters. Data from modern assemblages, as well as data, obtained during the deep sea drilling in the Atlantic, Pacific and Indian Ocean are used in the interpretations.

Occurrence of Dominant Species in Relation to Species Diversity

The availability of strong dominance of some species in relation to low species diversity suggests deviation from the norm of some of the parameters. The absence of dominant species in relation to high species diversity indicates stable environmental parameters.

PARAMETERS

The parameters that are interpreted in the majority of the investigations are bathymetry, temperature, salinity levels, dissolved oxygen levels, calcium carbonate availability, water energy, substrate conditions.

Bathymetry

Bathymetry is a part of three dimensional space and the parameters related with it – temperature, pressure, light, salinity, etc. (Gibson, 1988). Its interpretation is based on the comparison of upper and lower tolerance depth limits of modern foraminiferal genera, analogous to fossil ones. The depth limits of particular genera are shown on Fig. 3. Of grate importance are taxa showing narrow bathymetrical range.

Species diversity is also informative for bathymetry. The values of *Fisher*-index increase as the depth increases. Outer shelf is characterized by α=5-19, the slope – by α=5-25. The highest values of α demonstrates the lowermost slope (Murray, 1976).

Planktic/benthic (*P/B*) ratio depends also on the depth. According to Murray (1976) inner shelf is characterized by up to 20% planktic individuals, the middle shelf – 10-60 %, the outer shelf – 40-70%, and the upper slope - >70%. The highest values are established in the lowermost slope (about 90% - Boersma, 1983).

Gibson (1988) introduced *tau*-index as bathymetrical indicator. Depths up to 40 m are characterized by *tau* <100, depths between 40 and 1000 m are marked by values between 100-1000, and depths up to 2000 m – by values between 1000-10000.

Wall texture of the foraminiferal tests is connected with the bathymetry (Fig. 4). Porcelaneous tests as a rule are typical for the inner shelf. As an exception the genera *Pyrgo* and *Biloculinella* have been established in abyssal depths (Haynes, 1981). The percent abundance of hyaline forms increase as the depth increases. In the abyssal depths below the *CCD* only agglutinated forms are presented.

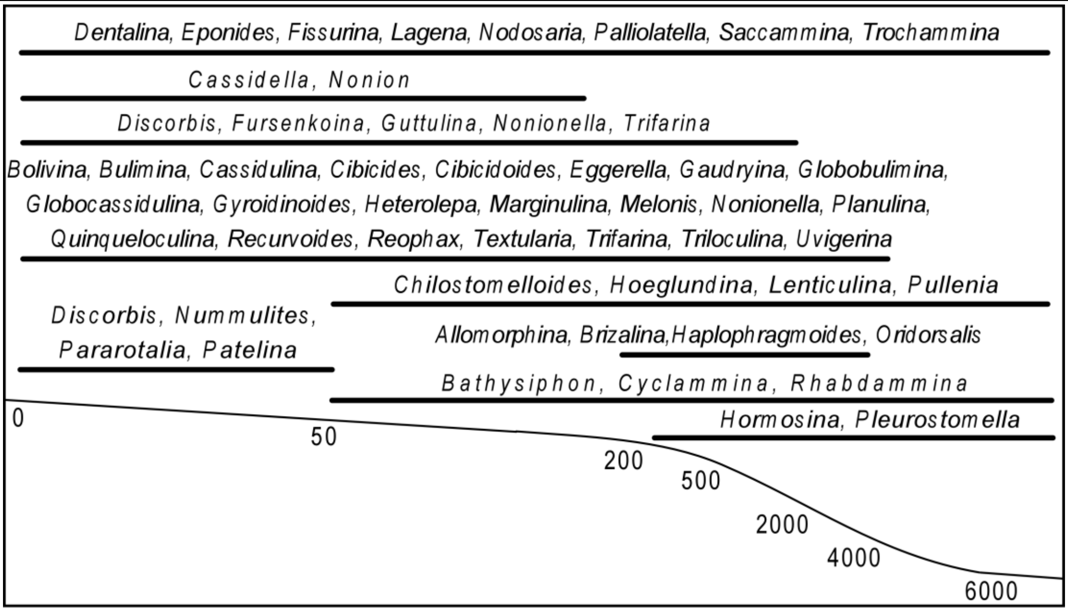

Figure 3. Bathymetrical distribution of modern foraminiferal genera (after Ujetz, 1996)

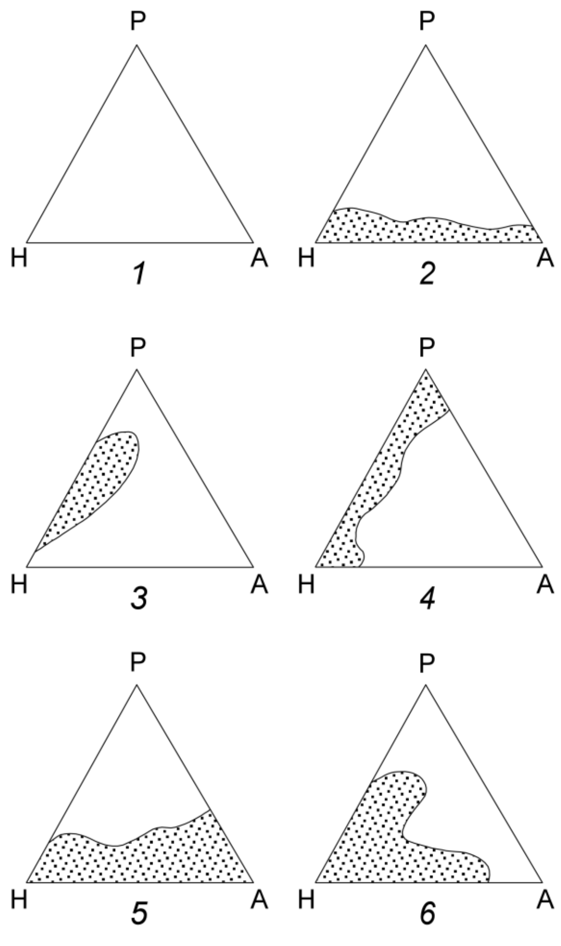

Figure 4. Triangular plots showing living foraminiferal assemblage structures from different environments (after Brasier, 1980)
1 - fresh waters; 2 - hyposaline lagoons; 3 - normal marine lagoons and carbonate platforms; 4 - hypersaline lagoons; 5 - shelf seas; 6 - normal marine continental slope waters; types of tests: P - porcelaneous; X - hyaline; A - agglutinated

The composition of the cement of agglutinated foraminifers indicates the deposition depth in relation to *CCD*. Assemblages composed of agglutinants with calcareous cement *(Gaudryina, Dorothia, Arenobulimina, Textularia, Vulvulina, Remesella, Marssonella, Karreriella* - King et al., 1989) indicates deposition above *CCD*, while assemblage comprised of taxa with noncalcareous cement (*Bathysiphon, Glomospira, Haplophragmoides, Ammosphaeroidina, Trochammina*) is a marker for sedimentation below *CCD*.

Agglutinated foraminifers change their test morphology with the depth changes. Their most deep-water representatives, comprising the so called "*Rhabdammina*-fauna" show simple test morphology (Brower, 1965, in Winkler, 1984) – unicellular, tube-like fragments, or multicellular uniserial (*Bathysiphon, Rhizammina, Saccammina, Hyperammina, Hormosina*). Bathyal agglutinants demonstrate higher morphological diversity. The assemblage is dominated by taxa with simple morphology, but there could be observed forms with biserial (*Textularia*), multiserial (*Gaudryina, Dorothia*), planispiral (*Cribrostomoides, Haplophragmoides*), trochospiral (*Trochammina, Recurvoides*), heteromorphous (*Spiroplectammina, Clavulinoides*) tests (Berggren, 1984).

During the investigations on the so-called "flysh-type" agglutinated foraminifera from the Paleocene of the North Sea, Jones (1988) established that the depth changes influence not only the test size and morphology, but the test colour. In the uppermost slope (200-500 m) finely to middle agglutinated middle sized white tests were observed. With the increase of the depth (500-1000 m) the tests become more coarsely agglutinated, large-sized and brownish-green in colour. At depths between 1000 and 1500 m middle to finely agglutinated, small-sized, dark green forms were established.

The morphology of some hyaline genera also demonstrate dependance on the depth. Typical examples are *Pullenia, Bolivina, Bulimina, Chilostomelloides*. The most changeable features are the test size and the oramentation. *Bolivina* loses its ornamentation as the depth increases, while *Bulimina* become more ornamented. Both genera increase their test size (Bandy, 1960, in Boltovskoy et al., 1991). With the increase of the depth the degree of inflation of *Pullenia* increases (Haynes, 1981),while *Chilostomelloides* increases its test size (Bandy, 1963). *Cibicidoides, Cibicides* develop inflected sutures (Bandy, 1960, in Ujetz, 1996).

Temperature

The tolerance of selected taxa of the changes of temperature is shown on Fig. 5 .

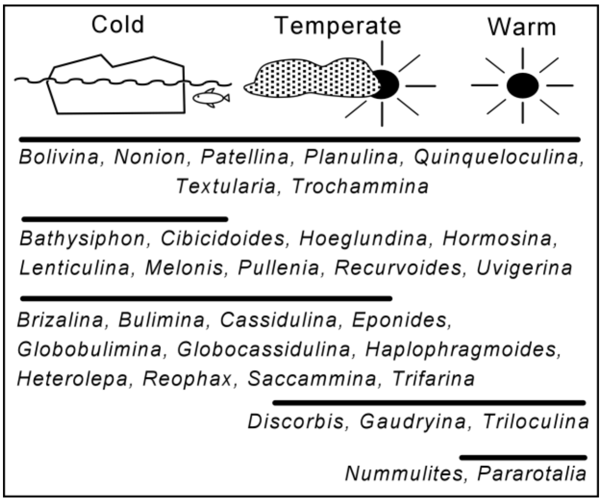

Figure 5. Distribution of living foraminiferal genera according to temperature (after Ujetz, 1996)

Temperature influences the test size and test morphology (Boltovskoy et al., 1991). The trends are towards an increase of the test size and the test porosity with the increase of temperature (Frerichs et al., 1963, in Ujetz, 1996).

Assemblages with high species diversity are typical for basins with constant high temperature (Boggs, 1987, in Ujetz, 1996).

Temperature influences also calcium carbonate availability in the water column. It values decrease as the temperature decreases. Such an environment is characterized mainly by calcareous thick-walled foraminifers (Boltovskoy, Wright, 1976 в Ujetz, 1996). The presence of large-sized agglutinants and low species diversity indicates constant temperature and stagnant water conditions (Haynes, 1981).

Salinity Levels

The vast majority of foraminifers is adapted to normal marine conditions – about 35⁰/₀₀ (Brasier, 1980). Genera flourishing in normalsalihe waters are the following: *Alabamina, Anomalinoides, Bathysiphon, Bolivina, Bulimina, Chilostomelloides, Cibicides, Cibicidoides, Cyclammina, Fursenkoina, Gaudryina, Globobulimina, Haplophragmoides, Heterolepa, Lagena, Lenticulina, Nonion, Paliolatella, Pullenia, Recurvoides, Reophax, Saccammina, Textularia, Trochammina* (Bolyovskoy et al., 1991; Murray, 1991; Murray et al., 1989). *Bolivina, Bulimina, Cibicides, Globobulimina, Nonion* are tolerant of both normalsaline and hyposaline environments (Murray et al., 1989).

The presence of planktic individuals as well as thick-walled calcareous forms in the samples also indicates normal marine environment (Boltovskoy, Wright, 1976, in Ujetz, 1996).

Salinity levels influence the species diversity. Values of α>5 suggest normal salinity (Murray, 1991). Hyposaline and hypersaline conditions are marked by low species diversity (α<5 – Fig. 1).

Additional data about the salinity provide triangular plots. Normal marine environments are dominated by hyaline-test foraminifers. Hyposaline realms (<32‰) are marked by abundant agglutinants, while hypersaline ones (>40‰) – by abundant porcelaneous tests. On Fig. 5 are shown triangular plots demonstrating assemblage structures from different environments (after Brasier, 1980).

The presence of agglutinated forms with noncalcareous cement could suggests shallow-water environment with low salinity (Haynes, 1981).

Dissolved Oxygen Levels

Well aerated environment is characterized by diverse calcareous foraminiferal fauna (α>5), thick-walled large-sized and ornamented tests (Murray, 1991; Boltovskoy, Wright, 1976, in Ujetz, 1996). High oxygenated realm is also marked by the presence of infauna. For example genera like *Lenticulina* and *Vaginulinopsis* are characterized by compressed tests with angulate periphery (often keeled) which are adapted to "slice" through well aerated substrate. According to Kaminski et al. (1988) elongate uniserial agglutinants are typical for the infauna. Such tests have genera like *Hormosina, Reophax, Subreophax*. Elongate tube-like and branched tests are characteristic for attached forms (*Bathysiphon, Rhizammina, Dendrophrya*). The absence of infauna could indicate anaerobic environment. Assemblages flourishing in well aerated realm are characterized by spherical and lenticular forms while low oxygenated realm are dominated by elongate and flattened forms (Bernhard, 1986).

The dissolved oxygen level could be established by the presence of definite genera in the assemblage. For example *Bolivina, Bulimina, Cyclammina, Haplophragmoides, Bathysiphon* flourish in low oxygenated environment (Boltovskoy, Wright, 1976 in Ujetz, 1996).

The presence or absence of ornamentation is also influenced by the oxygen levels. For example the presence of ornamented individuals of *Bulimina, Globobulimina, Chilostomelloides* suggests low dissolve oxygen levels. Foraminiferal tests with large-sized pores are adapted to low oxygenated environment (Perez-Cruz, Machain-Castillo, 1990).

Species diversity is also informative for the dissolved oxygen levels. Assemblages, characteristic for low oxygenated environment demonstrate low species diversity (α<7) and they are dominated by 2-3 species comprising over 80% of the total number of individuals in the samples.

Calcium carbonate Availability

In recent seas assemblages dominantly composed of agglutinated foraminifers are characteristic of low salinity levels or deep-sea bottoms undersaturated in calcium carbonate

(Haynes, 1981). The occurrence of microfaunas comprised of calcareous forms and characterized by high species diversity indicates high level of calcium carbonate-availability. Corliss (1979) suggested that the high solubility of calcium carbonate at great depths is one of the reasons responsible for the prevalence of small-sized specimens.

Substrate conditions

The influence of substrate on the test morphology is particularly important in agglutinated and sedentary forms. The wall texture in agglutinated foraminifers is characteristic feature for the substrate conditions. Finely agglutinated forms indicate fine grained substrate, while the coarsely agglutinated tests are typical for coarse grained sediments (Hada, 1957 в Boltovskoy et al., 1991). The differences in wall texture lead to differences in the test-shape in one and the same taxon (Boltovskoy et al., 1991).

The occurrence of infauna – lenticular or elongate compressed forms indicates a soft substrate allowing these forms to "slice" through sediment to obtain nutrients. Silty and muddy substrates are rich in organic debris and therefore attractive to foraminifers. Such conditions support large populations. Many of their species are thin-walled, delicate and elongate forms (Brasier, 1980). The hard substrate support sparcer populations and foraminifers from these conditions are thick-walled and heavily ornamented.

The occurrence of attached forms also suggests hard substrate (Murray, 1991). Characteristic genera of attached foraminifers are *Planulina, Patelina, Textularia, Cibicides, Cibicidoides, Gaudryina, Heterolepa, Bathysiphon*. Trochospiral attached forms have flat or slightly concave spiral side.

Water Energy

The study of modern agglutinated foraminifers of the so-called "flyh-type" or "A-type" from the Northwestern Atlantic showed that finely agglutinated small-sized and delicate tests are characteristic for low energy conditions and fine grained substrate. Conversely, coarse grained robust forms occur in high energy conditions (Schroeder, 1986, в Jones, 1988). Jones (1988) used this pattern in the paleoecological interpretation of the Upper Paleocene agglutinated assemblages from the North Sea. The results revealed that finely agglutinated small-sized forms (*Rzehakina, Rhizammina*) are characteristic for low energy conditions, which in this case were established at 1000-1500 m depth. Coarsely agglutinated robust forms (*Recurvoides, Psammosphaera, Bathysiphon, Hyperammina*) were established at 500-1000 m depth and they indicate highly energy environment.

Species diversity is another one indicator for the water energy. The occurrence of high species diversity suggests deep-water environment with stable low energy (Murray, 1979).

CONCLUSIONS

The presentation of the criteria and the possible ways of interpretation of the environmental parameters showed that small benthic foraminifera have considerable potential for paleoecological interpretation of data obtained from the study of the taxonomical composition and structure of foraminiferal assemblages. The significance of the interpretations increases in case of integration with paleoecological data from other groups benthic organisms, ichnofossils, as well as data from sequence and event stratigraphy, facies analysis, geochemical and mineralogical data.

The possible ways of paleoecological interpretations introduced in the present article come across some restrictions: 1) the precision of the interpretations decreases as the time distance increases because of the decrease of the resemblance between the species composition of modern and fossil assemblages; 2) the above mentioned criteria are based on quantitative methods which are not applicable in foraminiferal investigations in thin sections.

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COMPARATIVE CHARACTERISTICS OF ENDOGENIC KUTNAHORITE FROM RIBNITSA DEPOSIT AND EXOGENIC KUTNAHORITE FROM KREMIKOVTSI DEPOSIT

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ABSTRACT
The kutnahorite is considered to be a rare mineral with dominant hydrothermal or metamorphic origin. Two genetic types of kutnahorite (endogenic – from the Pb-Zn mineralization in Ribnitsa deposit, Madan ore field, and supergene – from the limonite ore in Kremikovtsi deposit) are objects of examination and comparison in the present paper. The mineral was found in the central parts of the quartz-galena-sphalerite veins, or as creamy to pale rose coloured monomineral veinlets in the Ribnitsa deposit. Kutnahorite, associated with supergene carbonates (spherosiderite, rhodochrosite, calcite), neotocite, goethite and supergene barite, was established at the lowermost levels of the oxidation zone in the Kremikovtsi deposit as colloform milk-white to pale creamy coloured, or snow-white fine needle-like aggregates. The mineral was studied by XRD, chemical and thermal analyses, SEM and TEM. The data obtained show that the two genetic types of kutnahorite studied are distinguished by their chemical composition and structural ordering. The endogenic kutnahorite is represented by ordered Fe-Mg varieties and the exogenic kutnahorite – by partially ordered Ca varieties.

INTRODUCTION

The kutnahorite is considered to be a rare mineral with dominant hydrothermal or metamorphic origin. Single finds of exogenic kutnahorite, associated with aragonite in sediments and karst terrains in Italy were reported by Bini and Menchetti (1985), Cancian and Princivalle (1991). In Bulgaria this mineral was found in several deposits: Ruen (Dragov, 1965), Ribnitsa (Kolkovski *et al.*, 1980) and Martinovo (Dragov and Neykov, 1991).

The morphology, structure, chemical composition and thermal behaviour of two genetic types of kutnahorite (endogenic – from the Pb-Zn mineralization in Ribnitsa deposit, Madan ore field, and exogenic – from the limonite ore of Kremikovtsi deposit) are objects of examination and comparison in the present paper.

The Ribnitsa Pb-Zn deposit is located in the western part of Madan ore field, Central Rhodopes. Kolkovski *et al.* (1980) distinguished 6 mineralization stages in the deposit describing the kutnahorite as developed in kutnahorite-rhodochrosite-Mn-calcite stage. The mineral has been found in the central parts of the ore veins in association with Mn-calcite. According to Kolkovski *et al.* (1980) the carbonates from this stage are formed in the 275-220°C temperature interval.

The Kremikovtsi complex-ore deposit is composed of three types of iron ores (siderite, hematite and limonite), large reserves of barite ore and low-grade polymetallic sulphide mineralization (Panayotov, 1974; Atanassov, 1977; Damyanov, 1998). It is situated in the Vraca-Kremikovtsi ore district from the Stara planina metallogenic zone. It is hosted in the dolomitic limestones of the Iskar Carbonate Group (T_2). A large part of the deposit is occupied by limonite formed during a prolonged three-stage (Pre-Pliocene, Pliocene and Post-Pliocene) secondary alteration. The Pliocene stage of supergene alteration took place under relatively reducing conditions, when secondary ores were overflowed by lake water. During these stages secondary carbonates, barite and sulphides were formed. The kutnahorite was established at the lowermost levels of the oxidation zone in association with supergene carbonates, neotocite, goethite and barite as colloform and stalactite–shaped milk-white to pale creamy coloured or snow-white fine needle-like aggregates in cavities within the limonite.

MATERIALS AND METHODS

The chemical composition, structural characteristics and thermal behaviour of morphologically different representative samples from the two genetic types of kutnahorite were studied. The quantitative chemical analyses were performed in CNIL "Geochemistry" (UMG "St. I. Rilski") and SU "St. K. Ohridski". The distribution of the major elements (Ca and Mn) in characteristic X-rays and the microprobe data were obtained using a JEOL JSM-35-CF device (Tracor Northem TH 2000) in "EUROTEST" Plc. X-ray diffraction (XRD) patterns were obtained with a DRON-1 diffractometer (CuKα radiation, Ni filter) and a 57.3 mm Debye-Scherrer TUR–M–62 camera in UMG "St. I. Rilski" and SU "St. K. Ohridski". DTA curves were recorded with a Derivatograph apparatus in static air at the following conditions: (a) DTA = 1/10, DTG = 1/15, TG = 500, sample weight – 1 g, rate of heating – 10°/min, and (b) DTA = 1/10, DTG = 1/10, TG = 1000, sample weight – 1 g, rate of heating – 5°/min. The morphology and the phase inhomogeneity of the mineral were studied by a SEM "JSM-T 20" and TEM "EMV 100L" in MSU "M. Lomonosov", Russia.

RESULTS AND DISSCUSSION

Mode of occurrence

Kutnahorite, associated with Mn-calcite, has been established at the lower levels of the ore veins in the Ribnitsa deposit. It forms pale rose to creamy coloured grain aggregates and partially cements or crosscut sulphide minerals. As a rule, the mineral occupies the central parts of the ore veins. It is formed after the main ore parageneses (quartz-galena and quartz-sphalerite-galena).

The kutnahorite from the Kremikovtsi deposit has been found at the lowermost levels of the oxidation zone near the boundary with the primary siderite. It forms colloform, rarely stalactite–shaped, milk-white to pale creamy coloured aggregates (3-4 mm in diameter and up to 15 mm in length). In cross-sections these aggregates show fine concentric-zonal structure and are needle-like at the periphery (Fig. 1a). The kutnahorite is deposited most often over supergene siderite (spherosiderite) in cavities within the limonite and associates with massive or fibrous goethite, neotocite, supergene barite and calcite. Snow-white fine needle-like or radial-fibrous aggregates with rare yellowish to brown surface pigmentation were also found. Fine fibrous white kutnahorite overgrowths over rhodochrosite have been observed rarely as well. SEM observations show rhombohedral habit of kutnahorite individuals (Fig. 1b).

Chemical composition

Chemical compositions of kutnahorite from the present study as well, as from other deposits – Ruen (Dragov, 1965) and Martinovo (Dragov and Neykov, 1991), Franklin, USA (Frondel and Bauer, 1955), Kutna Hora (Trdlička, 1963) and Chvaletice, Czech Republic (Žak and Povondra, 1981), Ryûjima, Japan (Tsusue,1967), are presented in Table 1 and Fig. 2. The compositions of some rare finds of Ca-rich kutnahorite (Gabrielson and Sundius, 1966; Tanida and Kitamura, 1982; Bini and Menchetti, 1985) are also shown.

The endogenic kutnahorite from Ribnitsa deposit is characterised by increased Mg contents (14,64–19,34 mol% $MgCO_3$) and according to the classification, proposed by Mincheva-Stefanova and Gorova (1967), should be described as Fe-Mg variety of this mineral. According to these authors, only carbonates containing $CaMn(CO_3)_2$ in the range 70-100% have to be denoted by the name "kutnahorite". Carbonates with lower contents of this component and respectively with higher $CaMg(CO_3)_2$ and $CaFe(CO_3)_2$ content should be considered as Fe-Mg varieties of kutnahorite that reflects more appropriately their chemical features.

The analysed samples from Ribnitsa deposit show compositions relatively close to the kutnahorite from Chvaletice (Žak and Povondra, 1981) and Ryûjima, Japan (Tsusue,1967). The bulk analyses of the carbonates studied have insignificant deviations from the standard composition of this mineral and a slight excess of Ca (Table 1). The kutnahorite compositional non-stoichiometry has been debated many times in the literature. It has been noted presence in nature of both phases with Ca deficiency (Ca < Mn+Mg+Fe) and Ca excess (Reeder, 1983; Goldsmith, 1983; Essene, 1983; Yanchuk *et al*., 1991). A part of Ca cations in the non-stoichiometric carbonates with dolomite-type structure and Ca >1 is considered to be in B-positions. Some authors accepted that instead of the preferable disposition of Mn^{2+} in the relatively smaller B-positions, a part of it at least is possible to substitute Ca^{2+} in the A-position at higher temperatures.

The possibility of Mn^{2+} disposition in both cationic positions (A and B) is determined by the Mn^{2+} ionic radius, the size of which is between those of Ca^{2+} и Mg^{2+} (Lumsden and Lloyd, 1984; Reeder, 1983; Goldsmith, 1983). This fact explains the presence of natural phases with non-stoichiometric compositions and some Ca deficiency as well, as the conventional and often established partial structural disorder of the mineral.

Table 1. Chemical compositions (mol%) of kutnahorite from different deposits.

№	Carbonate component (mol%) Formula coefficient of the respective cation			
	$CaCO_3$	$MnCO_3$	$MgCO_3$	$FeCO_3$
1	54.46 (1.09)	22.94 (0.46)	19.34 (0.39)	3.26 (0.06)
2	53.03 (1.06)	26.20 (0.53)	14.64 (0.29)	6.13 (0.12)
3	51.13 (1.02)	20.12 (0.40)	19.01 (0.38)	9.74 (0.20)
4*	49.00 (0.980)	23.55 (0.471)	13.60 (0.272)	13.85 (0.277)
5	51.50 (1.030)	42.00 (0.840)	5.77 (0.115)	0.73 (0.015)
6	51.00 (1.02)	35.85 (0.72)	10.12 (0.20)	3.03 (0.06)
7	51.22 (1.02)	23.73 (0.48)	12.42 (0.25)	12.63 (0.25)
8	47.45 (0.95)	34.75 (0.69)	11.30 (0.23)	6.50 (0.13)
9	48.53 (0.965)	24.90 (0.496)	24.81 (0.494)	1.76 (0.035)
10	74.00 (1.48)	19.00 (0.38)	7.00 (0.14)	- -
11*	66.95 (1.339)	26.35 (0.527)	6.50 (0.130)	0.20 (0.004)
12	64.03 (1.29)	31.06 (0.63)	4.12 (0.08)	0.79 (0.02)
13	68.86 (1.38)	25.37 (0.51)	5.36 (0.11)	0.41 (0.01)

* Microprobe data.

1 - Ribnitsa; *2* - Ribnitsa (Kolkovski *et al.,*1980); *3* - Ruen (Dragov, 1965); *4* - Martinovo (Dragov and Neykov, 1991); *5* – Franklin, USA (Frondel and Bauer, 1955); *6, 7* – Kutna Hora, Czech Republic (Trdlička, 1963); *8* - Chvaletice, Czech Republic (Žak and Povondra, 1981); *9* - Ryûjima, Japan (Tsusue, 1967); *10* - Långban, Sweden (Gabrielson and Sundius, 1966); *11* – Levane, Upper Valdarno, Italy (Bini and Menchetti, 1985); *12* - Fujikura, Japan (Tanida and Kitamura, 1982); *13* - Kremikovtsi.

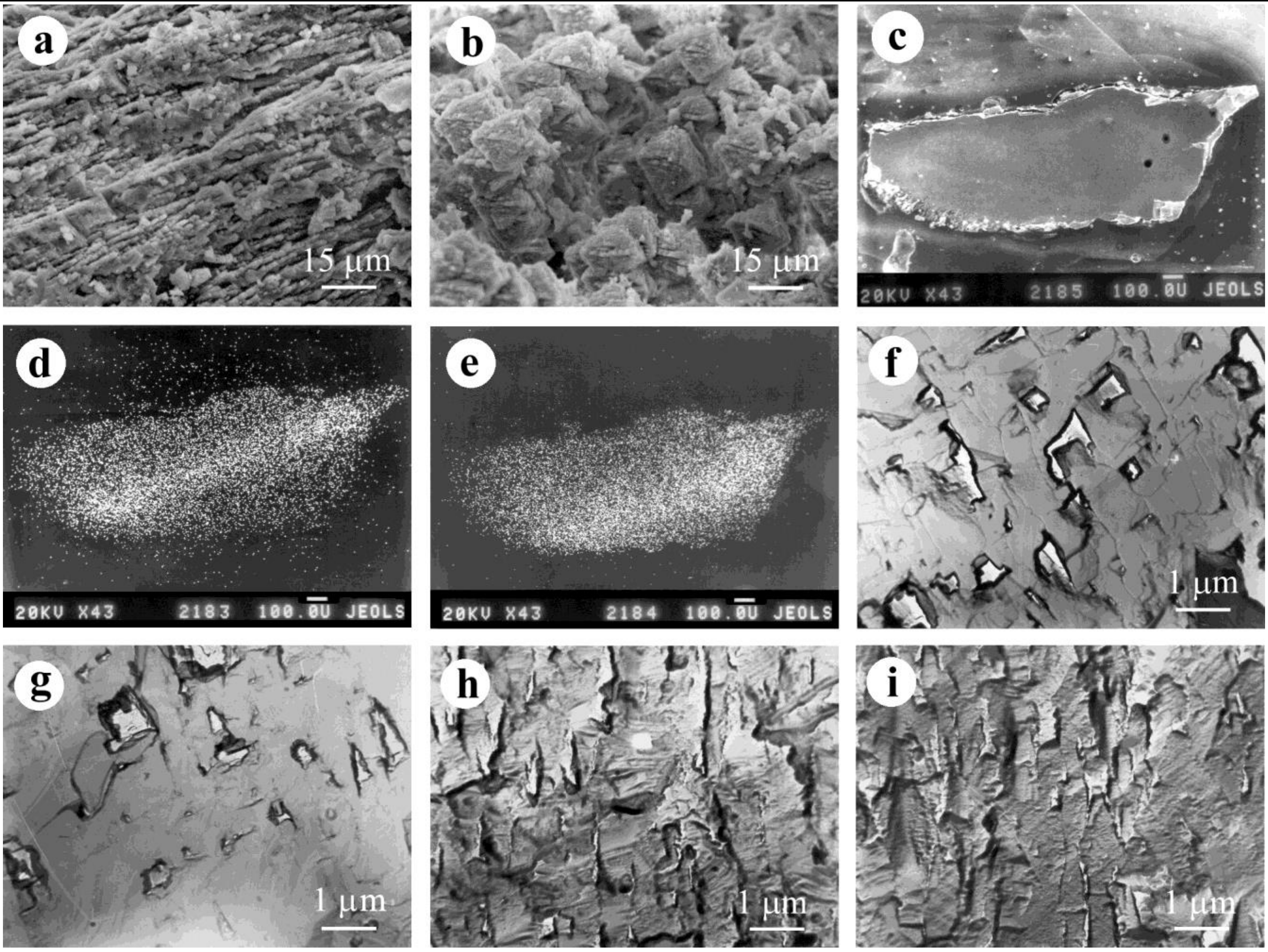

Figure 1. Morphological features of kutnahorite from Kremikovtsi deposit. a) needle-like aggregates of kutnahorite, SEM; b) aggregates of rhombohedral kutnahorite microcrystals, SEM; c) backscattered electron image of kutnahorite grain, SEM; d) MnKα image of kutnahorite, SEM; e) CaKα image of kutnahorite, SEM; f, g) heterogeneous fabric of kutnahorite surface, TEM; h, i) microrelief of fresh-broken kutnahorite surface, TEM.

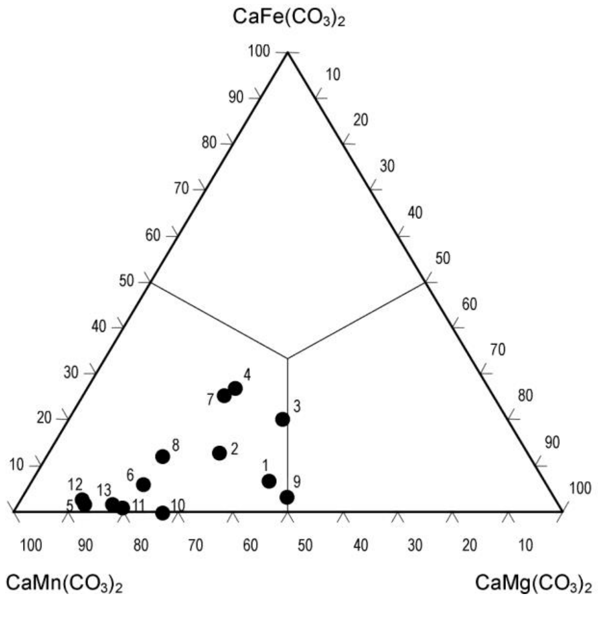

Figure 2. Compositional variations of kutnahorite in the $CaMn(CO_3)_2$-$CaMg(CO_3)_2$-$CaFe(CO_3)_2$ system. The numbers of analyses are as in Table 1.

The kutnahorite from the Kremikovtsi deposit is represented by Ca-rich varieties (Table 1). The Ca content is lower than that in the Ca-rich kutnahorite from Långban, Sweden. Compositionally, the mineral studied is very similar to the supergene kutnahorite, associated with aragonite in sediments from Levane, Upper Valdarno, Italy (Bini and Menchetti, 1985). The observed area distribution of the major elements (Ca and Mn) in the mineral is characterised by well-developed zoning (Fig. 1d, e). In some areas the Ca and Mn distribution is almost equal, whereas in other areas high Ca concentration and absence of Mn are apparent (see lower right corners in Fig. 1d, e).

The Ca and Mn distribution is an indication of phase inhomogeneity in the exogenic kutnahorite studied that was supported by the TEM examinations. In some of the samples micro-fissures and well-expressed cleavage planes were observed, along which irregular micro-inclusions about 1 µm in length (Fig. 1f, g) were observed. Well-expressed micro-relief is visible also in Fig. 1h, i (fresh broken kutnahorite surface). The phase micro-inhomogeneity is typical for the kutnahorite and has been noted by many authors (Žak and Povondra, 1981; Goldsmith, 1983; Peacor *et al*., 1987).

XRD and thermal data

XRD data of kutnahorite from Ribnitsa and Kremikovtsi deposits are presented in Table 2. They are compared with standards for ordered kutnahorite and Ca-rich kutnahorite. The data obtained show that the mineral from Ribnitsa deposit is distinguished by slightly lower d-values in comparison with the standard from Franklin, USA, because of the differences in chemical composition and higher Mg^{2+} content.

The XRD data of kutnahorite from Kremikovtsi deposit are similar to those of Ca-rich varieties, described in the literature (Gabrielson and Sundius, 1966; Tanida and Kitamura, 1982; Bini and Menchetti, 1985). The XRD patterns are an indication of partially ordered structure. Many authors noted that very often there are no reflexes of distant order on the XRD patterns of ordered natural kutnahorite and synthetic phases with $CaMn(CO_3)_2$ composition (Winter *et al*., 1981; Essene, 1983; Reeder, 1983; Goldsmith, 1983; Peacor *et al.,* 1987; Yanchuk et al*.,* 1991). This resulted in terminological difficulties, because the term "kutnahorite" was used the first time for an ordered phase with dolomite-type structure and Mn > Mg. Recently it has been adopted, this term to be applied for all the compositions close to the end member $CaMn(CO_3)_2$. Distinguishing of disordered natural phases with the same composition is complete by appending an adjective "calcian" or "disordered" (Essene, 1983; Peacor *et al.,* 1987).

As the XRD data and chemical composition are not good enough to distinguish adequate kutnahorite from other carbonates mineral diagnostics can be substantially improved by means of the DTA analysis (Pavlishin and Slivko, 1962; Yanchuk *et al.,* 1991). The kutnahorite has a dolomite-type structure and its DTA curve is characterised by two endothermic peaks related to the two stages of double carbonate decomposition (Pavlishin and Slivko, 1962). According to Yanchuk *et al*. (1991) at thermal examinations of Ca-Mn carbonates in air complication of shape of the thermal curves, because of the practically simultaneous development of two processes – carbonate dissociation and oxidation of the products obtained is possible. Therefore these authors recommend registration of DTA curves in helium.

Published DTA curves of chemically different natural kutnahorites show some differences: in some cases they are of dolomite-type, in other – of ankerite-type (Frondel and Bauer, 1955; Trdlička, 1963; Tsusue, 1967; Tanida and Kitamura, 1982; Bini and Menchetti, 1985; Dragov, 1965; Kostov, 1993). The chemical composition of kutnahorite reflects on the character of the DTA curves. According to Trdlička (1963) the higher Mn^{2+} contents leads to appearance of the first endothermic effect at lower temperatures, whereas the lower Fe^{2+} contents – decreases intensity of the typical for the mineral two endothermic effects. In contrast of the natural phases, the thermal curves of hydrothermally synthesised kutnahorite show an endothermic peak at 862°C only, corresponding to one-stage decomposition at heating following the reaction:

$CaMn(CO_3)_2 + O_2 \rightarrow CaMnO_3 + 2CO_2$ (Fazeli and Tarean, 1982). It is possible, that the synthetic phase studied by these authors was with disordered structure of calcite-type.

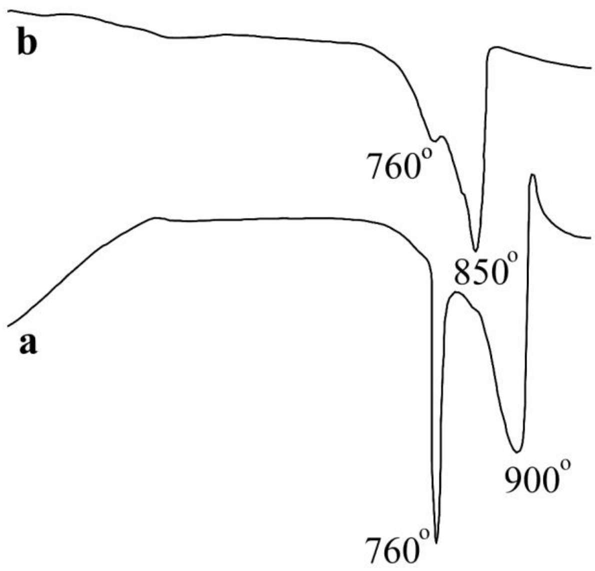

Figure 3. DTA curves of kutnahorite from Ribnitsa (a) and Kremikovtsi (b) deposits.

The DTA curve of kutnahorite from Ribnitsa deposit (Fig. 3a) shows two intensive endothermic peaks (at 760° and 900°C) and very slightly expressed another one (at 820°C) greatly resembling both the standard curve from Franklin, USA (Frondel and Bauer, 1955), and the curve published by Kostov (1993).

The DTA curve of exogenic kutnahorite from Kremikovtsi deposit (Fig. 3b) is of dolomite-type. It is characterised by the presence of two endothermic peaks at 760° and 850°C, the first one being slightly expressed. It is also scarcely visible endothermic peak 800°C. This DTA curve is very similar to the curve from the classic deposit Kutna Hora, Czech Republic (Trdlička, 1963).

CONCLUSIONS

The results from the present study show that the two genetic types of kutnahorite examined differ in their chemical composition and structural ordering. The endogenic kutnahorite from Ribnitsa deposit is represented by Fe-Mg varieties with high structural ordering. The supergene kutnahorite from Kremikovtsi deposit is formed under subaqueous supergene conditions in association with secondary carbonates. The mineral has partially ordered structure and is represented by calcian varieties.

Table 2. XRD data of kutnahorite from Ribnitsa and Kremikovtsi deposits.

Kutnahorite, Franklin, USA (ASTM 11-345)			Fe-Mg kutnahorite, Ribnitsa		Fe-Mg kutnahorite, Ribnitsa		Ca-rich kutnahorite, Långban, Sweden (ASTM 19-234)			Ca-rich kutnahorite, Kremikovtsi		Ca-rich kutnahorite, Kremikovtsi		Ca-rich kutnahorite, Kremikovtsi	
hkl	d (Å)	I/I₀	d (Å)	I/I₀	d (Å)	I/I₀	hkl	d (Å)	I/I₀	d (Å)	I/I₀	d (Å)	I/I₀	d (Å)	I/I₀
101	4.27	6					101	4.13	10						
012	3.75	20	3.73	1	3.74	2	012	3.78	40	3.80	8	3.8	4	3.75	2
104	2.94	100	2.902	10	2.916	10	104	2.981	100	2.986	100	2.96	10	2.96	10
006	2.73	6					006, 015	2.771	10	2.786	2				
015	2.59	4													
110	2.44	14	2.429	2	2.475	3	110	2.462	40	2.464	9	2.44	5	2.46	3
113	2.23	20	2.210	2	2.210	5	113, 021	2.248	50	2.253	10	2.25	6	2.24	4
021	2.10	4													
107	2.04	20	1.982	3	2.030	4	202	2.062	50	2.067	10	2.06	6	2.05	5
024	1.876	10			1.870	1	024	1.896	20	1.899	4				
018	1.837	25	1.828	5			018	1.869	50	1.875	12	1.878	6	1.867	2
009	1.814	30	1.803	5	1.813	7d									
							116	1.840	60	1.844	12	1.839	7d	1.831	3
211	1.588	6					211	1.601	20	1.606	2				
122	1.566	4	1.556	2	1.556	3	122, 1010	1.578	30	1.584	4	1.586	4	1.575	1
212	1.540	4													
214	1.486	8	1.477	2	1.482	1	214	1.501	20	1.503	3	1.500	3	1.499	1
028	1.469	4					208	1.487	10	1.492	3				
119	1.465	4					119	1.478	10						
125	1.409	6	1.394	3	1.397	2	125, 1011	1.448	10						
							300	1.418	30	1.422	3	1.424	2	1.414	1
0.0.12	1.363	6			1.358	1	0012, 217	1.386	20	1.391	2				
2.0.10	1.294	4					0210	1.311	10						
128	1.258	4	1.246	1	1.246	1	128	1.273	20						
2.0.11	1.189	4					2011	1.229	10						
2.1.10	1.145	4													
	1.141	4			1.137	1						1.138	1		
134	1.126	6	1.119	2	1.119	2									
0.0.15	1.089	4			1.108	1									
2.0.14	1.022	6	1.016	5	1.013	2						1.033	1	1.029	1
FeK_α (Ni)			FeK_α (Mn)		FeK_α (Mn)		CoK_α			CuK_α (Ni)		CuK_α (Ni)		CuK_α (Ni)	

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ON THE PALEOGENE DACITE-RHYODACITE VOLCANICS IN THE WESTERN AND CENTRAL RHODOPES AND THEIR GEODYNAMIC SETTING

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ABSTRACT
The Late Eocene–Early Oligocene dacite-rhyodacite volcanics are related to graben depressions located around block-dome structures that were metamorphosed during the Late Cretaceous and intruded by Late Cretaceous and Paleogene granite plutons. The volcanic rocks associate with coarse terrigenous successions of molasse type. Their petrographic and petrochemical composition is similar and typical of dacites, rhyodacites and trachyrhyodacites. The rocks form a normal to subalkaline potassium-sodium or hige-K calc-alkaline dacite-rhyodacite series and occurrence of ignimbrites. According to petrologic and geological data they are products of collision-related magmas related to tectono-magmatic activation of the metamorphic basement.

INTRODUCTION

The Paleogene sedimentary, volcano-sedimentary and volcanic rocks in the area of Western (WR) and Central Rhodopes (CR) are related to graben depressions superimposed upon Precambrian metamorphic basement of the Rhodope region (RR) and in parts upon Late Cretaceous-Paleocene granodiorite-granite plutons. The main Paleogene graben depressions or sedimentary and volcanic basins discussed in the present paper are: Mesta basin (MeB); Dospat basin (DoB) or Bratsigovo-Dospat depression from WR; Smolyan (SmB) and Upper Arda UaB) basin from CR, situated to the north of boundary Bulgaria- Greece. The volcanic rocks in Hvoina basin (HvB) are not discussed as an independent unit since they are similar to those in Smolyan basin and form part of the latter. The volcanic rocks in the area of Luky comprise latites, quartz-trachytes and trachy-rhyolites (Stoinov, Stoinova, 1969). They are analogous in composition to the volcanics of Borovitsa volcanic region in the Eastern Rhodopes (IR) and are also not discussed and interpreted in this paper.

The present work is a continuation of earlier studies of the author. The aim is, based on new geological and analytical data, to summarize the available information on the volcanic rocks from individual basins, to reveal their common and specific features, their regional geodynamic setting and to contribute to the understanding of the volcanism as a whole.

STRUCTURAL AND STRATIGRAPHIC FRAMEWORK

Structural framework

The development of Paleogene grabens and associated volcanic activity was related to Late Cretaceous-Paleogene tectono-magmatic activization of RR or to collisional events, respectively. The RR experienced Late Cretaceous amphibolite facies metamorphism and related magmatic activity (Arnaudov, Lilov, 1998; etc.). Main rock types are amphibolites, diverse gneisses and migmatites. Their mineralogical and petrographic composition is very close to that of the granitoids from the metamorphic-magmatic domes. The age of the coarse porphyric granites in WR, interpreted as synmetamorphic (Kamenov et al., 1999), is 70 Ma. The plutons in Northern Pirin are dated as Late Cretaceous (Zagorchev et al., 1987), the Barutin-Buinovo pluton (Elatia in Greece) – Late Cretaceous-Paleocene (Soldatos, Christofides, 1986; Cristophides, 1996). The interval Middle Eocene-Early Miocene marks a new stage in the development of RR. In WR, medium-grained hornblende-biotite granites (or granites of second type) were intruded 40 Ma ago (Kamenov et al., 1999) and in the area of Pirin – granites dated 37-32 Ma (Zagorchev et al., 1987). The growth of the domes was related to block-dome uplift and fracturing of the upper parts of the crust. Faulting was controlled by older faults and internal boundaries. During the Middle Eocene and later, graben depressions developed around the growing domes (Vatsev et al., this volume). The intramontane-type Late Eocene grabens accumulated coarse-terrigenous and terrigenous molasse. Around the boundary Eocene-Oligocene, extension and deep fracturing affected the crust and initiated calc-alkaline volcanic activity in the whole RR. The successions of sedimentary and volcanic rocks indicate a transition from early to mature and "hot" grabens.

The age of the sedimentary and related volcanic rocks from the depressions in WR (Vatsev, 1978a,b; 1991; Vatsev, Nedyalkova, 1984) and those from CR (Vatsev, 1981, 1982, 1985, 1988, 1989; Vatsev, Hristov, 1982; Vatsev, Cholakov, 1978), is Late Eocene-Oligocene as indicated by fossil flora. The same radiometric age is reported for some volcanic rocks (Palshin et al., 1974; Pecskay et al., 1991). The volcanic rocks in IR form a bimodal association of basic and intermediate subalkaline rocks and calc-alkaline rhyolites (Yanev et al., 1998, etc.) of Late Eocene-Early Oligocene age. In general, the volcanic activity in RR commenced toward the end of the Late Eocene, culminated around the boundary Eocene-Oligocene and terminated probably in the end of the Early Oligocene.

PETROGRAPHIC CHARACTERISTICS

The volcanic and volcano-sedimentary rocks from the individual depressions in WR and CR and their parts are of different stratigraphic position and origin but show a relatively similar mineralogical, petrographic and petrochemical composition (Bahneva, Stefanov, 1973; Vatsev, Nedyalkova, 1984; Vatsev, Katskov, 1988; Vatsev, 1989; Vatsev, 2002; etc.). The phenocrysts are idiomorphic, fractured and consist of plagioclase, K-Na feldspar, quartz, biotite, amphibole and augite. Their quantity varies from 10-20 to 40-65%. The plagioclase crystals (3-6 mm in size) are zonal, varying from the central parts toward the periphery from andesine (An 50-42) to oligoclase (An 30-22). Normal and inverse zoning is observed. There are also crystals of more basic composition, probably relictic nuclei. The K-Na feldspar (0,3 – 5 cm) is sanidine and in the ingnimbrites – orthoclase (2V = 60-64) (Vatsev, Katskov, 1988). Quartz crystals (0,2–6 mm) are irregular in shape with embayments of volcanic glass. There are also polymineral, xenogenic quartz grains and such containing gas and dust inclusions. Biotite is the basic and constantly present (3-6%) femic mineral. Varieties of relatively iron-rich biotite are typical. There are also crystals with thin and darker brown-green peripheral zones. Amphibole is a relatively rare (below 1%) mineral in the discussed K-Na rocks. It is represented usually by green hornblende, occurring mainly in dacites at the base of the volcanic successions. Small semi-automorphic grains of augite or diopside-augite are also present. They are replaced by amphibole. Accessory minerals are zircon, apatite, orthite, magnetite, titano-magnetite, titanite, etc. The rocks contain also crystobalite, tridimite, K-Na feldspar, ore minerals, etc.

The groundmass of the volcanic rocks consists entirely of volcanic glass, re-crystallized to different extent, but the minerals are analogous to the phenocrysts. The groundmass is uniform or two-phase. The latter variety is characterized by banding, indistinct brecciation of two immiscible components showing black and black-reddish color. There are also secondary devitrification structures – hyalopilitic, felsitic, spherulitic, etc.

Ignimbrites, ranging in thickness from the first tens of meters to 500-600 m occur in DoB, SmB and UaB (Vatsev, Katskov, 1988; Vatsev, 1989; 2002; Bahneva, Stefanov, 1973).

The mineral associations in the volcanic rocks are of polygenic origin. There is a strong positive correlation between the composition of the volcanics and their relictic inclusions of metamorphic and magmatic rocks from the basement.

The phenocrystal associations are typical of normal calc-alkaline biotite to amphibole-biotite dacites and rhyodacites.

PETROCHEMICAL CHARACTERISTICS

The Late Eocene – Early Eocene volcanic rocks in WR and CR are acidic rocks that do not differ essentially in the content of SiO_2 (64-74 wt%) and the other major petrogenic oxides. The subdivision of the main types of volcanic rocks is based on: 1) the classification and nomenclature of magmatic rocks (CN) - $(Na_2O+K_2O)/SiO_2$ (Bogatikov et al., 1981); 2) the classification of volcanic rocks (TAS diagram, Le Bas et al., 1992) complemented by Yanev, Andreev (2000); 3) the classification according to K_2O/SiO_2 content of Peccerillo, Taylor (1976) complemented by Ewart (1982). The normative mineral composition is calculated by the C.I.P.W. method using: 1) AQP diagram with field lines by Le-Bas Streckeisen (1991); 2) AbAnQ diagrams with field lines by Irvine and Barragar (1970). The rock complexes are characterized also by AFM and Na_2O-K_2O-CaO diagrams and the variation diagrams $SiO_{2/3}$+K_20-FeO-MgO-CaO of Larsen - Fig. 1-4.

The TAS plots of volcanic rocks from the depressions in WR and CR concentrate around the point that divides the fields of dacites, trachydacites and rhyolites (Fig. 1) and are defined as a trachydacite-rhyolite or trachyrhyodacite series. On the K_2O/SiO_2 diagram, according to the dividing lines of the cited authors but without a rhyodacite field, the volcanics from WR and CR may be characterized individually and as a whole as a high-K dacite-rhyolite series. The CNI – $(Na_2O+K_2O)/SiO_2$ diagram shows that the Paleogene volcanic rocks in WR and CR are of uniform dacite-rhyodacite composition. Rhyolites occur in SmB only, i. e. rocks with SiO_2 content over 73 wt% (in this case 73 to 74 wt %). The rocks from DoB, SmB and UaB are entirely of rhyodacite composition while in MeB there are dacites and rhyodacites but without any differences in the stratigraphic position and spatial distribution. According to the sum of alkaline oxides, the volcanics are normal calc-alkaline and subalkaline dacites and rhyodacites or trachydacites and trachyrhyodacites.

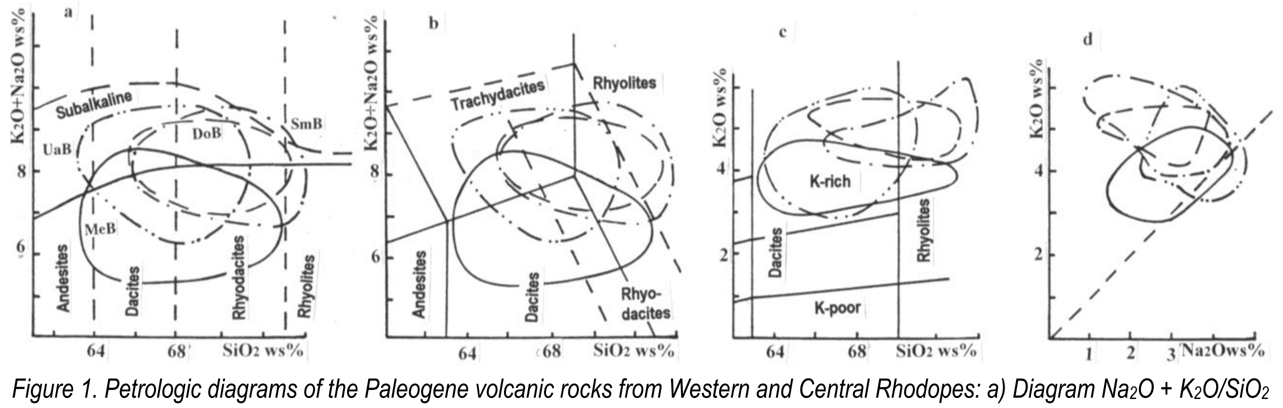

Figure 1. Petrologic diagrams of the Paleogene volcanic rocks from Western and Central Rhodopes: a) Diagram Na_2O + K_2O/SiO_2 wt%; b) Diagram Na_2O + K_2O/SiO_2 wt% (TAS); c) Diagram K_2O/SiO_2 wt%; d) Diagram K_2O/Na_2O wt%; data of diagrams see in paper.

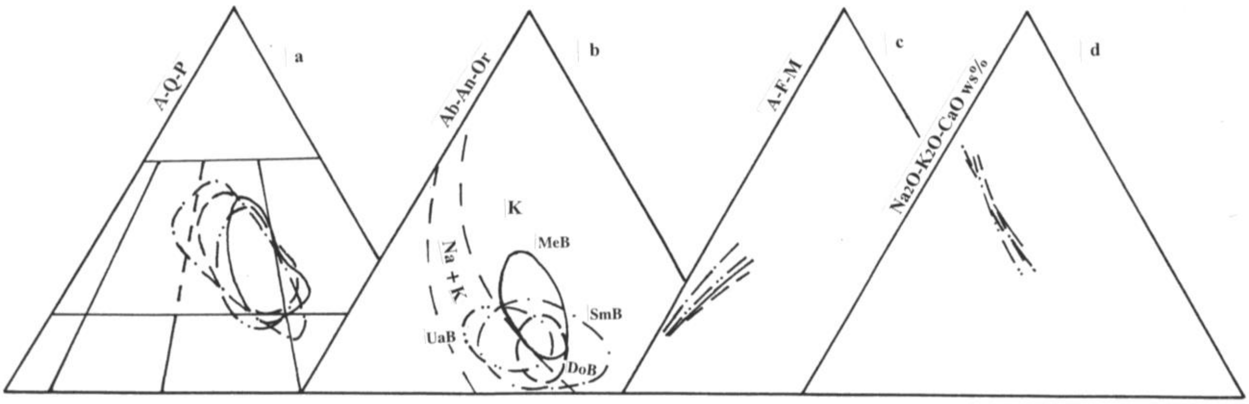

Figure 2. Mineralogical and petrologic diagrams of the Paleogene volcanic rocks from Western and Central Rhodopes: a) Diagram AQP, A – alkcaly feldspar, Q – quartz, P – plagioclase; b) Diagram Ab-An-Or normative minerals; c) Diagram AFM, A = Na_2O + K_2O, F = FeO + 0,9Fe_2O_3, M = MgO; d) Diagram Na_2O-K_2O-CaO wt%; data of diagrams see in paper.

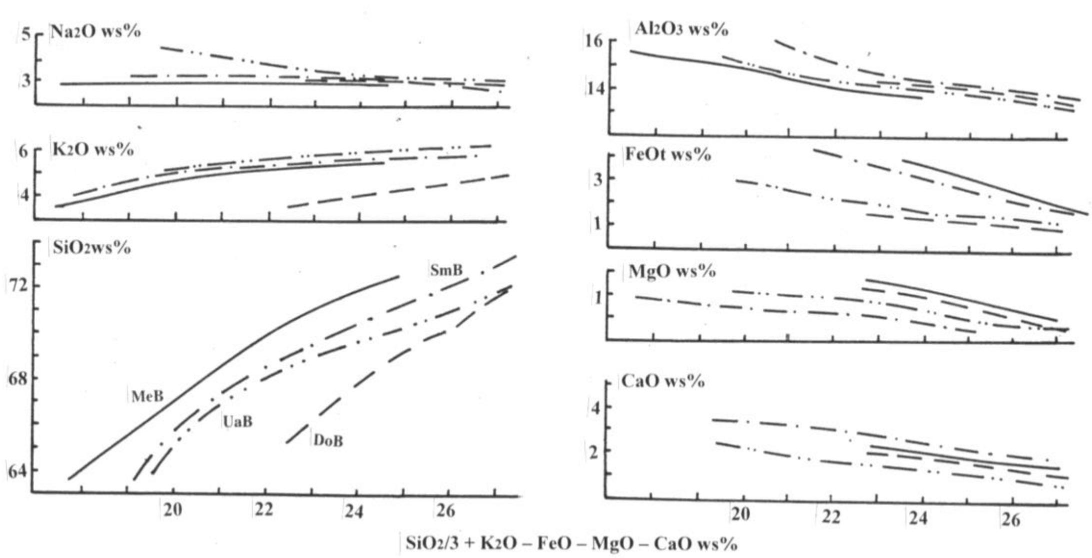

Figure 3. Variation diagrams of the parameter of Larsen of the Paleogene volcanic rocks from Western and Central Rhodopes.

According to the AQP diagram, the volcanic rocks in WR and CR may be defined as rhyolites and those from MeB – as dacite-rhyolites. There is no rhyodacite field in the diagram but the concentration of plots in the lower right part of the diagram shows that these are rocks of rhyodacite composition of relatively higher alkalinity. Single samples plot in the field of quartzlatites. According to the relationships between normative Ab-An-Or the rocks from MeB and DoB are K rhyodacites and those from UaB and SmB are K and K-Na rhyodacites.

Summarizing the above data on the volcanic rocks from the basins in WR and CR it is evident that they belong to a uniform in composition normal calc-alkaline to subalkaline dacite-rhyodacite series (CNI diagram) or trachydacite-rhyodacite (TAS diagram) series. Relatively more basic rocks (dacites) occur in MeB and UaB and more acidic (rhyolites with relatively lower SiO_2 content) – in SmB. In respect of the alkalinity it must be pointed out that the sum Na_2O+K_2O varies between 4,5 and 9,6 wt%, i. e. the rocks are calc-alkaline and subalkaline varieties. In general, K_2O dominates over Na_2O (Fig. 2). The relation between these oxides is inverse in hyalodacites poor in phenocrysts but they are represented by single or insignificant number of samples and the rocks are of limited occurrence. The ratio Na_2O/K_2O is not lower than 0,4 and as a whole the discussed rocks belong to the K-Na series (Bogatikov et al., 1981, p. 19). The alkaline K trend of the initial melts is not expressed but there is a higher-K content only.

In general, characteristic features of the volcanics are: low TiO_2 content (0,2-1,3 wt%), TiO_2 and FeO decreasing with increasing SiO_2 as a result of magnetite separation and depletion of the melts, FeO remaining low; a depletion of rocks and melts with respect to Al_2O_3 with decreasing SiO_2 is not well expressed – the rocks show moderately low and moderately high Al_2O_3 content, normative corundum is very rare; CaO increases with decreasing SiO_2; the rocks are poor in CaO and MgO, the content of normative wolastonite and enstatite varying in the range of the first several per cents; the content of P_2O_5 is low (0,05-0,4 wt%).

The Paleogene volcanics in WR and CR show similar mineral and petrochemical composition and form a typical Late Eocene-Early Oligocene K-Na calc-alkaline to subalkaline dacite-rhyodacite series. The composition and the similarity of the volcanic rocks from WR and CR show that a distinct differentiation is not expressed. The low amounts of rhyolites may be explained by a relatively rapid uplift of the melts. The depth of the magma chambers was probably about 15 km (Bahneva et al., 1978) and that of the intermediate chambers – 2-7 km (Katskov, 1987).

DISCUSSION AND CONCLUSIONS

Three stages can be distinguished in the Late Cretaceous-Pliocene evolution of RR: 1) early collisional, Late Cretaceous-Paleocene - formation of granite plutons and domes; 2) mid-collisional, Eocene-early Early Miocene – formation of grabens and volcanism; 3) late collisional Early Miocene – Pleistocene – graben formation without volcanism.

The Late Cretaceous collision resulted in reactivation of RR, amphibolite facies metamorphism, migmatization, growth of metamorphic-magmatic domes and intrusion of granite plutons as suggested by the discussed data. These processes were accompanied by development of zonal magmatic fields superimposed on a basement of diverse structure, thickness and tectonic activation. This is the field of normal granodiorite-granites in RR and of subalkaline gabbro-granodiorites, monzonites and syenites in the Srednogorie. These geological phenomena, the later Paleogene granites and volcanics, and the Early Miocene granites indicate high thermal gradients in the crust – now in an over 50 km thick.

During the second, Eocene-Early Miocene stage, like the previous one, there was initial accumulation of heat energy and compositional changes in the mantle and the lower crust that were less intensive in the upper crust. At that time, at the boundary with the upper crust, the heat and substance flow were directed also in the opposite direction. These processes initiated block-dome uplift, extension of the growing mountain structure and fracturing of the crust. In the upper crust there was inflow of heat energy – granite plutons, block-dome uplifts and rift depressions (grabens) formed. The latter were of intramontane type and accumulated Late Eocene – Early Oligocene dacite-rhyodacite volcanics and sediments. The depressions developed in the conditions of alternating compression and uplift, extension and subsidence (Vatsev et al., this volume). The extension was in general weak and related to block-dome uplift but typical rift valleys with rift volcanism were not initiated. The successive formation of uniform in composition Late Cretaceous-Paleocene, Paleogene and Early Miocene granite plutons and Late Eocene – Early Oligocene dacite-rhyodacite volcanic rocks suggests a repeated ascent of uniform in composition melts from the metamorphic, relatively uniform and partially melted in depth basement. The character of the lower crust and upper mantle in RR is not well known (Velev, 1996; Shanov, 1998). Taking into account the amphibolite-gneiss-granite composition of the basement composed of Proterozoic and probably unexposed Archean complexes and related granite plutons and migmatites in depth, we can assume a tonalite-amphibolite composition of the lower parts of the crust.

The Mid- and Late Alpine tectonic, metamorphic and magmatic phenomena and processes in RR were related to the collision between the Afro-Arabian and Eurasian plates as discussed in a number of publications. RR has been interpreted as part of the Eurasian plate (Dabovski et al., 1991, etc.) or at present – as part of the African plate (Yanev, 1999; etc.). In particular, in the area of the Balkan Peninsula (Boccaletti et al., 1974; etc.), the Vardar branch of Tethys subducted below the Eurasian plate and closed in the end of the Cretaceous. The Srednogorie zone has been interpreted as an island arc and the related volcanics – as ensimatic. During the Eocene, the last branch of Tethys – Pindos closed (Ricou, 1994). On these grounds the Eocene-Oligocene volcanic rocks in RR are assumed to be of ensialic origin (Dabovski et al., 1991).

We assume that the volcanism in RR was a result not only of deep regional processes below the volcanic regions, related to a strongly heated “anomalous” mantle and lower crust and its uplift, but also to global collisional processes that controlled the pattern of continental deformations in the neighboring blocks (terranes) including also the stress fields of extensional and wrench faulting. The thickening of the crust, the metamorphic processes and the fracturing of rock masses created favorable conditions for the origin of granite melts. The Early Miocene-Pleistocene stage is characterized by development of a new system of graben sedimentary basins without volcanic activity and cyclic structure of their fill (Vatsev, 1998 and others). From the end of the Cretaceous to the end of the Quaternary, typical continental structures developed in RR – dome-block uplifts, graben depressions and consolidation of the crust.

The development of graben depressions and sediment deposition in them in WR and CR covered the interval Middle Eocene (Vatsev et al., this volume) while in IR this occurred toward the end of the Paleocene (Atanasov et al., 1990; etc.). Cycles of lower order and transgressive-regressive depositional successions have been established in the development of the grabens (Vatsev et al., this volume and others). In general, the volcanic activity in the depressions in RR took place during the Late Eocene – Early Oligocene time span. A temporal shift of the Paleogene volcanic activity from NNW to SSE is reported in IR (Yanev et al., 1995; etc.). The available radiometric data on the age of the granite plutons in Pirin Mts. and south of it, in Greece and those from WR and CR in Bulgaria and Greece, mark a migration of the magmatic activity from NNE to SSW, i. e toward the collisional front and opposite to that in island arcs. The discussed regions are located at a distance of 250-400 km away from the Vardar zone. Late Cretaceous in RR and Priabonian (35 Ma) in IR metamorphism with typical crustal strontium ratio has been dated (Peitcheva et al., 1995). These facts indicate a stage character of subduction and collision. The subduction processes most probably did not affect directly the Late Cretaceous, Paleogene and Early Miocene granite plutons and Eocene-Oligocene volcanics in RR but created stress conditions that were favorable for metamorphism, origin of magmas and their ascent to the surface. The development of diverse in age granite plutons and Eocene-Oligocene volcanics is an evidence for repeated generation of magma of the same composition and ascent of melts within the same zone into the consolidated block and on the surface. In our opinion, the origin of granite plutons and volcanics was related to melting within the deep isostatic “root” and growth of magma chambers in the upper crust of RR. Yanev et al. (1998) suggested that, toward the end of the Eocene, the subducting and eclogitized plate broke off, penetrated into the mantle and disturbed its thermal gradient. The occurrence of Late Oligocene basalt dikes in IR and their petrologic and geochemical characteristics indicate deep fracturing of the crust (Marchev et al., 1998). This leads to the assumption that the transfer of heat energy from the activated upper mantle was accomplished probably through basalt melts. This induced an irregular increase of the thermal gradient in the crust.

One of the important features of the origin and development of graben depressions and their volcanic successions is the close mutual relation and even mutual control of the tectono-magmatic processes. This is marked on one hand by the concentration of volcanic rocks and activity within the grabens and, on the other, by the development of volcano-tectonic depressions (caldrons) in them. The latter are filled with volcanic and volcano-sedimentary rocks comprising wedge-like and inpersistent packets of terrigenous rocks.

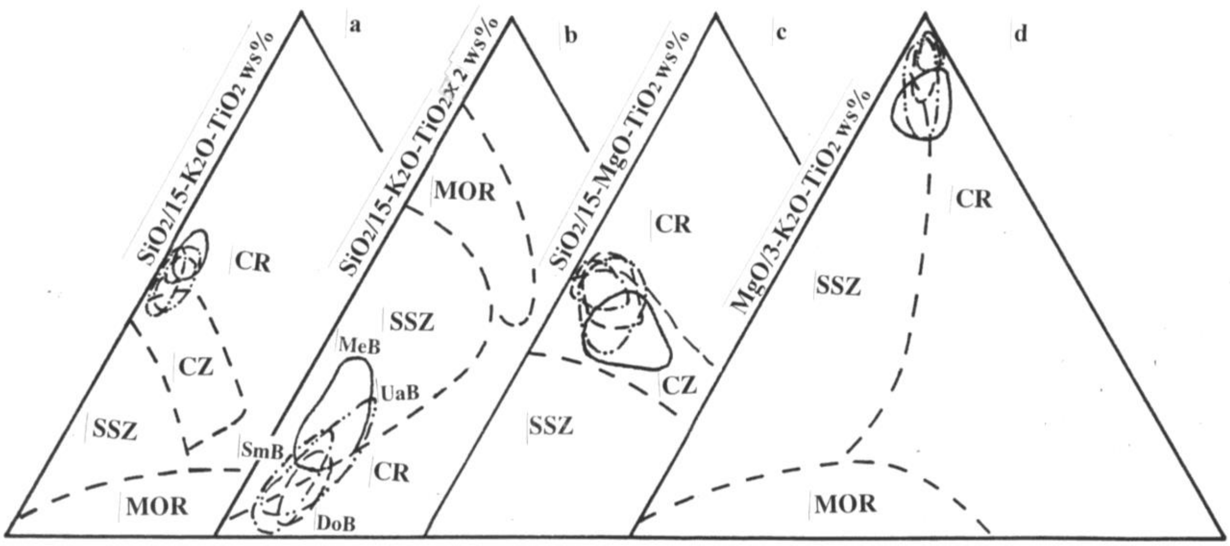

Figure 4 The Paleogene volcanic rocks from Western and Central Rhodopes on the diagrams of correlations of Si, Mg, Ti and K; environments: MOR – middle oceanic ridge, CR – continental rift, SSZ – subduction zone, CZ - continental collision; data of diagrams see in paper.

The variation diagrams based on Larsen’s parameter (Fig. 4) mark an increase of SiO_2 and K_2O – a potassic trend, weak variations of Na_2O and decrease in the content of the other main petrogenic oxides. The curved trend of the variation lines on the diagrams suggests that the portions of enclosed material in the melts did change. The volcanic successions in all depressions show a homodromous trend. It is marked by the development of relatively more basic, glass containing and poor in phenocrysts rocks in the lower parts of the successions. The upper parts contain larger amounts of phenocrystals (40-65%) and are relatively more acid in composition with higher alkalinity – subalkaline rocks. The crosscutting veins and necks, containing higher amounts of sanidine phenocrystals and relatively higher K_2O, mark an antidromous trend most probably related to melts from the lower parts of the magma chambers. However, these crosscutting bodies are rare. A calc-alkaline trend of poor in MgO volcanics is indicated on the AFM diagrams. The Na_2O-K_2O-CaO diagrams show an indistinct potassic trend and relatively higher content of K_2O. In general, the discussed volcanic rocks are characterized by a K_2O/Na_2O ratio that does not depend on the SiO_2 content . According to this parameter, they may be referred to the second series of magmatic rocks typical of tectonically activated stable crustal blocks (Marakushev, Yakovleva, 1975). The above geological data suggest that this is a collisional activation.

The petrochemical data on the volcanic rocks from WR and CR on the diagrams (Fig. 4) a) $SiO_2/15$-K_2O-TiO_2, b) $SiO_2/15$-K_2O-MgO, c) $SiO_2/15$-MgO-TiO_2x2 and d) MgO/3-K_2O-TiO_2 show a uniform grouping of the plots with respect to the dividing lines of Demina, Simeonov (1999). As a whole, the discussed volcanic rocks or melts may be defined as collisional. The concentration of plots close to the line of continental rifts (Fig. 4, a, c) may be explained by their origin in rifted “hot” graben depressions and block displacements in an over 50 km thick crust. The clustering of plots near the line that divides subduction zones and continental rifts (Fig. 4, b, d) may be related to synchronous occurrence of these events and processes in RR during the Late Eocene-Oligocene and an available in magma of components of the mantle, down crust and ancients subduction zone. The distribution of the plots depends also on the lower MgO and TiO_2 content in the rocks of. The disposition of the points of diagrams is analogical in big part with these of the volcanics of Africa rifts; the last are presented in paper of Demina and Simov (1999, Fig. 2). These data and the evidence from the geological development of the Rhodope and neighbouring regions suggest a complex tectono-metamorphic-magmatic character of the activation of RR during the collision.

The geological, petrographic and petrochemical data on the Late Eocene-Oligocene volcanic rocks in WR and CR, discussed in the present and previous papers of the author (Vatsev, Nedyalkova, 1984; Vatsev, Katskov, 1988; Vatsev, 1989b; Vatsev, 2002; etc.), allows to infer that most probably these rocks are products of eutectic melting of continental type crust, but in this process it is possible a participate of the down crust and mantle fluids or magmas. The successive formation of considerable in volume and uniform in composition acid melts in RR was related to complex and changing in time geodynamic settings and processes, related to the collision and activation of crustal blocks of different thickness and geological history.

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DEPOSITIONAL STAGES AND CORRELATION OF THE PALEOGENE FROM THE GRABEN BASINS IN SOUTHWEST BULGARIA

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ABSTRACT
The Paleogene basinal successions record transgressive-regressive fluvial-lacustrine/marine-fluvial depositional cycles. The graben basins and a basal gray colored, terrigenous, continental-marine association were formed during the Middle Eocene. Mature and "hot" grabens with cyclic deposition of a red-and-gray colored continental-marine and related dacite-rhyodacite association are typical of the Late Eocene–Early Oligocene stage. The Rupelian-Early Chattian and Middle Chattian–early Early Miocene stage is characterized by expanding sedimentation realm and deposition of a cyclic, gray colored coal-bearing, fluvial-lacustrine association.

INTRODUCTION

The Middle Eocene–Early Miocene terrigenous and Late Eocene-Early Oligocene volcanic-sedimentary successions, varying in thickness from 0,5 to 3 km, were formed and now exposed in graben depressions in Southwest Bulgaria (SWB). Major basins are: Mesta basin (MeB), related to the homonymous fault and river valley, Sandanski (SaB), Brezhani (BrB), Simitli (SiB) and Bobovdol basins (BoB), related to Struma fault and river valley; the basins located along the northeastern periphery of the Serbo-Macedonian massif and within the Strouma zone – Padezh (Suhostrel) (PaB), Kamenitsa (Prekolnitsa) (KaB), Poletinci (PoB) and Pianets (PiB), related to homonymous faults or fault belts; the basins west of Rila block in the Rhodope region or massif (RR) and west of Struma fault – Bobovdol (BoB) and north of it in Sredna Gora Zone – Pernik basin (PeB).

The aim of the present paper is, based on complex analysis, to correlate the basins, to define the main stages or tecto-sedimentary cycles and phases in sediment accumulation and to unravel their relationships with characteristic regional and global events. M. Vatsev, who has studied all mentioned basins, has written the paper. New horizons of marine sedimentation were established in Padezhq Poletinci and Mesta basins. S. Dzuranov did the micropaleontological studies. Some unpublished data of B. Kamenov were used in the basin correlation.

STRUCTURAL AND STRATIGRAPHIC FRAMEWORK

Structural framework

The Paleogene graben (trough) basins in SWB are superimposed on Precambrian basement of the RR and on folded Paleozoic and Mesozoic complexes of the neighboring parts of Struma and Morava units, and the Srednogorie. The grabens are linearly elongated mainly in NNW-SSE direction and vary in size – 30-70 km in length and 5-20 km in width.

These basins are elements of the Late Cretaceous-Paleogene collisional tectono-magmatic activation of the RR. Some authors describe them as post-collisional structures (Dabovski et al., 1991). The origin and development of the grabens is related to the progressive growth of domes cored by Late Cretaceous-Paleocene plutons (Zagorchev, Moorbath, 1987; Soldatos, Christofides, 1986; Christofides, 1998; Kamenov et al., 1999; Arnaudov, Lilov, 1998; etc.), break-up of the upper parts of the crust during the Middle and Late Eocene and formation of rift-related grabens and depression in the peripheral parts of the domes. The newly formed faults were controlled by pre-existing faults and inhomogeneousness. The grabens accumulated coarse-terrigenous and terrigenous sediments of molasse type that were accompanied by rocks of a dacite-rhyodacite association (Ivanov et al., 1971; Ivanov, Zidarov, 1968; Bozhkov et al., 1976; Vatsev, Nedyalkova, 1984; etc.). The intrusive magmatism is represented by Paleogene-Early Miocene granite plutons (Zagorchev, Moorbath, 1987; Christofides, 1998; Kamenov et al., 1998; etc.).

Stratigraphic framework.

The age of the terrigenous and volcanic rocks of the discussed basins is Late Eocene-Oligocene as indicated by fossils found in the water-basin sediments (Zagorchev et al., 1989; etc.) and by radiometric data for the volcanic (Palshin et al., 1974; Pecskay et al., 1991). In the course of our studies, biostratgraphic evidence for a Middle Eocene rocks in PaB, PiB and MeB (in this work down) and an early-Early Miocene – Aquitanian age of the uppermost part of the successions in BrB (Gaudant, Vatsev, in press) and in BoB and PeB has been established but the data are still not published. Most of the basins are coal-bearing and were studied by many coal experts, which in this short paper can not be mentioned. The stratigraphic data of the study basins are based of: PeB – B. Kamenov (1964), R. Beregov (1936), Zaharieva (1950) and unpublished materials of M. Vatsev; BoB - B. Kamenov (1959), S. Chernjavska (1977; etc.) and unpublished materials of M. Vatsev; PoB – S. Moskovski (1971) and unpublished materials of M. Vatsev; KaB - B. Kamenov (1942), R. Ivanov et al. (1971), M. Andelkovich et al. (1991) and unpublished materials of M. Vatsev; PiB – E. Belmustakov (1948), S. Moskovski, V. Shopov (1965), P.Mandev, S Zafirov (1967), S. Chernjavska (1977; etc.) and unpublished materials of M. Vatsev; PaB - E. Belmustakov (1948), I. Zagorchev et al. (1989) and unpublished materials of M. Vatsev; BrB and SiB – M. Vatsev (1984, 1991b) K. Zaharieva (1950), E. Palamarev (1967), J. Gaudant and M. Vatsev (in press) and unpublished materials of M. Vatsev; SaB – I. Bozkov et al. (1976, etc.) and unpublished materials of M. Vatsev; MeB – M. Vatsev (19778a, b, 1991a), M. Vatsev, S. Nedyalkova (1984) and unpublished materials of M. Vatsev. The summary stratigraphic sections of basin successions and correlate chart (Figure № 1) is prepare of M. Vatsev.

The age of the rhyodacites in the area of Kozhuh Height (Bozhkov et al., 1976, etc.) is 30 Ma (unpublished data of the former State Enterprise "Rare Metals"). This is an indication for the Late Eocene-Early Oligocene age of the rocks that are intersected by the volcanics. These rocks are red-colored, altered and silicated coarse-terrigenous and terrigenous sediments topped by opalized, probably rhyodacite tuffs.

The composition, structure, origin and correlation of the basinal successions allow distinguishing different stages in their stratigraphic-sedimentary evolution that are common for all basins. The basinal stratigraphic successions and data on their composition, structure, genesis and fossil content are summarized in Figure 1.

DEPOSITIONAL CYCLES

The Paleogene rocks are diverse conglomerates, sandstones, mudstone or argillites and minor limestones that form characteristic sequences. Their lithological compostion, fossil content, structure and genesis mark the development of transgressive-regressive depositional cycles (TRC), i. e. 3d (A-K) and 2nd order cycles (Fig. 1). The boundaries of these cycles are distinct wash-out and clear lithological contacts. The wash-out character of boundaries was related mainly to changes of the temporally base level, to higher suuply of coarse terrigenous material and re-distribution of the depositional areas within the grabens and region. The changes of the base level in the discussed continental basins were related to the subsidence, the depositional rates, the formation and with drawal of water basins – lakes, lake-lagoons and marine bays. These changes were controlled by tectonic movements, eustatic changes of the World Ocean level and their combination in time. The lack of well expressed deep erosional carving and the relatively small size of the morphologically linked basins, allows to assume that there were no essential depositional breaks and that the boundaries of the 3d order TRC or the cyclites (Karagodin, 1986) were nearly isochronous. There are also 2nd order cycles that integrate two to four 3d order TRC. They are divided by unconformities related to more intensive tectonic movements and changes in the depositional area of the basins. Individual sedimentary autocycles may be also traced – proluvial, alluvial (fluvial), alluvial-lacustrine-swamp, etc. that indicate increasing textural maturity in the transgressive successions and decreasing – in the regressive ones.

The established 2nd order cycles developed during certain stages or episodes and 3d order TRC that form the latter, are similar in composition and structure but show some individual features. The base of the 3d order cycles comprises fluvial-transgressive complexes (FTC) that correspond to low base level and probably of the sea level (LS) and lack of water basins in the grabens. The basal mono- to polylithoclastic breccia-conglomerates and conglomerates originated during the early transgressive fluvial phase while the interbedded conglomerates and sandstones on top of them formed during the late-transgressive fluvial phase. Their genesis is proluvial-alluvial. The thickness of these rocks is variable and they are texturally and mineralogic-petrographic immature. The inundation-transgressive complexes (ITC) comprise mainly terrigenous rocks – polymictic and arkose sandstones and diverse mudstones that were formed in water basins – lakes, barred lagoons or open sea bays. They are characterized by higher textural and mineralogic-petrographic maturity. Coal seams are related to the sediments of the initial inundation phase while the sediments of the late inundation phase comprise mudstone and clay-carbonate rocks. These successions record the stages of transgression including also the maximum transgression of the water basins – TS. The regressive complexes (RC) correspond to high level of the basins – sea, lake – but with retreating coast – HS. RC comprise sandstones, sandy argillites and conglomerates in the lower parts that were formed during the early regressive phase. They are overlain by conglomerates and sandstones of the late regressive phase that show strongly varying quantitative relations and decreasing textural and mineralogic-petrographic maturity. This is due to erosion of rocks from the bordering, already uplifted blocks. RC was deposited from bottom rivers within the retreating water basins.

These sediments and the accompanying volcano-sedimentary rocks may be interpreted as syn-rift or syn-tectonic successions. The 3d order TRC of low and middle part of the 2nd order cycles are progressive and asymmetrical and grow bigger thickness of the water-basin sediments and small of the RK. The last cycles are progressive-regressive (Karagodin, 1985) and have well developed RK. The evolution of these successions in the individual basins is similar throughout the discussed region and may be caused and explained by a combination between tectonic subsidence and long-lasting eustatic changes.

Middle Eocene 2nd order cycles – cycles A and B: Rocks of this 2nd order cycle were established in PaB, PiB and MeB. The basal conglomerate-sandstone complexes of TRC A overlie pre-Paleogene basement rocks and are related to paleo-river valleys within the grabens. ITC are represented mainly by bituminous silty shales, clayey sandstones and sandstones. Pinching-out layers of coal and coal schist occur in the basal parts. In the upper parts, the argillites are gray-green, sandy-silty, locally calcareous. In these rocks, in PaB and MeB, we have found remnants of foraminifers, gastropods and bivalves for the first time. The water basins were bay-lagoons to open bays. RC of cycle A, represented by irregularly intercalated sandstones and conglomerates, is not so well developed (10-50 m) as compared to that of cycle B (80-150 m).

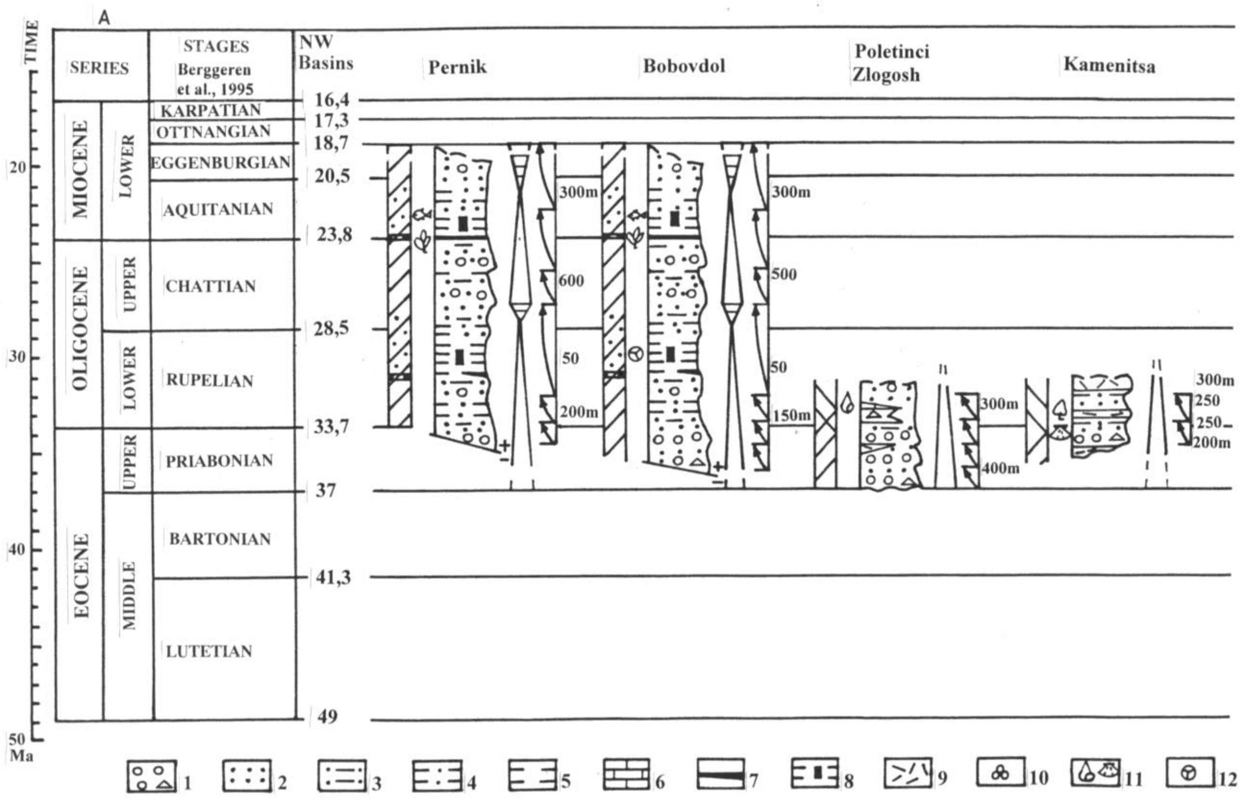


Figure 1. Correlate chart of the Paleogene successions and cycles of deposition of basins of the SW Bulgaria. Lithology: 1 – breccia-conglomerate and conglomerate; 2 – sandstone; 3 – clayey sandstone; 4 – sandy mudstone; 5 – mudstone; 6 – limestone; 7 – coal; 8 – bituminous mudstone; 9 – rhyodacites and tuffs; paleontology: 10 – foraminifers; 12 – gastropods and bivalvias ; 13 – spores and pollen; 14 – Eocene and Oligocene fossil flora; 14 – fossil fishs; environments: 15 – alluvial plain; 16 – lake; 17 – bog; 18 – bay-lagoon; 19 – marine coastal and shelf; 20 – transgressive succession; 21 – regressive succession; 22 – transgressive-regressive cycle; 23 – synsedimentary fault; 24 - synsedimentary faulting and volcanism.

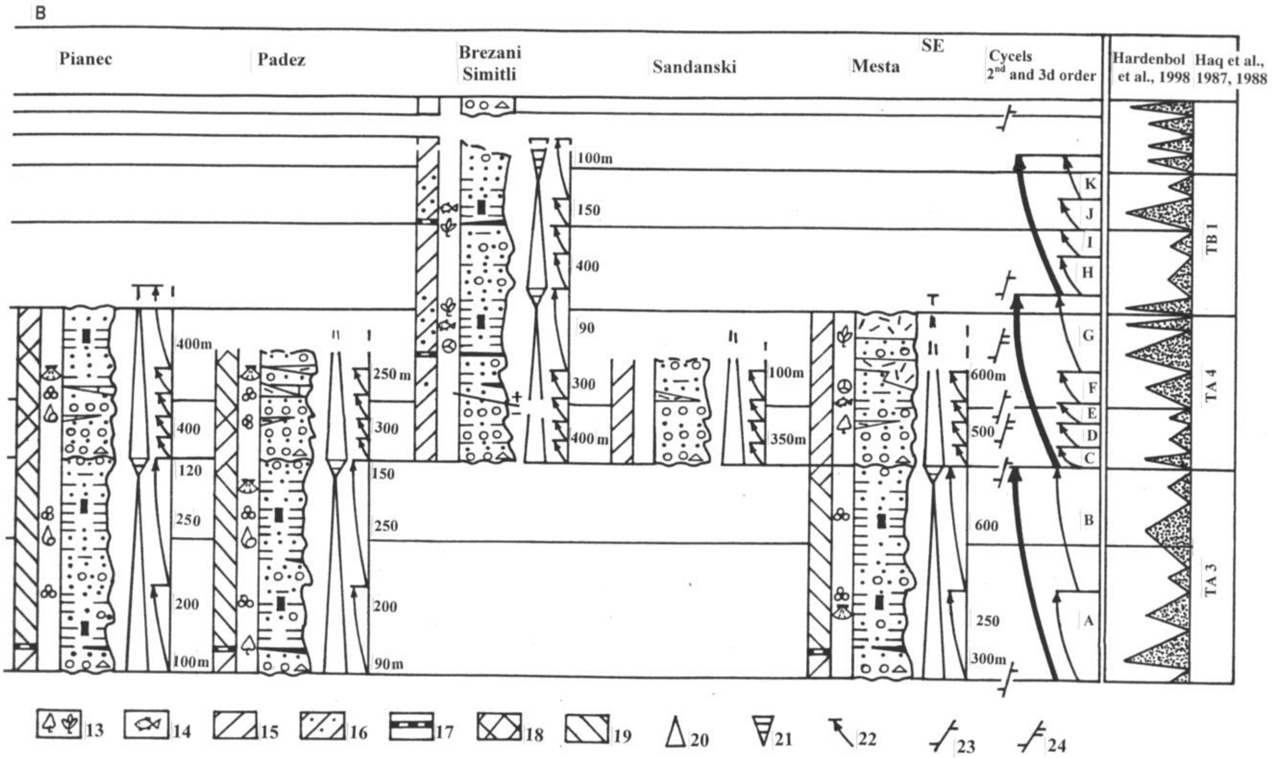
This witnesses a more complete development of the discussed 2nd order cycle. As a whole, the succession of TRC A and B is a gray-colored terrigenous, continental-marine association and has complicated structure.

Foraminifers for the first time were found in gulf-lagoon bituminous shale of the Suhostrel Formation (Zagorchev et al., 1989) of PaB, in bituminous shale of the Pelatikovo area of PiB and Dobrinishte Formation (Vatsev, 1978a, 1991a) of MeB. In PaB in middle part of theTRC A they are at four level. In their larger part, the associations are composed of plankton foraminifers. The following species were defined: *Acarinina bullbrooki* (Bolli), *A. spinuloinflata* (Bandy), *A. primitiva* Morozova, *A. rugosoaculeata* Subb, *Pseudohastiregirina micra* (Cole), *P. danvilensis* (Howe & Wallace), *Subotina eocaena* (Gumbel), *S. linaperta* (Finlay), *Globigerina senni* Beckman, *G. medizzai* Toumarkine& Bolli; and others. This association proves Middle Eocene age of the rocks.

In middle part of the TRC B at two level foraminifer and Radiolaria associations were found. The foraminifer association is almost fully composed of plankton foraminifers. The following species were defined: *Acarinina bullbrooki* (Bolli), *A. spinuloinflata* (Bandy), *A. pentacamerata* Subbotina, *Subotina eocaena* (Gumbel), *Pseudohastiregirina micra* (Cole); and others. These taxa determine Middle Eocene age of the rocks. The foraminifers from MeB still did not study.

This 2nd order cycle may be correlated with supercycle TA 3 (Haq et al., 1987, 1988; Hardenbol et al., 1998).

Late Eocene-Early Oligocene 2nd order cycle – cycles C, D, E, F and G: A typical feature of FTC is that they are build up almost entirely (up to 80%) of red-colored breccia-conglomerates, conglomerates and sandstones. At the same time, they form the dominant (60-80%) part of cycles C and D. Those two cycles are progressive asymmetrical. The rocks of cycle C overlie unconformably the basement or older Paleogene sediments. ITC comprises sandy argillites and clayey sandstones with interbeds of fine conglomerates and sometimes in the upper part – limestones. They were deposited in lakes (SaB), lakes or bay-lagoons and marine bays (PiB, KaB, PaB, MeB). Late Eocene and Oligocene bivalves and gastropods were found in KaB (Kamenov, 1942). Lithothamnian algae, ehinids, corals, nummulites and planctonic foraminifers are known from PaB and PiB (Belmustakov, 1948, Zagorchev et al., 1989; etc.). A progressive increase (from 15-30 to 150 m) in the thickness of the conglomerate and sandstone succession is typical for RC of TRC. TRC C, D and E are characterized by a progressive increase of the thickness and persistence of ITC and RC. Cycle F and G are progressive-regressive.



The upper parts of cycle D, E and F comprise rhyodacites and tuffs. The volcanic activity provoked some disturbances in the structure and development of the sedimentary and volcano-sedimentary successions. The volcanic activity terminated probably during the Early Oligocene but a dated cover of sedimentary rocks is lacking. It must be pointed out that the development of KaB and the neighboring Pchin basin in SE Serbia (Andelkovich, et al., 1991) commenced with volcanic activity. The early volcanic rocks and their sedimentary cover are exposed along the Tlamina Ridge, directly west of the Bulgaria-Serbia border. As a whole, this is a red-and-gray colored terrigenous, continental-marine succession with related normal calc-alkaline, dacite-rhyodacite association (Ivanov et al., 1971; Ivanov, Zidarov, 1968; etc.). The sequences of the TRC F and G of BrB, BoB and PeB do not contain volcanic rocks and are presented of coal-bearing formations; their short characteristic is in lower part.

Extremely rich foraminifer association were found at several levels and place in the upper part of the cycles D and E in PaB. Prevailing in them ate the Benthic foraminifers. Plankton taxa are also present in the smaller fractions. The following species were defined: *Globigerina officinalis* Subbotina, *G. yeguaensis* Weinzierl & Applin, *G. praebulloides* Blowq, *G. officinalis* Subbotina, *Subbotina eocaena* Gumbel, *Trurborotalia cerr. pomeroli* (Toumarkine & Bolli) and others. As a whole this association proves Upper Eocene age of the rocks of cycle C, D (Komatinitsa and Logodazh Formation) and lover part of E. In upper part of section of the Padezh Formation is presented different Late Eocene-Early Oligocene fauna (Belmustakov, 1948, Zagorchev et al., 1989; etc.). Analysis of the biostratigrafical materials in this short paper can no be do. The age of this 2nd order cycle, incidences Komatinitsa, Logodazh and Padezh Formation (Zagorchev et al., 1989) on the basis of new and published data is Late Eocene-Early Oligocene.

This 2nd order cycle may be correlated with supercycle TB 4.

Late Oligocene-early Early Miocene 2nd order cycle – cycles H, I, L and K: The rocks of this 2nd order cycle and cycles F and G were deposited in new graben basins or in lateral branches of old ones. The volcanic rocks absence in these grabens. The successions of the 3d order TRC F-G and H-K have analogical structure and development. Their first cycles are progressive asymmetrical incomplete. FTC of those 3rd order cycles are represented by alluvial conglomerates and sandstones, the letter dominating. Their thick is variable. Their ITC consist of irregularity alternation of sandy-silty shales and clayey sandstones and are wash away. The upper TRC are progressive-regressive. Their ITC are composed of bituminous clay shales, clayey sandstones and calcareous shales (70-150 m). The coal seams are developed in their base and are mined in BrB (cycle G), BoB and PeB (cycle J). The RC comprise of fluvial sandstones, sandy argillites and conglomerates.

According to fossil flora (Palamarev, 1964; Vatsev, 1984; Zakharieva, 1957), spores and pollen (Chernjavska (1977; etc.), fossil fishes – *Barbus macrurus,* Ag., of PeB and BoB (Beregov, 1936), *Barbus steinheimehsis* Quenst (Zakharieva, 1957) and other of BrB (Gaudant, Vatsev, in press) the rocks of cycle F-H are of Rupelian-Early Chattian age. The rocks of cycles I-K are dated as Late Chattina-Aquitanian on the basis of fossil fishes and flora in BrB (Vatsev, 1984; Gaudant, Vatsev, in press); the age of these succession in BoB and PeB is analogous but the data are still not published. According to stratigraphic position, the age of the RC of cycle K is probably late Late Aquitanian-Egenburgian and the depositional break occurred during the Ottnangian age. The cover is of Carpathian sediments of the SiB (Vatsev, 1991b) and BrB (Vatsev, 1984). In general, the Early Oligocene successiin of TRC H-G and this of cycles H-K Late Oligocene-early Early Miocene is a complex cyclic, gray colored, coal-bearing, terrigenous fluvial-lacustrine association.

This 2nd order Late Chattian-early Early Miocene cycle may be correlated wit supercycle TB 1.

DISCUSSION AND CONCLUSIONS

The analysis of the Middel Eocene-early Early Miocene successions and the basin history suggests several stages in their formation, evolution and sediment accumulation: 1) The formation of the Middle Eocene sedimentary graben basins was related to the Illyrian tectonic phase; a gray colored, terrigenous-marine association deposited in the conditions of a warm and humid climate. 2) The Late Eocene-Early Oligocene 2nd order cycle was controlled by the Pyrenean phase under conditions of expanding basins, deep and narrow fault zones, development of elongate mature and "hot" grabens with deposition of a red-and-grey colored continental-marine and related dacite-rhyodacite association accompanied by granite intrusions. The volcanic activity and the related growth of thermo-tectonic domes as well as the intrusion of granite plutons resulted in essential changes in the character and size of depositional areas during the Early Oligocene. 3) The LateOligocene-early Early Miocene 2nd order cycle was related to the Pyrenean and Savian phases; typical features are development of new graben basins, expanding depositional area, deposition of a gray colored, coal-bearing, fluvial-lacustrine association, changes in the geodynamic regime during the Early Miocene from extension and subsidence to compression, block-dome uplift and termination of the sediment deposition, onset of plastic deformations mainly around the periphery of the grabens as a result of general horizontal compression and block movements. In general, this 2nd order cycle (stage) is characterized by development of new graben depressions and formation of a gray colored, fluvial-lacustrine association. The bordering horst blocks were not highly uplifted and were covered by vegetation under conditions of a warm and humid climate. These data indicate a general crustal stabilization. 4) The differences between succession 3rd order TRC cycles and the 2nd order cycles which they form are interpreted as a result of the subsidence in different affiliated graben basins to form wide depressions of similar type resulting from sediment loading, thermal cooling, crustal stabilization and their combination with eustatic changes. 5) A link between depositional cycles and changes in the World Ocean level can be established (Haq et al., 1987, 1988; Hardenbol et al., 1998) – the development of water basins (lakes and marine bays) in the grabens correlates well with episodes of high World Ocean level but at present a more accurate correlations are not possible due to insufficient information concerning a more detailed biostratigraphic dating of the successions and the boundaries between the cycles. 6) As a whole, in the interval Middle Eocene – Early Miocene and later, the discussed region of SWB suffered a progressive, irregular expansion, complicated by unperiodic compressional impulses and related block displacements, cyclic volcanism and intrusions of granite plutons.

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TECTONOMETAMORPHIC AMALGAMATION: FIELD EVIDENCE FROM SOUTH BULGARIA

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ABSTRACT
The term "tectonometamorphic amalgamation" is proposed to designate a process of tectonometamorphic recycling when rocks and rock formations of different age and composition are tectonically mixed and metamorphically homogenized in such a manner that a new complex is formed, and the primary elements are recognized with difficulty. Several examples from South Bulgaria are discussed, and they concern both insertion of higher-grade metamorphics into a lower-grade metamorphic or a non-metamorphic cover or insertion of non-metamorphic cover beds into additionally sheared basement rocks. Large parts (Prerhodopian and/or Ograzhdenian Supergroup, Osogovo Formation, Lisets complex) of the Precambrian high-grade metamorphic basement in Bulgaria may be regarded as products of Cadomian recycling and tectonometamorphic amalgamation of pre-Cadomian and Cadomian metamorphic and igneous rocks.

INTRODUCTION

The term "amalgamation" is used in geology in terrane analysis, and "is defined as tectonic combination of two or more terranes into a single larger tectonic unit prior to their attachment to a craton" (definition by L. Parfenov, A. Khanchuk and W. Nokleberg). Another application of the term is used in modern sedimentology, – relative to merging of two or more beds (usually, turbidites) into a single bed.

The first and most popular meaning of the word implies the production of a single and more or less homogenous product from two or more clearly defined and essentially different initial components, as, e.g., in the case of obtaining a metal alloy of mercury.

Another most appropriate application of the term could concern cases when essentially initially different rocks or rock associations (complexes) are tectonically mixed, and due to strong deformations and metamorphism, reach a homogeneity that makes the recognition of the initial elements very difficult or even impossible. When molten and homogenized, such mixtures give birth to anatectic magmas. Even without reaching such a stage, the degree of homogenization might be sufficiently high thus allowing for the term "tectonometamorphic amalgamation" to be used.

Several cases of tectonometamorphic amalgamation have been observed in South Bulgaria. Although not covering the whole possible range of amalgamation phenomena they may serve as a source for a future classification. The principal cases may be related to: (1) insertion of higher-grade metamorphics into lower-grade metamorphics or non-metamorphic cover rocks that suffer a low-grade metamorphism together with the inserted diaphthorised high-grade rocks; (2) insertion of lower-grade metamorphics or initially non-metamorphic rocks and formations into sheared higher-grade metamorphics or sheared igneous rocks; (3) progressive metamorphism of thick shear zones or thrust zones; (4) polydeformational and polymetamorphic processes in high-grade complexes, with consecutive adding of new igneous material (as sill-like bodies, dykes, etc.), and a partial homogenization during subsequent deformations and metamorphism.

TECTONIC INSERTION OF HIGHER-GRADE ROCKS INTO A SEDIMENTARY COVER

Tectonic insertion of higher-grade (amphibolite facies) basement lenticular bodies into a sedimentary or volcano-sedimentary cover has been observed in a number of cases in South Bulgaria. They have been described with a different degree of detailization. The presence of coeval and later homogenization through deformational and metamorphic overprint gives the ground to designate some of these cases as tectonometamorphic amalgamation.

The tectonic insertion of basement inliers (*Fig. 1*) built up of diaphthorized mica gneisses, migmatites and amphibolites (Ograzhdenian Supergroup) into the covering (tectonic or primary depositional contact) diabases, tuffs and phyllites (Frolosh Formation) has been first described in the Vlahina Mountain, near the western edge of the Lisiya basement fragment (Zagorchev, 1974, 2001). Gneisses, migmatites and amphibolites have been transformed into greenschist-facies blastomylonites grading into chlorite-sericite schists and phyllonites. The resulting sericite-chlorite-actinolite phyllonites are often undistinguishable from the green schists and metadiabases of the Frolosh Formation. The deformational and metamorphic (greenschist facies syntectonic metamorphism) homogenization of the resulting complex (Lisiya strip of inliers) proceeded during multiphase folding. Several possible mechanisms of the insertion include the formation of first-phase anticline(s) near the edge of the fragment that have been consequently tightened and refolded. Another possible origin may be related to early Cadomian thrusting pre-dating or coeval with the greenschist-facies metamorphism of the Frolosh Formation.

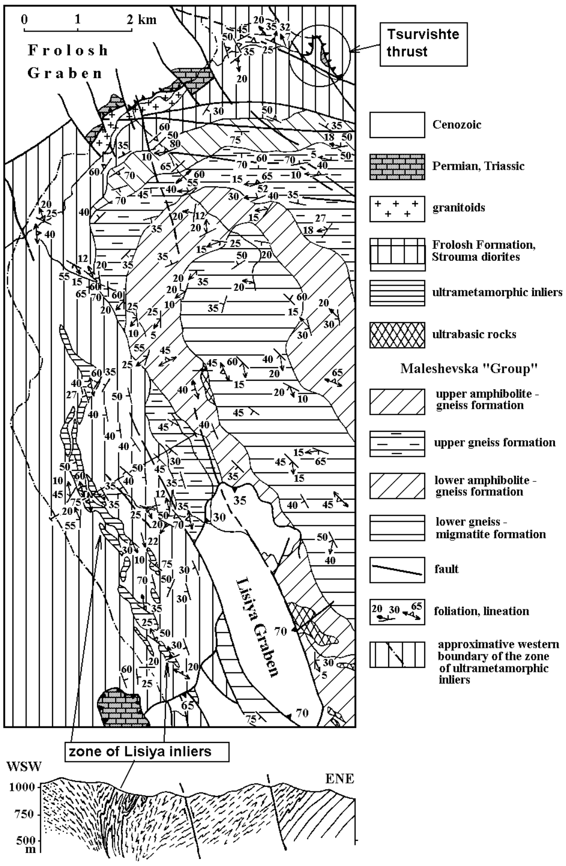

Figure 1. Zones of Cadomian? tectonometamorphic amalgamation (inliers) and of Alpine amalgamation of Triassic rocks into sheared Strouma diorites. After Zagorchev (1974)

The insertion of basement (Frolosh Formation, Strouma diorite formation) lenticular bodies of metadiabase, gabbro or diorite into the cover (with a primary depositional unconformable contact) of Permian and Triassic rocks (Skrino Formation, Gurbino Formation, Mogila Formation, Bosnek and Radomir Formation) has been described (Загорчев, 1984; Загорчев *et al*., 1999) along the Poletintsi-Skrino fold-thrust zone (*Fig*. 2) characterized with very high strains. Coeval or consequent amalgamation through high strains and greenschist facies metamorphism with chemical interchange of components and incipient or partial recrystallization has been recently observed, too.

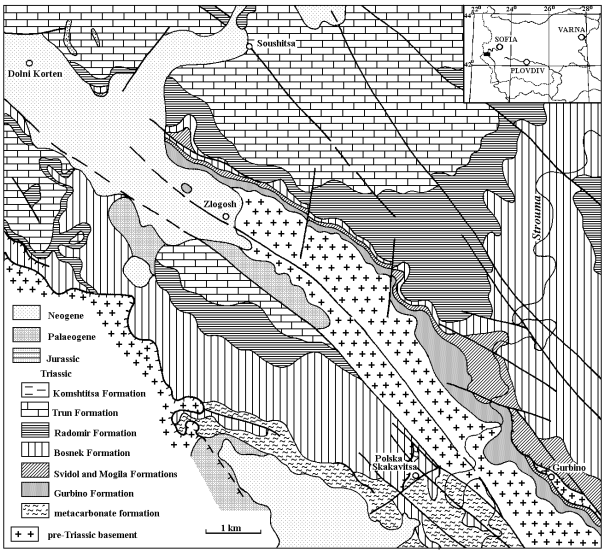

Figure 2. Insertion of basement rocks into the Triassic of Gurbino and Svidol Formation. After Загорчев et al. (1999)

TECTONIC INSERTION OF LOW-GRADE ROCKS INTO SHEARED HIGH-GRADE METAMORPHICS OR IGNEOUS ROCKS

A typical example of this phenomenon is the insertion of a series of lenticular Triassic rock bodies (red beds of Murvodol Formation, and limestones and dolomites of the Mogila and Bosnek Formation) along the thrust surface (Tsurvishte thrust) into sheared diorites of the Strouma diorite formation (*Fig. 1*). This event probably occurred when the lower south-western limb of a tight to isoclinal fold (Tsurvishte anticline) has been sheared and reduced into a series of lenses, and the core (built up of Strouma diorites) has been intensely sheared and thrusted (*Fig. 3*). The whole tectonometamorphic mixture has been syntectonically transformed into a greenschist – marble – phyllite-like sequence (Zagorchev, 1996).

Figure 3. Tsurvishte thrust in the road cutting near the village of Tsurvishte. Lenses of MiddleTriassic dolomites inserted into the Strouma diorites sheared and transformed into mylonites

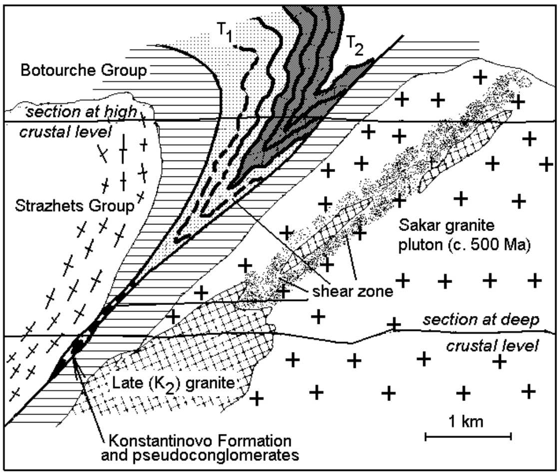

Figure 4. Lisovo syncline and shear zones in the southern slope of the Sakar Mountain. After Zagorchev (1994).

A similar case is the so-called Lisovo graben-syncline (or Konstantinovo shear zone) in the southern slope of Sakar Mountain (*Fig. 4*). A tight and pinched-in syncline is built up of Triassic metasedimentary rocks initially covering with a depositional contact the Precambrian complex (Кожухаров *et al.*, 1968). Intense Alpine synmetamorphic (amphibolite facies) shear transformed the Triassic carbonate-terrigenous sequence into garnet- and staurolite-bearing micaschists and amphibolites, their foliation becoming parallel to the reoriented foliation of the Precambrian metamorphics. Some geologists questioned the Precambrian age of the basement pretending that the whole sequence was conformable without taking into account the complex depositional and tectonic history. At deeper structural levels, the complex synmetamorphic shear led to formation of blastomylonites and pseudoconglomerates (Zagorchev, 1994) possibly partially formed at the expense also of a Palaeozoic Konstantinovo Formation (Кожухаров, 1991). Later Ivanov *et al.* (Иванов *et al.*, 2001) named the zone as "Konstantinovo shear zone" still not fully elucidating its origin, age and tectonometamorphic evolution.

PROGRESSIVE METAMORPHISM OF THICK SHEAR ZONES OR THRUST ZONES

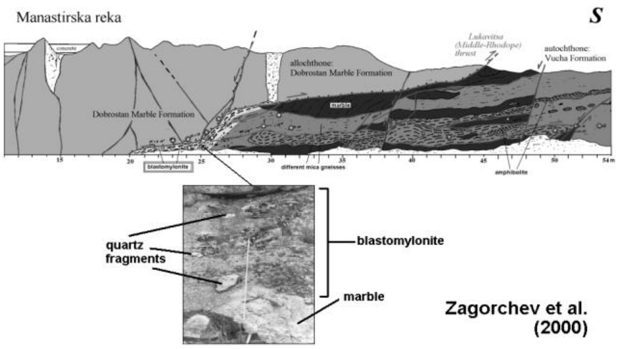

Figure 5. Blastomylonites in the zone of the Lakavitsa thrust

This mechanism is considered as a possibility based on observations in different localities of the Rhodope massif. Some of the major fault structures underwent a prolonged evolution, with several major events with different kinematics recorded. Thus, the West-Pirin fault belt is up to 2 – 3 km wide, and contains more than 10 – 12 individual fault zones (thrusts, upthrusts, wrench faults and normal faults) activated in Palaeogene, Neogene and Quaternary times. The related very low-grade to greenschist-facies mylonites obliterate the older structures of the basement, and have been locally considered by some inexperienced geologists as a normal progressive metamorphic sequence. In the Central Rhodope area, the low-grade to greenschist-facies mylonites along the Lakavitsa thrust (*Fig. 5*) have been formed at the expense of gneisses, marbles, amphibolites and foliation-parallel or oblique aplite and quartz veins during consecutive south-verging thrusting and later normal faulting (Zagorchev *et al.*, 2000). The purely tectonic amalgamation of these rocks induced some inexperienced geologists to consider them as sedimentary ones (conglomerates, sandstones, limestones), and even to seek (and "find") microfossils. In case such a blastomylonitic sequence would suffer a more intense metamorphic event, and the amalgamation would have a tectonometamorphic character, the resulting mixed and amalgamated rock could be considered as a completely new rock type (schist or metaconglomerate), and the origin and evolution of the whole sequence could be entirely misunderstood.

POLYDEFORMATIONAL AND POLYMETAMORPHIC PROCESSES IN HIGH-GRADE COMPLEXES

High-grade metamorphic complexes are usually characterized by a polydeformational and polymetamorphic evolution. Penetration of intrusive rocks (usually dykes) that belong to a later tectonomagmatic cycle or event may be followed by subsequent deformations common for host and intrusion that may efface any differences between the older and younger rocks thus forming a new amalgamation complex. This is the case of many high-grade polymetamorphic complexes, the classical examples coming from the Scottish Highlands, the Alps, and elsewhere.

Figure 6. Boudinage and shear of aplites and pegmatites in the Ograzhdenian Supergroup (Mikrevo, SW Bulgaria) later refolded and amalgamated into the complex

Stoyanov *et al.* (1997) observed such amalgamation of diorites, basic dykes and quartz porphyries in the eastern parts of the Republic of Macedonia, where later deformations and metamorphism transformed the complex into interlayering granite-gneisses and amphibolites.

Zagorchev (1976) reported different generations of igneous and metamorphic markers within the Ograzhdenian and Prerhodopian Supergroup in the Ograzhden unit and the Madan-Davidkovo dome. In both cases, the presence of markers and the lack of a complete homogenization allow for at least a partial recognition of the sequence of igneous and metamorphic events; thus, the amalgamation has not been completed. For example, aplites and pegmatites near the village of Mikrevo had intruded the folded tourmaline-bearing gneisses of the Ograzhdenian Supergroup, and were later transformed into leptitoid gneisses boudinaged and refolded together with the host rocks (*Fig. 6*) in Cadomian times. This is obviously not the case in the strongly sheared polymetamorphic and polydeformational pre-Cadomian Osogovo-Lisets gneisses intruded by the Cadomian Lisets granitoids: they have undergone together a profound tectonic and metamorphic homogenization.

AMALGAMATION ENVIRONMENTS

The geodynamic environments that can host tectonometamorphic amalgamation phenomena, may vary but are certainly mostly related to island arcs and subduction zones where high strains and shear are associated with increased geothermal gradient. Possible depths vary but the estimates are that the phenomena may be related to the whole range of greenschist to amphibolite facies conditions. Partial melting may usually accompany the process in lower amphibolite facies conditions. Amalgamation of docked terranes would certainly lead to tectonometamorphic amalgamation of their rock complexes within the suture zone, and intra- and intercontinental collision would also favor such phenomena. First indications for a tectonometamorphic amalgamation may be sought in the isotopic homogenization that finally reaches a "resetting of the isotopic clock" to the time of this reworking (Загорчев, Мурбат, 1986).

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THE GEOLOGICAL FACTORS OF ECOLOGICAL RISK OF RUSSIA

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ABSTRACT
The geological factors (natural or technogenically transformed lithosphere), which organisms react by adaptations is possible to consider as ecological-geological risk factors (ERF). They cause sickness of the people, oppression of ability to live phyto-, zoo- and microbocoenoses. Nowadays the majority of the investigators of the ERF allocate paramount importance to the study of negative effect of technogenic (geochemical, physical) factors. However, the biotic component of the ecosystem is affected a constant pressure of the natural geochemical and geophysical factors. Their synergetic influence appreciably causes a degree of comfort of existence of the biota, because the evolution of the lithosphere and biosphere goes in close relation. According to the systematics of the medical-ecological, biogeochemical, geological, hydro-geological data, soils, rocks, fresh water of Russia and the other countries do not provide stable receipt in with a feed of all spectrum of vitally - important elements (I, F, Ca, etc.). As functional relations in "the lithosphere – biota" system the geological factors of ERF can be subdivided on a majority as: I - ecological - geochemical, II - ecological - geophysical and III - ecological – geodynamic by the time of influence (constant, temporary and short-term); the area of influence (local, regional and global); by a source of indignation (litho-, hydro-, atmogeochemical) and complex type by the form of ecological target (phyto-, zoo-, antropocentric and complex). The executed complex researches both natural, and transformed regions have allowed revealing the conducting local and regional ERF. Their knowledge allows at a regional level to adjust the quality of the imported foodstuffs (together with correction of a drinking water-supply) and to promote equalization of natural and technogenic effect of ERF.

Introduction

The biotic component of the ecosystem tests the continuous integrated effect of various abiotic factors (climatic, atmospheric, hydrological, space, geological, etc.). The article is focused on the analysis of dependence of a condition of alive substance from the structure and properties of the lithospheric substance.

The geological factors (natural or technogenically transformed lithosphere), which organisms react by adaptations is possible to consider as the factors of ecological-geological risk. They cause sickness of the people, oppression of ability to live phytocoenoses, zoocoenoses, microbocoenoses and their death in the critical situation.

Close functional connections in the system "lithospheric substance - person", which are fixed at present were formed during evolution of the lithosphere and biosphere as a result of the integrated effect on alive substance of the geophysical, geodynamic and geochemical fields [14-17].

Ecological-geological system is understood as complex dynamically open system in which sybsystem elements (sources of effect, geological component of natural environment, an ecological target) are closely connected by the cause - effect direct and feedback connections [7, 14].

If in the ecogeosystem the negative connections exist even between one of the components of the lithosphere and biota, i.e. representatives of abiotic and biotic subsystems, the ecogeosystem is possible to relate to the category of ecogeopathogenic.

The close negative functional connections existing between abiotic and biotic components cause formation of the ecogeosystems of a various hierarchical level - local, regional or global. Example regional ecogeopathogenic of systems of Russia are the biogeochemical zones (fig.1). The problem deficit in components of rock sphere members vitally indispensable for a biota and person (J, F, Zn, Se etc.) is an example of global nature encompassing Eurasia and other continents [4].

Proceeding from a type of a biotarget it is possible to talk about microbocentrical, phytocentrical, zoocentrical, antropocentrical or complex type of the system.

The system of modern criteria [3, 5, 6,12, 13] of valuation of quality of abiotic and biotic components is indicated in the table 1. Their cumulative usage allows to execute an integrated ecological-geochemical valuation of territories on the comfortability of existence for the various representatives of biota.

There are three levels of intensity of negative abiotic subsystem influence on biotic system, which coincide with ranks of lithospheric classes accepted in ecological geology, correlated with the condition of ecosystem [11, 14]. Ecogeopathogenic systems of the first level of effect correspond to a class of a conditional - satisfactory condition of lithospheric components and ecosystem zone of risk. Ecogeopathogenic systems of the second level of effect are adequate to a class of the unsatisfactory condition of lithospheric components and ecosystem zone of crisis. Ecogeopathogenic systems of the third level of effect correlate with a class of a catastrophic condition of lithospheric components and ecosystem zone of disaster.

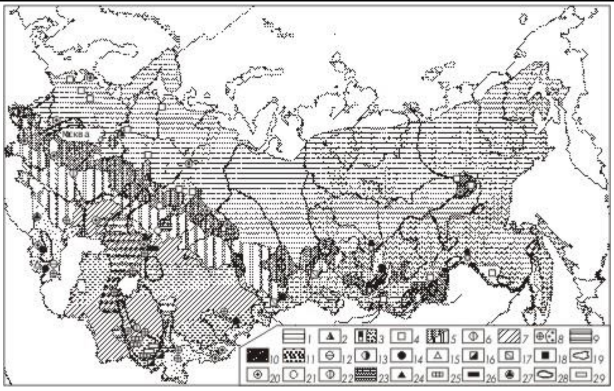

Figure 1. Schematic card of biogeochemical territory division of Russia and neighbouring countries [8]

I *- Biogeochemical zones (regions of biosphere) and zone provinces (zone subregions of biosphere).*
1 - 4 - Taiga-wood nonchernozem a zone [provinces: 1 - Poor of Co, Cu, J, Ca and P, 2 - Poor of J and Co, 3 - Enriched by Sr, poor of Ca, 4 - With the normal contents of Cu and Co, and also enriched by B and Sr on frozen soils (azonal provinces)]. 5 - Wood-steppe and steppe chernpzem zone (on grey wood and valley soils there are provinces, poor of J). 6 - 8 - Dry-steppe, half-deserted, deserted zone (provinces: 7 - With the rather unsufficient contents of J, superfluous — Mo and SO_4^{2-}*; 8 - Enriched by B; there are provinces, poor of J. 9 - The mountain zones (meet provinces, poor of Co, Cu, Ca; the provinces, poor of J are widespread).*
II *- Azonal provincaes (azonal subregions of biosphere). Provinces: 10 - Enriched of Co; 11 - Poor of J and Mn; 12 - Enriched by Pb; 13 - Enriched by Mo; 14 - Enriched by Sr and Ca; 15 - Enriched by Se; 16 - With the broken ratio of Cu, Mo, Pb; 17 - Enriched by U; 18 - Enriched by F, 19 - Enriched by Cu; 20 - With the broken exchange of Cu; 21 - Enriched by Ni, Mg, Sr, poor of Co, Mn; 22 - Enriched by Ni.*

If leading negative effect on biota on the territory render the ecological-geochemical factors of risk, it is possible to talk on the ecogeopathogenic systems of geochemical specialization.

If pathogenicy of tha ecogeosystem is stipulated mainly by ecological-geophysical or ecological-geodynamical factors of risk, so we has business with ecogeopathogenic systems of geophysical or geodynamical specialization.

However, more often there is a joint effect of ecological-geodynamical, ecological-geophysical and ecological-geochemical factors of risk. It is possible to speak about synergetic ecogeopathogenic systems, within the limits of which the wide spectrum of negative biological reactions at alive organisms is observed. The ecogeopathogenic systems are subdivided into three classes of genesis: natural, natural – technogenic and technogenic. We shall consider in more detail the above items on an example of ecogeopathogenic systems of geochemical specialization and we shall analyse the mechanism of diagnostics of the factors of ecological-geochemical risk, which have a leading role for the formation ecogeopathogenic systems of geochemical specialization. Depending on a component of the lithosphere, the factor, acting in a leading role of ecological-geochemical risk, ecogeopathogenic systems are classified on lithogeochemical, hydrogeochemical, atmogeochemical or complex type. It is necessary to note, that specifity of the urban area is the infringement of trophic connections. The natural-technogenic ecogeopathogenic systems of a complex type are more often in the urban area. This type of systems is allocated everywhere within the limits of urban territories (Ekaterinburg, Moscow, Norilsk, St.-Petersburg etc.) [9, 10,11, 18].

Table 1.The scheme of valuation of the ecological-geological system (Piece)

<table>
<tr><td rowspan="6">Component of the ecosystem</td><td rowspan="6">Geological component (Factor of effect)</td><td colspan="8">Zone of violation of the ecosystem</td></tr>
<tr><td colspan="2">NORM</td><td colspan="2">RISK</td><td colspan="2">CRISIS</td><td colspan="2">DISASTER</td></tr>
<tr><td colspan="8">Class of an ecological state of the lithosphere</td></tr>
<tr><td colspan="2">Satisfacto-ry</td><td colspan="2">Conditional satisfactory</td><td colspan="2">Unsatisfa ctory</td><td colspan="2">Disastrous</td></tr>
<tr><td colspan="8">LEVEL OF EFFECT OF THE GEOLOGICAL FACTORS ON AN ECOLOGICAL TARGET</td></tr>
<tr><td colspan="2">0</td><td colspan="2">I</td><td colspan="2">II</td><td colspan="2">III</td></tr>
<tr><td rowspan="5">ABIOTIC</td><td>Ground sedi-ments</td><td colspan="2">< 10</td><td colspan="2">10-30</td><td colspan="2">30-100</td><td colspan="2">> 100</td></tr>
<tr><td>Snow cover</td><td colspan="2">32-64</td><td colspan="2">64-128</td><td colspan="2">128-256</td><td colspan="2">> 256</td></tr>
<tr><td>Rocks soils</td><td colspan="2">8-16</td><td colspan="2">16-32</td><td colspan="2">32-128</td><td colspan="2">> 128</td></tr>
<tr><td rowspan="2">Under-ground waters</td><td colspan="8">General contents of substances</td></tr>
<tr><td colspan="2">< MAC</td><td colspan="2">3-5 MAC</td><td colspan="2">5-10 MAC</td><td colspan="2">> 10 MAC</td></tr>
<tr><td rowspan="21">BIOTIC</td><td rowspan="13">PHYTOCOENOSES</td><td colspan="8">Concentration of microelements in hay crops, pasturable plants and vegetative forages (mg/kg of dry substance)</td></tr>
<tr><td rowspan="3">Element</td><td rowspan="2">0</td><td colspan="6">Threshold concentration</td></tr>
<tr><td colspan="2">I</td><td colspan="2">II</td><td colspan="2">III</td></tr>
<tr><td>Norm</td><td>Lower</td><td>Upper</td><td>Lower</td><td>Upper</td><td>Lower</td><td>Upper</td></tr>
<tr><td>F</td><td>5-30</td><td>3-5</td><td>30-100</td><td>1-3</td><td>100-200</td><td>< 1</td><td>> 200</td></tr>
<tr><td>J</td><td>0,2-2.0</td><td>0,1-0,2</td><td>2-5</td><td>0,05-0,1</td><td>5-20</td><td>< 0,05</td><td>> 20</td></tr>
<tr><td>Se</td><td>0.05-1.0</td><td>0,03-0,05</td><td>2-10</td><td>0,01-0,03</td><td>10-50</td><td>< 0,01</td><td>> 50</td></tr>
<tr><td>Cu</td><td>5-20</td><td>2-20</td><td>20-80</td><td>0,5-2</td><td>80-100</td><td>< 0,.5</td><td>> 100</td></tr>
<tr><td colspan="8">As Cd Cr Pb Ni Hg Sb contents in forages and hay crops of plants (exceeding MPL, times)</td></tr>
<tr><td colspan="2">1,1-1-5</td><td colspan="2">1,5-5</td><td colspan="2">5-10</td><td colspan="2">> 10</td></tr>
<tr><td colspan="8">Contents of elements in dry weight: a) of pages of a birch; b) to needles of a pine, mg/kg</td></tr>
<tr><td colspan="2">a) 10-30</td><td colspan="2">30-50</td><td colspan="2">50-130</td><td colspan="2">> 130</td></tr>
<tr><td colspan="2">b) 10-30</td><td colspan="2">30-70</td><td colspan="2">70-100</td><td colspan="2">> 100</td></tr>
<tr><td rowspan="2">Microorg anisms</td><td colspan="8">Level of active microbic of biomass (decreasing in a number of times)</td></tr>
<tr><td colspan="2">< 5</td><td colspan="2">5-10</td><td colspan="2">10-50</td><td colspan="2">> 50</td></tr>
<tr><td rowspan="3">Animal</td><td colspan="8">Case of home animals, %</td></tr>
<tr><td colspan="2">Random</td><td colspan="2">Sporsdic</td><td colspan="2">Regu-lar</td><td colspan="2">Total</td></tr>
<tr><td colspan="2">< 10</td><td colspan="2">10-20</td><td colspan="2">20-50</td><td colspan="2">> 50</td></tr>
<tr><td rowspan="3">The person</td><td colspan="8">Pb contents in biosubstances (c – in the blood, in mkg/100 ml; d - in a hair mkg/g)</td></tr>
<tr><td>c)</td><td>0-9</td><td colspan="2">15-19</td><td colspan="2">15-44</td><td colspan="2">>45</td></tr>
<tr><td>d)</td><td colspan="3">9,8+-1,9</td><td>8</td><td>24</td><td colspan="2">30</td></tr>
</table>

Notes: the criterions are indicated selectively; Zc - total contents of toxic elements; MAC – maximum allowable concentration; MPL – maximum permissional level

One of the problems of ecological-geological researches is the revealing and mapping of ecologicical-geochemical factors of risk (natural and technogenic) capable to result in development of pathologies at biota. The minimal set of parameters for concrete regions will be determined by a type of its functional use and is vital to allocate ecogeopathogenic systems both surplus, and defect and bias of chemical elements.

The usual practice of norming of limiting - high of concentrations of toxic substances in drinking waters and a meal, disregarding of achievement of biogeochemistry in the field of the lower threshold concentrations of biophilic (vital - important) elements is pernicious for health of a nation. A natural produce market of a meal generated in Russia, alongside with other social factors is one of the reasons of sharp deterioration of the health of the population. For want of anarchy of import of the foodstuffs, disregarding of the regional features and factors of ecological-geochemical risk, is possible the appearance of artificially generated food endemias, which are secondarily imposed on natural or tertiary imposed on innovated technogenic endemias.

The knowledge of the local factors of ecological-geochemical risk allows at a regional level to adjust the quality of the imported foodstuffs (together with correction of a drinking water-supply); also promote of equalization of the effect of natural and technogenic factors of ecological-geochemical risk.

The type of the ecogeopathogenic system predetermines the resource potential of the region, its functional usage and level of material inputs necessary on minimization of negative effect from the party of the lithosphere on biota.

Let's consider an example natural technogenic ecogeopathogenic of a system developed within the limits of an axial zone of Large Caucasus.

The ecological – geological researches within the mining area represent a complex of ecological – geochemical, ecological – geophysical, ecological – geodynamic, landscape-geochemical, biogeochemical, medical –ecological and social - ecological researches. The main purpose of it is determination of natural and technogenic geochemical impact on a biotic condition and health of the population. Technogenic anomalies have polycomponent composition so an integrated parameter of pollution (Zc) is used for valuation of a degree of pollution [1, 2]. At realisation of ecological - geochemical researches it is necessary to use criterion of environment evaluation from the position of an impact on a man's health. Cnsidering the total heavy metal content of in the soil (Zc), the 4-range estimation scale was worked outfor a system "a soil - a man" in the Tyrnyauz mining region.

The purpose of ecological – geological researches - an ensuring of the ecological safety of population existence. A component of ecological geological investigations is an ecological - geochemical studies. The primary task of ecological geochemical evaluation of condition of lithosphere is determination of the pathogenic lithogeochemical (technolitho-geochemical) anomalies, render their negative influence on the condition of the biota and the man's health, development of the objective criteria of determination of the areas of different ecological - geochemical environmental level.

The main purpose of the work was the development of methods of documenting of natural and technogenic geochemical factors of ecological risk for mining regions. For achievement of it a number of tasks was resolved: 1) typification of the region by ecological - geological conditions; 2) allocation of types, subtypes, kinds of ecological - geological systems by biotic and abiotic parameters; 3) ecological - geochemical demarcation of the region.

In the region 12 types of ecological - geological systems, 31 subtypes of ecological - geochemical conditions conditioned by the natural - technogenic factors are recognised. A major factor of ecological risk in the region is natural anomalies and technogenesis. The composition of contaminants is determined by a composition of ores and their source-rocks.

Technogenic anomalies have an element composition, so a total concentration factor Zc is the most useful factor for evaluation of contamination degree. A factor of soil pollution by metals is a sum of coefficients of metal concentration with the deduction of number of metals reduced to the unit. The factor is used traditionally for determination of the pollution level, but without the analysis of relationships in a system "lithotechnical environments - a man". It can be acted as a standard criterion of ecological -geochemical conditions and will allow to value a situation from the position of influence on a man's health. It is possible to conduct a correlation in a system "a soil - a man" according to the four-rank approximate estimation scale.

The most important is the factor of geochemical activity (GAF) as a characteristic feature of ability of vegetation of certain type to accumulate microelements. The factor could be defined as a sum of dark concentrations (coefficients of biological absorbing. Ah) of elements in the plant ashes.

As an example we will consider the region of Tyrnyauz Town (North Caucasus, Kabardino-Balkary, Baksan River basin). It is situated in mountainous mining region characterising by the presence of pathogenic natural and technogenic anomalies (Borisenko E.A., 1970; Alekseenko V.A. 1990; Avessalamova 1992, 1996; Gavrilenko 1993; Baraboshkina & Ziling 2000;). Tyrnyauz High Mountain tungsten-molybdic field is nearly 1,5 km high above the Baksan River valley. The region is characterised by sharp swings of absolute heights and broad spectrum of landscapes from mountain - steppe and mountain - meadow up to glacial - nival. It predestines heterogeneity of natural environments, fall into the area of influence of Tyrnyauz mining factory. The factory consists of the complex of separated enterprises, in accordance with mining and enriching a tungsten-molybdic ore: quarries of an open mining, mines and enriching factory with tailing dumps.

Technogenic anomaly was formed in the result of mechanical, water and air transportation of material during the exploration of the tungsten-molybdic field and technological cycle: (1) removing of the greater masses of rocks during the exploration and it storage in the dump; (2) destroying of the tailing dump under the influence exogenous processes (erosion, mud flows, eolation); (3) discharging of unrefined water from the mine, enriching factory and tailing dumps and (4) dusting of the excavated rocks in all stages of the technological chain. Those reasons have stipulated an intensive technogenic migration of material.

The composition of technogenic flows is characterised by polyelement paragenetic association (bismuth, molybdenum, tungsten and in scant fews - tin, stibium, arsenic). There ob-serve sharp excess of fit in the grass within technogenic anomaly: 30-300mqs/kgs and more. Biogeochemical haloes of Mo have a complex structure and elongate along Baksan River valley. Their configuration is asymmetric and the largest local anomalies exist on the left bank of the river, where their contrast increases in the region of industrial enterprises of mining and enriching ore. A possibility of molybdenoses exists at the excess of threshold concentrations of fil in the grass at 6-14 mgs/kgs in calculation on the dry material according to Kovalsky (1974). It is the first standard criterion of ecological situation judgement in Baksan River region. However the biochemical processes in mammals is controlled by the complex of elements. For instance, Cu promotes a conclusion Mo from the organism, that reduces its toxicological effect. So correlation of Cu and Mo concentrations in herbs and the degree of their natural balance breaking were used as a second standard judgement criterion.

The most disadvantage situation was recognised for the region of Tyrnyauz factory mouldboards, along communications of an enriching factory and beside Bylym tailing dumps.

It is possible to consider a total factor of toxic elements concentrations (Zc) as a third standard criterion of judgement. It varies from 16 up to 128 in the region. Because of it one can recognise pneumoconiosis, chronic dust bronchitises, dust parinopharengiteses amongst typical professional diseases in the region, which were caused by the technogenic anomaly and by dusting.

The features of fluid and hard sewer were based on factors of it, main ions content, weighted materials, microelement composition of the bottom precipitation (dominates of Mo, W, Bi, Sn). They have different detour degree from the natural background under the influence of the factory. The technogenic flow of diffused elements (heavy metals) in the bottom deposits is denominated stronger and more long-lasting, han in the hydrogeochemical halo. So significant change of chemical and saline composition of Baksan River water is fixed in the limited area below Bylym tailing dump and is small in places of unset of mining water. A contrast geochemical anomalies are formed in the bottom deposits. They are fixed by the increase of element concentration degrees and an expansion of paragenetic associations with the evident prevalence of tungsten, molybdenum, tin and bismuth. These elements do not occupy such a leading position in background areas. The intensity of anomalies is downstream changed depending on new portions of industrial sewers. The total degree of elements accumulation falls with the distance from industrial zone. However, the flow of diffusing tracks over 10 km below field.

There are two main factors affect on the regional contamination level in Baksan River valley, which could reflect the integral evaluation of Tyrnyauz tungsten-molybdic factory influence.

The first one is enabling of the dust surges of the factory in airstreams. The process promotes a growth of the module of technogenic influence on the landscapes and leads to formation of the pedogeochemical anomalies with the accumulation of elements high destructive activity (Bi, Sb, As, Mo, V and others). The epiphyte and scum lichens are the indicator of the phenomena (Avessalamova 1996).

The second one is enabling of the industrial discharges (technogenous sewers) of the factory in the water flow of Baksan River with the formation of hydrogeochemical anomalies and diffusing haloes in the bottom deposits. This factor is considered above.

There were chosen three classes of ecological - geochemical condition in the region on the grounds of the analysis of all provided standard criteria of judgment: satisfactory, conditionally satisfactory, unsatisfactory conditions, which corresponds to standard, risk and crisis ecological zones.

The first zone (I) - ecological standard (background conditions) is more then 10 km far from the factory and includes the area where natural geochemical pathogenic anomalies and technogenic contamination are practically absent. The value of total factor of concentration of the elements is less than 16. The morbidity level of population is within average statistic limits.

The second one (II) - an ecological risk zone comprises both natural pathogenic geochemical anomalies and the region of moderate technogenic contamination. It is characterised by several parameters: module of the dust load (Dl) varies from 1 to 5 g/cm per day; fit content in the grass ash varies from 30 to 100 mgs/kgs at Mo<Cu correlation and from 15 to 30 mgs/kgs at Mo=Cu correlation; coefficient of microelement accumulation in scum lichens varies from 5 to 20; value of biochemical activity (GAF) varies from 30 to 100 and coefficient of microelement accumulation in bottom deposits varies from 2 to 10. The value of total factor of concentration the elements is Zc=16-32 and there is a medium possibility of appearance of molybdenoses besides the livestock and in consequence - besides the man. There is also possibility for single diseases by the bronchitis and pneumoconiosis in the dust areas. It is the region where contents of fil in the milk and dung of livestock, wool of sheeps should be subjected to a constant checking.

The third zone (III) is a zone of crisis, which possesses a complex structure. It reaches its maximal pollution level in the quarries, mining enriching factory and tailing dumps. The area of such regions could be estimated at radius of first hundreds meters from the source of contamination. The whole area is chosen by the prevalence of the high level of techriogenic pollution of the components of natural environment. It is characterised by a module of the dust load variation from 6 to 16; variation of Mo content in the grass ash from 100 to 200 (and over 200 closer to the area of disaster) at the correlation Mo>Cu; variation of the factor of microelement accumulation in scum lichens from 20 to 50, value GAF from 100 to 300 (and over 300 closer to the area of disaster); variation of the factor of microelement accumulation of in the bottom deposits more than 10. The total contamination factor is 32-128. This is an area with the high degree of probability of disease an molybdenoses and professional pulmonary diseases of population. The duration of the livestock staying on its pastures requires shortening and following to the strict rules. The Bylym depression is a good example for it. There was fixed increasing of anionogenic elements mobility on quest slopes (under pH= 8,5-9,5), where the dust enters from highalkaline artificial soils of tailing dump. The infiltration of highalkaline Mo- rich sewers from the tailing dump also affects the grass if the hayfields and creates a real threat of mass molybdenoses disease of live stock.

Thereby, the region of Tyrnyauz Town is situated in the area of ecological crisis. It needs an urgent realisation of engineering -ecological protection for ecological - geochemical stabilisation of the situation in the region. The ways of protection should be focused on the reduction of dusting of the mouldboards, surges from the mining factory and preventing of infiltration of toxic sewers from mouldboards and tailing dumps.

The concluding

Nowadays the studying of the ecological risk is going mainly on the technogenically transformed territories. However, studying of the natural factors of the ecological risk is also of a high importance. This is confirmed by the simultaneous drop of the technogenic pollution and the rise of the illness by the ecological-dependant pathologies and the shortening of the life of the population in Russia and the other countries of the Former Soviet Union (p.1) Partially it was caused by the liquidation of the state programmes of rehabilitation of endemic territories that are characterized by natural geochemical and geophysical factors of natural ecological risks.

The development of mentioned ecological - geochemical criteria in the practice of engineering - ecological prospecting will enable classify the area according to their ecological - geochemical conditions and more objectively estimate the natural and technogenic factors of ecological risk.

It will enable to elaborate the programs of steady development at a local, regional and global level.

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INVESTIGATIONS ON THE MIGRATION ABILITY OF SOME RADIONUCLIDES IN GROUNDWATER

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ABSTRACT
A series of dynamic migration tests were carried out aiming at clarifying the migration ability (mainly sorbtion characteristics) of some important radionuclides in filtration media. The investigations include: Tritium, Carbon-14, Cobalt-60, Strontium-90 and Cesium-137, which are in primary importance in the assessment of the environmental risk from "Novi Khan" radioactive waste disposal. The tests were carried out with laboratory set, especially designed for the purpose. Two types of phylittes, building the site and the area around the waste disposal, were subject of investigation. The main migration parameters, characterising the sorbability (distribution coefficient K_d , resp. "retardation factor" R), as well as the dispersivity λ, were determined. The parameters were calculated by the following methods, depending on the duration of the test and the obtained data: *method of characteristic points* (at reached relative activity during the test A* > 0.85), *method of the straight line* (at 0.5 < A* < 0.85) and *method of maximum* (at A* < 0.5). At the first two methods a "continuous" feeding with radioactive solution was realised; at the third one – a "package" feeding was used. The results obtained reveal substantial differences in sorption behaviour of the radionuclides under investigation, which can be characterised as follows: Tritium – unsorbable, C-14 – low sorbtion, Sr-90 and Co-60 – high sorption, Cs-137 – very high sorption. The values of migration parameters, determined by the tests, were used for prognostication of the possible propagation od radionuclides in groundwater around the site of waste disposal (it was made by means of mathematical modelling). The most substantial propagation among the above mentioned radionuclides has Carbon-14, which is distinguished by low retention in the aquifers and has a long life ($\tau_{1/2}$ = 5730 years).

1. General notes

Prognosis of propagation (migration) of contaminants in groundwater can be made, as it is known, on the basis of some important factors, characterizing the interaction between contaminants and filtration media. The most substantial one undoubtedly is their sorbability in the soil media. The effect of retention (sorption) is presented in the equation of filtration mass-transport by the distribution coefficient (K_d), respectively by the generalized parameters "sorption porosity" (n_s) or "retardation factor" (R). Besides them, the dispersivity factor (λ) of the media, the coefficient of irreversible elimination (decay) γ etc. are significant as well.

Laboratory experimental investigations were carried out aiming at clarifying some of these characteristics (mainly the sorption ones, which are of decisive importance for the migration velocity of contaminants in the subsoil and groundwater) in the particular hydrogeological conditions at "Novi Khan" radioactive waste disposal.

The laboratory tests were made with the following soil varieties and radionuclides :

- Paleozoic phyllites, which build both the site of waste disposal and the whole surrounding area;
- Radionuclides: Tritium, Carbon-14, Strontium-90, Cesium-137 and Cobalt-60, being of primary importance for the present project.

Two types of tests were carried out : "static" (with 14 samples) and "dynamic" (with 10 samples). The samples were taken from different points of the site under investigation (from different boreholes and depths) in order to get more representative results. Below are shown the results of "dynamic" tests, which are in principle more reliable and give more certitude in the prognosis calculations.

2. Methods of implementation and interpretation of migration tests

The dynamic tests were carried out in a special set, including a reservoir for the feeding solution with the different radionuclides, filtration tube (column) with the built of sample, connecting microbore tubings, collecting reservoir. The feeding of solution was realized by means of a peristaltic dual channel pump "Master-flex C/L", assuring a constant flow rate, resp. constant velocity of filtration. The column had a diameter of 2.5 cm and the length of samples varied between 5 and 7 cm. The solution was fed from bellow upwards. It was prepared by using water from the aquifer. Samples of the solution were taken periodically at the outlet and their activity was determined.

Two migration tests were made with each of the radionuclides – one with the so called red-brown phyllites and another one with the so called grey-yellow phyllites. It was found out that these two phyllite varieties possessed very close migration characteristics.

The following parameters were determined on the basis of the results of dynamic tests:

- *"Sorption porosity"* (n_s). It is a generalized parameter, representing $n_s = n_o + \rho K_d$; n_o is the effective porosity, ρ –

bulk density of the sample, K_d – distribution coefficient, characterizing the sorption.

- *Distribution coefficient*: $K_d = (n_s - n_o) / \rho$ (after determining the "sorption porosity" n_s).
- *Dispersivity coefficient* (λ). It characterizes the convection dispersivity ($D_c = \lambda v$, v is the filtration velocity).

The effective porosity of the sample (n_o) was found from the passage of Tritium, which is practically unsorbable and moves with the pore velocity of water. For it $K_d = 0$ and $n_s = n_o$. For radionuclides with highly expressed sorption (as Sr-90, Co-60 and Cs-134) $n_s >> n_o$, i.e. $K_d \approx n_s / \rho$. The bulk density of each sample was determined by the conventional weight method.

Experimental data were processed in the ordinary co-ordinate system A* = f(t) where t is the time from the beginning of the test; A* - relative activity ($A^* = A / A_o$; A_o – input activity of the solution, A – current activity of outgoing solution during the test). Migration parameters were calculated by different methods depending on the duration of the test and the relative activity reached during the test. The methods are the following.

a. Method of characteristic points. This method is described in detail in the literature (for instance, *Fried J.,1975, Galabov M., 1981 etc.)*. Proceeding from the curve A* = f(t), the times $t_{0.16}$, $t_{0.5}$ and $t_{0.84}$ corresponding to the relative activity A* = 0.16 , 0.5 and 0.84 , were determined. Then

$$n_s = \frac{v}{l} t_{0,5} \quad (1)$$

$$\lambda = \frac{l}{8}\left[\frac{1-t_{0,16}/t_{0,5}}{\sqrt{t_{0,16}/t_{0,5}}} - \frac{1-t_{0,84}/t_{o,5}}{\sqrt{t_{0,84}/t_{0,5}}}\right]^2 \quad (2)$$

where: l is the length of the sample; v – filtration velocity during the test.

This method was used for interpretation of the tests with Tritium and Carbon-14, which are of short duration and a relative activity above 85 – 90 % is quickly reached (because Tritium is unsorbable, and C-14 is with low sorbability – see below).

b. Method of the straight line. The method is described in (*Shestakov V.M.,1979, Galabov M.,1981 etc*). It is based on the equation of one-dimensional mass-trasport in test conditions, namely:

$$A^* = 0,5 erfc\left(\frac{l-(v/n_s)t}{2\sqrt{\lambda v/n_s}}\right) = 0,5 erfc(X) \quad (3)$$

In (3): erfc – symbol of the "complementary error function". The other symbols are the same as above mentioned. X is the argument of the function erfc, which is determined from the test data, by using the existing tables for the erfc function and its related functions.

On the basis of the test data, the relationship $X\sqrt{t} = f(t)$ was plotted. It represents a straight line, intersecting the abscissa in point t_o , corresponding to $t_{0.5}$. Migration parameters are calculated as follows: "sorption porosity" – by formula (1), i.e. by the intersection point with the abscissa, and the dispersivity λ – by the following formula:

$$\lambda = \frac{n_s l^2}{4vB^2} \quad (4)$$

where B is the intersection point of the straight line with the ordinate; l and v – as mentioned above.

The straight line method was used for interpretation of the tests with Cobalt-60 and Strontium-90, where the duration of test made possible to reach A* = 0.5 , but not values over 0.85, when the method of characteristic points could be used.

c. Method of the maximum. It is described in (Shestakov V.M.,1979, Mironenko V.M. et al.,1988 etc). This method was used only at the test with Cesium-134, because of the exceptionally high sorbability of Cesium. Under such conditions the test was carried out by "package" feeding of solution (during a fixed part of time) and allows to determinate the migration parameters without A* reaching 0.5. The dta are processed in the traditional c0-ordinate system A* = f(t), and then the parameters are calculated as follows:

$$n_s = \frac{v(t_m - 0,5t_0)}{l} \quad (5)$$

$$\lambda = 0,06l\left(\frac{t_0}{A^*_m\, t_m}\right)^2 \quad (6)$$

where: t_o – duration of feeding with solution; A^*_m – maximum relative activity reaching during the test; t_m – time corresponding to A^*_m .

All the methods described above are illustrated in the applied figures.

3. Test results

All the results of "dynamic" migration tests are presented in table 1 and part of them are shown in figures 1 – 6. (Computer design of the figures is made by Al. Damyanov).

Table 1. Results from migration tests

Radionuclide	Sample	*l cm*	*v cm/min*	*n_o [-]*	*K_d cm^3/g*	*λ cm*	figure
H-3	1	6,0	0,054	0,135	0	1,5	1
"	2	7,0	0,025	0,160	0	2,8	
C-14	1	6,0	0,34	-	0,48	1,9	2
"	2	6,0	0,30	-	0,62	4,5	
Sr-90	1	5,0	0,22	-	32	17,0	3
"	2	5,0	0,21	-	30	8,0	-
Co-60	1	5,5	0,29	-	41	15,3	4
"	2	5,0	0,27	-	49	1,3	-
Cs-134	1	5,0	0,30	-	259	2,2	5
"	2	5,0	0,28	-	280	1,6	6

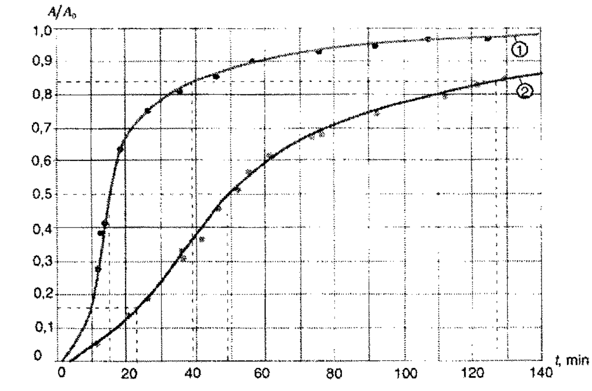

Figure 1. Test with ^3H (samples 1 and 2)
1. $n_o = 0.135$; $\lambda = 1.5$ cm; $K_d = 0$ cm³/g
2. $n_o = 0.16$; $\lambda = 2.8$ cm; $K_d = 0$ cm³/g

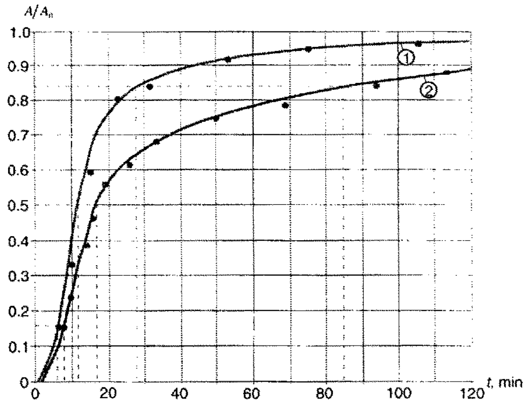

Figure 2. Test with ^{14}C (samples 1 and 2)
1 $K_d = 0.48$ cm³/g; $\lambda = 1.9$ cm;
2. $K_d = 0.62$ cm³/g; $\lambda = 4.5$ cm;

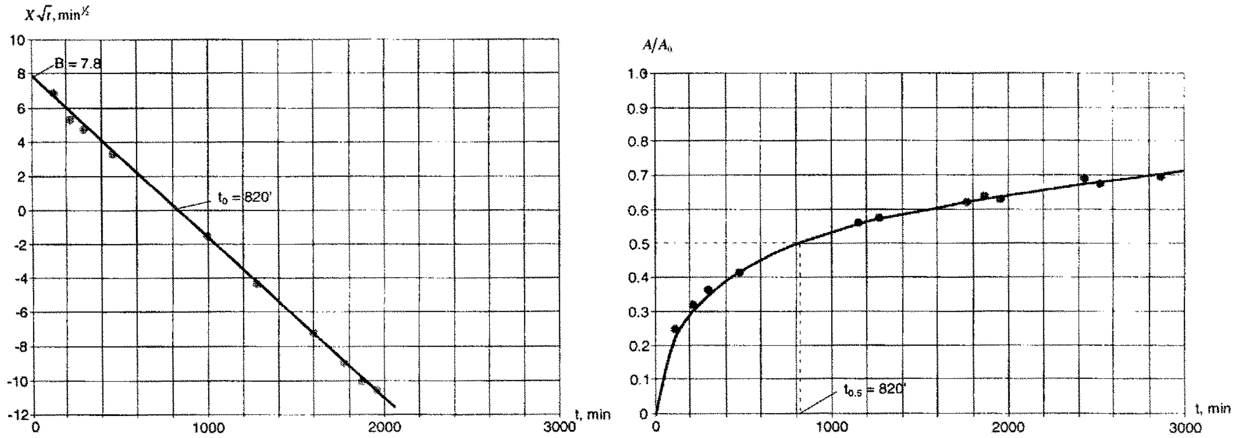

Figure 3. Test with ^{90}Sr (sample 1)
$K_d = 32$ cm³/g; $\lambda = 17.0$ cm

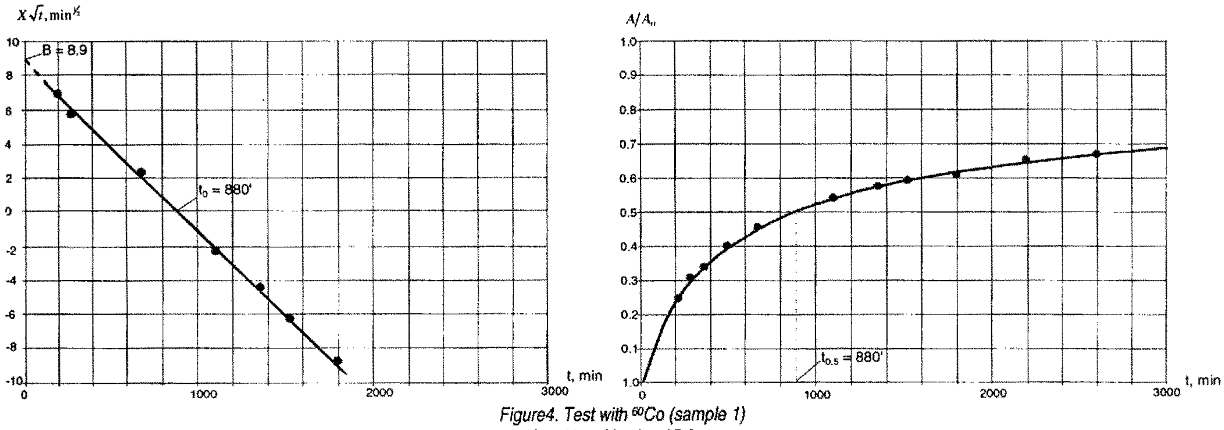

Figure4. Test with ^{60}Co (sample 1)
$K_d = 41$ cm³/g; $\lambda = 15.3$ cm

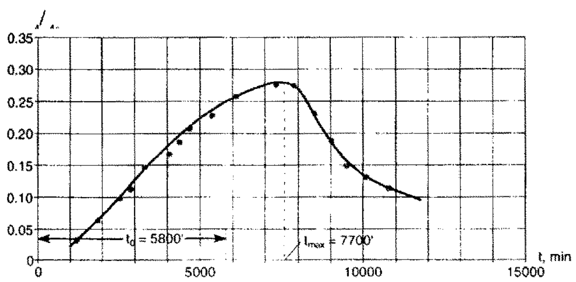

Figure 5. Test with ^{134}Cs (sample 1)
$K_d = 259$ cm³/g; $\lambda = 2.2$ cm

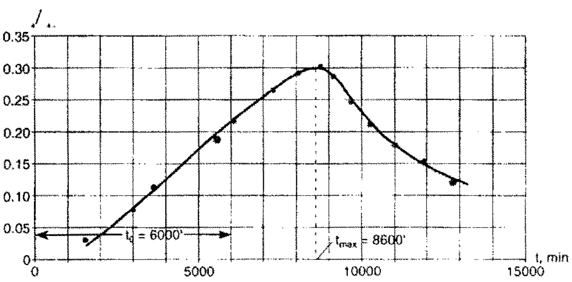

Figure 6. Test with ^{134}Cs (sample 2)
$K_d = 280$ cm³/g; $\lambda = 1.6$ cm

The following conclusions can be made on the basis of the migration tests results.

- The characteristics obtained for the two types of phyllites – red-brown (samples 1) and grey-yellow (samples 2) are very close and it is easy to explain (having in mind their similar composition and grain-size distribution).
- The correlation between sorbability of different radionuclide remains the same (as with the “static” tests), increasing in direction H-3 < C-14 < Sr-90 < Co-60 < Cs-134.
- Coefficients of distribution (K_d) obtained at dynamic tests are considerably lower than these obtained at static tests (between 3 and 5 times). It is logical, because at static tests there is a full fragmentation of the sample and a long contact period. In all cases, at prognosticating of possible migration of radionuclides, the values obtained from dynamic tests should be accepted. They are not only closer to the reality, but also provide some reserve in the prognosis calculations.
- Dispersivity coefficient λ is relatively low – in order of centimeters (between 1.3 and 17 cm at different tests). As it is known, it defines the intensity of the mechanical dispersion and its values depend only on the structure and geometry of pores, but not on the composition of the flowing water, resp. on the radionuclide content in it.

Assuming the following conditional classification of contaminants according to their sorbability (retention) in filtration media (see table 2), then radionuclides under consideration with regard to phyllites can be defined as follow:

- Tritium: unsorbable
- Carbon-14: with low sorbsbility
- Strontium-90 and Cobalt-60: with high sorbability
- Cesium-137: with very high sorbability.

Table 2.

Degree of sorbability of the contaminant	***Distribution coefficient K_d, cm^3/g***
Lack sorption	≈ 0
Low sorption	0-2
Moderate sorption	2-20
High sorption	20-200
Very high sorption	> 200

The same sequence in sorbability of radionuclides was found out also with “static” test, the values of K_d being considerably higher.

The obtained experimental values of the migration parameters were used afterwards in the prognosis calculations and mathematical modeling of the possible migration of radionuclides in the subsoil and groundwater in the area of waste disposal “Novi Han”.

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SOME CURRENT ISSUES IN BULGARIAN GEOECOLOGY

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ABSTRACT
The issues of evolutional development of matter, of its structure and redistribution have been intensively explored in the last decades by various geological sciences. However, the issues of setting geochemical zones apart from zones of anthropogenic invasion of soil compolexes has only recently become an object of careful studies. To an extensive degree these are problems of agroecology, but have already been incorporated within the framework of geoecology. Geoecology has consolidated as a science of polygenic and three dimensional components (both geological and soil) and effects upon the environmental ecological characteristics.
Bulgaria is one of the countries of unique landscape features, geological and geochemical peculiarities admitting definition of the fundamental principles of geoecology and also, to a considerable degree, understanding how the geological and soil substrata exert their effect upon waters and biocenoses. The present paper examines some basic issues of Geoecology:
- Kinds of geochemical barriers, anomalies and accumulations;
- - Kinds of geochemical processes;
- - relations between geogenic and technogenic pollution, etc.
- The Bulgarian theoretical and applied geoecological studies are leading in European science.

INTRODUCTION

The issues of evolutional development of matter, of its redistribution and structuring have been intensively explored in the last decades by various fundamental and interdisciplinary earth sciences. It is interesting to note that these studies turn to the dynamic natural and nature-anthropogenic systems, i.e. to the issues of the dominant significance of dynamics in their development and forecasting. In this respect of extreme importance for geological knowledge today is the formation of new interdisciplinary sciences which examine the processes in the earth's crust in their dynamic development: from past static geological systems through current dynamic and static ones to prognosticated states and development of the natural and anthropogenic environment. In our opinion and interesting developing interdisciplinary science is geoecology.

BASIC STAGES IN DEFINING GEOECOLOGY

1. General definition of Geoecolo gy:

Geoecology has consolidated as a scienceof the polygenic and three-dimensional geological soil components and effects upon environmental ecological characteristics (dachev, Teoharov, Dochev, Mianoushev, 1994).

Scientific justive requires (insofar as this still exists) to pass a note on the one-sided stance of a number of colleagues in respect of the issues of defining and setting down the goals and objectives of this interdisciplinary science. Many think tha t the research spectrum of Geoecology is limited to individual specific methods for studying the effects of geological and neogeological processes upon the environment. Some colleagues, for example, are attempting hard to implant the concept of 'ecogeology'. But as regards the naturrre of their studies and formulation of theses what one really sees is an old science, established throughout the world – biogeochemistry – i.e. studying the ecological status of a certain region by means of in-depth analysis of chemical characteristics of plants and their relationship with soil and rock substrata. Other authors bring geoecological methods down to an in-depth analysis of some engineering geological parameters, such as the ones of landslide and earthquake processes, erosion, geological risk (as a whole), etc. We must expressly underline our firm conviction that these concern individual methods and scientific branches in the large family of Geoecology! In this sense also is the position of another interdisciplinary science defined by us (Geosozology), for studying and preserving non-living nature (Дачев, 1986; Костов), i.e. this also is a branch of Geoecology.

2. Short Histoical Refence on Defining Geoecology:

First (preliminary) stage – till 1990;

Some western publications (Goldschmidt, 1954; Keller, 1979) consider the issues of defining the specific knowledge of preserving the geological environment and its relation to the other components of environment. Almost simultaneously similar ideas appeared in works that came out in th eformer Soviet Union (Перельчян, 1972; Сает и кол., 1980). At the end of the period under consideration editions and publications came out that discussed specific geoecological issues (Grudev, 1981; Крайнов, Галицын, 1989; Грудев, Браун, 1989).

Second stage:

It is noted for identification of objects of geoecological studies. The name of the science Geocology begins to appear at approximately this sense that has since been precisely defined (Всесоюзная научно-техническая конференция "Геология: проблемы и решения", 1991). At the sited

Moscow conference a relatively exact definition was formulated: Geoecology is a a scientific branch on the border between geology and ecology, which studies the relations arising as a result of natural laws, between living organisms, incl. Man, the technogenic and geological environment (Фролов, 1991). It is important to point out that in this period (till 1993-1994) in the debates of the conferences of the Carpathian-Balkan geological association the serbian and Bulgarian geologists expressly formulated the issue for setting apart geoecological studies as an interdisciplinary science, but it did not receive a precisely formulated definition. However, the advanced studies of some researchers as well as the imprecise definition of geoecology up till then stimulated the dilution of the problem area in too wide a spectrum of highly specialised studies. We acknowledge these todayas contributive to the orbit of the science Geoecology (as we wrote above), but in our opinion these engineering, geological, geotechnological and similar studies can only be acknowledged as geoecological (sansu strictu) if they fall within the research chain formulated in the definition of this science.

Third stage:

We brought forward the issue of revising the relations between certain interdisciplinary sciences for the first time in 1991 (Dachev, 1991). But in the article by a team of geologists and soil scientists "Outlines of Geoecology" (Dachev, Teoharov, Dochev, Mianoushev, 1994) the definition, goals and objectives of this science are precisely laid down, i.e. the thrid stage – since 1994 to the present – has focused our attention to the principles underlying the research. It is important to point out that a number of academic and university publications and monographs came out (Близнаков, 2000; Георгиев, Манолов, 1999; Недялков 1988), considering the relations in the system 'lithosphere – ecosystems'.

3. Principles of Geoecology:

The basic principles of the science Geoecology can be brought down to the following postulates;

- Research is carried out from the most ancient (lowest) geological formations and water levels to the most recent; thence, to soils and other components of the environment;
- Geoecological studies are multifaceted, which means that depending upon the tasks, the research teams must be expert in the specific fields of science and in concrete terrains; however, multivalent specialists are to b epreferred (Dachev, 1991);
- Geoecology holds that the methods employed in studying static and dynamic geoecological systems to be equal (Дачев, Узунов, 2000) with a view to an exact estimation of the status and effect upon the environment;
- Geoecological studies can be regional and local with basic methods landscape-cum-geochemical mapping, using point geological profiling (Dachev, 1995), as well as biogeochemical methods.

Doubtless, new principles will be formulated in the process of perfecting the methods and scope of geoecological research.

BASIC GEOECOLOGICAL PROBLEMS, CHARACTERISTIC FOR BULGARIA

In the last decade the term "geogenic pollution of the environmet" has been adopted. This in fact is an autogenic natural pollution with various geochemical elements (and substances: oxides, sulphides, etc.), especially characteristic to the entire Alpian-Himalayan orogen. We have been drawing the attention to this geoecological phenomenon for some time, actually for the closing ecade of the previous century (Дачев, Чунев, 1994; Дачев, Теохаров, 1995; Дачев, 1997; Дачев, Мърхова, 2002); within the same period a number of other Bulgarian and foreign authors have also directly or indirectly brought forward this phenomenon to attention (Куйкин, 1989; Витов, 2000; Куйкин, Атанасов, Христова, Христов, 2001; Teritze, Atanassov, 2002). In our opinion the geogenic environmental pollution with **geonoxes** (poisonous substances of geological origin) is caused by erosive and accumulative processes in the zones of geochemical concentration of these substances. Therefore a detaled geochemical mapping should be carried oout as soon as possible in the zones of geochemical anomalies and accumulations. With a view to setting technogenic anomalies apart from geochemical ones, while both had been brought under one heading in the list of polluted land (Дачев, 1997).

We think that a generalised overview of topical geoecological problems in our country necessitates a strategy for **detailed study and monitoring of the following geological phenomena:**

- **Geoecological anomalies and accumulations;**
- **The torrential cones** at the foot of mountains which are the cause of a negative dynamic geoecological system not only with their erosive effect, but also with accumulated geonoxes (from ore-bodies located higher up the mountain side) in the soils of the fields and valleys;
- **Seasonal accumulation of pollutants** in the river, lake, dam and sea sediments;
- **The processes of sea, river and dam abrasion**;
- **Specific geological, geomorphological and biological processes**, such as: landslides, earthquakes and other natural risk factors (Бручев, 2000; Велев, 2000; Янев, Дачев, 2001), acting upon the ecodynamics of the earth's crust, soils and waters.

CONCLUSIONS AND RECOMMENDATIONS

1. Geoecology was defined and consolidated as an interdisciplinary science in Bulgaria, which oblliges us to continue the research and applied work on a wide field of issues, in consolidated teams.
2. Topical and not to be further delayed are the activiites relating to **delineation of geochemical anomalies and accumulations with extremely high content** of geonoxes and technonoxes with a view to the necessity of making national agroecological politics more precise.
3. The formation of interdisciplinary research teams is necessitated, to study geoecological phenomena and problems, contrary to current practice of teams with too narrow a spectrum of scientific and appplied knowledge of experts.
4. When studying dynamic geoecological systems to estimate the effect upon the environment, the truly and justly balanced approach should be applied, i.e. actual benefits from business and technogenic invasion should not be for the account of natural geoecosystems. Only with the recognition and spread of this approach in our geoecological practice can

we speak of the sustainable development of prospecting, extraction, construction, urban and industrial activities.

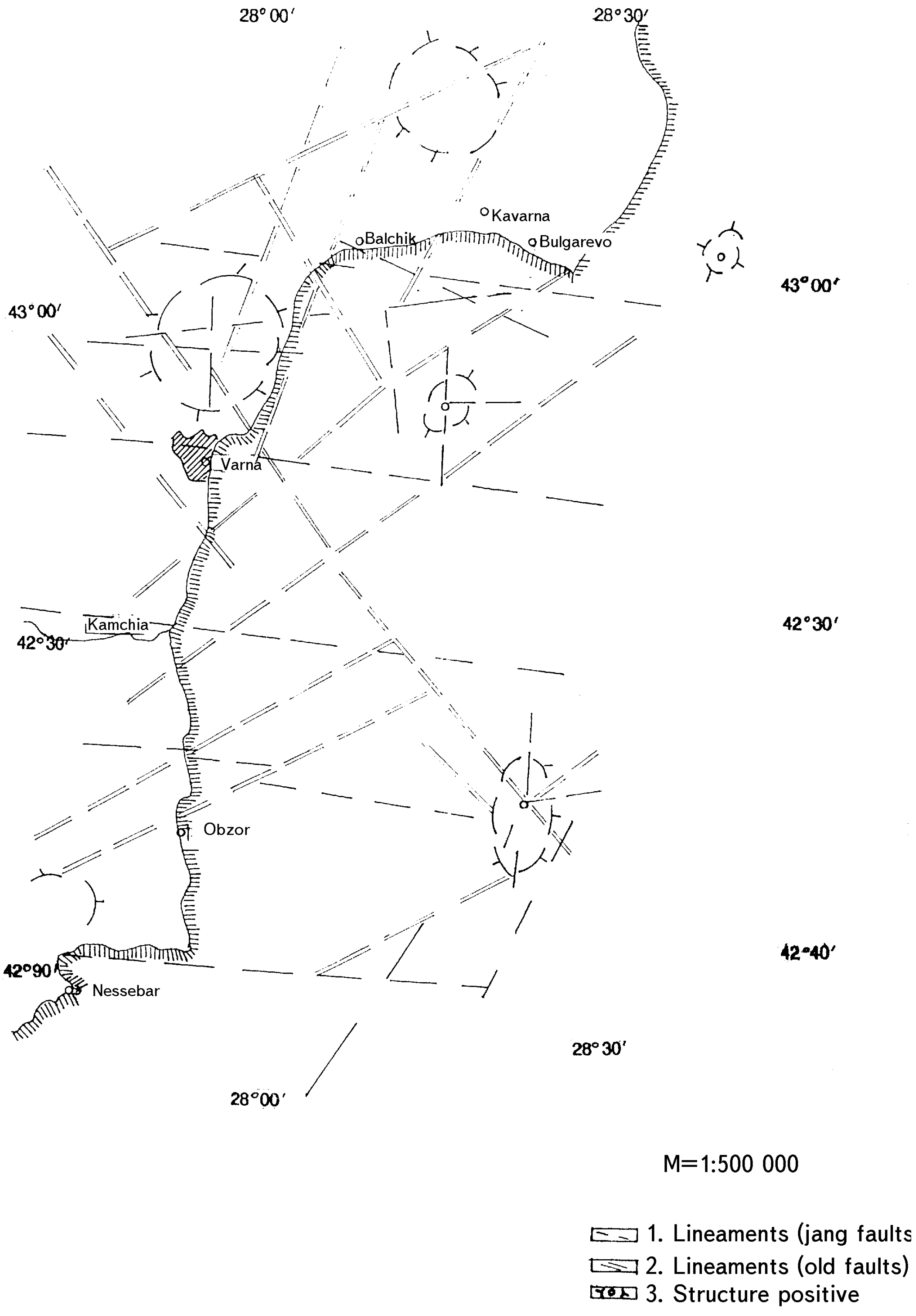

Figure 1.

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HARMONIZATION OF NATIONAL STANDARDS IN PRACTICE AND EDUCATION IN HYDRAULICS

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ABSTRACT
Water ecology has two major aspects - pollution prevention as a qualitative indicator and prevention of water overuse as a quantitative indicator.
The process of integration of the country to the EU and the problems arising from climate changes in the region demand precise measurement, adequate usage and pollution prevention of surface and underground water.
Standard methods and equipment for measuring and monitoring should be developed. The saved information must be editable, reliable and comparable. Good methods for processing and analysis mean good management and preservation of water.
The results of two international projects concerning the establishment of an information bank on basin principle about water resources are explored.

INTRODUCTION

No one can deny the importance of water in everyday life. Water is one of the most important natural resources. Today's easy access to fresh water and modern facilities makes it easy to forget the enormous efforts and complicated co-ordination, necessary to provide constant water flow for households, offices, factories and agricultural areas.

Water resources in Bulgaria are poor. Precise measurement, adequate use and preservation of surface and underground water resources are therefore of great importance.

Till 1989 water facilities were state-owned and governed through centralised planning. Since then, after the start of democratic development of the country, a need arises for development of standard methods and equipment for measuring and monitoring. The saved information must be editable, reliable and comparable. Furthermore, water cannot be viewed at a national level. It does not recognise borders and its availability depends on complex system of local and regional processes, interconnected with global climate, its changes and deviations.

The process of integration of the country to the EU and the problems arising from climate changes in the region demand the implementation of approved international standard methods. The harmonisation of our national law determines the importance of implementation of international standards in practice and education of hydraulics. Good management and preservation of water highly depend on the methods of processing and analysis of the regime information.

WATER AND WATER CONSUMPTION IN BULGARIA.

Rain is the major factor for formation of water resources. The average annual value of rain in Bulgaria is 673 mm, where the value for lowlands is 430 mm and for highlands – 1200 mm.

The total average annual rain is about 75 billions cubic meters; but 75% of it evaporates and only 25 % of it transforms into a surface outflow flowing into underground water resources and forming river outflow.

The irregularity of rain, small areas of river networks and climate specifics of outflow formation determine the regime of internal rivers, reaching correlation 1:2000.

Only 2 of 43 internal rivers, crossing national borders or flowing into the Black Sea and the Danube, have bigger network areas, over 10 000 sq. m. – Maritsa (21083 sq. m.) and Struma (10797 sq. m.). Half of the rest have a network area less than 1000 sq. m.

Typical for the river outflow is its territorial irregularity. Scarcest on water resources is the area of rivers directly flowing into the Black Sea.

Table 1.Hydraulic characteristics of some major rivers in Bulgaria

River	Watershed	Length of River	Density of the river network	Modulus of outflow	Mean Annual Discharge	Water Volumes 10^6 м³
	km²	km	km/km²	L/s/km²	m³/s	Average annual
1	2	3	4	5	6	7
1. Ogosta	3157	144	0.73	6.0	25.21	795
2. Iskar	8648	368	1.08	6.5	56.9	1794
3. Vit	3225	188	0.50	5.87	17.05	538
1	2	3	4	5	6	7
4. Osum	2824	314	0.36	6.02	17	536
5. Yantra	2947	285	0.75	6.34	49.83	1571
Danube basin	**45831**					
7.Provadiiska	2132	119	0.48	1.05	2.23	70.3
8. Kamchia	5358	244	0.72	4.92	26.34	831
9. Veleka	995	147		12.24	12.18	384
Direct inflow into the Black Sea	**14500**					
10. Tundja	7884	349	0.52	4.51	35.56	1121
11. Maritsa	21083	341	0.74	6.09	128.5	4047
12. Arda	5201	241		14	83	2484
13. Mesta	2767	126		13.83	38.3	1206
14. Struma	10797	290		8.03	86.8	2733
Basin of the White Sea	**50300**					

Table 2 Dynamics of the annual water resources – water source (billions м³) and year(1)

Year	1988	1995	1997
Surface water	13.066	10.092	12.037
Danube	n.a.	3.962	4.932
Dams	4.644	3.11	4.179
Inner rivers	n.a.	2.67	2.463
Lakes and marshes		0.45	0.463
Underground waters	1.458	0.906	0.841
Fresh water total	14.524	10.998	12.878
Turnover water	6.195	5.287	4.964

Table 3. Dynamics of annual (3) water usage (billions м³)

Year	1988	1995	1997
1. Households	0.389	0.306	0.269
2. Trade and services	0.419	0.148	0.153
3. Water losses	0.33	0.61	0.989
4. Agriculture	0.309	0.21	0.236
5. Irrigation	2.725	0.179	0.209
6. Industry	2.043	1.454	1.426
7. Hydroelectric/ atomic wer stations	8.253	8.27	9.805
Total	14.524	10.998	12.878

INTERNATIONAL STANDARTS IN HYDROMETRY.

International standards in hydraulics and their publication is co-ordinated by the International Organisation for Standardisation (ISO) (Table 4), European Committee for Standardisation (CEN) and the World Meteorological Organisation (WMO). According to the Vienna Agreement these organisations are in close co-ordination and do not duplicate identical activities.

In Bulgaria there is an old practice for instructions creation. These instructions have often poor legislation adequacy and are often to be used only by particular authorities; the instructions easily and sometimes unreasonably are changed, expanded or revoked, e.g. in 1995 the requirement for a project for "Estimation of the impact of a facility on the environment" in the "Law for environmental preservation" was revoked, which later on was considered a mistake.

The harmonisation of the Bulgarian and EU legislation will improve:

- the overview of the accumulated experience;
- development and implementation in practice of new facilities and equipment;
- quality and reliability improvement of data and its usefulness for comparative analysis and international exchange;
- the implementation of national standards in university programmes will improve the future activity of specialists and will prepare them for work in various conditions in Bulgaria and abroad.

Table 4. ISO Standards in hydrometry

ISO 748:1997	Velocity area methods
ISO 772 :1996	Glossary of terms
ISO1070: 1992	Slope area methods
ISO1088:1985	Data for the determinations of errors
ISO 1100/1:1996	Establishment and operation of a gauging station
ISO 1100/2:1998	Stage discharge relation
ISO 1438:1980	Thin plate weirs
ISO 2425:1999	Tidal channels
ISO 2537:1988	Current meters
ISO 3454:1983	Sounding suspension equipment
ISO 3455:1976	Current meter calibration
ISO 3716:1977	Sediment load samplers
ISO 3846:1989	Rectangular broad crested weirs
ISO 3847:1997	End depth method
ISO 4360:1984	Triangular profile weirs
ISO 4362:1999	Trapezoidal broad crested weirs
ISO 4363:1993	Measurement of sediment transport
ISO 4364:1997	Bed material sampling
ISO 4365:1985	Determination of concentration particle size and relative density
ISO 4366:1979	Echo sounders
ISO 4369:1979	Moving boat method
ISO 4371:1984	End depth method(non rectangular channels)
ISO 4373:1995	Water level measuring devices
ISO 4374:1989	Round nose horizontal weirs
ISO 4375:1979	Cableway system
ISO 4377:1989	Flat V weirs
ISO 5168: 1978	Estimation of uncertainty of a flow rate measurement
ISO 5168:1998	Evaluation of uncertainties
ISO 6416 :1992	Ultrasonic method
ISO 6418:1985	Ultrasonic velocity method
ISO 6419/1:1984	Hydrometric data transmission system – general
ISO 6419/2:1992	Hydrometric data transmission system – requirements
ISO 6420:1984	Position fixing equipment
ISO 6421:2001	Method for the measurement of sediment in reservoirs
ISO 7066/1:1997	Uncertainty in linear calibration relations
ISO 7066/1:1989	Uncertainty in linear calibration relations
ISO 7066/2:1988	Uncertainty in non linear calibration
ISO 7178:1983	Errors in velocity area methods
ISO 8333:1985	V shaped broad crested weirs
ISO 8363:1997	Guide for the selection of methods
ISO 8368:1999	Guidelines for the selection of structures

HARMONISATION OF THE BULGARIAN WATER LEGISLATION AND E U STANDART.

Exploring the directives of EU for water preservation, it should be considered that they are related mainly to pollution prevention and not to prevention of water overuse. Consequently greater attention is paid to the qualitative not to the quantitative side of the problem.

The directives themselves divide into frame directives – determining the main requirements and legal means for water preservation, and subordinate directives – connected with the implementation of the requirements of the frame directives and giving more precise legal means in the respective direction, including limit values for certain hazard contaminate substances.

According to EU laws for water usage any legal subject consuming water carries the responsibility for water self-monitoring and is eligible to control. Management and control in most of the EU countries – France, Spain, Italy – is based on basin monitoring; for example, in France 6 basin committees are formed, with representatives of the central and local authorities, professionals and concerned specialists.

Water management through basin planning for major rivers in Bulgaria started in 1920 with the introduction of the "Law for water unions". In 1963 the "Law for preservation of air, water and soil" is introduced – an integrative approach towards preservation of environmental components – 11 years before the UK adopted such legal approach. Democratic changes during the past decade lead to decentralisation of water management.

The government's inability to maintain financial support for water management leads to neglection of hydraulic stations and facilities. This might lead the country to the situation of France, which in 1970 closed most of its hydraulic stations for "uselessness" after over a hundred years constant work. The period of continuous drought that followed brought up a severe necessity of information, resulting in restoration and further development of the monitoring network. The new "Law for water" introduced by the end of 1999 in Bulgaria includes integrated management of water resources, divided by river basins. Its goals are:

- preservation of water ecosystems,
- ecological and economically efficient water usage,
- achievement of reasonable prices of all activities related to water usage;

in other words, ceasing government subsidies on water economy.

DETERMINATION OF THE STREAM FLOW USING DATA OF WATER MONITORING AND WITH THE RECENT MODELS FOR STREAM FLOW SIMULATION

It is essential that students, studying in the field of hydrology, learn the most up to date methods and tools that are being used for the assessment of water resources.

It is well known that fresh water is a vital resource and will become even more significant in the near future as demand increases. Integrated management of water resources is essential to ensure the most effective functioning of the resources within the river basin; including water use, the environment, and economic investments. This is a complicated, inter-related system involving different spatial and temporal scales, as well as varied anthropogenic activities. Water resource management can not be effective without the incorporation of complete information pertaining to the present situation of the basin and also accounting for trends of the past useage of resources (Янчева и др. 1995).

The effectiveness of water resource management, taking into account the stochastic character of the flow, is directly dependent on the quality of the environmental information.

There are two types of appraches for streamflow assessment:

- Using water monitoring data, and;
- Simulating streamflow using mathematical models.

Monitored stream flow data are based on the streamflow measurements from Bulgaria's national monitoring stations. It is very important that regulated stream flow, resulting from intensive anthropogenic activities in the river basin, is measured at the gaging stations. This makes using water balance methods for distribution of stream flow and for water resources management impractical because alterations to natural stream flow are not taken into account, such as reservoirs and irrigation channels. Also, gaging stations for stream flow observation are irregularly distributed in the river basin, which makes the assessment of stream flow in the upper part of the basin very difficult. This creates problems for governmental institutions when trying to determine the actual available resources that may be allotted to the users.

Simulation of stream flow using mathematical models is a field of hydrology which has developed with very quick progress over the past years. The main achievement obtained by using this manner of stream flow assessment, is that it gives the possibility to simulate undisturbed stream flow at every point of the river net.

The use of mathematical models for stream flow simulation requires:

- full, detailed information for daily precipitation and temperature, soils and land use, relief and other data for testing the models;
- complete monitoring data for the stream flow, necessary for calibration and validation of the mathematical models.

Hydrologic, and other data necessary for water management in Bulgaria, are dispersed throughout different governmental organizations. At the present time, it is too difficult for one department to undertake and maintain this entire database due to lack of funds. Another obstacle is the lack of digital computer systems for gathering, analyzing, and saving this vast information. These records need to be converted into long term time series in order to be entered into mathematical models used to simulate the functioning of water systems (Николова, 1979; Николова и др., 1996).

All these arguments motivated the creation of the structure for a GIS-based

GEOGRAPHICAL WATER RESOURCES INFORMATION SYSTEM

for the whole territory of Bulgaria (Hristov, Ioncheva, 2002).

The structure of the water resources information system was created in the Institute of Water Problems at the Bulgarian Academy of Sciences. All necessary data for the Yantra River Basin was entered into the system, called "*GeoWateRIAS-V.0"* (Hristov, Ioncheva, 2002), fig. 1.

Geographical water resources information systems are modern, powerful tools for gathering and organizing information. With this information, analysis and assessment of water resources, in relation to the development of the economy and agriculture in the river basin, can be used together to maintain ecological sustainability.

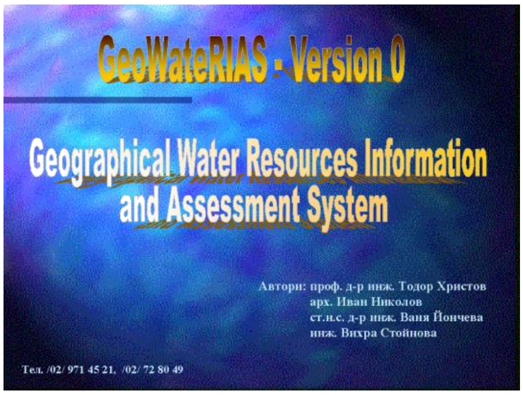

Figure 1.

The information system is able to include new information, which will expand the scope of the database, not only in detail but also in time, to include subsequent years. This is the necessary condition to have a water resource information and assessment system, as opposed to simply an information system.

The information system can be updated to include new information, which will expand the scope of the database; over successive years, the detail and time span may be increased to reflect changes in the basins. This is the necessary condition to formulate a water resource information and assessment system, as opposed to simply having an information system.

All available information in the water resources information system is situated in the topographic maps of the Yantra River Basin, as shown in figure 2.

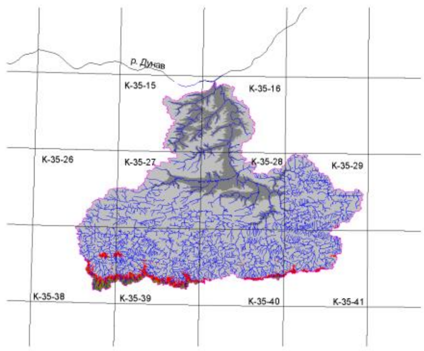

Figure 2. Network of Maps of the Yantra river Basin (Hristov, T., V. Ioncheva. 2002)

Hydrologic mathematical models are used to simulate the stream flow in 75 specific points of the Yantra River Basin (Ioncheva V.,T.Hristov. 2002). The simulated hydrograph for each gaging station is then compared with the observed hydrograph and detailed statistical assessment is made.

As a result of the investigation, the following conclusions can be made:

- Hydrologic mathematical models, used for stream flow simulation in Yantra River Basin during a ten year period, can be reccomended for incorporation into the decision support system;
- To ensure the optimal use of available funds, it is necessary to re-evaluate the location of the every gaging station to have the possibility to reduce the total number of stations. The remaining stations must be the most technologically advanced to produce the best quality of observed data.
- The net of the meteorological stations must undergo ongoing evaluation to more accurately represent and assess the precipitation for each river basin. Precipitation and temperature are the most sensitive meteroeological input parameters influencing on stream flow simulation for the hydrological model.
- It is necessary that every alteration of stream flow, in the territory of the river basin, is accounted for and then reflected in the information database. This will assist in the implementation of the mathematical simulation models for the assessment of the stream flow.

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HUMAN PHYSIOLOGICAL STATUS AND ENVIRONMENT

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ABSTRACT
In this paper we present results from investigation of the influence of meteorological parameters on human physiological status. A group of 86 volunteers was examined in Sofia city during the periods: 01.10.2001 - 09.11.2001 and 08.04.2002 - 28.05.2002. The group included males and females at age between 25 and 65 years, concerned with scientific activity. Among the persons examined there were 26 persons who had cardio-vascular disturbances and were taking respective medicaments. The Fiodorov-Chubukov's complex-climatic method was used to characterize meteorological conditions because of the purpose to include in the analysis a maximal number of meteorological elements. 16 weather classes are defined in dependence of the meteorological elements values according to this method. The results obtained by MANOVA revealed statistically significant influence of the weather classes investigated on some of the physiological parameters examined. A higher sensitivity of some of the physiological parameters of females and persons taking medicaments to some of the weather classes was found through Post hoc analyses.

INTRODUCTION

It has been proved that environmental factors influence considerably on human health, physiological state and general condition. A lot of investigations, which confirm this impact, have been carried out. The mechanisms of this effect for the separate factors are not completely clarified and therefore the investigations in this direction are of a great interest. During the last years in a lot of publications the authors attempt to clear up these mechanisms (Hong, 1995; Oraevskii, et al., 1998; Zhadin, 2001) as well as to separate the impact of different factors from the factor complex of the environment, which influence on humans. The separation of the independent impact of each of the factors is a difficult and often almost impossible. Different approaches and methods for analysis have been used to find out the prevailing impact of definite factors. By collecting solid data sets, using reiteration of definite phenomena and employing different statistical data processes successful attempts have been made. Significant results are obtained in clarifying the influence of different environmental factors on cell processes (Hong, 1995), different organs and functional systems (Oraevskii, 1998; Pikin, et al., 1998) and human health (Stoupel, 1993).

Bulgarian scientists have also performed investigations in this field. From 1973 dated scientific investigations of J. Naumov, A. Mateev, P. Velinov for influence of different environmental factors including geophysical, meteorological etc. on human health at different regions in Bulgaria (Naumov, et al., 1973; Mateev and Spiridonov, 1976; Velinov and Mateev, 1977).

We have performed investigations in this field for several years. We have tried by collecting a significant number of measurements for each physiological parameter (about 3000 measurements), measuring at one and the same time during the day for each person and using statistical data processes to obtain significance and differentiation of the influence of different geophysical factors on physiological parameters examined. We have employed MANOVA, Post hoc comparisons, correlation analysis etc. It was proved a statistically significant influence of geomagnetic activity changes on physiological parameters and behavior reactions (Dimitrova and Stoilova, 2002; Dimitrova, et al., 2002).

In this paper we present results obtained by employing 3-factor MANOVA for investigation of the influence of different meteorological factors on human physiology.

MATERIAL AND METHODS

Medical examinations performed in Sofia city[1] during the periods: 01.10.2001 - 09.11.2001 and 08.04.2002 - 28.05.2002 were used. The data are from registrations of physiological parameters of a group of 86 volunteers (33 males and 53 females) at an average age 47.8 г. ($\pm$11.1).

Systolic and diastolic blood pressure and pulse-rate were measured. The difference between systolic and diastolic blood pressure was calculated and questionnaire data about subjective complaints (heart thumping, tachicardia, arrhythmia, stitches in the heart area, headache, dizziness, sleep problem etc.) were collected.

The measurements were performed at one and the same time during the day for different persons and totally 2799 registrations for each of the physiological parameters examined were got.

[1] Latitude: 42° 43' North Longitude: 23° 20' East

26 persons in the group examined had cardio-vascular disturbances and were taking medicaments prescribed by relevant specialists. They were referred to a group "persons taking medicaments" and the rest formed a group "persons without medicaments".

The Fiodorov-Chubukov's complex-climatic method adapted to climatic conditions for Bulgaria (Tishkov, 1970) was used to characterize meteorological conditions. According to this method a maximal number of meteorological elements are taken in consideration. This enables a detailed characterization of a different kind of changes in the weather. In the frame of this classification the numerous manifestations of the weather are grouped in 16 classes according to the values of the following meteorological elements: mean day temperature, mean day humidity, mean cloudiness for the day and night, wind speed, maximal and minimal air temperature for the day. For each class each of the meteorological parameters has exactly defined range of values.

During the periods when the medical examinations were performed 6 of the 16 weathert classes were observed:
III class - little cloudy,
IV class – cloudy during the day,
V class - cloudy during the night,
VI class - gloomy,
VII class - rainy,
IX class – with negative transition of the temperature through 0^oC.

3-factor analysis of variance (MANOVA) for factors: weather class (6 levels - III, IV, V, VI, VII and IX weather class), gender (2 levels – males and females) and medicaments (2 levels – persons taking medicaments and persons not taking medicaments) was employed to reveal a statistically significant influence of the factors under consideration on the physiological parameters examined. Post hoc comparisons were performed to check the statistical significance of the obtained changes between the levels of the factors.

RESULTS

Arterial blood pressure

When a 3-factor MANOVA for the factors investigated was employed it was found that the main effect of the weather class on the arterial (systolic and diastolic) blood pressure is statistically significant ($p<0.05$). The systolic blood pressure was highest during III, VI and IX weather class and lowest when V weather class was observed (Fig. 1a). The diastolic blood pressure is highest during III and VI weather class and lowest also during V class (Fig. 1b).

The two-way and three-way interactions of the factors under consideration (weather class, gender and medicaments) did not reveal significant influence on the arterial (systolic and diastolic) blood pressure. In consequence of that it could be supposed that the both genders as well as taking and not taking medicaments have a slight influence on the arterial blood pressure for the weather classes investigated.

However Post hoc analysis revealed statistically significant differences in the influence of V and VI weather class on the diastolic blood pressure of females - when the weather is gloomy (VI class) women rise statistically significantly the diastolic blood pressure in comparison with the weather when it is cloudy during the night (V class). For males and for persons taking and do not taking medicaments Post hoc analysis did not reveal a statistically significant difference in their reaction to changes of the weather classes regarding the arterial blood pressure.

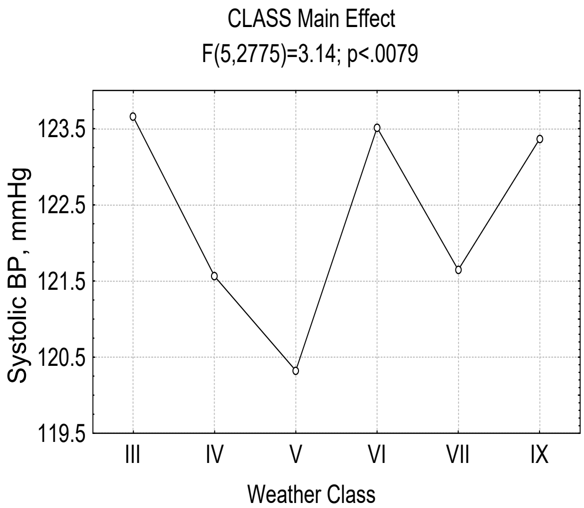

Figure 1a. Influence of the weather class on the systolic blood pressure.

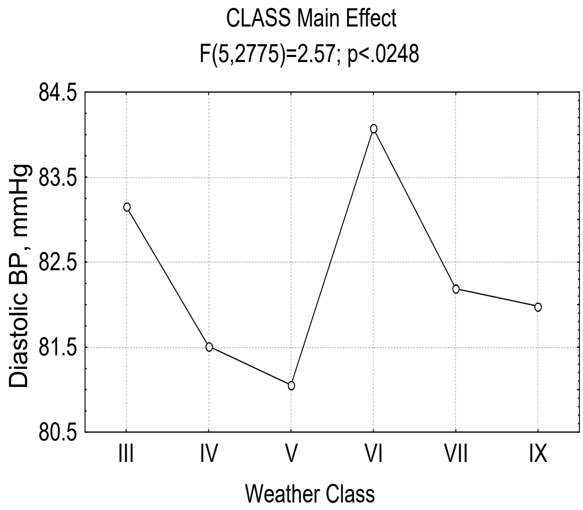

Figure 1b. Influence of the weather class on the diastolic blood pressure.

Difference between systolic and diastolic blood pressure

The tree-factor MANOVA employed revealed a trend to influence ($p<0.06$) of the main effect of the weather class on the difference between systolic and diastolic blood pressure.

The difference between systolic and diastolic blood pressure is narrowest for V, VI and VII weather class and widest for IX class.

The two-way and three-way interactions of the factors investigated as well as Post hoc comparisons employed did not reveal a difference in the reaction of males and females as well as of persons taking and not taking medicaments regarding the difference between systolic and diastolic blood pressure.

Subjective physiological complaints

Three-factor MANOVA for the factors investigated regarding the part of the persons examined, who reported subjective physiological complaints, revealed a statistically significant influence (p<0.0001) of the weather class main effect (Fig. 2).

The results show that the percentage of the persons who had subjective physiological complaints is smallest for V class (cloudy during the night) – 5.8% and largest for IV and VI class (cloudy during the day and gloomy), respectively: 16.6% and 18%.

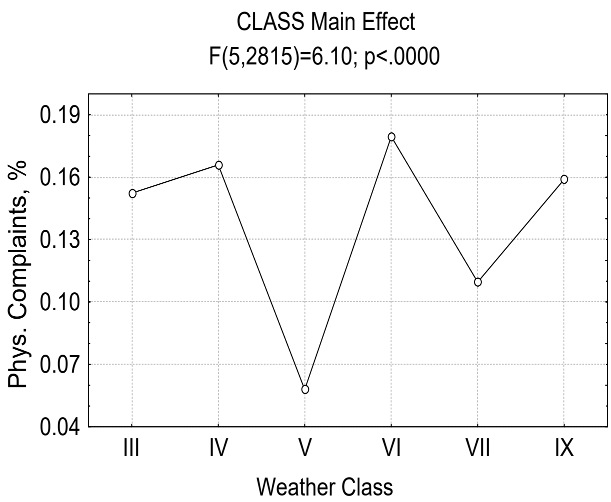

Figure 2. Influence of the weather class on the percentage of the persons reported subjective physiological complaints.

The two-way and three-way interactions of the factors investigated (weather class, sex and medicaments) did not reveal significant influence on the subjective physiological complaints, which suppose identical sensitivity of the both genders as well as of the persons taking and not taking medicaments to the weather classes investigated regarding subjective complaints.

The additional investigations by Post hoc comparisons revealed that subjective physiological complaints are statistically significantly smaller when the weather is cloudy during the night (V class) in comparison with the weather when it is a little cloudy, cloudy during the day and gloomy (III, IV and VI class). And as well that the percentage of the persons with subjective physiological complaints, who were taking medicaments, rises statistically significantly when the weather is gloomy (VI class) in comparison to V class. It suggests a higher sensitivity for them in comparison with the persons who were not taking medicaments.

Pulse-rate

Although 3-factor MANOVA did not reveal statistically significant changes (p<0.25) of the pulse-rate upon influence of the weather class main effect (Fig. 3), Post hoc analysis revealed that the pulse-rate increases statistically significantly during VI class (gloomy weather) in comparison with all of the rest weather classes investigated.

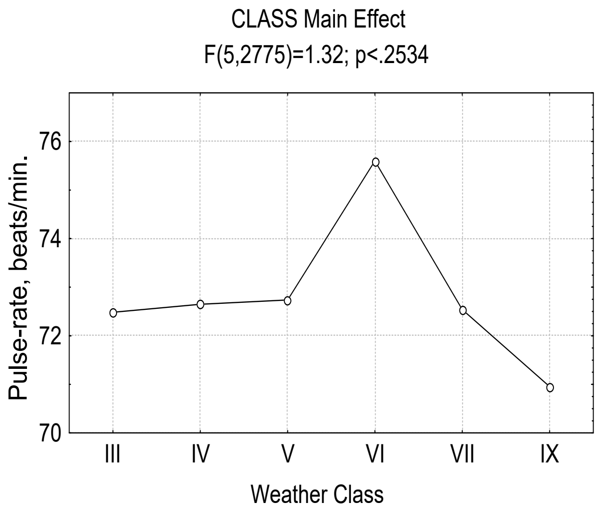

Figure 3. Influence of the weather class on the pulse-rate.

Post hoc comparisons also revealed a higher sensitivity of the pulse-rate for the persons taking medicaments – they increase statistically significantly the pulse-rate during VI class (gloomy weather) in comparison to all of the rest weather classes, while for the persons not taking medicaments any significant differences were not established.

The results obtained by Post hoc analysis revealed a higher sensitivity of the pulse-rate for females in comparison to males upon weather classes influence. It turned out that females increase statistically significantly the pulse-rate during a gloomy weather (VI class) in comparison with IV, V, VII and IX class.

DISCUSSION

The results presented are an initial attempt for a generalized presenting of the influence of meteorological factors on the physiological parameters examined. It was established a presence of definite effect of meteorological conditions changes on the physiological reactions of the group examined.

A lot of scientists have investigated different meteorological factors and aspects. They have proved their influence on the physiology, behavior reactions and human health (Gavryuseva and Kroussanova, 2002; Belisheva, et al., 2000; Ivanova, 2002; Marinov, et al., 1989 etc.).

The three-factor MANOVA employed revealed that the arterial (systolic and diastolic) blood pressure is highest when the weather is a little cloudy and gloomy and it is lowest when the weather is cloudy during the night. And the systolic blood pressure is high also during weather with negative transition of the temperature through $0^{o}C$.

The examination of the arterial blood pressure is an easily available and quite informative method for estimation of the functional state of the cardio-vascular system. There are different external and individual factors that could influence on the arterial blood pressure. But when there is a set of a lot of everyday measurements for a big group of persons and a statistically significant changes in blood pressure upon influence of changes in a definite external factors are obtained, we could suggest that this factor has a prevailing impact.

The difference between systolic and diastolic blood pressure is narrowest when the weather is cloudy during the night, gloomy and rainy, and widest during weather with negative transition of the temperature through 0°C. Having in mind that widening as well as narrowing of the difference between systolic and diastolic blood pressure is unfavorable indicator, especially for persons who have cardio-vascular disturbances, the dependence obtained could be used for precautions during advent meteorological precursors.

The percentage of the persons who had subjective physiological complaints is largest when the weather is cloudy during the day and gloomy – IV and VI class according to the classification used and smallest when it is cloudy during the night – V class. The increase of the cloudiness in combination with a decrease of lighting turns out to be considerably more adverse factor.

On the basis of the results obtained by 3-factor MANOVA and Post hoc comparisons the most unfavorable weather class in respect of all of the physiological parameters examined turns out to be VI class (gloomy). When the weather is gloomy systolic and diastolic blood pressure increase statistically significantly, the difference between them is narrowest as well as the subjective physiological complaints reach the largest percentage. The higher sensitivity of females as well as of persons taking medicaments is also related to VI weather class – then females increase statistically significantly the diastolic blood pressure in comparison with V class (cloudy during the night) as well as the pulse-rate in comparison with IV, V, VII and IX class. And the persons taking medicaments increase statistically significantly pulse-rate in comparison with the rest of the weather classes investigated as well as the subjective physiological complaints in comparison to V class (cloudy during the night).

The general review of our results obtained for the influence of geophysical (Dimitrova, et al., 2002) and meteorological factors reveals that geomagnetic activity (planetary and local) has more clearly expressed influence on physiological parameters examined in comparison with meteorological factors. This summary of course refers only for the group and factors examined. Additional investigations are needed to confirm the common validity of these results.

The influence of solar activity changes on human health goes through meteorological and geophysical factors. That is why the investigations of these environmental factors are very important. As far as they could be foreseen to some extend the results obtained could be utilized for prevention adverse consequences.

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RADIOCHEMICAL PROCEDURES FOR DETERMINATION OF NATURALLY OCCURRED URANIUM ISOTOPES IN ENVIRONMENTAL SAMPLES

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ABSTRACT
In the present paper different methods for uranium determination in the environmental samples are discussed. The developed procedure in the framework of IAEA Contract No 11298 for more precise determination of the uranium isotopes concentration in the soil and rock materials is presented. This methodology is very suitable for the regions where geo-ecology of uranium is disturbed. The main steps in the procedure described and discussed in this study are: 1) isotopic delution by use of the tracer ^{232}U for chemical yield estimation; 2) full acid digestion of the sample in several consecutive steps with HF, HNO_3, HCl; 3) radiochemical separation of uranium from other matrix elements by ion exchange resin (BIO-Rad AG1-X8) and further purification by recently developed chromatographic material UTEVA.Spec of Eichrom Ind. (USA); 4) source preparation for alpha spectrometry by a) microprecipitation as fluorides whit c NdF_3 и b) electrodeposition. After extensive investigation of the specific parameters for every step the developed procedure was tested successfully on soil reference materials. Large number of analyses of uranium isotopes content in samples of the new developed reference material from the region of the village of Eleshniza were performed. The results proved the homogenity of the material and its applicability for use as reference material for naturally occurring uranium series.

INTRODUCTION

Uranium industry has been developed during the second half of the XX century mainly in connection with nuclear energy generation chain. Mining, enrichment, nuclear fuel preparation and waste management require a number of chemical methods for extraction, purification and enrichment. The industry leads to the environmental impact with remarkable spread pollution in some regions of the uranium mining and milling.

Uranium, which is metal has the highest atomic weight of the naturally occurring elements. The primary isotopes of natural uranium are ^{238}U (99.28 wt%), ^{234}U(0.71 wt%), and ^{235}U(0.0054 wt%), Merck Ind. 1989. Average concentration of Uranium in soil is 2 mg/kg (about 25 Bq/kg of ^{238}U) ranging from <1mg/kg for basalt rocks to >8 mg/kg for granites, Canadian SQG for Uranium (2002).

Widely used methods for measuring uranium in environmental samples are fluorimetry, gamma-spectrometry and alpha spectrometry. Although high concentrations of uranium can be measured successfully without destruction of the sample (instrumental analysis) by gamma spectrometry it is not appropriate when determination of isotopic composition of Uranium in the material is sought. The method estimates the ^{238}U through its daughter ^{234}Th (requiring long period for equilibrium –approx. 1 year) can measure accurately ^{235}U if the ^{226}Ra (daughter до ^{238}U) does not exceed significantly ^{235}U activity, and ^{234}U can not be measured directly in soil and rock samples.

Fluorimetry is historically first developed method and widely used for elemental determination of the uranium. The method is significantly improved by use of laser fluorimetry. For low level concentrations of uranium in food and other biological materials after pre-concentration and purification neutron activation analyses NAA is used, Dang and Chatt (1986) for example. The use of ICP MS and AMS (accelerated mass spectrometry) is the other method with extending use during the last decade for actinides including uranium. For chemical separation adsorption and ion exchange are common processes for soluble substances among others such solvent extraction and precipitation. It is hard to present in limited space a review of references of the analytical methods for determination of uranium but it is worth to mention that more than 14 analytical methods are standardized in ISO-95 (10): ASTM-95 (4), and in Bulgaria - BDS 12578-75 about uranium in drinking waters.

EXPERIMENTAL SECTION

One of the approaches for evaluation of the isotopic ratio necessitates an application of a radiochemical procedure for extraction of uranium and measurement of uranium isotopes by its alpha energies on alpha spectrometer.

Therefore in the frame of the IAEA Research contract No 11298 "Development and characterization of a reference material for naturally occurring uranium series" a radiochemical procedure for isotopic analysis of Uranium in samples from the area of former uranium mines in the village of Eleshniza was developed. The main steps of the developed procedure: total acid digestion, anion exchange separation of the uranium from the basic matrix, further separation and purification by employing recent solvent extraction resin UTEVA-Spec, and thin alpha source preparation of alpha source is summarized in Fig.1.

Alpha spectrometry was performed by ORTEC Octete Alpha Spectrometric system equipped with 8 Ortec ULTRA-SA™ low background ion implanted detectors with 300mm^2 active area. The alpha spectrometric system was obtained under IAEA TCP RER 2/003. More information about the features of the spectrometric system are given in Veleva (1998).

The measured total system resolution FWHM for ^{241}Am 5.486 MeV alphas is close (or even lower) to 19keV for 4cm source to detector distance for all detectors. Energy calibration as well as efficiency calibration for one of source geometry (co-ppt. Source) is done by mixed radionuclides standard containing ^{238}U, ^{234}U, ^{239}Pu and ^{241}Am with known activity, and for geometry of electroplated sources the efficiency calibration is estimated by Amersham ^{241}Am standard.

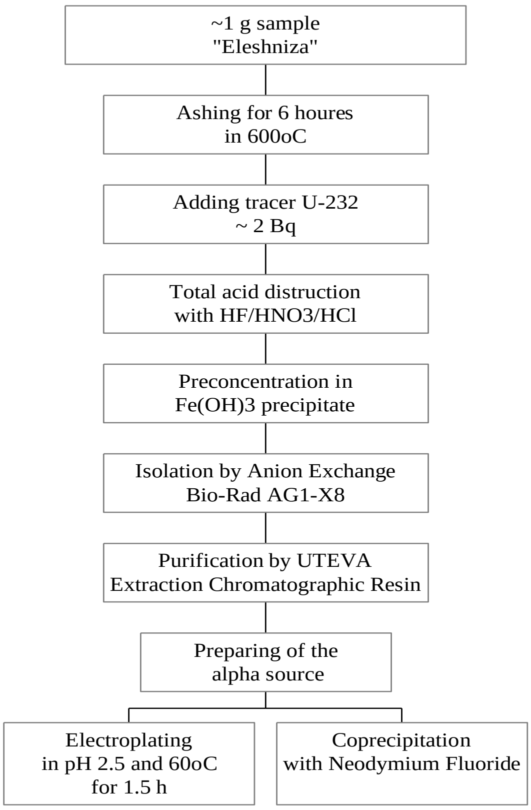

Figure 1. Main steps of radiochemical procedure for extraction of uranium

For correct determination of the uranium isotopes by alpha spectrometry the source preparation is essential. A number of experiments were carried out on two techniques with purpose to achieve higher yields and finer alpha spectra.

Experiments on optimization of co-precipitation with NdF_3 for alpha source preparation:

The technique of co-precipitation of three and four valent actinides with lantanides (or micro-precipitation) for preparation of source for alpha spectrometry is developed by C. Sill (1987) and was successfully used by Taskaev et al. (1996) for determination of Plutonium in soils, following La Rosa (1990).

Because first results on analyzing of this material were with stable but low yields (around 20%), the behavior of the solution with known U concentration on different steps of the procedure was tested extensively. We analyze the condition of micro co-precipitation according to the quantity HF needed for forming the fine NdF_3/UF_4 precipitation, Table 1.

Table 1. The Results of samples with different quantity of HF and their recoveries:

Sample	HF (ml)	Recovery %
U+5HF	5	19.1
U+7HF	7	18.1
U+10HF	10	18.4

The conclusion that could be drawn from this data is that the quantity of added HF does not influence on the low recovery results, it remains unchanged.

The second test was connected with finding the optimum quantity of 15% $TiCl_3$ used for reduction of U (VI) to U (IV) for precipitation of NF_3/UF_4, Table 2.

The need of reduction of the Uranium high valency states with strong reduction agent was demonstrated by experiments where no Ti $^{(3+)}$ was added and there was no uranium in precipitation.

Table 2. The results of samples with different quantity of $TiCl_3$:

Sample	Weigh (g)	$Ti^{(3+)}$ (μl)	Recovery %
10A1	0.1899	200	55
10A2	0.1930	400	55
10A3	0.1973	600	52
10A4	0.1748	800	50
10A5	0.2472	1000	41

As we can see, the quantity of Ti $^{(3+)}$ also doesn't influence on the recovery. The fact that the recoveries reach about 50% is because of the smaller samples taken for this experiment (note that it is five times smaller than previous experiment).

Finally a doubled amount of the Nd^{3+} increased the recovery almost twice. Further increase of Nd^{3+} could lead to thickner source and degradation of alpha spectrum and was not tested.

The conclusion is that not the quantities of HF and $TiCl_3$, but the deficiency of co-precipitated NdF_3 micro-precipitation in high concentration uranium samples is the reason for low recoveries. It is questionable whether so called matrix effect - smaller samples have low level of salinity plays some role to obtain the higher recovery than it in the larger samples. The dependence of the observed recovery from the sample mass, respectively U concentration is shown on Fig.2.

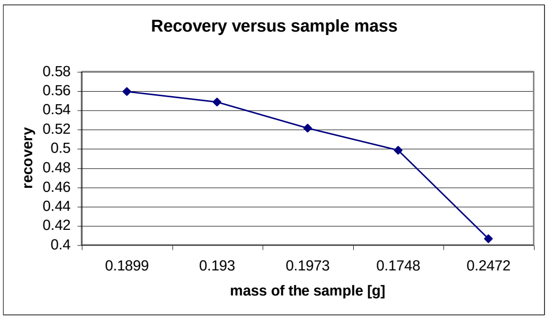

Figure 2. Initial dependence of recovery from the sample mass

Alpha spectrometry of the samples was performed at distance of ~ 1cm to the detector and at the typical range of 15-35 mbar pressure in the vacuum chambers, thus preventing detector contamination with recoil atoms. Every sample was measured at least twice. The recovery is estimated with some uncertainty, because it is not possible to reproduce exactly the geometry of the uniform standard. This uncertainty is different from the statistical one, depending on the number of counts in the peak of certain isotope.

Experiments on optimization of electrodeposition for the preparing of alpha source

We decided to implement electroplating as an optional technique for preparation of alpha sources with the purpose to achieve thinner source and respectively finer alpha spectrum. Some tests for spontaneous deposition of uranium on aluminum disks were done but the received recovery does not exceed 10%. In the literature there are described different conditions of electroplating of Uranium. One of the important points for successful electroplating is the electrolyte. In classic Talvitie (1972) method $(NH_4)_2SO_4$ is used, in DIN 38404-20 and ASTM C1000-90 it is $NaHSO_4$ + $6MH_2SO_4$ and $NaHSO_4$ + $1NH_2SO_4$ respectively, B. Burnett (2002) applyed H_2SO_4. In this study $(NH_4)_2SO_4$ was chosen and proved. Other characteristics of the listed methods are summarized in Table 3. The optimal distance of 10mm between cathode and anode was held. Several experiments were carried out on electroplating conditions, mainly changing pH and temperature. The tests for electrodeposition of uranil nitrate show an average 72% recovery ranging from 25 to near 100%. The best results with the highest yields were achieved at pH 2.5 and without cooling the solution (it reaches around 50-60°C during the process of electrodeposition)

The main advantage of the electrodeposition compare to micro-precipitation is the source thickness, estimated by energy resolution FWHM (Full Weight at Half of Maximum) of the alpha peak. This spectrometric characteristic is widely used in alpha spectrometry both for spectrometer and for source features and depends on the source to detector distance. The average FWHM in case of co-precipitation with 50 μg of Nd is about 80 KeV, for 100μg increases to 90KeV, but for electroplating sources is as better as 35-45 KeV.

Table 3. Specific characteristics of the electrodeposition methods

Ref.	**DIN 38404-20**	**ASTM C1000-90**	**Talvitie (1972)**	**Burnett (2002)**	**This study**
Sample type	Water	Soil	Envir. Objects	Envir. objects	Soil
Ph	2.4-2.5	2-2.3	1.2-2.8	3.2	2.5
Depos. Time, (min)	60	60	120	-	90
Volume (ml)	11	15	10	50	8 –11
Anode-Source d, (mm)	-	10	13	10	10
Current (A)	1.2-2	1.2	1.2	1.2	5min-0.5 90min-0.75

Radiochemical separation

During the process of development of the procedure three types of materials were used: depleted uranil nitrate solution; IAEA reference materials; and samples from new prepared and evaluated for possible reference material Eleshniza uranium ore. The initial tests for radiochemical separation were done with uranil nitrate solution spiking the tests solution with known amount of uranium mass Richter et al. (1999).

The main part of the analyzed samples of developed new reference material consists of a fine fraction of the raw grounded material (passed through the sieve with pore size of 0.074-mm). The non- homogeneity of the material in relation to particle size was established to be less than 1.5 %. The material was sampled and prepared according to BSS 8.892 (1996) and Claude&David (1995). The initial gamma measurements showed about 2 Bq/g of ^{238}U therefore about 1 g of this fine powder was weighted to have enough material for alpha measuring.

Prior acid digestion, the sample to be analyzed is ignited in a porcelain crucible in an electric muffle furnace up to 600°C and held at that temperature for 6 hours to burn off all carbonaceous material. The final ash should be homogeneous like a fine powder.

The applied technique of total acid digestion of soil samples is close to J. La Rosa (1990) and has been used many times by the authors for analysis of radionuclides in environmental samples. The main advantages are: a) all quantity of radionuclides is transferred to the sample solution, and b) the conditions ensure full isotope exchange between radioactive tracer ^{232}U and the natural isotopes of uranium - $^{234, 235, 238}U$. Use of a tracer provides the most accurate estimation of the chemical yield for every sample.

Discarding the main matrix of the rock sample was the next step in procedure. To achieve this purpose, we used co-precipitation of Uranium with $Fe(OH)_3$ in pH 9-10 and removed all soluble hydroxides in this conditions – mainly alkali and alkaline-earth metals. The precipitate was dissolved in 9M HCl and anion exchange chromatographic column of Bio - Rad AG 1-X8, 100-200 mesh was prepared for radiochemical separation of Uranium.

There are many procedures for extraction of uranium, all dealing with water, soil and rock samples with low content of uranium. The classic ion exchange resins (organic and inorganic) are recently replaced or supported by UTEVA.Spec chromatographic material (Renpo Wu et all., 1998, B. Burnet, 2002, Ann.Rep.of Helsinki University, 2001). Chemical separation of the spiked with uranil nitrate 9M HCl solution started with extraction by ion exchange resin only. Uranil nitrate spike vary from 0.0003 to 0.2019 mg uranium, the last value, equivalent to 2.49Bq ^{238}U is closed to the activity in typical 1g sample from the Eleshniza material. The test showed that some Thorium impurities ($^{228, 230}Th$) presents in the alpha spectra, thus interfering determination of ^{234}U and ^{235}U. Therefore the second UTEVA.Spec column was introduced for purposes of further purification of the Uranium fraction from some actinides and Iron employing a recent chromatographic resin, commercially available product of Eichrom Ind. (USA).

The uranium eluat from BIO-Rad AG1-X8 column is coverted in nitrate form and loaded in 3M HNO_3+1.0M $Al(NO_3)_3$ solution. Prior the Uranium other elements and radionuclides (Th, Am, Al, Pa, Pu) are removed. The final uranium strip of 0.01M HCl is ready for source preparation.

Finally alpha sources were prepared by using two techniques: (1) co-precipitation as fluorides with Neodymium Fluoride and (2) electroplating.

RESULTS AND DISCUSSION

Every set of samples was accompanied by spiked with ^{232}U blank. The concentration of U isotopes in blank was very low and it was considered only in 2 sets. Typical alpha spectra of electroplated sample source is shown on Fig.3

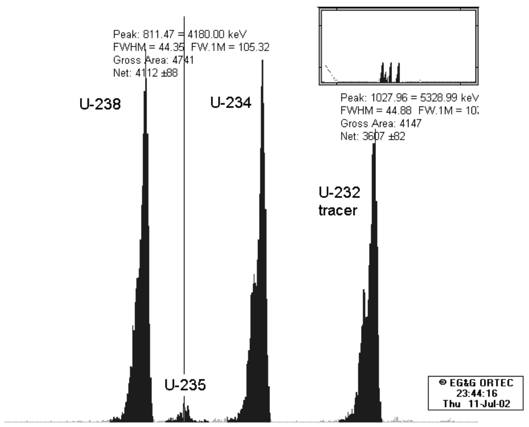

Figure 3. Alpha spectra obtained by elctroplating. One of the Eleshniza sample from the final test serie.

The activity of every uranium isotope is calculated according to the Equation 1.

$$A= (N_a.A_{tr}) / (N_{tr}.w) \quad (1)$$

where, A is activity of the analyzed isotope in Bq/kg, N_a is the number of counts in the peak of the analyzed isotop, N_{tr}.is the number of counts in the tracer peak, A_{tr} is the activity of the added tracer (^{232}U), w is the weight of the sample. When some of detectors has background counts in the peak energy regions they are subtracted.

The first tests of the procedure on real samples were done by IAEA reference materials, Table 4. The ^{235}U concentrations are not listed, but are taken into account. Soil-5 is certified for U content (3.15 +/- 0.45 µg/g), so the value (Bq/kg) for uranium isotopes in Soil-5 was calculated using data for uranium isotopes content in natural uranium.

Table 4. Results of analysis of two types of reference materials.

Sample	^{238}U Bq/kg	^{234}U Bq/kg	Total U ±2 σ Bq/kg *Recovery (%)*	Cert. Value Bq/kg
Soil-5	35.7	37.1	75.4±5.2 *(93)*	79.6+/11.4
Soil-5	35.2	36.3	71.5±5.8 *(91)*	79.6+/11.4
IAEA 135	27	26.5	54.9±2.3 *(93)*	58.3
IAEA 135	23.2	23.8	48±2.8 *(79)*	58.3

The value for uranium in IAEA 135 reference material is not certified but is information value only. Nevertheless the results are very close and accepted as satisfying.

The samples from new reference material from Eleshniza were analyzed after the material was homogenized, sieved and packed in 0.5-kg vials. From each two samples of approximately 1g of the material were taken for radiochemical separation of uranium. Both samples passed through the same radiochemical procedure of uranium separation and purification. At the final step from one alpha-source was prepared by microprecipitation and from the other by electroplating. The summarized results are presented in Table 5 and Table 6.

Table 5. Results of determination of uranium isotopes by micro co-precipitation

Micro co-precipitation	U-238 Bq/kg	U-235 Bq/kg	U-234 Bq/kg	Recovery %
Average	**2.260**	**0.113**	**2.232**	**35.3**
sd 95%	0.135	0.010	0.117	
Rsd	6.0	8.8	5.2	
sd av	0.043	0.003	0.037	
rsd av	1.9	2.8	1.7	
Min	**1.95**	**0.09**	**1.97**	**14**
Max	**2.41**	**0.126**	**2.35**	**58**
Confidence	**0.084**	**0.006**	**0.072**	

Where

Sd 95% = $\sqrt{\sum (\mathrm{Xi} - \mathrm{Xav})^2 / (\mathrm{n}-1)}$ (2)

Rsd s = 100*Sd s/Xav

Sd av = Sd s/ $\sqrt{n}$

Rsd av = 100*Sd av/Xav

Table 6. Results of determination of uranium isotopes by electroplating

Electro-plating	^{238}U Bq/kg	^{235}U Bq/kg	^{234}U Bq/kg	Recovery %
average	**2.284**	**0.114**	**2.247**	**24.5**
sd 95%	0.078	0.009	0.071	
rsd	3.4	8.0	3.2	
sd av	0.026	0.003	0.024	
rsd av	1.1	2.7	1.1	
min	**2.18**	**0.103**	**2.15**	**13.3**
max	**2.43**	**0.126**	**2.36**	**38.4**
Confidence	**0.041**	**0.006**	**0.047**	

The results in the tables above are based on 10 samples proceeded by microprecipitation and 9 by electroplating. Other five electroplated samples were taken out because were apparently spoiled during the procedure (recovery below 10%).

It was mentioned that the occurrence of natural uranium in the environment consists of the three isotopes, ^{238}U, ^{235}U and ^{234}U. ^{234}U is a decay product of the ^{238}U series and given sufficient time it approaches secular equilibrium with its parent activity. However under some circumstances secular equilibrium may not always be reached. On the other hand, ^{235}U isotope is associated with a separate decay chain (the actinium series) and it is anticipated that ^{235}U/^{238}U ratio in geological materials should provide a consistent activity ratio. It can be seen from the tables that isotopic ratios in the analyzed material corresponds within the standard deviation to the ratios of naturally occurring uranium series – 0.0466 for ^{235}U/^{238}U and about 1 for ^{234}U/^{238}U. The last ratio in our case is slightly lower than 1 that according to Larsen (2000) is observed in rocks, soils and sediments where some depletion in the ratio can occur under certain environmental conditions.

CONCLUSIONS

The developed procedure for uranium naturally occurring isotopes determination in environmental samples is producing reliable and reproducible results. The procedure gives the possibility to determine ^{238}U, ^{235}U and ^{234}U concentrations and their isotopic ratio. The procedure could be used for low activity samples with high chemical yield and in environmental samples with approximately high uranium content, where the lower yield does not affect the accuracy of uranium isotopes determination.

The new method for alpha source preparation by electrodeposition is worked up and is considered a task for further improvement.

The results obtained contributed in the process of certification of the new reference material from the region of the village of Eleshniza.

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SOME ASPECTS OF ANTHROPOGENIC ACTIVITIES OVER GROUNDWATER QUALITY

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ABSTRACT
As rule groundwater quantity and quality forming is determined by interaction of basic natural and anthropogenic factors. The anthropogenic influence appears multilateral: urbanization, industry, agriculture and others. In the Sofia kettle it is already reflected in the general organic groundwater pollution. It is expressed in the sharp raising values of the permanganate oxidation, appearance of nitrite, phosphates and ammonium, which trace the alteration into oxidizability - deoxidization parameters of the system soil-water. This alteration causes the groundwater loading with the harmful for the human being heavy metals: such as: Fe, Mn and Zn.

Urbanization poses a risk to groundwater quality in several ways, many of witch can be characterized with the next categories: Disposal of domestic and industrial waste; Disposal of sewage effluents and sewage sludge, spillages and atmospheric dust produced from some industrial enterprises.

The domestic wastes are largely biodegradable. Leachate may be produced if there is a source of water equal to or greater than about 120mm per meter of fill. If water is eliminated, domestic refuse will decompose slowly and little leachate may be produced, but if water is allowed to enter the fill a hilly polluting leachate be produced, with a strength some ten times greater than domestic sewage. The polluting potential of such leachate is greatly increased if industrial wastes are included in the refuse. Industrial wastes may include metal sludge, acids, oils, tarry wastes, phenols, pharmaceutical wastes and many other materials, of which some may be inimical to underground water quality.

The discharge of untreated and partially treated sewage into the ground can occasionally give rise to microbial and ammonia contamination in nearby abstraction wells. Usually the cause is found to be a broken pipe or leakage from sewers and cesspools. Generally, bacterial removal is remarkably effective.

The disposal of sludge from sewage treatment works is a continuing problem. Some of the sewage sludge is incinerated, disposed at landfills and the remainder spread onto farmland as useful organic fertilizer. Normally this does not constitute a serious hazard because of the bacterial removal and biodegradation of organic matter, which occurs in the top few meters of soil and unsaturated bedrock.

Run-off from housing developments may contain dirt - wash from roads, oils from spillages and leakages from domestic heating systems. Urban run - off may contain, in addition, wastes from shop and industrial yards and sewage from over-loaded or broken sewers, while run-off from industrial developments may include a wide variety of organic and toxic substances. . Stockpiles of rock salt for de-icing highways constitute another potential source of pollution. Methods of disposal may be by means of soakaways, porous pipes, or sometime boreholes.

Aquifers are also vulnerable to spillages from industrial plants, fuel storage tanks and pipelines and from the wide variety of chemicals transported by road

Although the excavation themselves do not cause pollution of underground waters the storage of fuel and other materials, spillages from fixed and mobile plant, and on-site disposal of sewage, can present a hazard to aquifers, particularly as ingress of pollutants directly to the water table can occur. However, the provision of satisfactory safeguards can minimize the risk of pollution.

In the Sofia district the anthropological influences appear multilaterally: urbanization, industry, agriculture and other. The water groundwater utilization is appointed mainly into two directions: agriculture and industry.

List of groundwater monthly observed stations:
1-s- German village
2-s - Vrajdebna district
3-s - Novi Iskar town
4-s - Levski district
5-s - Orlandovtzi district
6-s - Svetovrachane village
7-s - Chelopechane village

From all active anthropological factors on the examined the Sofia field districts brightly exhibits the influence of agricultural activities, causing general organic pollution (in particular - nitrate) of the Quaternary aquifer. As a whole, the hydrodynamic regime in the observation points during the spring months (predominately May) records general increase of the permanganate oxidizing values ($_2O_{Mn}$), appearance of nitrites, phosphates, ammonium and raised metal saturation - mainly with Fe and Mg ions and in more rare cases Zn.

In the investigated districts water material composition during the spring (strengthened agricultural activity) is predetermined by the intensive vertical seepage through soils cultivated with different sorts of fertilisers. In this respect the nitrate pollution (village German 1-point, residential district Vrajdebna 2-point and village Chelopechane 7-p), it is essential the fact that it goes into three stages:

- nitrogen migration through soil layer;
- it's movement across unsaturated zone;
- circulation into saturated zone.

During every stage specific processes perform (biological, physical, physical-chemical), which are influenced by different factors - heterogeneity of the surroundings, the layer's active porosity, the water level alterations, indexes of the conventional transfer, parameters of diffraction and others. Also over the nitrate migration very strong influence exerts the temperature. It is directly connected with the active activities of the plants and microorganisms in the soil layer, creating so called soil barrier. It could be relied on it only during the plantations` vegetation period. The increased nitrate content during the spring period leads to decrease of the oxygen concentration (increase of the permanganate oxidisation $_2O_{Mn}$) and respectively change the Eh -pH of the soil-rock system.

Analogous pattern, but more slightly expressed, is manifested during September. At the end of the summer, because of the slowed down water exchange and the duration of the processes of dissolving, exolution and ionic exchange, the general mineralization of the water increases. As a result of the autumn rainfalls, causing water level raising, groundwater again are enriched with organic substances (indigestible by the plants nitrogen), and heavy metals. Taking into account increasing mineralization and their salt composition it is recommended the use of low irrigation norms with big frequency.

In respect of their industry utilization we should take into account that the water are: mainly middle - hard and hard; with thin hard incrustation forming; semi and foam -free; corrosive, i.e. required preliminary softening.

The problems connected with usage of groundwater for irrigation and domestic water supply are due to the excessive nitrogen application by fertilizers in Sofia district. On one hand, this is due to inappropriate managed fertilization, followed by N leaching which leads to the groundwater contamination/ average at and above 50mg/l NO_3. On the other hand we should emphasize that several factors affect the accumulation in plants. The level of fertilized N applied is important, though in many cases there is no simple relationship. Other important factors include moisture conditions, amount of sunlight and even the use of herbicides. Many cases of nitrate accumulation by plants occur during drought conditions – the decline in moisture depresses the activity of the nitrate redustase enzyme. In such conditions (August – September) we usually use our NO_3 –contaminated water for irrigation. In this way we just support a high content of NO_3 in our agricultural crops. The situation is complicated because we have not established limits on the amounts of nitrate in a plant matter for some vegetables, e.g. 3g NO_3 kg^{-1} fresh weight, for lettuce and there also simple tools available for measuring the nitrate content generally indicator papers or there also simple tools available for measuring the nitrate content generally indicator papers or similar devices, and the precision's is not great.

Recently, we have no data reporting the link between the NO_3 content in our food and water and some cases of methaemoglobonemia or suggestive link between nitrate uptake and the incidence of certain cancers. But we should emphasize that in some villages around Sofia city farmers, simultaneously consuming vegetables and contaminated groundwater, are really exposed to the adverse circumstances by high NO_3 ingesting.

Methaemoglobonemia

In particular, it is now well established that nitrite is cause Methaemoglobonemia, often referred to as the blue-baby-syndrome (2). In this disease the capacity of the blood to carry oxygen is lessened, and affected people – normally infants-exhibit a slate-blue discoloration (cyanosis) of the skin, usually beginning around the lips, finger and toes, and spreading to the face and body.

In addition should be point, that the medical examinations prove the appearance of the disease connected with the combined presence of iron and nitrates in water. In the human constitution, in conditions of alkaline medium, runs the deoxidization reaction, i.e. the transition NO_3 - NO2. The released oxygen oxidizes the divalent iron - Fe_2 to Fe_3, which leads to appearance of methahemoglobin, causing muscular exhaustion and widening of the vascular system .

For example the concentration of NO_3 determined into groundwater derived from wells disposed in Sofia district (German, Svetovratchane, Vragdebna etc.) are unacceptable (above 22.6 mg/l NO_3- N). These high contents of NO_3 are mainly due to the excessive fertilizer input – NH_4NO_3, ammonium salts and organic forms such as urea $(NH_2)CO$, which are very soluble. There are also very favorable conditions for N leaching and the highest contents of NO_3 are appeared in spring and late summer. Predominantly, water from wells is used for the irrigation of vegetables, which are the part of chain water- plant- animal – human, and rarely is used as drinking water. Thus in this case (Sofia district) we have should take this fact into account because nitrate clearly harmful to human beings in an least one respect:

Another problem is appeared to be connected with the atmospheric pollution due to the different kind of industrial enterprise activities. For example the Kremicovzi steel factory, the biggest Bulgarian steel producer discharges about 44000 tons dust in the atmosphere. Heavy metals in the air emissions enter into the soil mainly by precipitation. In general soils are saturated with arsenic, manganese and lead. The maximum contents of heavy metals are closely linked to the upper soil layers and two main subsequences follow this fact.

On one hand heavy metals are toxic for soil microorganisms and reduce the plant growth and productivity.

This depends on their specific chemical forms at the time of impaction and the extent of their solubility:

- simple or complex in soil solution;
- exchangeable ions;
- link to organic substances;
- occluded or co-precipitated with oxides, carbonates and phosphates or other secondary minerals;
- ions in the crystalline lattices of the primary minerals.

The different type of chemical forms depends on temperature and pH of the soil. As pH of the soil medium is lower as heavy metals are more mobile and more available for plant activity.

Soluble forms will be free to move by diffusion and react with other soil constituents; biotic forms will be released as decomposition form. Insoluble forms will move down the soil profile and contaminate groundwater directly.

On the other hand heavy metals are potential threat for groundwater contamination. Usually groundwater pollution is noticed after the pollutants have already entered the aquifer, which is too late. Groundwater monitoring without monitoring the unsaturated zone is illogical. We should bring all relevant information about water, solutes and even gas transfer, obtained in-sito and in the laboratory. In addition it enable the determination of groundwater recharge, contaminant travel rates in the unsaturated zone and the field distribution coefficient for contaminants. Natural variability of all porous media characteristics at different depths may also be studied.

Up to now groundwater level in this concrete region varies between 7.50 - 8.25 m under surface land and concentrations of Mn in groundwater have already been higher than potable water requirements standard. The studied heavy metals in the soils are: manganese (Mn), zinc (Zn), lead (Pb), cadmium (Cd) and arsenium (As). Some of them exceed the maximum permissible levels (MPL).

The estimated soils' heavy metals contents has been provided in three villages (Gorny Bogrov, Yana and Rudnika, subsequently situated away of Kremikovzi and tracking the prevailing wind directions (East and South East). For the first two villages we have data concerning three different soil layers: depth 0-40, 40-80 and 80-120 cm and for the Rudnika depths are: 0-40 and 40-80 cm.

In general, soils are saturated with arsenic, manganese and lead. The contents of arsenic in the Gorny Bogrov and Yana villages are four - five times more than the maximum permissible levels (MPL). Only in the Rudnika the concentrations of arsenic and manganese are lower than the (MPL). Two-three times higher than MPL concentrations of manganese around Gorny Bogrov and Yana villages have been observed. The highest contents of manganese have been estimated in the Yana area in the surface layer and it decreases the depth. The contents of lead in the studied area have been measured also, noting obvious declining values with the distance from the Kremikovzi plant. In the studied regions the evaluated concentrations of Cu and Cd are less than maximum permissible levels.

In the future investigations a regular check of: groundwater recharge; the field of distribution of contaminated zone; the concentrations of heavy metals into the unsaturated zone; creation of lithological profile; establishment of pore fluid composition and of capillary pressure in constant points of a profile; laboratory study of water-solute transfer parameters will be desirable especially in spring and late autumn months when an intensive vertical flow exists. That will be a reasonable act on the basis of the complexity of the problem and all ecological difficulties in our country.

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METHODOLOGY OF DESIGNEE OF GEO-TECHNIQUE AND GEO-PROTECTIVE STRUCTURES IN THE LIGHT OF STRUCTURAL FORM-MAKING

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ABSTRACT
Developing and effective application of structures is always an outcome of creation based on accumulated experience and science knowledge. Theoretic elaboration continuously displays and creates new and higher regularity of organization and structure of material, forms and systems.
The system's methodological approach to structural creativity is displaying by deduct transition to the special structural form-making and structural detailing.
Methodology of structural form making is a new area for conventional science approach. In Bulgaria this methodology has elaborated by prof.Milcho Braynov who bring concretely illustration by steel rod structures.
The general principles can be appreciated to other kinds of structures too, including geo-technique and geo-protective. By deductive approach it reach to concretely forms and in the same time is giving an account of interaction between structures of general geo-protective system.
Objective connections between function, form and structure are examined from point of view of geo-protection and geo-technique.
It is proposed a methodology for designing of structures and complex geo-protective systems. There are cited an examples for illustration and confirmation of theoretical treatment.
Developing and effective application of structures is always a outcome of creation based on accumulated experience and science knowledge. Theoretic elaboration continuously display and create new and higher regularly of organization and structure of materials, forms and systems.
Actually methodological approach to the structural creativity is dispelling by deduct transition to the special structural form making and detailing.

INTRUDUCTION

Developing and effective application of structures is always an outcome of creation based on accumulated experience and science knowledge. Theoretic elaboration continuously displays and creates new and higher regularity of organization and structure of material, forms and systems.

The system's methodological approach to structural creativity is displaying by deduct transition to the special structural form-making and structural detailing.

Methodology of structural form making is a new area for conventional science approach. In Bulgaria this methodology has elaborated by prof.Milcho Braynov (1980) who bring concretely illustration by steel rod structures.

The general principles can be appreciated to other kinds of structures too, including geo-technique and geo-protective. By deductive approach it reach to concretely forms and in the same time is giving an account of interaction between structures of general geo-protective system.

OBJECTIVE CONNECTIONS BETWEEN PURPOSE, FORM AND STRUCTURE, FROM POINT OF VIEW OF GEO-PROTECTION AND GEO-TECHNIQUE

The different geo-protective and geo-technique structures are distant to satisfy different functions of concretely protection systems. Structures have different material forms related from his destination. Forms can be defined by functional material organization system, keeping and integrating them in the space. This is their bearing structure. Technology is transmission to real execution of the structures. Hear logic connection between destination-form-structure-technologic.

There is objective connection between function, form and structure.

Destination of the structure is to insure these form in the space that will accept and transmit all forces and actions, borne of function and external conditions. Structure is spine with highest and large.

Unity can be illustrated. Function requires places (roadbed, pavements etc.) for transporting on the time of protection works of roads, railways, bridges etc. These places are organized from point of view of his destination. They define requires of his functional-technological form.

As other structures, forms are conformed by structure requires, aesthetic, ecology and technology considerations.

Form is develops in the space and receives functional forces by the structure. The structure is relevant to the form, but it is primary directive for the form and has to respect to destination.

METHODOLOGICAL DIRECTIONS OF DESIGNING OF GEO-PROTECTIVE STRUCTURES AND SYSTEMS

Designs of structures can development on two directions.

First direction -inductive approach. This standard direction utilization many prepared elements organized to work together.

Second direction -deductive approach. By the way of structural form making to the functional considerations, levels of form making and finally structure. General exit conditions of deductive approach are forming –preliminary and especially on the base of accumulated large experience and information by inductive way.

There is a logic connection between these two approaches. Standard approached is a primary, when receive a concretely information and experience. After that it pass to the general deductive approach. By virtue of second approach elements develop and improve. Elements are preliminary structure material of the standard method. Streamline of the progress is obviously. It is a result of permanent interaction between two approaches.

Development of deductive approach as higher level of effective and resource for creativity of more complicate systems and structures is necessary. It has to display new possibilities and directions for structural creativity.

Standard direction of designee:

This is more dissipate direction in the practice now. The best his characteristic is a line to reduce calculations and detailing of more and more elements of structure and of here general static shim too. Forces are standard too.

Composition elements have four hierarchy levels:

First level-cross sections:

Universal different cross sections are worked out with their geometry and technique characteristics. It is necessary only to be selected and apply in concrete case.

These sections are worked out for the anchor's cable and fittings, for the reinforcement of pilots and other concrete structure, sections of tubes 9sleel, plastic, concrete), artificial blocks for board- protection, geo-synthetic materials, etc.

Second level - structure elements and zones.

The question is about three-dimensional elements, with all their limits of bearing capacity. For examples: breakwater blocks, a large past of steel passive anchors, support for tunnels, etc.

Third level - kinds of structure shims. Type designs of structures are developing for consideration diapason of measures, forces and destinations. It can develop structural composition on this base.

For examples: dowel piles or groove wall, forced by sliding. Complex anchor structure (passive or reinforcement is a brightly example. There is a high level of type –structure in area of board-protection systems.

Fourth level – structural compositions.

Talking about catalog of complexly structural compositions. When there is a catalogue, designing convert to creative process of composition and construction convert to complex montage activity.

Generally fourth level is not attain in construction, including geo-protection and geo-technique.

Matura is natural process for the designer. When he has accumulated experience enough, information and theoretical knowledge from the work on standard shim, coming a moment of become aware of many general relations, result of general view to the structural problems. This is the way to higher quality level, where become deductive approaches of structural form making and form detailing.

Design is suitable for automation on the four levels and it has attained yet with high quality. Naturally, automation is the faster developed in high-industrialized countries, where decisions of structure problems have very large practice.

Level of automation follows above hierarchy order but in reverse direction. The higher automation is activity on fist and second level, on a smaller scale on thirty, but with many picks yet. The poorly developed is the higher forth level.

Level of automated and unification design and construction of geo-technique and geo-protection projects is on a low level in comparison with superior structures (building, brigs, towers, etc.). The reason is the great diversity of terrain and geological conditions and of streamline to correspond with ecological principia of minimum actions in to natural process. Underground construction cycle as the protection keeps his character of small and labor-consuming stage. Way of automation and unification design and construction by inductive approach give home intellects a time and possibilities to decision of high level questions.

Wrote above doesn't neglect many unique structures, borne by catalog-standard approach. The great number standard cross-sections and structure elements don't limit creative process of unique decisions.

Direction of activity and thinking way of the deductive approach is exactly opposed to above approach. It is following a logic line of structural form making. It is starting from general ideas and considerations and step by step it is walking to detailing.

STRUCTURAL FORMS MAKING -BASIC DIRECTION OF ELABORATE A METHOD FOR DESIGNING OF GEO-PROTECTION AND SUPPORT STRUCTURES

Methodic structure can be show on three levels:

I level – to basic structure forms:

- Initial function -technological forms.

These can be different type structures: anchors, dowels, contra-forces, brigs.

- Initial cross sections, type of material, loading capacity, general static schemas:

The cross can be box, circle, ellipse, rectangular, double-T.

Construction materials are concrete, reinforced concrete, steel, stones, geo-synthetics, wood etc.

II level - to final structure forms-flat and space structures.

III level - to entire volume –space structure systems.

Structural form making represents deductive way, starting from preliminary structure forms, conforming with purpose to finally decision for all system.

Finally form of structures will be definite by multiple cycle: function-technological form - initial structural forms - structural cross section - basic structural form - finally structure form.

The process is multiple because it is interactive, multi-factorial. Discover of the decision is a creative process, first of all. Accumulation of great personal experience, as information enough and theoretic knowledge out cycle and make easier the work for definition of finally form.

Structural cross sections with defined kinds material and form receive, stand forces M, Q, N by their reinforcing and deforming condition.

All ordered characteristics of structural cross sections have dynamic connections between them, because all of them are developing continuously. For example, section's, forces change himself continuously in reaccept with increasing of external forces. The development of people lead to increasing of functional forces, those structures have to stand. Weight of vehicles over transport structures is increasing, floors-number of buildings increasing too etc. By this way it is boring a necessary of higher loading capacity of sections, improving of materials etc. Such a way from initial circle section to double-T, box etc.

Other approach for increase of loading capacity is increase of section's high.

Direction of structural forms is developing to these, which work by N only, without M, from solid-walled to lattice structures. Tendency is objective and if reflect way of technical progress to more simple but more effectively static schemas, covered in improving structure forms.

World experience of landslide protection shows the same indications. Flexible one-dimensional anchor protection structures (working by N-forces only) dominant in the best-industrialized countries. Reinforced concrete structures go on from circle full pilots dowel to large-dimensional, that are obviously higher effectively under bigger loads.

Physique-mechanic characteristics of geo-synthetic have unsteady evolution, categorically, the new raw material PEHD is dominating.

When structure's element forms are determining, there is a contradiction between considerations for minimum expense of material on side and expense of labor and energy on other side. This thesis has a good illustration by more complicated structures (anchors, piles and shafts). Their expense of labor is principally more and changes reflect brittle on the time and the price of execution.

Minimum expense of labor and energy consider maximum typical elements, which lead to over dimensioning and over expenditure of material insertion level.

In this case optimization has a high level of indetermination, but it is normal for geo-protect structures, to prefer economy of labor and energy, respectively time, to answer the consideration of emergency and all spectra of undetermined external loads. In the spirit of snowed method it has be display the principia of effectively geo-technique and geo-protective structures, of their economic and reliability. So will create completed initial impression about methodological direction.

PRINCIPIA OF EFFECTIVENESS OF STRUCTURE

The principle for effectiveness of structure is following:

- Concentration of materials
- Parallel execution of more destinations.
- Translating of loads on the shortest way to the basic.
- Maximum exploitation of material load capacity

By concentration of material bigger loads are standing by smaller number elements. So load capacity of presstreced anchors attained 1500kN, shafts and groove wall change the pilots under the biggest loads, support-walls and other flat elements, generally, rice to thin-walled but ribbed etc.

Execution of more of one destination is a characteristic of geo-technique and geo protection structures. Their infrastructure character is a primer condition. Their destination for protection is other premise, to be loaded by horizontal, forces, generally. Their grad load capacity on vertical direction stay without exploitation. There are brightly examples for rational multifunctional and celebrate decisions. That is Monte Carlo's Casino, constructed on protected structure of great landslide on see board. There are similar ideas in Bulgaria to utilize flat on the piles that support Kabacum.

According to the standard has a possibility well based buildings to receive and horizontal load from landslides-reverse process.

All coast-protection shown dam on the See have concrete pavements over the crown. That has transport function. There is a send behind for artificial beach. Buildings and installations have constructed on other places of dams. Many ruble groins are ports in the same time. There are many cases of rood and railway protection, where great rectangle wool based by piles stand horizontal forces from sliding and load of vehicles and superstructure.

Geo-technique and geo-protect structures in quality of infrastructure principally transfer load to the art basic directly, on the shortest way.

The problem of maximum exploitation load capacity is permanent for engineers. Higher levels of indefinite of soil characteristics, included in calculations create some complications. Tanks of intensive development of Soil Mechanic, of accumulation of long order hydrologic meteorology information, of rapid technological development in the world, methods for static calculations and dimensioning are carried out to correspondence with these, about superior structures.

There is not exclude in Bulgaria in this direction.

Executable economy of decisions for building transport and hydraulic structures is creating by the Methods of limit conditions and Method of admissible tensions.

ECONOMY AND RELIABILITY OF DESIGNED OF GEO-TECHNICAL AND GEO-PROTECTIVE STRUCTURES

Optimal economy, raise security and reliability are two general considerations of structural designing.

Optimal designing is subordinate to logic, as to the structural form making, as to investment process, including planning-investigation-design-construction-exploitation. This logic calls interaction parts of the project (analyses about destination, calculation, technology and exploitation).

Criteria about optimal structure are different as following - *qualitative* (functional, durability, maintainability and reliability, aesthetic) and *quantitative* (expense of materials, labor and energy, time). It has to look for maximum about quality and minimum about quantitative.

Approaches and principia of optimum economy and rice security and reliability of geo-technical and geo-protective structures and systems are subordinated of approach to structural form making.

Analyze can be settled by adducing of these principia to concrete task.

Showed methodological approach is one of first steps to general analyzing of structural creative in area of geo-protective and geo-technical activity. First his task is to reduce principia to specific aims. Obviously, there are shades, borne of connection between geo-protection and nature, of natural sensitive to humane intervention in processes, as of unique relief and geological morphology.

Conclusions from methodical analyze are adducing to followed:

- Design and construction of geo-protective and geo-technical structures and systems are quite writing in the principia of structural form making.
- There is experience, information and theoretic knowledge enough, to go on from inductive to deductive approach in this area and to look for more new general system's relations, new strictures, their elements and cross sections.
- The process of increasing of exploitation loads and derivative of them section forces, of section height and strengthening of materials is valid.
- The new materials, structures and technologies, borne of technical progress provoke need of developing of great level of creative- the structural composition.
- Principia of structure effective, of economy and reliability can be serve for create and improve of methods related comparison, valuations and analyses of projects and structures.

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GEOTECHNICAL PROBLEMS OF THE CULTURAL HERITAGE MONUMENTS IN BULGARIA

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ABSTRACT
Located in a region with favourable geographically and climatically conditions Bulgaria has a rich historical and cultural heritage main part of which are its cultural monuments. As far as these monuments are situated in certain geological structures and are submitted to natural destructive geological and anthropogenic processes the question of their survival is closely related to the management of the hazardous geological phenomena. Unfortunately the geotechnical conditions at the sites of the most important cultural monuments are infavourable. The changes in their environment visibly accelerate the distructive effects on them. The most endangered monuments and sites are those of the Madara Horse-man rock bas-relief, the Ivanovo rock churches, the Stambolov Bridge and the "St. 40 Martyrs" Church in Veliko Tarnovo, the Rila and the Preobrajenie Monasteries. In certain degrees these monuments are harmed and for some of them the destruction processes are irreversible. Although most of the causes for that are clarified and technical solutions for management exist till now very few was done for the preservation of this unique cultural heritage. In such no intervention conditions a great part of them will be lost in the near future.

One of the most endangered monuments is the Madara horseman bas-relief. It is carved in the limy sandstones of the western cliff of the Madara plateau. (fig. 1). Its existence is effected by the geological processes related to the natural development of the cliff and to its surface weathering.

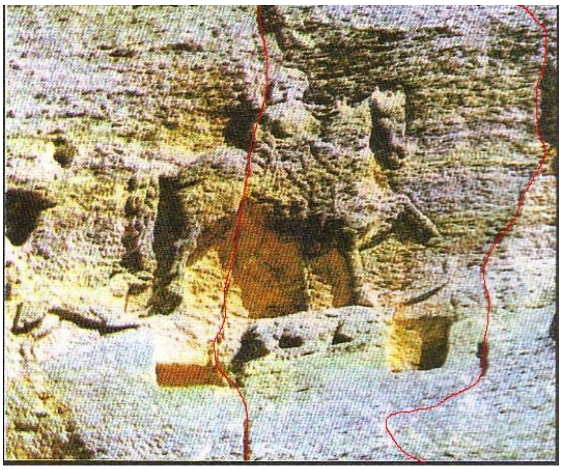

Figure 1. View from the Madara horseman and the contours of the rock block.

The cliff development is determined by Smyadovo fault structure along which the plateau was elevated. In the upper section of the cliff were revealed three parallel joints systems. During the engineering geological site study it came out that the rock cliff traveled for 60 m east for a period of 6 million years. The composition of the deluvial deposits from the cliff base revealed that the major factor for the development (destruction) of the cliff zones of the Madara Plateau were the seismic and the gravitation processes. The destruction mechanism consisted of three stages: weathering jointing of the surface zone and shaping of separate blocks in the cliff; acceleration or the process due to creep movements in the bedrocks due to the inverse geologic structure – plastic base (marls), overlaied by fragile rocks (sandstones); separate blocks demolition after earthquakes in the region. This process is proved by the big blocks floating in the deluvial deposits from the cliff toe.

The level of the cliff bearing the bas-relief had finished its second stage of development. A vertical fracture that crosses the bas-relief joins a neighbour one located at 1 m south. The two fractures completely separate a block in the massif that being interlocked with the adjacent blocks is actually stable (fig. 2). The stability calculations reveal that a strong earthquake could loosen the block ant it would fall out with a significant portion of the bas-relief. The estimated total stabilizing horizontal force is about 2300 kN. The technical solution is the anchoring the rock block.

Another significant problem is the biologic degrading of the rock due to micro-organisms decomposing the surface layer of the cliff. The process is quite vigorous and if not stopped in the following 1-2 decades all other interventions will be senseless. Our studies revealed that the microflora and microfauna populations are developed due to the changes in the humidity regime of the air and the rock respectively. During the geophysical electrical surveys it occurred that the resistivity of the lower quarter of the cliff is several times lower of those from the other levels of the cliff. The change of the environmental equilibrium after artificial foresting the toe of the plateau at the 30-ies of the last century was estimated to be the major cause for that.

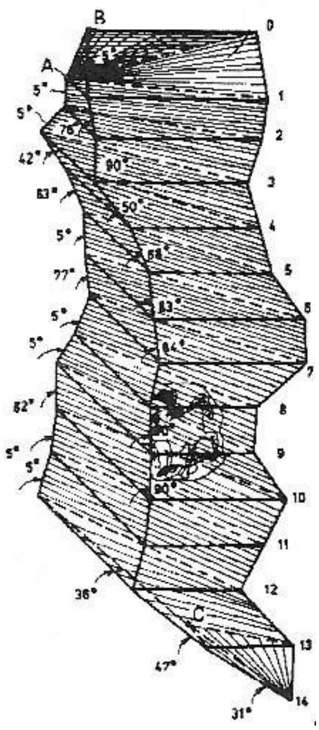

Figure 2. 3D model of the rock block bearing the Madara horseman

In general the geotechnical conditions of the site of the monuments are very well studied: the geological structure, the physical and the mechanical properties of the rock, the cliff block structure were established; monitoring of the interblocks movements is carried out; seismic microzoning of the site with static and dynamic stability calculations were carried out; the degradation has been continuously studied.

Considerable similar problems exist at the site of the Ivanovo rock churches. The religious complex was carved in the limestone cliff of the Canyon of Cherni Lom River. The rock Monasteries (churches) are located in additionally enlarged and shaped karstic caves. With the time blocks falling has occurred from the ceilings and the walls. In most of the churches the processes are irreversible. Real possibilities exist to preserve the tourist site “The Church” only if appropriate enforcing intervention is realized. The studies revealed the seismic and gravitation character of the development of the massif – strong earthquake induces rock blocks falling down. Practically this means that for long time periods there should not be disturbing movements while during an earthquake a massive block fall is expected.

The study of the Ivanovo Monasteries is in their initial stages although the first fragmentary studies were carried out 30 years ago. The detailed investigations of the site in the spring of 2002 supplied valuable data for the joints systems, the dimensions of the rock blocks from the cliff, some initial data for the physical and mechanical properties of the rock and the hydrogeological conditions (fig. 2). The necessary continuation of the studies should be spotted on the strength of the massif, the seismic microzoning, the modeling of the static and dynamic stability of the cliff.

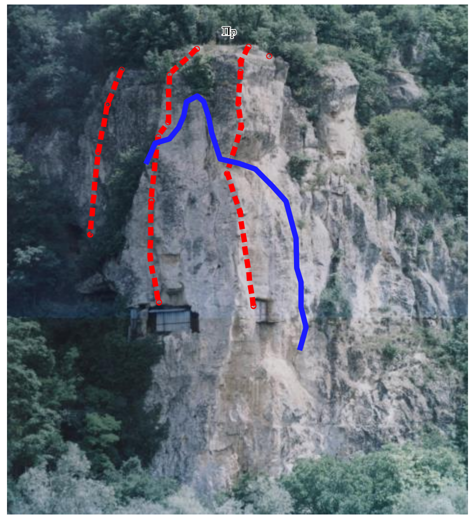

Figure 3. View to Ivanovo rock church and the contours of the external block and survey profiles.

The site of the Preobrajenie Monastery complex including the “The Assu” Church as a cultural monument famous with its frescoes named “The Circle of Life” and the bell-tower built-up by the famous Bulgarian constrictor Koljo Ficheto also is exposed to complicated geotechnical conditions. The Monastery was established in the XIV[th] century. It was located north of Veliko Tarnovo on a deluvial plane level at the toe of a picturesque 120 m high limestones cliff of the canyon the Yantra River. The Monastery was partially destroyed after the falling of rock block during the Gornooryahovo earthquake in 1913. In 1974 a landslide developed in the deluvial slope completely destroyed the eastern wing of the complex and directly endangered the Church. In consequence the landslide was reinforced by back ties and drainage gallery. In 1991 as a consequence of intensive rainfalls a 300 m^3 rock-fall occurred from the cliff and completely destroyed the western wings of the Monastery. No casualties occurred by chance. The chance preserved the Church when the rock flow was divided to two by a tree and run beside its sides (fig. 4).

The geotechnical problems of the Preobrajenie Monastery are very well studied. All practical aspects are embraced: strength of the massif, seismic microzoning, static and dynamic stability of the cliff including with FEM, prognosis for the cliff development was stated. On the base of variants studies a project for cliff reinforcement was designed. Regardless of the fact that at certain moment the financing was secured the project was not realized.

The geotechnical problems of the Stambolov bridge in Veliko Tarnovo are related to the stability of a rock slope. The bridge conects the central part of the town with “Sveta Gora” hill. It was built in 1922 and presents a metal arch structure fixed by two bearings at both practically vertical Yantra River banks. Survey investigations revealed some displacement of the left foundations of the bridge where visibly the road was settled and the stone masonry confining the left flank embankment partially collapsed. The river terrace at the site is an erosional type. The height of the bank ranges between 25-28 m. The slope consists of limestones, rated by their uniaxial strength as “very strong”. The subsurface zone of the slope is fractured due to neotectonic and contemporary tectonic movements, weathering and technical activities. At the area of the left foundation the joints are with unfavourable orientations towards the abutment reactions. Separate fault lines were revealed with the boreholes drilling. Their width was in the range of 0.1-0.6 m and they were marked by brecciaed zones in the limestones and fill of dark grey tectonic clay. The values of the abutment reactions related to the deformation properties of the fracture rock cliff suppose that displacements in the bridge are quite likely. In the case of a strong earthquake from the Gorno Oryahovo focus zone they could go beyond the critical values. The technical solution of the problem is anchoring the slope in the area of the abutments where the anchors will play a double role: hardening of the rock foundation to the depth of the active zone and preventing movements of loaded joint pyramids with critical dimensions.

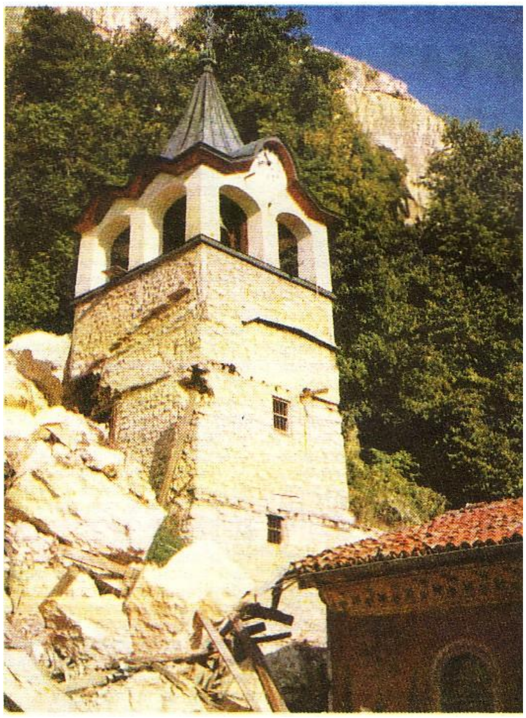

Figure 4. View to Preobrajenie Monastery bell-tower after the rock-fall in 1991

Another cultural heritage monument in region – the "St. 40 Martyrs" Church – suffers different kind of problems. The church and the ossuary are located at the foot of "Tzarevetz" hill on the low bank of Yantra River. The church foundations are in deluvial soils (sandy clays) lying over a bedrock of marls. The building is systematically inundated. The recent investigations revealed to a great extend the engineering geological and hydrogeological conditions of the site. It became clear that the inundations are related to high groundwater in the slope deposits caused by high river levels. To protect the monument a grout curtain was recommended but still not designed. The irresponsible attitude towards the monument was revealed with the last natural disaster at its site in January 2003. A massive leak from a destructed water-supply pipe caused a destruction of the ashlar retaining wall above the church and the stone and backfill materials endangered the metal scaffolding bearing the structural columns in the church.

Quite serious are the geotechnical problems at the Rila Monastery site. The present monastery complex is built up on quaternary deposits presented by gravels and boulders with sandy filling interlayered by plastic clays up to 3.0-3.5 m thick. The total thickness of the quaternary deposits is ranging to 16-45 m with free groundwater level is 5-9 m deep. The monastery buildings are with shallow foundations – 3.0-3.5 m deep. The inside area of the complex was filled up with up to 9 thick embankment (cultural layer). From engineering geological point of view the site is very well studied. Seismic microzoning was carried out. The present state of the buildings is bad and at some sections is critical. The revealed structural failures include fracturing along bearing walls, around windows and below the top mouldings. Most damaged is the eastern edge of the south wing where the building is with maximum height (28 m). Fractures occur in the central and western sections the south wing, less fractured is the eastern wing. The monitoring of the fixed marks reveals movements along the fractures.

The geotechnical conditions of the site are complicated by the high level of realized and the expected earthquakes in the region. According to the Paraseismic Regulations the expected seismic activity for a 1000 year period is of 9° MSK. The maximum realized seismic activity is of 9° MSK.

Three initial hypotheses for the destructing factors were tested: overall failure of the stability of the terrain; suffusion settlements of the terrain; local and total failure of the bearing capacity of the soil (fig. 5).

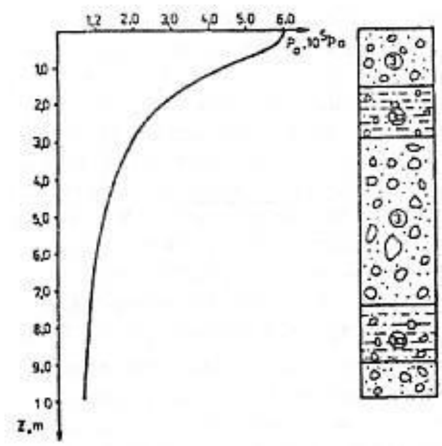

Figure 5. Stress distribution under the south wing foundations and the geological structure of the soil base (3 – alluvial gravel and boulders with sandy filling, 3a – soft and plastic alluvial clays)

The calculations results rejected the first two of them. The comparison between the foundations loading and the soil bearing capacity revealed that they are very close in range while the foundation loading is higher that the dynamic bearing capacity of the soil. So it was accepted that structural failures are consequent to a local stability failure of the soils probably initiated from the Krupnik earthquake in 1904. Further they continued due to creep processes in the soft clay interlayers. In 1934 the construction of abutments at the eastern and southern walls probably stabilized the structure. During the 60-ies parts of them were demolished and that caused new activation of the movements. Before any action for reinforcement of the monastery buildings it is necessary to decrease the loads on the soils. The possible technical solutions include widening of the foundation and/or meliorating their bearing capacity by micro-piles.

The conclusion from the present review is that the unique cultural heritage monuments in Bulgaria are endangered by unfavourable geological processes some of them being in critical situations. Although the conditions and the trigger factors of the destructive processes are well studied and for son of the monuments technical solutions for reinforcement exist practically no action for their execution is realized. The main reason is no much the financial shortage as the lack of geotechnical competence of the decision taking authorities which results in refusing to take any responsibility while their inaction dooms the future existence of the monuments.

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PROBLEMS AND PERSPECTIVES FOR THE ENGINEERING GEOLOGY IN BILGARIA

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ABSTRACT
Bulgaria is a country with high levels of geological hazard on it territory which is related to the predominance of various and mainly complex engineering geological conditions on its territory. With the acceptance of the Law for Regulation of Territory the engineering geological investigations were established as an obligatory stage for compiling the regulation plans and the engineering geological reports were constituted as an irrevocable part of the constructions design. The strategic objectives of the engineering geology at the present state are the compilation of engineering geological map of the country in scale 1:25000, regional digital models of the geological hazard, monitoring of dangerous geological processes, engineering geological background for seismic microzoning. Major problem of the engineering geology in Bulgaria is the lack of consolidated state policy and of a unique administrative body that should coordinate and control the engineering geological activities mainly on regional and national levels. The presence of still highly qualified professionals and reasonable administrative decisions will highly contribute to the realization of a series of actions related to prognostication and management of the geological hazards. This will reflect in a considerable and long-lasting financial and economic effect.

The engineering geology is a science with in Bulgaria. The process of construction of the national infrastructure was realized in highly varied and complicated geological conditions of the territory was inconceivable without the engineering geological studies. In this field worked eminent specialists as R. Beregov, D. Yaranov, B. Kamenov, A. Demirev. The accumulated experience, unfortunately not always successful, contributed to the creation of highly qualified professionals. One of the most considerable national achievements of the engineering geology for the period were the elaboration of engineering geological map is scale 1:500000, the extended prospections for hydrotechnical constructions, for the Dobrubja coal basin, the investigation of the large landslides along the Black Sea coast and the Danube river bank, the ambitious "Asparokh val" project, the Kozlodui and Belene nuclear power stations sites, the exploration and exploitation of Maritza coal basin.

With the close down of the Committee of Geology the state completely retired from its tender engagements towards the geological science and practice, that was a serious impact on the Bulgarian geology. That was not as painful for the engineering geology as till that moment its activities were not such centralized. After numerous re-organizations during the planned economy period the management of the engineering geological activities was quite chaotic. Different structures established in different ministries worked with no co-ordination between them. The scientific work was concentrated in the Geological Institute of BASc., the department of Hydrogeology and Engineering Geology in the UMG and the present department of Geotechnics in the UACG. The practical activities were carried out by the geological departments of the state specialized departmental project and design companies as "Energoproject", "Vodokanalproject", "Vodproject", "Zavodproject", "Minproject", "Patproject" etc. The protection of the territories was governed by the regional anti-sliding directions in Varna, Pleven and Pernik, which further were unified in the National Works for Drive against Landslides and Abrasion under the direct management of the Committee for Territorial, Town and Villages Planning. Occasionally some typically engineering geological projects were transferred to the Committee of Geology, for example the studies of the impacts of the Strajitza earthquakes. The major regulative documents as "Rules for Plane Foundations" and other parts of the Bulgarian State Standards were elaborated in the National Institute of Civil engineering. The Major Prices Administration and the Ministry of the Finances issued costs regulations documents. The scientific departments of the different state departmental project and design companies compiled and constantly re-edited manuals, branch regulations etc. The engineering geological information was available in geo-stocks of the state companies and in the State Stock but often the field campaigns were doubled due to the extensive character of the economy.

The training of the professionals was realized by the UMG (for engineering degree) and from BASc (for doctorial degree) with the help of skilled and highly qualified scientists. The acquisition of a minimal practical experience during student education was realized during practical teaching at equipped educational sites and during the obligatory individual practical training in appropriate companies. The submitted at the end of the education Diploma Reports were elaborated on important projects with large amount of initial data.

Despite of the chaotic management and the scarce communications the engineering geological body to great extend succeeded to act in collaboration in organizing conferences, seminars, qualification courses. The scientific and the applied information were effectively disseminated. The Centre for Earth Sciences of BASc issued the thematic series "Engineering Geology and Hydrogeology" that was umpired from the most competent foreign editions. Periodical issues were compiled form the greatest training companies as well. All scientific materials were published in considerable prints. Extremely rich information was acquitted from available Russian literature as well other foreign editions.

During the transition period these small achievements were destroyed and new did not happen. The major, in continuous, problem is the lack of executive state authority that will plan, finance, control and approve all engineering geological activities. Such kinds of authorities are established in all states suffering the impacts of hazardous geological processes. Both in the past and in now-a-days it is not realizes that the dangerous geological processes are defined by regional geological factors, they affect simultaneously great territories and for their management are necessary management decisions of national state level.

Actually the management and the financing of the engineering geological activities are even more decentralized. The scientific work is planned and reported in the Geological Institute of BASc. Recently with similar matter was engaged the Institute of Water Problems of BASc. The planning and a part of the protectional activities in the populated areas are managed by the Ministry of Regional Development and Public Works with finance support from its own budget and the Permanent Commission for Disaster Prevention. Landslides along the roads are from the competence of the Executive road Agency. The Ministry of the Environment and Water finances several regional projects on engineering geological monitoring. The engineering geological prospections of granulates quarries are approved by the Ministry of the and Communications Permanent Commission for Disaster Prevention finances the reclamation after disastrous events either directly or through the local authorities. The dangerous processes along the rail-ways is supported and approved by the Ministry of Transport and Communications. The Ministry of the Energy and Energy Recources is dealing with the engineering geological problems in the coal mines and the energetic system sites.

The control on the engineering geological activities, when available, is practiced in different manners. The financed from the Ministry of Regional Development and Public Works projects are subjected to investor's supervision realized by "Geogard" companies or from other independent supervisors. The financed from the Ministry of the and Communications projects are submitted to its High Expert Council. The financing from the Permanent Commission for Disaster Prevention is rendered in and Communications Councils for Territorial Planning where the participation of engineering geologists or geotechnitians is a matter of good will. These Councils approve the designs of geo-protective structures. The assumption of implicit consent is practiced where the invited professional, no matter if he attended the Council meeting, in 14 days does not present a written statement on the he is considered to accept the concerned project. The practice in other ministries is quit similar.

A considerable part of the engineering geological activities is financed by companies or private persons. Such are 100 % of the engineering geological investigations for civil structures. Most of these investors seek a minimum cost of the campaign that is decisively reflecting on its quality and on the costly constructions.

The absence of centralization caused important and irreversible losses. Practically all huge information stocks of held in different state companies and structures were destroyed. There is no state concept for decreasing the geologic hazard in the country. The "Geogard" services are registered as "commercial" companies with insufficient staff and limited state financial support which makes them to deal with alien commercial activities. The declared in the technical regulations engineering geological background of urban territories necessary for the initial study and final designs for certain engineering structures is still not elaborated. The impossibility of centralized informational services results in direct and mediate financial losses for the state. The authors are acquainted of tens of cases of failed investment projects due to lack of preliminary information for the unfavourable geotechnical conditions. At least three of the cases were related to major foreign investors.

Serious problems, as in many other fields, are regarded to the trained professionals. Although the engineering geology as a closely related to civil constructions branch is not in direct financial dependence from the state the average age of its professionals is getting higher. It is difficult for young people to get in the area due to numerous causes. The major one is that the university degree is not sufficient. Couples of years of practice are a must. In the past that was provided from the state. Great part of the present acting specialists was trained on the "probe-error" principle which actually no investor shall welcome. Being a sore subject it should be admitted that the educational quality reveals a significant dropdown. The problems arise with the decreased criteria in the secondary schools, the low social prestige of the geological studies (not only in the Bulgarian syndrome), inadequate payment in the educational spheres, lack of motivation, low computer skills and linguistic training (especially in Russian language regarding the available sources), practically inaccessible western editions, lack of educational textbooks. It is very indicative that with labour agreement (in the structure of BASc) are only two engineering geologists with higher degree of habilitation. In the UMG, the unique school for training specialists with bachelor's and master's degree in engineering geology there is no lecturer with higher degree of habilitation. In UACG there are no habilitated lecturers in engineering geology.

The body of engineering geology in Bulgaria is trying to react against the chaos in the state management. In 2000 was established the Bulgarian National Association of Engineering Geology and Hydrogeology with mail targets to ameliorate the activities in the field and to protect the interests of the engineering geologists and the hydrogeologists.

What is the future of the Bulgarian engineering geology? Two scenarios are possible. The pessimistic one supposes actual physical liquidation of the engineering geology and in the near future its activities should be carried out by foreign companies and consultants.

The optimistic scenario is possible if only the state recuperates its functions in the field of geology and namely of the engineering geology. Its high time to be realized that the natural hazard is related exclusively to the dangerous geological processes (earthquakes, landslides, rock falls, mud streams). These are in essence geological processes, triggered by regional geological factors and affecting large territories. In these terms their study, prognostication and management must be organized at regional levels that is not in the capacities of the small and medium commercial subjects.

In practical aspect it is of primary necessity to create a National Council (National Geological Service) with the task of strategic planning of the geological (engineering geological) activities and of a Executive State Body (Executive Agency) with the task of managing and control on the geo-protective (in particular the engineering geological) activities. The main targets of the last should be: elaboration of rules and regulations, creation of data base for the engineering geological conditions (geologic hazards) in the country in a reasonable for the territory planning and information services of the authorities scale; development of long-term strategy and assignment of tasks in the field of the scientific and methodological developments; assessments of the relevance, the volume and the content of the engineering geological activities with state financing, control and approval of their results, including those evolved Law for Regulation of Territory; consulting of corporations and private persons on the activities they are financing separately; support of the professional education and post-educational qualifications; issuing of a periodical for the innovations in the geotechnical field.

The most urgent tasks to be worked on are: compilation of a legend for the existing engineering geological map of the country in scale 1:25000 relevant to the contemporary concepts for the natural hazard, the principle of analysis, synonymity and openness; collection, evaluation and systematization of still not destroyed engineering geological information on the base of 1:25000 scale; conducting an mapping campaign in the regions with no sufficient or reliable information on their engineering geological conditions.

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IMPACT MONITORING OF MINING ENTERPRISES IN BULGARIA PORTION OF THE NATIONAL SYSTEM FOR ENVIRONMENTAL MONITORING

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ABSTRACT
Changes that recently took place in the mining sector and originating environmental issues are discussed in the paper. Changes in the strategy of development of the national system for environmental monitoring are observed. In this connection the approach for constituting local monitoring systems and points for the needs of the mining sector is systematized. General and specific requirements for the constitution of those systems are developed as a portion of the national system.

INTRODUCTION

Issues related to protection of environment and sustainable development of each country, biospheric region or sector might be decided only on the background of data, sufficient in scope and reliability. Furthermore, knowing both the natural background contents, which is a natural fact and the impact of anthropogenic activity is equally important. In this connection, the establishment of an effective system for monitoring, combined to the collection and distribution of data about environment is the only correct approach for the formation of a correct environmental policy, which does not admit exceeding the threshold of tolerance, i.e. the threshold abilities of nature to rehabilitate and restored itself.

Difficulty of the task is evident in scientific and economic aspect, as far as the environmental monitoring is defined as a system of repeating observations according to a certain schedule aiming a certain purpose on one ore several components of the environment.

Uniqueness of ecological systems, integration of sites of nature and industry and trans-boundary effect do not admit a standardization of decisions. Specific research developments are required for each specific case. Especially, the specifics of background content, partial presence or complete absence of certain components and characteristics of antropogenesis for specific sectors, technologies etc. need to be studied.

NEW CONDITIONS AND REQUIREMENTS FOR THE NATIONAL SYSTEM OF ENVIRONMENTAL MONITORING

For the last years Bulgaria has been experiencing a period of significant economical and social difficulties, revealed in reduction of production and unemployment. Power cost is in a period of reformation, which does not encourage production and use of low quality coal. New enterprises are being opened, mainly in nutrition industry with low power consumption, which involves environmental difficulties. Closure of enterprises of proven environmental inadvisability meets an opposition because of the high rate of unemployment.

After the year 1990 there is a significant reduction in ferrous and non-ferrous metallurgy, machine building, electrical engineering, transport and transport vehicles, chemical industry and ore mining, end consumption and ore mining. End consumption of electric power in the sectors of industry is at a level of 65,5% compared to 1990, and nearly 50 % of this is in the industry. That view brought to significant reduction of contamination, except for energy, where the portion of thermal power plants is 58,2%. In the meantime, we witness a very sensitive attitude of society for environmental issues.

In that connection the following environmental programs are being developed and introduced into practice a program for monitoring (environmental audits 1995 – 1997 of operating large enterprises, contaminating the environment; governmental program for stage-by stage reduction of ozone destroying agents (with the financial support of CEF); National Program for limiting the emissions of sulfuric oxides, National Program for chemical safety; National Program for waste management; Program for management the Black sea on-shore zone; Program for step-by-step re-categorizing the major river valleys and projects for management of waters along the valleys of rivers in South Bulgaria; Integral National Program "Environment and Health", Program for preservation of the biological variety of Bulgaria, Program for implementation of projects related to the inter-regional program for environmental protection in the valley of the Danube river etc.

The work on the National Analytical System for environmental monitoring (ACEM), basis for environmental management, has been carrying on for more than 10 years. The system involves a combination of background and impact monitoring, i.e. monitoring of reactions of main components of biosphere and factors of sources of contamination. The idea for its constitution is based in the general principles of reliability, unity, compatibility, efficiency and development. The ACEM maintains relations with all the European information systems and programs as CORINE-AIR, CORINE-LAND

COVER and the International Program for protection of nature in the valley of the Danube River.

Hierarchically the system is constructed in three levels: I-level – Central dispatchinng point; II level- Regional points and III level – Network for observation, assessment and control.

Depending on the rate of human participation the system is automated or non-automated in the specific subsystems and it aims the following goals:

- To implement regular observations on the condition and changes of environment;
- To accumulate and process data;
- To provide information for operative monitoring;
- To predict the impact and provide alternative decisions for optimization;
- To reason the environmental advisability of development of different activities;
- To automate processes of registration, transmission and processing of information.

Tasks and principles for construction of the system involve requirements towards the technical means. Before the year of 1992 within the system of the Ministry of environment there were only laboratories of the classical type – for routine analyses, which were carried out manually. Since the beginning of the 1992, according to an agreement with the European Union, an implementation of PHARE program started for delivery of new equipment for laboratory analyses, of automated mobile and stationary stations.

Apparatuses, which are suitable for initial monitoring of "shot" contamination: pH-meters, oxygen-meters, conductivity-meters; DV-VI spectrometers, samplers etc. for heavy metals were delivered as well as AAS, ICP, chromatographs, gaseous, liquid, ions, gas-chromatographs, mass detectors, segment analyzers for water – automated, with a capacity of 140 samples per hour, automated and robotized analyzer for BPK/HPK for 50 samples for hour. The laboratories are equipped with the most modern micro-processors. Modern biological laboratories for biological and micro-biological monitoring are created for the first time.

Emission mobile laboratories provide an opportunity for complete monitoring of emissions of air through the truck mounted laboratories.

It may be mentioned that ACEM has availability of the most modern equipment for observation, monitoring and control of the quality of environment, which is comparable to the most recent world manufactures. That allows the participation of the country into large regional international programs and investigations. The system supports the formation of correct policy of the country in the aspect of nature protection.

ALTERNATIVE OF ENVIRONMENTAL MONITORING IN THE MINING SECTOR

Within the above setting of the construction of ACEM, the only reasonable alternative for environmental monitoring of mining enterprises in the country is their construction as a part of the whole, observing the general national principles. Thus a bilateral exchange of information will be carried out and especially objective assessment of real condition will be performed for trans-boundary contamination etc. An opportunity for using the data basis of long-term meteorological observations is established, use of data about forest and biospherical components. Those data are especially useful for predicting the anthropogenesis and reasoning the environmental advisability of development of natural systems.

The analysis, prepared from a point of view of metrological provision of data about local monitoring points at mining enterprises, brings to the following recommendations:

- Selection of the most appropriate mode for monitoring should be complied to sources and type of contaminants, with their quantitative characteristic, availability of biospheric components, loading of the background with contaminants; manageability of factors and other specific peculiarities. Number and density of points for observation, mode of operation – discontinuous, continuous, with periodical sampling.
- Important aspect of the stage of preparation is the establishment what regular observation are implemented in the ACEM or another national and regional systems. What are the data bases established in them and what are the technological requirements for compatibility. In the meantime, the information, technological and qualitative characteristics, means and systems for monitoring, technical requirements for compatibility need to be analyzed.

An opportunity for development of the system need to be scheduled based on data about prospective development of the site, neighbor sites and trans-boundary contamination.

Aiming optimum economic and technical advisability, mathematical interpreting and statistical processing the following need to be established:

- Needed precision of specific measurements;
- Frequency of measurements and sampling;
- Opportunity for averaging the results of specific measurements;
- What are the technological decisions that satisfy the needed rate of reliability in data transmission , cable connection etc.
- The needed rate of mechanization and automation of observations, processing and data transmission
- possibility for realizing the observations by a standard equipment, compatible to local, regional and national systems.

As it has already been mentioned, the specifics of impact for each specific case may not be subjected to unified schemes and technical decisions. For each specific site they are implemented after specific investigation and represent an individual decision. The most complicated at this stage and in the nearest future are the issues related to closure of mining enterprises. The difficulties due not only to non-standard organization but also to non-predictable character of development of anthropogenesis after interruption of activity. In that aspect the role of the University of Mining and Geology "St. Ivan Rilski" and the department "Engineering geoecology" is extremely important.

As a conclusion, it is worth mentioning that one of the most important pre-conditions for development of environmental monitoring is the improvement of general environmental knowledge of staff and training of higher educational professionals in engineering geoecology. That education has been commissioned into practice for more than 10 years by the University of Mining and Geology "St. Ivan RilskI".

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CHARACTERISTICS OF EXTREME VISOCICA RIVER FLOW RATE – INFLUENCE OF HYDROGEOLOGICAL CONDITIONS

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ABSTRACT
It is common that the specific outflow rate of the water current (q) decreases as its basin area increases. Characteristic example which deviates previous rule is river Visocica, which enters the Serbia from the Bulgaria near Donji Krivodol. At the downstream water gage profiles (Visocka Rzana and Paklestica) the specific outflow rate is two times greater comparing to the upstream profiles (Izatovac and Brajćevac). The maximal (Q_{max}) and minimal (Q_{min}) flow rates of the Visocica are indicative too. The fact that the part of the Visocica flow in its river source area in the Bulgaria was moved to the adjacent basin, was considered through the observing of the mentioned example. In this paper, as one of the main causes for mentioned unique case, hydrogeological characteristics of the part of the Visocica basin at the southwest hillside of the Stara Planina are pointed out. Through the general review of the climatic, hydrological, geological and hydrogeological characteristics of the Visocica basin up to the water gage profile Paklestica, hydrogeological conditions influence on the extreme flow rates is interpreted, as well as the inverse relation of the specific outflow rate

INTRODUCTION

In natural conditions there are numerous factors that influence the extreme outflow rate of the water currents. It is unbeatable fact that climatic factors and phenomena such are heavy rainfalls, snow melting, or the combination of these phenomena, determine intensive and maximal outflow rates. Minimal flow rate is common in dry periods, and its value depends on the quantities of accumulated water in hydrogeological collectors in the past period. However, one of the main factors of extreme outflow rates are geological and hydrogeological factors at the river basin area with Visocica river as characteristic example of that.

Visocica river is located in southeast Serbia and belongs to the Nisava river basin, i.e. South Morava river basin. Visocica originates in the Bulgaria below the mountain peak Kom (2016 m) on the Stara Planina mountain. It enters Serbian territory near the village Donji Krivodol. There are two parts of the Visocica river basin (574 km^2) that are clearly distinguished. In the first one, downstream of the water gage profile Paklestica, accumulation reservoir with the dam "Zavoj" is formed. The second part of the river basin which extends upstream of the Paklestica is observed in this paper. This part is specific due to the existance of numerous phenomena caused by the geologic structure and tectonics and its influence on hydrogeological characteristics of river basin area. This is very significant for the Visocica outflow regime.

At the part of the Visocica river basin area which extends on the Bulgarian territory, there were performed hydrotechnical works which enabled the capturing of the certain quantity of the water. This water is later moved to the adjacent river basin area. According to M. Ocokoljić (1987) 1/3 of the average annual flow rate (measured on hydrological station Brajcevci) is captured. However, way back in 1896, J. Cvijić found out that in the summer period, the real source of the Visocica is spring "Jelovicko vrelo" which lies in Dojkinacka reka basin river, and not the part of the Visocica which inflows from the Bulgaria. Since there are appropriate data in the literature, certain corrections of outflow are done, as well as the attempt of interpretation of the extreme outwlow rates of the Visocica river.

GENERAL CHARACTERISTICS OF THE RIVER BASIN

Visocica river basin area which extends up to the water gage Paklestica is 446 km^2 and 26% of it is in the Bulgaria. River basin area is surrounded from the northeast by Stara Planina mountain (peaks: Kom 2016 meters above sea llevel, Srebrna Glava 1932 m asl, Dobro Jutro 1678 m asl, Tri Kladenca 1967 m asl), from the southwest by mountail Vidlic (peaks: Gradište 1088 m asl, Goli Vrh 1371 m asl, Basarski Kamen 1377 m asl), from the northwest by the watershed which connects mountain peaks on the north from Tri Kladenca, over Mramor (1760 m asl) to the Basarski Kamen on the south. The climate is continental (mountain type). The average temperature for the long time period is 8,4°C. In the table 1, some precipitation characteristics (n – number of the years for monitoring, P_{sr} – average precipitation amount for the long time period, δ_{n-1} – standard deviation, P_{max} – greatest registered annual precipitation amount, P_{min} – smallest registered annual precipitation amount).

Table 1. Some precipitation characteristics from the rain gage stations in the Visocica river basin

Rain gauge	Dojkinci	Visocka Rzana	Velika Lukanija
Altitude	880 m asl	700 m asl	600 m asl
n (year)	50	36	32
P_{SR} (mm)	931,4	719,11	720,23
δ_{n-1} (mm)	168	140,4	108,59
P_{max} (mm)	1334	1055,3	948,5
P_{min} (mm)	577,9	466	576,7

Annual rewiev of the precipitation amount shows that may (13% of total annual sum of precipitation) and june (12% of total annual sum of precipitation) are the months with the highest average precipitation amount, while october (6% of total annual sum of precipitation) is the month with the lowest average precipitation amount. Uneven distribution of precipitation is noticable, with high precipitation amount on the mountain area compared to the valley area of the river basin.

General direction of the river flow is from southeast to northwest. Visocica river basin area is tipical example of asimetric river basin. The left valley side placed on the northeast hillside of the mountain Vidlic is very narrow and steep, without any significant water currents. The right valley side developed on the southwest hillside of the Stara Planina mountain is jagged, intersected by numerous streams and rivers. More significant tributaries from the right side (from Serbia–Bulgaria border up to Paklestica) are: Kamenicka river, Rosomacka river and Dojkinacka river.

Relatively long period of "small water" which sometimes lasts untill November is tipical for the Visocica river. During the recession period, upstream from Dojkinacka river mouth, Visocica dries for cca 10 days.

Apart from water gage Paklestica, on the river Visocica, there are water gages Izatovac, Brajcevci and Visocka Rzana as parts of the RHMZ (republic hydrometeorological buerau) of Serbia net. Some of the basic data and the values of extreme flow rates measured on mentioned water gages are given in table 2.

GEOLOGICAL STRUCTURE OF THE RIVER BASIN AREA

The oldest rocks at the river basin area are quartz–albite–muscovite–chlorite shales of Cambrium age (Cm) which builds the core of the vast antiform of Stara Planina mountain (Anđelić, et al., 1975). The cambrium shales are overlied by the thick clastite complex of perm and lower triasic age (P,T_1) built of fragments of various rocks with grain size of 0,1 cm alevrites to 20 cm (conglomerates). The next stratum is thick limestone–dolomite complex of middle triasic age (T_2). Mixture of pure, high fractured rate thick–bedded limestone with dolomitic limestones, dolomites and marls of low fracture rate is typical. The next overlying stratum are sandstones, conglomerates, shales of low metamorphic rate and marls of lower and middle Jurassic age (J_1,J_2). The youngest rocks of Jurassic age are limestones with cherts, sandbar and marly limestones of upper Jurassic age (J_3). This limestone complex is also fractured but in lower rate. The youngest rocks in Stara Planina antiform are marls, sandy limestones, carbonate sandstones and shales of lower Kretaceous age (K_1). All mentioned Kretaceous rocks are mutually intersected, sometimes in the rhytm which is characteristic for flysch. Finally, over these rocks, along the bottom of the Visocica cut, lies quarternary alluvial and terrace sediments.

Table 2. Some of the basic data of hydrological stations and the values of extreme flow rates (group of authors, 2002)

Hydrological station (H.S.)	Starting year H.S. (year)	Magnitude A (km^2)	Zero point "0" (m asl)	km from confluence (km)	Q_{max} (m^3/s)	Date	Q_{min} (m^3/s)	Date
Izatovac	1963	156	753,11	38,6	88	10.07.1967.	0,000	10.08.1963.
Brajcevci	1963	227	447,07	37,8	118	10.07.1967.	0,000	10.08.1963.
Visocka Rzana	1958	403	684,90	33,8	202	20.04.2002.	0,176	15.08.2000.
Paklestica	1959	458	610,46	21,0	241	08.06.1966.	0,350	13.09.1965.

All sediment series in the lap of the Stara Planina antiform have mild slopes, rarely greater than 20°. Therefore, horizontal projections of the thin formations stand out, which is very significant from the hydrogeological aspect. Large ruptures are rare, but the sediments are very fractured and imbued with small cracks and fissures.

HYDROGEOLOGICAL TERRAIN CATHEGORIES OF THE RIVER BASIN AREA

Three hydrogeological cathegories of the Visocica river basin area are distinguished on the basis of porosity, permeability and the presence of aquifers (Čubrilović and Nikić, 1999). The sizes of these hydrogeological cathegories areas, expressed in percentages are given in the table 3. The basic characteristics of the distinguished hydrogeological cathegories from the aspect of Visocica outflow are the following:

- Terrains hydrogeologically typically cathegorized as aquifers of intergranular porosity (A) are: alluvial and terrace sediments of Visocica river and slope detritus on the northeast hillsides of the Vidlic mountain. These hydrogeological units are of secondary significance for interpretation of extreme outflow rates of the Visocica river.
- Terrains hydrogeolocically cathegorized as aquifers in carst and carst–fissured porosity (C) are limestones and dolomites of middle Triassic age and limestones with cherts of upper Jurassic age

Middle Triassic limestones and dolomites are highly karstified which is confirmed by the existance of large karst springs, sinkholes, caves and sinking rivers. Due to favourable geological and hydrogeological conditions, large karst aquifer is formed in these limestones. Underlying formation of this aquifer is built of clastic sediments of lower Triassic age. The aquifer recharges through the infiltration of the precipitation, and through surface water currents–sinking rivers which inflow from the non–karst terrains. The aquifer discharges through the Jelovicko vrelo in the river basin of Dojkinacka river. This rock complex has hydrogeological function of reservoire–conductor. The complex is highly significant in the forming of small water outflow of Visocica river.

The second carbonate complex–limestones of upper Jurrasic age, do not participate in the forming of extreme outflow rates of Visocica river due to the space placement and considerably less karstification rate.

- Terrains hydrogeolocically cathegorized as "waterless" (D) are Paleosoic shales, Perm–lower Triassic clastites, lower and middle Jurassic sediments and lower Kretaceous flysch. This terrains have hydrogeological function of bedrock and overlying isolator, as well as lateral barrier for ground water in the karstified middle Triassic limestones. Mentioned lithological complexes take up large part of the river basin area of all water gage profiles, mostly they are impermeable, so there is no possibility of any importance for infiltration of atmospheric precipitation. This is the main reason for high rate of surface run off. Water currents have torrential character and terrain erosion processec are developed. "Waterless" hydrogeological cathegory does not contribute to the quantity of small water outflow of Visocica river, but is essential for the forming of its maximal flow rate.

Table 3. Percentage of present hydrogeological cathegories surfaces at the river basin areas of water gage profiles

Hydrological station	Area of hydrogeological categor (%)		
	A	C	E
Izatovac	8	30	62
Brajcevci	6	29	65
Visocka Rzana	4	25	71
Paklestica	4	26	70

THE ROLE OF THE HYDROGEOLOGICAL CONDITIONS FOR THE FORMING OF EXTREME FLOW RATES OF THE VISOCICA RIVER

Formerly presented characteristics of the Visocica river basin terrain are essential in the clarifying of the the role of the hydrogeological conditions for the forming of extreme flow rates and the specific outflow rate of the river. Significant fact is the existance of favourable space placement of porous and permeable karstified limestones and dolomites of middle Triasic age which are undrlyied by impermeable bedrock.

Visocica river basin area, from river source in Bulgaria to the water gage profile Paklestica, encompasses the river source areas of all the right tributaries (Krivodolstica, Kamenicka reka, Rosomacka reka, Dojkinacka reka) at the Stara Planina hillsides. All these rivers have steep slope, precipitation amount is high, and the snow retains untill April. Rich with water, these rivers come across karstified limestone and dolomite area where they sink through numerous sinkhole zones and concentrated sinkholes (Čubrilović and Nikić, 1999). On the parts of the brooks Karibanje and Gradisnica, there are sink zones which are few hundred meters long. Concentrated sinkholes are typicall for the Vodevička and Rosomacka rivers.

During the period of small water, all water that inflows sinks completely and the riverbeds are dry over the time period of several weeks and it directly influences Visocica river flow rate. Sinking takes place also in the period of high water, but due to steep slopes and high flow rates all rivers reach and inflow into the Visocica river. Due to favourable space placement and high rate of karstification of middle Triassic limestones, sinking rivers are directed to the 6 km distant karst spring Jelovicko vrelo which belongs to Dojkinacka reka river basin. Maximal yield of Jelovicko vrelo is cca 5 m^3/s, while minimal is cca 200 l/s. In the Dojkinacka reka river basin there are other numarous large springs as well.

During the recession period large quantities of water outflow from Jelovicko vrelo, while quantities of water that inflows from Bulgaria through Visocica river becomes very small, or completely dries up. Jelovicko vrelo, then, represents the real source of Visocica river. This is illustrated with figure 1 which shows specific outflow rate (q) in four water gage profiles at the Visocica river.

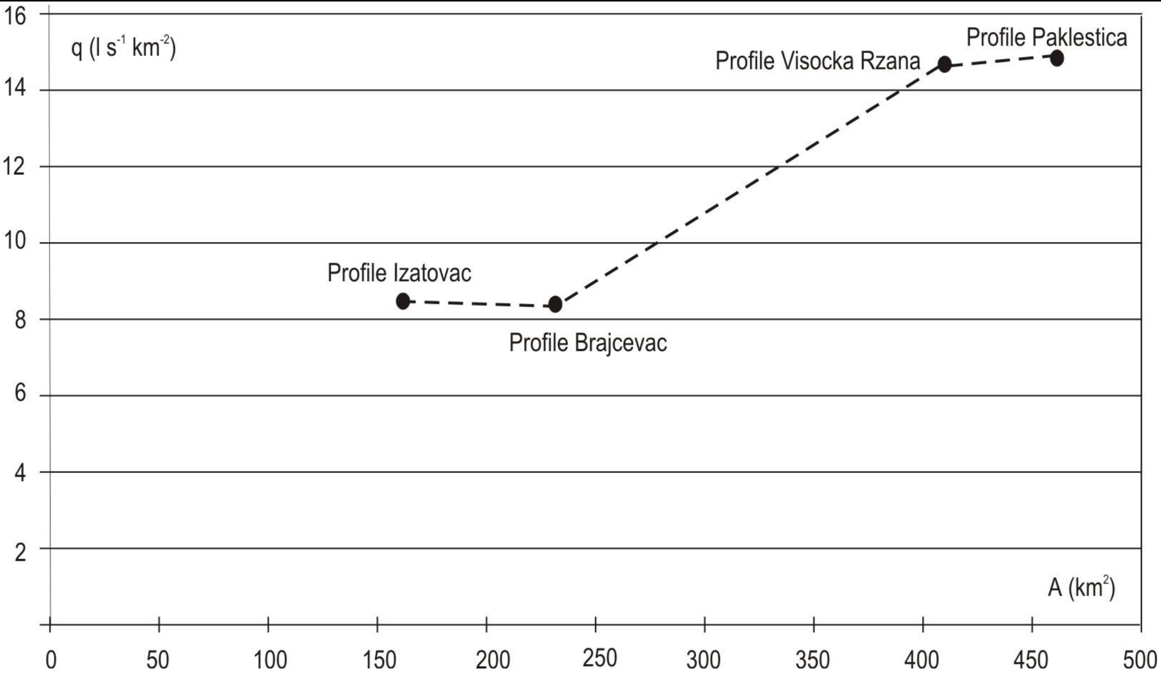

Figure 1. Specific outflow rate of theVisocica river measured on water gage profiles

CONCLUSION

On the analyzed part of the Visocica river basin area, hydrogeological conditions have significant influence on the forming of extreme and specific runoff. It is reflected in the time and space distribution of the water resources.

Space distribution is carried out by redirection of some quantities of the right treibutaries water which sink in the part of the flow over the middle Triasic karstified limestones. Sinking unables its inflow into Visocica river. Sinking rivers are directed to the 6 km distant karst spring Jelovicko vrelo and inflows into Visocica river through the Dojkinacka river.

Time distribution is carried out due to the considerable accumulation–retardation abilities of the karst and dolomite aquifer of the Triasic age. Therefore, during the recession period, the predominant outflow of the Visocica river is performing through the Jelovicko vrelo and Dojkinacka river.

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ORGANIC POLLUTION OF THE MESTA RIVER BED SEDIMENTS

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ABSTRACT
The goal of the investigation is the qualitative content of the bed sediments along the Mesta river. The special attention is given on the organic compounds in the thin fraction because of higher active surface is the main absorber of organic matter. The problem is directly linked with the ecological and economical assessment of the natural resources.
The results of the investigations carried out show that toll the inflow of the Iztok river there are not registered significant sedimentations of organic matter with anthropogenic origin into the bed sediments. The pollution begins from the mouth of the Iztok river and is spread on a big length diminishing progressively to the Gotze Delchev town.

INTRODUCTION

The processes of urbanization and industrialization increase significantly the water consumption for irrigation, drinking and industrial purposes. With reference to these processes the quantity of wastewater increases deterioration the river water quality. Depending on the number and the type of pollutants the different river catchment areas are characterized with a different level of pollution.

The prevailing part of the pollutants inflowed into the river water are permanently accumulated in the bed sediments and in appropriate hydrological conditions they could turn into suspended matters becoming a source for a secondary pollution. The problems concerning the bed sediments pollution as well as the mechanism of secondary pollution are not investigated yet. In this sense the carried out expeditions along the Mesta river represent a practical interest from the point of view of the possible economical usage of the bed sediments and assessment of the ecological conditions in the studied river.

OBJECT OF INVESTIGATION

The catchment area of the Mesta river, with a size of the area 2767 km^2, includes uniform landscapes - the eastern slopes of the Pirin mountain, southern slopes of the Rila mountain, the western slopes of the Rodopi part Dabash. The mountain character of the catchment area with the average altitude 1318 m defines the formation of a dense river net. Combined with the Mediterranean climatic influence that mountain character impact significantly on the hydrological and sediment regime. The average water discharge near the Bulgarian-Greek boundary reaches 38 m^3/s that arranges the Mesta river among the typical Bulgarian rivers with mean size.

The main polluters in the studied catchment area are the industrial enterprises in the region of Razlog, Bansko and Goce Deltchev. Partly or entirely these enterprises as the factories for cellulose, condenser paper and yeasts do not work at present. Nevertheless the output pollutants into the rivers for many years partly are still preserved in the bed sediments witch are more conservative medium.

INFORMATION BASE

The expeditions were carried out at the beginning of the spring flood (the month of March) when the natural biotic component was minimum and in the bed sediments were kept the permanently accumulated pollutants from anthropogenic origin. The sampling was carried out at several monitoring points along the Mesta river from the Iakoruda town till the Bulgarian-Greek boundary. The monitoring points are noticed on the Figure 1. A special attention was paid to the Istok river – the main transporter of the pollutants for years. The sampling was done according the standard procedure adopted in the Laboratory for water quality to the National Institute of Meteorology and Hydrology – BAS.

The cellulose and paper production as well as the yeast production were the main sources of pollution of the bed sediments. The wastewaters from the municipal and agricultural point and no-point sources have smaller impact on the bed sediments pollution. First of all, their quantity is smaller but major reason is the quick degradation of the organic substances. The wastewaters from cellulose and paper productions are characterized with very high level of pollution because of the harmful solutions, colloid solutions and suspensions.

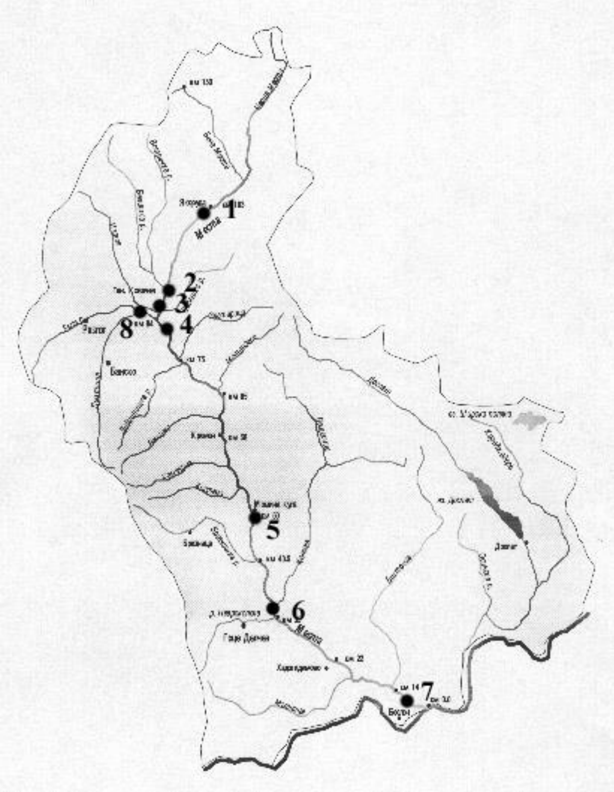

Figure 1. The monitoring points situation along the Mesta river: 1 - Iakoruda town, 2 - after the inflow of the Belica town, 3 - before the Iztok river inflow, 4 - after the Iztok river inflow, 5 - Momina kula site, 6 - after the Goce Deltchev town, 7 - near the boundary, 8- at the Iztok river estuary

The main polluters are the lignins which turn in water-dissolved compounds as a result of alkaline boiling of the cellulose. The lignin gives the wastewater very peculiar brown-red color. The modern methods of water treatment assure a high level of mineralization of a part of dissolved, easy oxidized organic compounds. These methods however do not eliminate the lignin due to their stability. They decompose only 10-15%. Entering the river they are accumulated in the bed sediments jeopardizing the river water with secondary pollution with phenols, hydrogen sulphide, sulphur alcohols etc.

RESULTS AND DISCUSSION

The results of the carried out investigations show that before the inflow of the Iztok river into the Mesta river there is not any significant accumulations of organic compounds from anthropogenic origin in the bed sediments. The content of anthropogenic organic compounds is registered immediately after the Istok river month and is spread over a long distance, diminishing to the Goce Deltchev town. It is found out accumulated content of lignin, yeasts, and secondary products as a result of their degradation.

The main part of the accumulated in the bed sediments pollutants is absorbed in the fine fractions because of their high specific surface. On the other hand it is interesting to investigate the organic content in the fine fractions because of the possible secondary pollution – the fine fractions are more dynamic. On the Figure 2 can be followed the alteration of the granulometric content of the suspended matters in 3 points along the Mesta river which reflects the change of the particles size in summarized percentages able permanently to absorb organic matter and to accumulate it on the river bed.

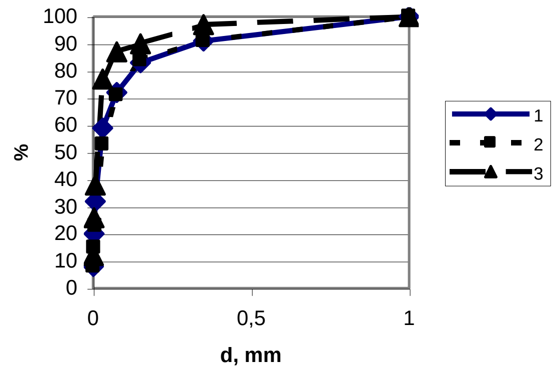

Figure 2.. Granulometric distribution of the suspended matters in the Mesta river water for 1- Iakoruda town, 2 – after Momina kula site, 3- after Goce Deltchev town

That imposes the needs of granulometric analyses and the separation of the fractions between 1 - 5 mm for further chemical and physico-chemical treatment. These particles are undergone of weaker dynamics and at the same time possess higher specific surface area.

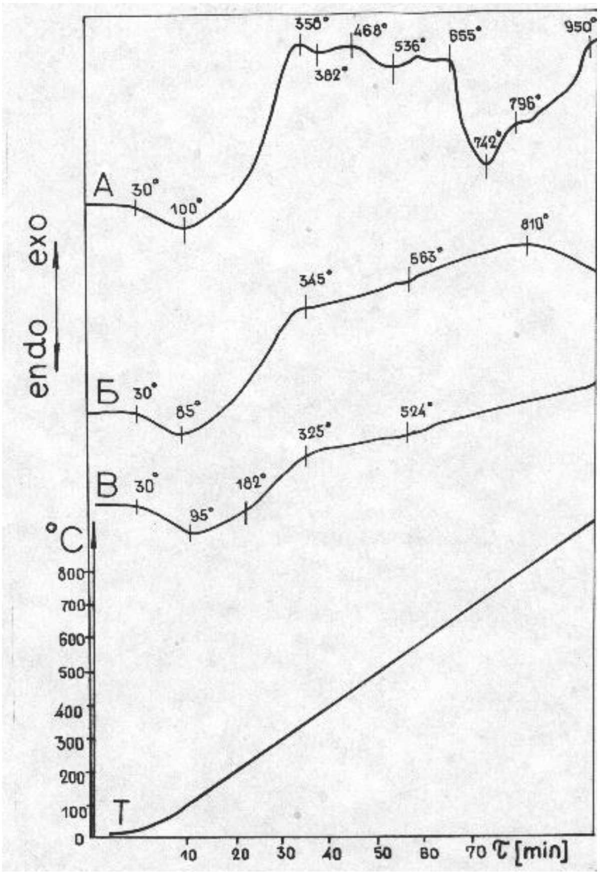

Figure 3. Differential thermal analysis (DTA) of the samples from the stations: A – Iakoruda town, Б - after the inflow of the Iztok river, B – Momina kula site

The results of the differential thermal analysis (DTA) are shown on Fig.3. This method registers the thermal effects in the process of heating. The processes of evaporation of the physically and chemically bonded water are completed up to 200^{o}C. These processes are characteristic of the endothermal peak which is typical of the all DTA curves. The oxidation of the lignin is the most intensive on the Fig.2-Б, due to their accumulation in the region immediately after the inflow of the Iztok river.

In the sample taken at the Iakoruda town, Figure 2-A, these processes are not observed linked with the full absence of lignin and yeasts. The content of accumulated organic compounds from anthropogenic origins diminish along the Mesta river. The sample taken at the Momina kula site, Figure 2-B, where the graphic is almost uniform, gives ground to the acceptance that their content is insignificant.

On the Fig. 4 are presented the results of the thermogravimetric (TG) analysis, reflecting the kinetics of the thermal decomposition. Comparing the spectra of the samples taken from the Iakuruda town till Goce Deltchev can be seen that the percentage lost of weight diminishes. That is a result of the presence of the big quantity of easy degradable organic compounds which are compounds from natural origin in the most upper part of the studied river stream. The accumulated organic compounds in the bed sediments are a result of the natural process of decay of the vegetation and living organisms which can not be looked at pollutants. As an exception could be examine only the process of human intervention when the biotic medium increases in a large dimension. In the studied case there are not the similar processes.

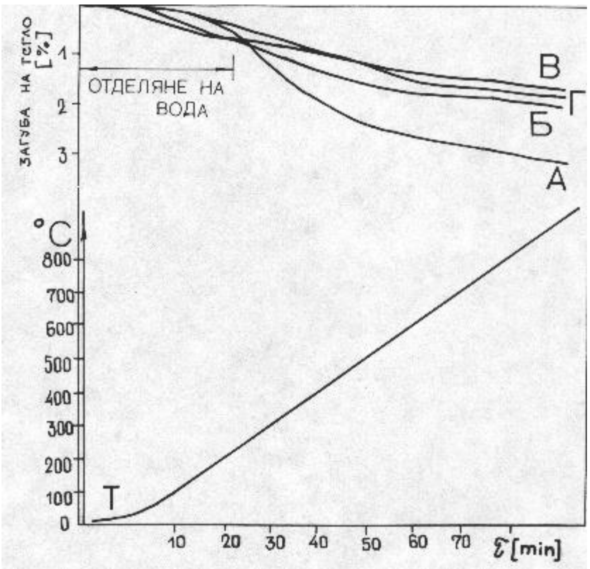

Figure 4. Thermogravimetric (TG) curves for the samples from: A – Iakuruda town; Б – after the inflow of the Iztok river; B – Momina kula site.

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The presence of the mentioned above main pollutants are confirmed by the results of the carried out infra-red (IR) analysis. The registered spectra show the presence of organic compounds. The data of the X-ray fluorescent analysis show the existence of the elements as Al, Ca, K, Fe, Na etc. Consequently the comparison of the results of the both analysis show that above mentioned metals could form metallo-organic compounds of artificial origin (for instance Ca ligninsulphonate) in addition to the basic pollutants. These elements could be also included in the inorganic compounds. This question is not clarified yet therefore additional investigations are necessary. In any case their quantity would be not big.

CONCLUSIONS

Basing on the carried out investigations could be concluded that the main organic pollutants from anthropogenic origin in the bed sediments of the Mesta river are lignin and the products of their secondary degradation. The highest level of concentration in the bed sediments is registered just after the inflow of the Istok river. The assessment of the quantity of the organic compounds from anthropogenic origin is very difficult to be done mainly because of their irregular distribution. Furthermore it is supposed that their content is diminishing in the time after the close of the main industrial polluters. Some additional explorations and elaboration of the standard for sediments quality assessments and cauterizations are necessary. Ecological condition of the bed sediments is a constant characteristic of the rivers much more conservative then the river water quality. The investigation of the sediments specification and territorial distribution is directly connected with the economical assessment of the natural resources.

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CHARACTERISTIC FEATURES OF WATER YEAR 2002 FOR GROUNDWATER IN BULGARIA

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ABSTRACT
The purpose of the present contribution is to clarify the impact of the temperature and precipitation anomalies during the Water Year 2002 on the groundwater regime in Bulgaria. The analysis is based on data from National Hydrogeological Network: spring discharges and water levels for observational wells. Mean monthly temperatures and monthly precipitation values originate from synoptic stations in Bulgaria.
The period November 2001 – February 2002 is characterised with precipitation sums below normal. As a result very low spring discharges and groundwater levels were registered. Heavy rainfalls in March in combination with snowmelt caused very high springflows. Then primary maximums for karstic springs in most regions of the country were observed.
The summer 2002 was very wet. During September and October the precipitation sums were above normal. The secondary maximums for springs were registered in October or August.

INTRODUCTION

The problem of water resources in Bulgaria is of common interest, especially after the drought period 1982-1994. Gerassimov et al. (2001) analysed the impact of this drought period on water resources in Bulgaria. The behaviour of the groundwater was analysed as well (Bojilova et al., 2000; Orehova et al., 2001 and 2001a; Andreeva et al., 2001).

A comparison between Water Years (WY) 2000 and 2001 for groundwater in Bulgaria was made by Orehova (2002a). Summer droughts 2000 and 2001 caused reduction of spring discharges. Extremely dry beginning of the WY 2001 had strong negative impact on groundwater as well. The end of the Water Year 2001 was very dry.

The aim of the present study is to characterize the general behaviour of the groundwater regime in Bulgaria during the Water Year 2002. The influence of the dry and wet periods on the regime of selected karstic springs and observational wells was estimated. For this reason the variations in the groundwater time series were studied in relation to the previous observational period. In Bulgaria the beginning of Water (Hydrological) year is accepted on the 1st November of the previous calendar year. It lasts exactly 12 months.

INFORMATION DATA BASE

Data from National Meteorological and Hydrogeological Networks located in the National Institute of Meteorology and Hydrology were processed. For this study, time-series of precipitation, air temperature, discharge for karstic springs and water level for observational wells were utilized.

The hydrogeological stations with long period of observation and minimal human impact were selected. Time series from National hydrogeological network that starts from 1958-1960 were used. They are spring discharges and water levels for the observation wells. For the chosen springs the measurements are made usually from 12 to 24 annually (once-twice in a month). For some springs the daily data are obtained using rating curves. Water level in observational wells is measured usually once in a month. Some of the stations are observed several times monthly. Water level recorders are available only for small number of the stations.

For the purpose of this study, some representative springs were chosen related to elevated massifs of Mesozoic limestone and Proterozoic marbles (Antonov et al., 1980; Boyadjiev, 1964). The selected wells refer to porous aquifers in alluvial and proluvial deposits.

The variations of spring discharges and ground water levels during the Water Year 2002 were estimated expressed in relation to the 1961-1990 periods.

ANALYSIS OF THE PRECIPITATION AND THE TEMPERATURE ANOMALIES

The Water Year 2002 started in November 2001 with lower rainfall amounts relative to normal in most regions of Bulgaria. The tendency continued during the next month December. The temperature anomalies were below normal almost everywhere during this period. The two winter months – January and February were warm. February was extremely warm – with the anomalies 6-7 °C above normal. The rainfall totals were below normal everywhere with some exceptionally heavy daily falls bringing totals between ½ and ¾ to the month normal. For all period November 2001 – February 2002 the rainfall amounts were below normal.

Rainfall during the spring was about normal in more regions and above normal in Northeast Bulgaria. The wettest month on record in most places was March.

The summer was very wet. The wettest month was July with rainfall amounts between two and three times above normal. September was cool and wet everywhere. The rainfall amounts were up to five times the month normal at the Black Sea region. September 2002 was extremely wet. The tendency was preserved during the second autumn month, October. For all period November 2001 – October 2002 the rainfall amounts were about and above normal.

BASIC FEATURES OF THE GROUNDWATER REGIME

To reveal anomalies of the groundwater regime during the Water Year 2002, the basic features of it are presented. The natural groundwater regime in Bulgaria is described here for some common cases of karstic and porous aquifers.

Mean yearly values for the Water Year 2002

In this section, average values of spring discharges and water level for observational wells are presented. The groundwater regime during the Water Year 2002 is executed in deviations for some representative karstic springs (see Table 1).

Table 1. Deviations of the mean yearly spring discharge for the Water Years 2000 - 2002.

WR, river basin	Spr. N	Village	2000 ε, %	2001 ε, %	2002 ε, %
the North Bulgaria					
18, Iskar	25	Zl.Panega	-23	-33	-26
23, Jantra	396	Musina	-18	-70	-19
43,Kamchia	48	Kotel	-24	-56	-20
32, Dobr.r.	130	Voden	-22	-15	-20
the Upper Struma basin					
51, Struma	86	P.Skakav.	-19	-47	-59
51, Struma	40	Drugan	-20	-45	-51
the mountain Pirin					
52, Mesta	59a	Razlog	-32	-66	-35
the mountain Rhodopes					
72, Maritza	39a	Beden	-27	-39	-42
the Southeast Bulgaria					
83, Veleka	63	M.Tarnovo	-33	-10	-31

The deviations of mean yearly values for spring discharges were calculated in respect from their multiannual values by

$$\varepsilon = \left(\frac{Q}{\overline{Q}_N} - 1 \right) 100\,\% \qquad (1)$$

where N refers to the period 1961-1990. This period was chosen taking into account the recommendation of WMO for defining of normals (WMO, 1984).

For the Upper Tracian Kettle in the Maritza watershed, the regime of the groundwater during Water Years 2000 - 2002 is characterized on the base of water levels in observational wells (see Table 2). The deviations for water levels are given in absolute values in respect from their multiannual values for the climatic period 1961-1990.

Table 2. Deviations of the mean yearly water levels in wells for the Water Years 2000 - 2002.

WR, river basin	Well N	Village	2000, m	2001, m	2002, m
17, Scat	442	B.Slatina	-0.15	-0.25	-0.49
72, Maritza	208a	Rakovski	-0.63	-1.10	-1.17
72, Maritza	266	V.Levski	-0.54	-0.74	-0,41
73, Maritza	526	Trakia	-0.26	-0.41	-0.23
73, Maritza	287a	Sabrano	-0.09	-0.65	-0,82
74, Tundja	271	Tulovo	-0.15	-0.27	0.24

The number of the water region (WR) is indicated in the beginning of the first column in Tables 1-2. It refers to the watershed of one river or to part of the watershed for larger river body (i.e. Maritza).

The analysis shows the reduction of spring flow and falling of water levels for most of stations for the years 2000-2002. In average, the decrease for the Water Year 2001 was stronger - about 42% for spring flow compared to 24% and 34% for the Water Years 2000 and 2002 respectively. Low values of spring discharge and water levels were typical for the year 2001 due to extremely dry beginning of the Water Year and dry summer.

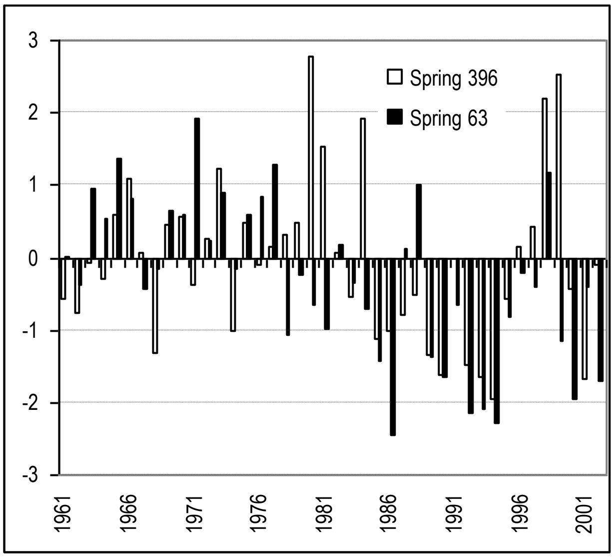

Figure 1. Discharge of springs 341and 63 in relative deviations

The chronological structure for two karstic springs is presented in Figure 1. The deviations here are dimensionless and are calculated using annual discharges:

$$\psi = \frac{Q - \overline{Q}}{\sigma_Q} \qquad (2)$$

where $\overline{Q}$, σ_Q are average values and standard deviations for the 1961 - 1990 period respectively. Low values of spring discharges for years 2000 - 2002 are evident.

Interannual regime for karstic springs

The predominance of drought during the first 4-month period of the WY 2002 resulted in very low spring discharges. An additional reason for this was extremely dry October 2001 that finished the previous WY 2001 (Orehova, 2002a).

Heavy rainfalls in March in combination with snowmelt caused floods in rivers and increased discharges of karstic springs especially in Northern Bulgaria. The primary maximums for the rivers and springs were observed in the country in March - April.

The wet period July-October caused high springflows and water levels. Then secondary maximums were observed.

Some examples of the interannual regime for karstic springs from the North and Southeast Bulgaria are presented in Figures 2-5. Due to predominance of drought during the first 4-month period of the WY 2002, very low discharges and levels were registered. The primary maximum was registered during March or April and the secondary one – in October or August.

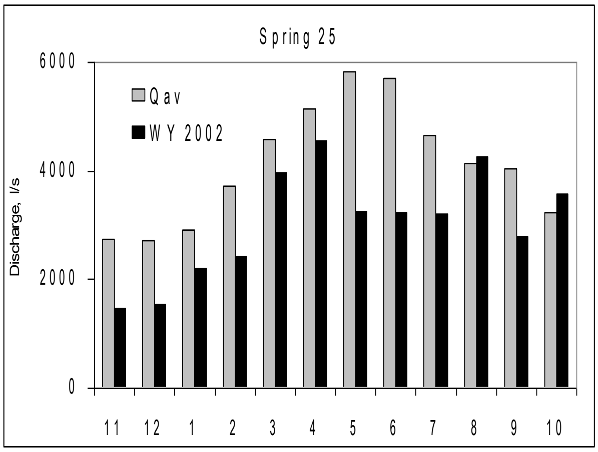

Figure 2. Regime of spring 25 in the North Bulgaria.

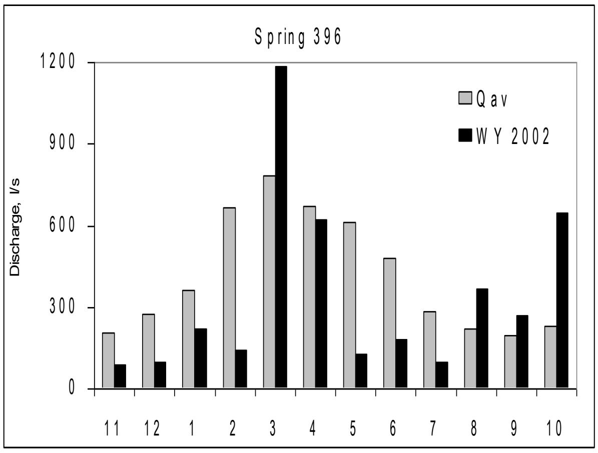

Figure 3. Regime of spring 396 in the North Bulgaria.

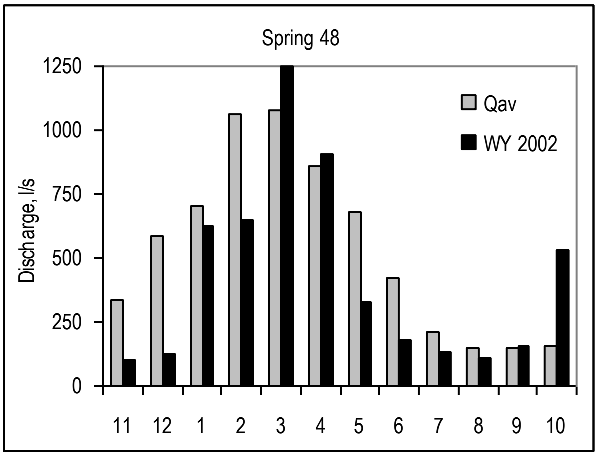

Figure 4. Regime of spring 48 in the North Bulgaria.

Regime of springs in mountainous regions

The karstic springs with watersheds in high mountains Pirin and Rhodopes are characterized with specific regime. Their maximal springflows are observed later due to later snowmelt.

During the first half-year period of WY 2002 extremely low discharges were registered, whereas in September and October the values about or above their multi-annual norms were observed (Fig. 6-7}. The maximal monthly discharge for spring 59a was registered as usual in June, and for spring Beden 39a – in April.

The drainage basin of the spring 59a is located in preserved area of Pirin mountain. Pirin mountain is included in the list of United Nations Organization as a part of World natural heritage.

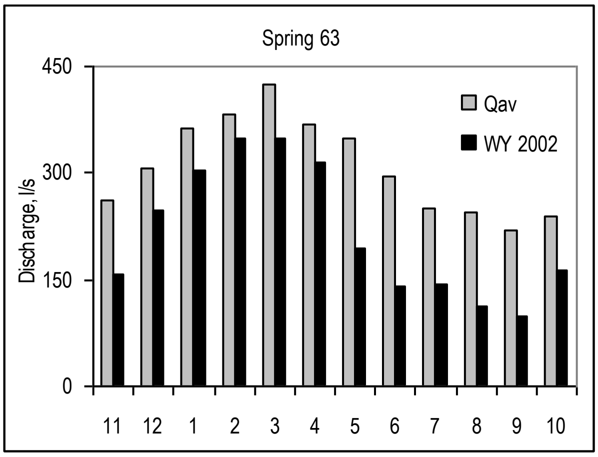

Figure 5. Regime of spring 63 in the Southeast Bulgaria.

Regime of water levels in porous aquifers

Aquifers in porous media in alluvial and proluvial deposits do not show quick reaction to the precipitation occurrence as karstic springs. They however are sensible to droughts or wet periods. The drought during the first several months of the WY 2002 caused falling of water tables (Figures 8-9).

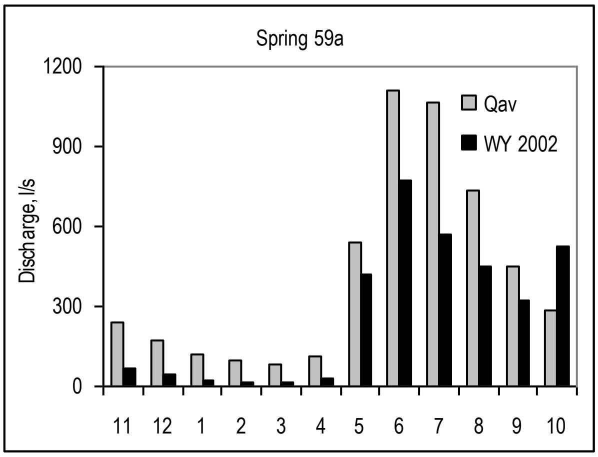

Figure 6. Regime of spring 59a in the mountain Pirin from the Southwest Bulgaria.

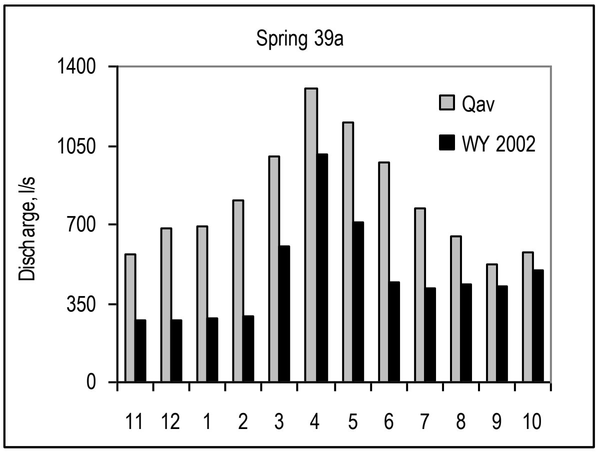

Figure 7. Regime of spring 39a in the mountain Rhodopes from the South Bulgaria.

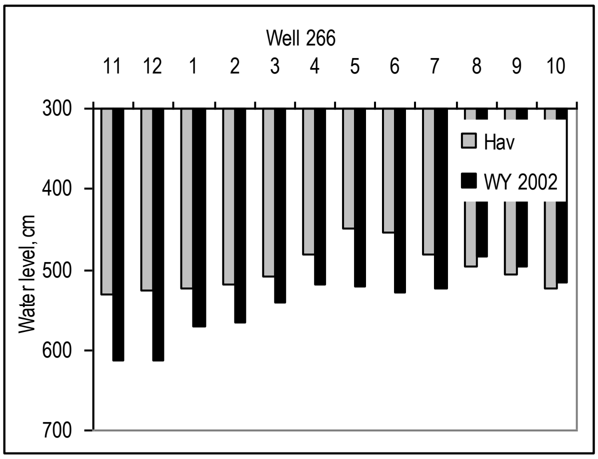

Figure 8. Regime of observational well 266 in the Upper Tracian Kettle.

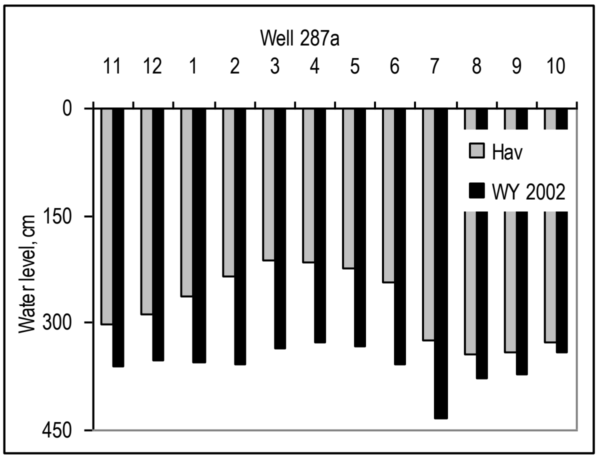

Figure 9. Regime of observational well 287a in the Upper Tracian Kettle.

March was very wet month, and precipitation together with snowmelt contributed to effective recharge of porous aquifers. The highest water levels however were observed later during April.

Precipitation amounts during summer were used to evapotranspiration by plants, and regardless of very wet summer they did not contribute to important recharge of groundwater.

Minimal water levels were registered in July or in the beginning of the WY 2002 – in November-December.

September 2002 was extremely wet, followed by wet October. The autumn precipitation contributed to recharge of porous aquifers in the country.

CONCLUSION

Long lasting drought during November 2001 – February 2002 caused low values for spring discharges and water levels in wells during Water Year 2002.

The reduction of the precipitation during the winter (December, January and February) had strong negative impact on groundwater regime in WY 2002. The last winter month February - extremely warm, had negative impact on the rainfall amount and on the springflows and water levels.

The first spring month March was the wettest month on record and caused the highest discharges for springs in the country. The secondary maximum for springs and wells were observed during October. Precipitation amounts about and above normal during autumn had positive influence on the groundwater recharge.

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HYDROGEOLOGY OF THE DOLNA BANYA THERMAL WATER BASIN

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ABSTRACT
The study is devoted to mineral water occurrences at Kostenets, Dolna Banya, Momin prohod, Pchelinski bani, revealed within the Kostenets graben depression. Specific geological, hydrogeological and hydrochemical conditions of the above mentioned occurrences of mineral water are the reasons for treated them as parts of a common hydrogeological structure, denoted as Dolna Banya thermal water basin.
Scope and boundaries of the basin are delineated. A description of individual mineral water occurrences is presented. The discharge of each of them is assessed on actual measurements and observations of discharge regime. The total outflow of mineral water from the occurrences of the Dolna Banya thermal water basin recently amounts to 53 l/s. The hydrochemical characteristic of mineral waters is presented as well as regularities in the distribution of composition and temperature.
A conceptual computer model of the Dolna Banya thermal water basin is compiled and it is used for determining the cathcment areas for each of the mineral water occurrences. The model confirms hydraulic connection between specific parts of the basin and in the meanwhile studies the determination of Kostenets occurrence of mineral water as an autonomous part of the basin.

INTRODUCTION

The Dolna Banya thermal water basin is located in the central part of west Bulgaria, between the Rila Mountain and the Ihtiman Sredna Gora Mountain. Four mineral water occurrences are revealed in the basin: Kostenets, Dolna Banya, Momin prohod and Pchelinski bani. The region under investigation belongs to the Maritsa River catchment area, comprising the southern slopes of Cherni rid of the Ihtiman Sredna Gora Mountain, the eastern slopes of the Shumnatitsa heights, northeastern slopes of the Rila Mountain and the Kostenets valley.

A. Boue and A. Viquesnel provided first data about the geology of the area. Later the area is studied by G. Zlatarski, G. Bonchev, S. Bonchev, P. Bakalov etc. Results of geological mapping in the area are summarized by Dimitrova and Katskov (1990), Iliev and Katskov (1990, 1993) in the geologic map of Bulgaria in scale M 1: 100 000 – map sheets Velingrad and Ihtiman.

First analysis of mineral water composition were carried out by N. Dobrev (1905) and Azmanov (1929, 1940). Data about the capture of water sources in the mineral water occurrences are presented in the papers of G. Vasilev (1938, 1939), B. Radoslavov (1939) and Pavel Petrov (1943). Data about mineral waters of the mineral water occurrences are published by P. S. Petrov (1964). Hydrogeological conditions of the four mineral water occurrences are analyzed by K. Shterev (1964), who includes them in the "Kostenets area" and draws attention to its hydrochemical zoning.

For the first time the mineral water occurrences of Kostenets, Dolna Banya, Momin prohod and Pchelinski Bani are grouped under the name "Dolna Banya basin" by P. Petrov etc. (1970). According to the last authors the basin is a graben structure, shaped by the faults between the Rila-Rhodope massif and the Srednogorie, and the major recharge area is located down the northeastern part of the Rila Mountain. Authors did not make overall assessment on hydrogeologiacal conditions in the region - their investigations were concentrated mainly on the individual occurrences of mineral water within it.

In the present study the separate mineral water occurrences are considered as integral parts of a general hydrogeological unit, denoted by the authors as Dolna Banya thermal water basin. The last unit is described through detail review of all available reference information and the results of field investigations, conducted by the authors in 2001 – 2003 period. Actual data for mineral water discharge, temperature, chemical composition and radioactivity are presented as well.

DOLNA BANYA THERMAL WATER BASIN

From geological point of view the area under investigation is represented by: Precambrian metamorphic formations – gneiss, amphibolite, shale and marbles, Paleozoic granitoid plutons, Upper Cretaceous granodiorite intrusions, Paleogenic continental depositions down the Rila Mountain slopes, Neogene -Quaternary lake-river depositions and Quaternary alluvial depositions in the Dolna Banya valley.

The major water bearing formations collecting thermal (mineral) water in the region are Rila-Western Rhodopes batholite and Upper Cretaceous intrusions within the Srednogorie and the Rhodopes massif. Thermal waters have an infiltration genesis, they are accumulated and circulate along fractures and tectonic zones within the above described Paleozoic granitoids and Upper Cretaceous intrusions. Both rock complexes may be treated as parts composing a united hydraulic reservoir, denoted as Dolna Banya thermal water basin.

Boundaries of the basin (Fig.1) are delineated on the base of geologic map of Bulgaria in scale 1: 100 000 and hydrographical network of the region. They coincide with the boundaries of Rila-Western Rhodopes batholite and Upper Cretaceous intrusions outcrops and the surface water divides.

Northern part of the basin is composed of granodiorites of the Gutsal pluton and diorites of the Plana pluton, and the southern one – of granitoids of the Rila-Western Rhodopes batholite with individual intruded bodies of the Upper Cretaceous.

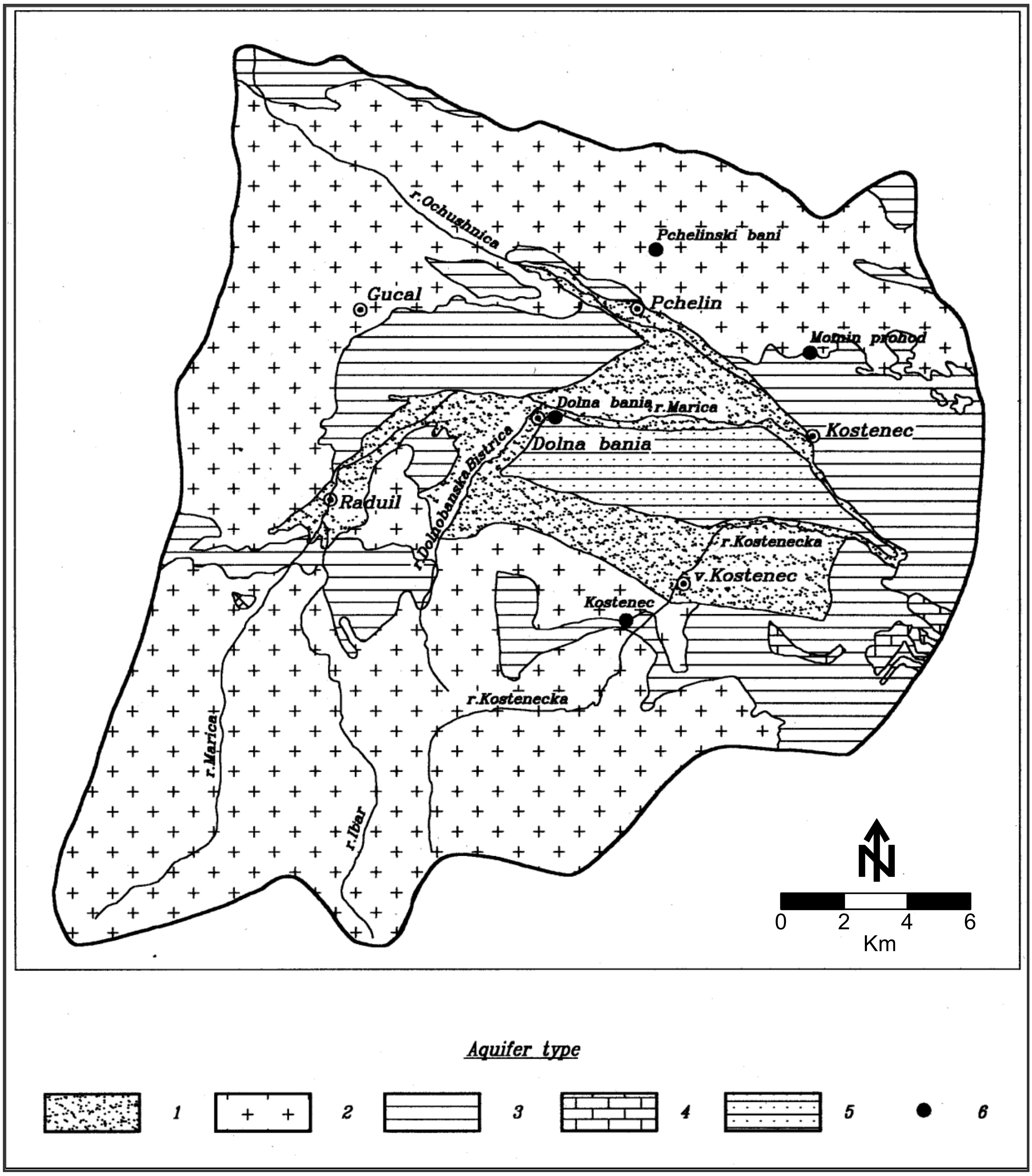

Figure 1. Hydrogeological map of Dolna Banya thermal water basin
1 - Porous aquifer in Quaternary deposits (gravel, boulder, sands and loamy sands), middle to high water bearing capacity; 2 – Fractured aquifer in Paleozoic and Upper Cretaceous intrusions (granites and granodiorites), low to middle water bearing capacity; 3 – Non aquiferous geological formations in Precambrian metamorphic complex (gneiss, shale, amphibolite) and Paleogenic sediments (conglomerate, sandstone, argellite, bituminous shale and coal); 4 – Fracture-karst aquifer in Dobrostan formation (Precambrian fractured and karstified marbles), middle to high water bearing capacity; 5 - Non aquiferous geological formations in Pliocene depositions (clay, sand and breccia-conglomerate); 6 – Location of the mineral water occurrences

Hydraulic link between ground water from both parts is complicated by faulty structures of the Maritsa fault. The south-verging over-thrust, where granites and metamosphites are thrust over Paleogenic sediments, follows the line Borovets – Raduil – Kostenets, presents a hydraulic impermeable boundary for groundwater flow to northern direction. That impermeable boundary probably brings to showing of mineral waters in the Kostenets occurrence of mineral water, which is treated as an autonomous part of the Dolna Banya thermal water basin.

Paleozoic and Upper Cretaceous intrusive formations contact directly only in the western part of the basin in the location between the town of Dolna Banya and village of Raduil, where the hydraulic link of ground water is direct. In the central and eastern part of the basin (Kostenets – Dolna Banya depression), Precambrian metamorphites and Tertiary and Quaternary sediments outcrop on the surface. In the depression, below the Neogene and Quaternary deposits there are granites and granodiorites, established in boreholes. That is a reason for supposing the availability of zones of direct contact between Paleozoic granites of the Rila-Rhodope massif from south and the Gutsal pluton. This is a precondition for establishing a hydraulic connection between ground water accumulated in both structures. In that parts the hydraulic connection between waters, accumulated in both complexes is realized through tectonically fractured Proterozoic gneiss, which represent a secondary collector of mineral waters in the Dolna Banya mineral water occurrence.

Discharge areas

Drainage of mineral water in the basin is performed by four thermal spring occurrences - Kostenets, Dolna Banya, Momim prohod and Pchelinski Bani. Results from the actual investigations, performed by the authors in the period 2001 - 2003, and the data obtained from regular observations during the 1983-2001 period, are shown on Figure 2. The trend of discharge changes of mineral water occurrence is visualized by linear function. Unessential decrease of the total discharge from all mineral water occurrences is established. The reasons for this will be investigated in the future. Now the total outflow from the four occurrences of mineral water is assessed to 53 l/s.

Kostenets mineral water occurrence. Mineral water springs in a dislocation of east-west direction, at the boundary between granites of the Rila-Rhodope batholit and the Paleogenic sediments. The major recharge area of those waters is located in the northeastern part of the Rila Mountain. The occurrence of mineral water were presented by two natural springs (at elevation 850 m) and three boreholes. Before the beginning of borehole-hydrogeological exploration (1960) the discharge of springs had changed from 3.3 to 4.2 l/s, and water temperature - from 35 to 41.7 °C. Thermal springs dried after drilling the boreholes and their exploitation. Now, only one of the drilled boreholes is exploited (Well № 2), with a depth of 444.70 m. There is a catchment aiming the exploitation of the well in a mode of artesian flow, and now its discharge amounts to nearly 14.3 l/s for temperature of the water 46 °C.

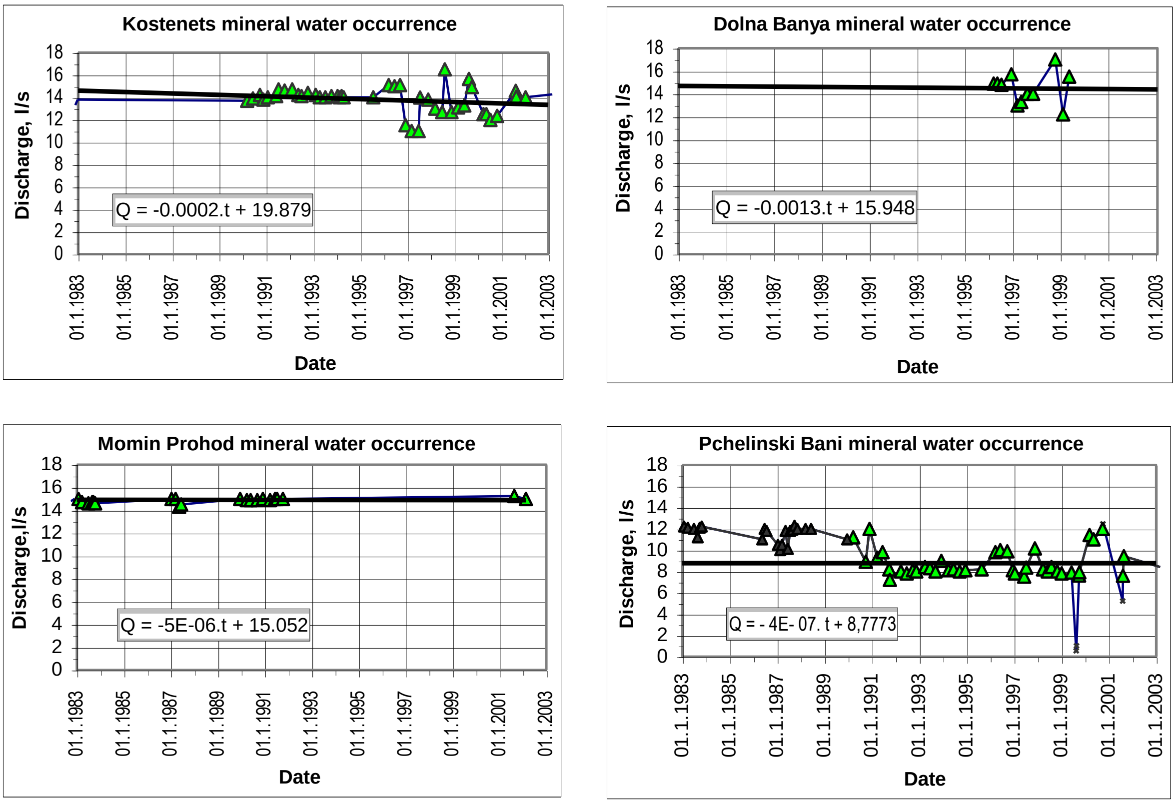

Figure 2. Visualization of data, obtained from regime observations on the discharge of mineral water occurrences for 1983 – 2003 period

Dolna Banya mineral water occurrence. The occurrence of mineral water is located on the right branch of the Ludja dere River, which is an tributary to the Maritsa River. Before the capture thermal water had been out flowing at three locations in the river terrace at an elevation of 615 m. During the time of the spring capturing it was established that water outflows from crystalline schists along a dislocation of nearly 1 m width and east-west direction. Initially the spring had a discharge from 2,25 to 4.0 l/s for temperature of the water of 56 °C. Due to drilling boreholes the discharge of spring was reduced to 1.4 l/s. As a consequence a hydraulic equilibrium was established between water sources, and recently the exploitation resource of the mineral water occurrence is assesses to approximately 15 l/s, for temperature of water in the range 56 - 62 °C (from the spring and from the exploitation boreholes, respectively).

Momin prohod mineral water occurrence. It is located on the southern slopes of the Sredna Gora Mountain, in the valley of the Bashnitsa River. Mineral water outflows from faulted and fractured granodiorites of the eastern part of the Gutsal pluton, at elevation 538 ÷ 540 m. Nearby the spring zone there is a contact of dislocated Precambrian gneiss and gneiss-shales, which are an impermeable boundary for seepage of mineral water. Major fault and fractured systems near the springs are directed in east west and north-northwest – south-southeast. Before the capture mineral waters had been draining from 10 springs, ordered on the fault zone in a distance of 25 m. Temperature of water in individual springs had been changing from 20 to 68.8 °C, and their total discharge before capturing amounted to 11.10 l/s. After the capture of thermal springs in 1936 at elevation, which is maintained even now, discharge was established at 15.00 l/s for temperature of water 65.4 °C. The captured spring of the Momin prohod mineral water occurrence flows at the lowest elevation in the thermal water basin with a constant discharge of 15 l/s.

Pchelin mineral water occurrence. The terrain is composed of the granitoids of the Gutsal pluton. Mineral water before the capture had been drained through several small springs, coming from a faulty zone of 3 to 10 m width, with an east-west direction and steep slope. Springs had appeared in a location, where the fault is crossed by tectonic fractures of north-south direction. Rocks in and near the faulty zone are hydrothermally altered. Total discharge of springs before the capture amounted to 11.17 l/s, and after - 11.7 l/s, for temperature of the water 73°C. This mineral water occurrence represents a seismo-hydrogeological phenomenon – for all severe earthquakes, taken place in Bulgaria and neighbor countries there is a reduction of the spring discharge. Three boreholes of depth 349 to 497 m were drilled in the period 1965 – 1967. One of them was closed, the second was equipped as a seismohydrogeologic observation point, which does not function recently, and the third is set to reserve exploitation water source. Recently the discharge of "Pchelin" spring amounts to nearly 8.8 l/s.

Physical and chemical characteristic of mineral water

There is a certain chemical and genetic similarity in the composition of mineral waters of the four mineral water occurrences. Thermal mineral waters from the Kostenets mineral water occurrence (46 °C), Dolna Banya mineral water occurrence (62 °C), Momin prohod mineral water occurrence (65 °C) and Pchelin mineral water occurrence (73 °C) contain nitrogen, helium, with medium to heavy radioactive content and total dissolved solids from 0.29 to 0.96 g/l, and high content of fluoride (up to 12.5 mg/l) and silica (up to 127 mg/l H_2SiO_3). In the aspect of cation composition waters are characterized as sodium, and anion composition – from hydro carbonate -sulfate (Kostenets) to sulfate (the other three mineral water occurrences). Availability of some rare and disseminated microelements is established, increased are the micro-contents of Li, Ga, Ge, W etc. Spring waters from the Pchelin bani have the highest temperature (73 °C), and those in Momin prohod – the maximum radioactivity (up 580 emanes).

Regularities in the distribution of composition and temperature of mineral water in the basin show the way of seepage through water-bearing rock formations. Paleozoic granitoids of the Rila-West Rhodope batholite are older and therefore, fractures in them are "more rinsed", i.e. water-soluble salts are removed and ground water, formed and circulating in them has a lower quantity of total dissolved solids. An example is the composition of the mineral water from the Kostenets mineral water occurrence. Paleozoic granitoids of the Rila-West Rhodope batholite are older and therefore, fractures in them are "more rinsed", i.e. water-soluble salts are removed and ground water, formed and circulating in them has a lower quantity of total dissolved solids. An example is the composition of the mineral water from the Kostenets mineral water occurrence.

Table 1 Hydrogeological and physico-chemical characteristics of mineral waters in the Dolna Banya thermal water basin

Mineral water occurrence	Elevation	Discharge	Tempe rature	Radioactivity (content of Radon)		Parametric formula
-	m	l/s	°C	еман	Bq/l	-
Kostenets	824.47	14,3	46	33 ÷ 86	122 ÷ 318	$M = 0.29 \frac{(CO_3 + HCO_3)^{42} SO_4^{42} Cl^7}{Na^{95} Ca^5} \; pH = 9.2$
Dolna Banya	608	15.0	56 ÷ 64	50 ÷ 270	185 ÷ 999	$M = 0.60 \frac{SO_4^{68} (HCO_3 + CO_3)^{18} Cl^6}{Na^{94} Ca^6} \; pH = 8.8$
Momin prohod	537	15.0	65	560	2072	$M = 0.98 \frac{SO_4^{80} HCO_3^{12} Cl^5}{Na^{81} Ca^{16}} \; pH = 7.5$
Pchelinski Bani	632.9	8.8	73	120	444	$M = 0.98 \frac{SO_4^{80} HCO_3^{11} Cl^5}{Na^{87} Ca^{11}} \; pH = 7.2$

Upper Cretaceous neointrusions are significantly lower and therefore less rinsed, which directly affects the higher content of dissolved components in accumulated in them waters. That explains the enhancement of quantity of total dissolved solids, concentration of sulfates, fluorides, meta-silica acid in northern direction – from Rila to the Srednogorie. In the same direction content of hydrocarbonates and values of pH are relatively reduced. There is a regular increase of temperature of mineral water in northern direction, which is due to higher depth of ground water circulation.

Summarized information about discharge and main physic-chemical parameters of mineral waters from the four hydrothermal mineral water occurrences in the Dolna Banya thermal water basin is presented in table 1.

HYDRODINAMIC MODEL OF THE DOLNA BANYA THERMAL WATER BASIN

The conceptual computer model of Dolnd Banya thermal water basin is generated to determine the hydrogeological conditions in the basin. The purpose of the model is to confirm the basic hypothesis presented above, to determine the recharge areas of each occurrence of mineral water and to investigate the hydraulic link between the occurrences. Because there is no specific data for filtration parameters of the basic lithological formations, their typical values are used. The model is general and its future improvement is forthcoming.

Hydrodynamic conditions of the Dolna Banya thermal water basin are illustrated by a computer model, generated by module MODFLOW 96. Boundaries of modeled field coincide with boundaries of distribution of granites from the Rila-Rhodope massif and granodiorites of the Gutsal and Plana plutons, which form the Dolna Banya thermal water basin.

Outer boundaries of the basin are considered impermeable (barrier) boundaries. The south-verging thrust, which supports the ground water flow from the Rila-Rhodope massif towards the central parts of the basin, is assigned as an impermeable inner boundary.

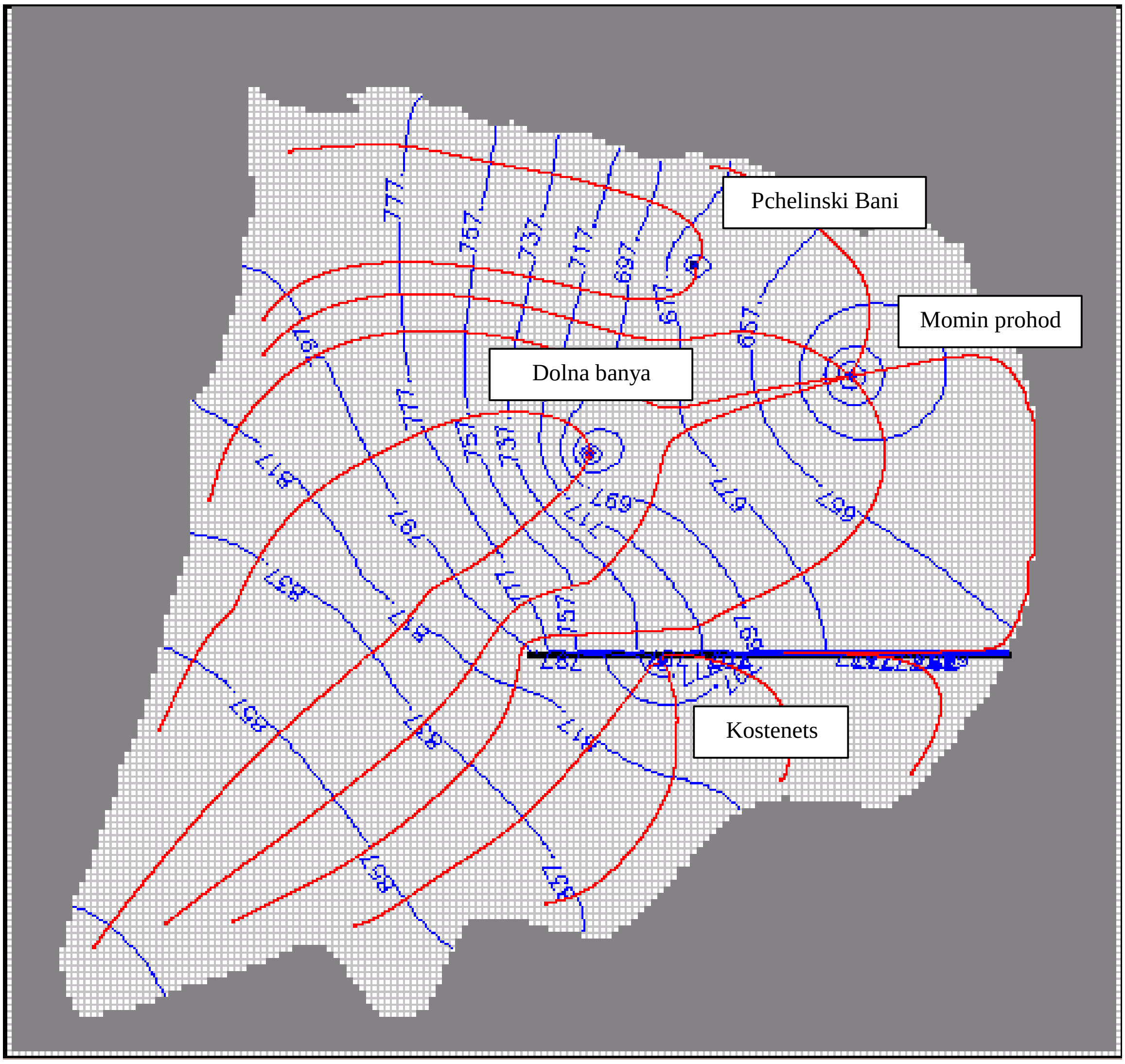

Figure 3. Conceptual model of Dolna Banya thermal basin

Thermal water basin is reduced to a homogeneous unconfined-confined aquifer of the following parameters. Bottom of the aquifer– 300 m; Top of the aquifer – 400 m; Hydraulic conductivity – k = 0.08 ÷ 0.2 m/d; Transmissivity - T = 8 ÷ 20 m^2/d; Thickness of the aquifer – m = 100 m; Active porosity – n_o = 0.05.

The modeled area is transformed in a discrete type by the method of finite differences through a square grid of nodes with 171 columns and 161 rows.

In both main recharge areas of ground waters in the basin – the Rila Rhodope massif and the Ihtiman Sredna Gora the values of infiltration are assigned as $1,3.10^{-5}$ m/d and $0,8.10^{-5}$m/d, respectively. In the central parts of the basin, Kostenets – Dolna Banya valley a zero value for infiltration is assigned. A constant head (boundary condition of first order) is assigned for the box approximating the capture at "Pchelin" – absolute elevation of water head 632.9 m. Average annual discharges for the boxes, approximating the mineral water occurrences of Momin prohod, Dolna Banya and Kostenets, namely Momin prohod - 15 l/s; Dolna Banya - 15 l/s; Kostenets – 14.3 l/s. The hydrodynamic grid of ground flow is generated through the module MODFLOW96 for steady-state conditions. Results from modeling are shown in Figure. 3.

Presence of hydraulic connection between individual parts of the thermal water basin is confirmed. The recharge areas of the four mineral water occurrences are well determined: mineral water occurrences of Momin prohod and Dolna Banya are recharged from the both areas, recharging of the Pchelin bani mineral water occurrence is done extremely through the Ihtiman Sredna Gora, and the discharge of Kostenets mineral water occurrence is completely to recharging from the Rila Mountain.

The Kostenets mineral water occurrence may be treated as an autonomous part of the thermal mineral basin, which is shown in Fig.3. The effect of the impermeable boundary is explained by the higher elevation of draining of mineral water – nearly 200 m higher than Dolna Banya and Pchelin. Differences in the composition of waters from the Kostenets mineral water occurrence in comparison to waters from other mineral water occurrences are explained through that model - mineral water there has the lowest quantity of total dissolved solids and temperature for the whole basin, which is due to the proximity of the recharge area.

CONCLUSIONS

Dolna Banya thermal water basin has complicated structure and hydraulic links between its parts. Four occurrences of mineral water are revealed within the basin – Kostenets, Dolna Banya, Momin prohod and Pchelinski Bani. Boundaries and scope of the basin are delineated, recharge areas of the groundwater are determined. Hydrogeological descriptions of each individual occurrences of mineral water are given.

The discharge of each one of them is assessed on the basis of actual measurements and analysis of data obtained from regular observations. Up-to-date the total discharge of mineral water is assessed to 53 l/s. Hydrochemical characteristic of mineral water is given. Regularities in distribution of mineral water composition and temperature are described.

Conceptual computer model of Dolna Banya thermal water basin is generated through the module MODFLOW. It confirms the hydraulic links between the parts of the basin and also clarifying the separation of Kostenets mineral water occurrence as an autonomous part of the basin. Model is conceptual and it generalizes the hydraulic conditions in the basin, so that a continuation of hydrgeological investigations in the area is recommended as follows:

Studying the basin structure of basin and connection between the four occurrences of mineral water;

Studying the effect of global climatic changes on mineral water resource by a comparative analysis of regime observations with data for changes of climatic elements;

Investigation with the objective of collecting a more detailed information and model calibration and optimization.

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ENGINEERING - GEOLOGICAL CONDITIONS OF THE TOWN OF SILISTRA

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ABSTRACT
The town of Silistra is a cultural and business-administrative center, situated at the Danube riverside at km 375-377. It has been found during the I-st century and during the Rome and Turkish days it had played a role of an important stronghold. It extends at area of 7 square km and has 62 000 inhabitants.
Silistra town is constructed at the flooding terrace (T_0) of the River Danube, the slope section (S) and loess plateau (OAL). Loess delluvial is accumulated at the rearward part of the floodplain terrace. The slope is formed in Pliocene clays and sands, covered by delluvial loess. The plateau is built from Pliocene clays and loess complex (38 m) above. The town has been destroyed or burned down several times and as a result thick embankment has been generated.
Basing on geomorphological, litophacial and engineering-geological signs the following engineering-geological regions on the territory of Silistra have been separated: 1. Region with collapsible loess type II (loess plateau); 2. Region with active slope processes and collapsible loess type I (slope section); 3 Region with technogenerative, collapsible and alluvial soils (floodplain terrace). Ground waters are Karst-leaking one in the low-Cretaceous limestone and porous one in the alluvial terrace sediments and the slope Delluvial. Geological hazard at the territory of the town is determinate primarily from the high seismicity - VIII grade on MSK, presence of collapsible loess soils type I and II, thick anthropogenerated embankments (up to 9 m), shallow groundwaters and from erosion development at the Danube riverbank.

INTRODUCTION

Silistra town is constructed at quaternary sediments. They are characterized with great diversity of genetic types, facial variety and also they have different engineering-geological behaviour. The quaternary sediments genetic types are attended to definnite geomorphologic forms. Each geomorphologic formation has a typical lithologic texture, hydrogeological conditions and lithofacial bodies with equal physic-mechanical indexes could be identified within its bounds. Geomorphological formations are generated during the Neotectonic stage (2,5 million years to nowadays). They are an important indicator for the geodynamics in the region. Their footing is formed in Pliocene clays and Barem limestone. This approach for investigation, in compliance with the geological conditions in broad aspect, has been used in studying the engineering-geological conditions in Silistra.

Geologic research has been done in the region of Silistra town by numerous scientists. Among the first researchers have been Zlatarski (1927), Bontchev and Cheshitev (1953, 1954). Neogenetic sediments are very detailed investigated by Stancheva (1966), Stoikov and Breskovsky (1966), Popov (1986), Kojumdjieva, (1981, 1989), Problems on Quaternary are discussed in published materials by Jaranov (1961), Popov (1964, 1968), Minkov (1968), Philipov and Mikova (1967, 1977, 1983), Evlogiev (1988, 1993, 2000). Engineering-geological conditions in the region are studied by Kamenov, Iliev (1963); Minkov (1968), Minkov, Dontchev, Evlogiev (1984); Brutchev, et col. (1994); Karachorov, Evlogiev, Glavtcheva (1996), All this information is a basis for the current research. Number of stock materials have been considered, belonging to "Energoproject - Sofia", RPO - Varna, RPO - Rousse and Research Laboratory in Geotechnics - Rousse, having totally 110 lithologic and geotechnical drillings and 160 soil samples. Individual drilling studies and mapping in scale 1:5000 have been done additionally.

GEOMORPHOLOGIC FORMATIONS AND LITHOLOGIC STRUCTURES

Basic geomorphological forms in the region of Silistra town are the low floodplain Danube terrace, the loess plateau and the slope between them. The town is located mostly on the floodplain and the slope (fig. 1).

Low floodplain Danube terrace (T_0). Its surface in proximity to the river has an absolute elevation 12-15 m, and the terrace is rising up to 30 m to the south. The terrace is spread out between the Danube bank and the slope. It reaches the state border with Republic of Romania to the east, and includes Aidemir lowlands to the West. The terrain is plain with a low-grade to North. The erosion footing of the terrace has absolute elevation - from -6 to -8 m. It is formed in Barem limestone with strong massive structure and in Alb marls. Floodplain terrace is built of the following lithologic varieties:

- Above the footing lies alluvium of the terrace. The cross-section starts with coarse gravel, sand - filled, having layer thickness 5 to 13 m. Gray dust-sandy clays follow, with layer thickness 6 to 16 m.
- The central and back parts of the terrace are covered from delluvial clayey loess, light brown, with layer thickness 3 to 12 m. Contemporary soil is developed on the alluvial and delluvial deposits.
- The surface of the terrace is covered by a technogenetic embankment, represented by black humus clays or loess, mixed with fragments of construction materials. It has been generated as a result of ruining the old Rome settlement Durostorum. It has satisfactory area dissemination, with maximum thickness 9 m, which is getting thinner going southward up to 3 m.

Slope (S). It covers the terrain between the low terrace and the loess plateau. The slope is slanting in its low part (at absolute elevation 30-40 m), and is becoming abrupt in height (at absolute elevation 40-80 m). The structure is the following:

- Upper Pontian dust-sandy clays, Dackian sands and bottom-middle Roman clays, marls and sands.
- Pliocene sediments are covered by thin delluvial clayey loess, which reaches up to 16 m in its slanting part of the slope.

***Loess Plateau* (OAL).** It is rising southerly from the town with absolute elevation 80–127 m. It forms wide plains, incised by several gulches. The Loess plateau is called in the geomorphologic literature old abrasive level that is generated from the Dacian lacustrine-fluvial basin. The abrasive surface of OAL is developed in Middle Roman clays at the absolute elevation 88 m during the time - period 2,60-0,99 Ma BP. The following lithologic varieties are accumulated above its surface:

- Crust of weathering from red clays, formed above the Middle Roman clays, aged 0,99-0,80 Ma BP.
- Loess complex with 38 m thickness, covering the relief like a mantle. It is built from 8 dust-sandy loess horizons (the forth and seventh one are weathered), divided from 7 buried soils of loess-like clays. The loess complex is 0,80 Ma BP aged (Evlogiev, 2000).

ENGINEERING-GEOLOGICAL CHARACTERISTICS OF LITHOLOGIC VARIETIES

Fourteen types from the lithologic varieties have been found on the territory of Silistra, which build up the floodplain terrace, slope and loess plateau (Fig. 2). Physical - mechanical indexes of the lithologic varieties are determined in result of numerous drillings (25 per km^2 average) and laboratory testing. The lithologic varieties have been also preserved as engineering-geological varieties (soils) almost everywhere. They consist of dispersed and rocky soils. The technogenetic embankment, dellivial clayey loess, alluvial clays and gravel, Pliocene clays and loess complex were studied from the dispersed soils. The rocky engineering-geological varieties occur in depth. The values of the presented physical-mechanical and strenght indices are average for the engineering-geological varieties (Table 1).

Technogenetic embankment. It is found ubiquitously within the boundary of the floodplain terrace. It has maximum thickness 9 m, and it becomes thin up to 3 m to the south, near the backside of the terrace. It is built of black humus clays and loess, mixed with ceramic fragments and constructional wastes. The consistency of the embankment is considered as having semi-plastic (I_c=0,58) to solid-plastic (I_c=0,83) for the determined natural water content w_n=26,0-26,5 %. The embankment is more compact at the forehead of the terrace and it is characterized with volume density ρ_n=1,79 g/cm^3 , volume density of the skeleton ρ_d=1,42 g/cm^3 , specific density ρ_s=2,76 g/cm^3 , porosity n=48,6 %, water saturation level Sr=0,93 and total deformation module E=80.10^{5}Pa. The embankment is not firm in the central part and it has the following characteristics ρ_n=1,66 g/cm^3, ρ_d=1,32 g/cm^3, ρ_s=2,71 g/cm^3 n=51,3 %, Sr=0,66 and E=60.10^{5}Pa.

Contemporary soil. It is formed within the low terrace on alluvial clays and clayey loess. It is built of dusty clays and dust-sandy clays. It is black-colored and contains organic substances. The thickness of the layer varies between 0,3 and 2 m. It is often replaced by embankments, and as a result it is considered as not well sustained. The consistency of the contemporary soil is semi-plastic (I_c= 0,75). The physical indices have values as follows w_n=24,8 %, ρ_s=2,73 g/cm^3, ρ_n=1,89 g/cm^3, ρ_d=1,54 g/cm^3, n=45,1 % and и strenght indices - angle of internal friction φ=21°, cohesion c=0,14.10^5 Pa.

Dust-sandy clay (alluvial). It forms well sustained layer with 6-16 m thickness. It occurs at depth from 10 to 15 m. Dust-sandy clays are grey-colored, and turn to grey-beige in the upper part of the layer. They have semi-plastic consistency (I_c=0,60), plasticity index I_p=15,7, w_n=25,5 %, ρ_n=1,93 g/cm^3, ρ_d=1,54 g/cm^3, n=43,6 %, Sr=0,90, ρ_s=2,73 g/cm^3 and E=121.10^5 Pa.

Coarse gravel. It occurs under the alluvial clays. It forms layer with thickness between 5 to 13 m that becomes thinner to the backside of the terrace. The gravel in the footing of the layer consists of gravel with bigger size and sandy filling. The characteristics are ρ_d=1,90 g/cm^3, ρ_s=2,65 g/cm^3 n=28,3 %, E=600.10^5 Pa.

Collapsible loess type I. Clayey delluvial loess from the backside of the terrace and the slanting slope belong to this type. Its thickness is between 7 and 16 m. It does not collapse under geological load and drench. It shows collapsible properties under additional load. The initial load of collapsibility is higher than the geological load for the collapsible layer (p_{ini}>p_Y). It is characterized with w_n=18,3-21,5 %, ρ_n=1,72-1,85 g/cm^3, ρ_d=1,45-1,52 g/cm^3, ρ_s=2,73 g/cm^3 n=44,3-46,9 %, coefficient of relative collapsibility δ_{col2}=0,020 under p=2.10^5 Pa and δ_{col3}=0,025 under p=3.10^5 Pa, Sr=0,56-0,74 and E=114-135.10^5 Pa.

Non-collapsible loess. It forms thin delluvial covering of clayey loess in the center of the floodplain terrace and abrupt slope.

The clayey loess is between 3 and 9 m thick in the center of the floodplain terrace. It occurs immediately above the water level. It is under the influence of subsurface water, when the River Danube water level is at high water position. This type of loess is non- collapsible under additional load.

The abrupt slope is also covered with not powerful (3-5 m) non-collapsible clayey loess. It occurs above the accumulated on Pliocene clay water body. Physico-mechanical properties of the layer show the following values w_n=14,9 %, ρ_n=1,82 g/cm^3, ρ_d=1,58 g/cm^3, ρ_s=2,75 g/cm^3, n=42,5 %, δ_{col3}=0,012 under p=3.10^5 Pa and Sr=0,54. Shallow sliding rashes may occur there in case of violation on the slope stability from excavating works.

Collapsible loess type II. The surface part of the loess complex from loess plateau belongs to this engineering-geological variety. The thickness of the collapsible zone is 21 m. Here belong first loess horizon (L1), first buried soil (B1), second loess horizon (L2), second buried soil (B2) and third loess horizon (L3). The total collapsing under geologic load is up to 75 cm, according to Minkov (1968). The initial load for collapsing about the collapsible loess is lower than the geologic load (p_{ini}<p_Y). All apprehensions about the security of the terrain and the constructions on it in case of collapsing derive from the condition p_{ini}<p_Y . The indices of load-bearing will reduce its values up to three times in case of accidental moistening of the loess base. Depending on the depth of moistening several types of deformation could occur:

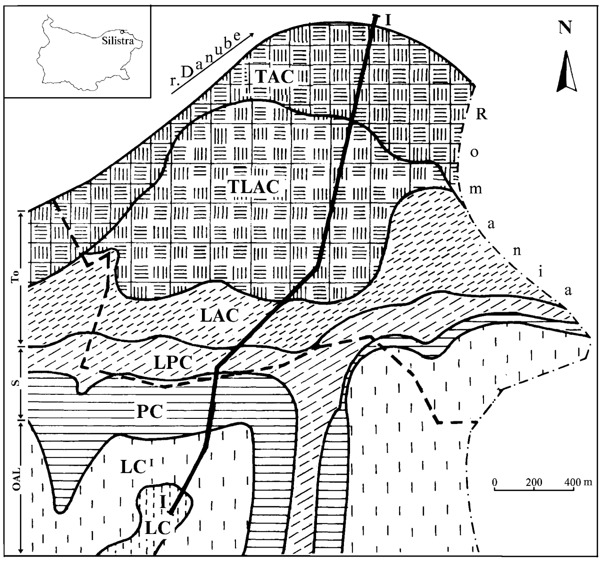

Figure 1. Engineering–geological map

I district - technogenetic, collapsible and alluvial soils: *1. Technogenetic-alluvial complex section (TAC): Technogenetic embankment – thickness up to 9 m, consistency semi-plastic, E=80.10⁵Pa; Dust-sandy clay - thickness 6-16 m, consistency semi-plastic, E=121.10⁵ Pa; Gravels - thickness 5-13 m, E=600.10⁵ Pa; Water level 4-6 m. 2. Technogenetic-loess-alluvial complex section (TLAC): Technogenetic embankment – thickness up to 7 m, consistency solid-plastic, E=60.10⁵ Pa; Non-collapsible loess - thickness 3-9 m, consistency solid-plastic; Water level 8-13 m. 3. Loess-alluvial complex section (LAC): Collapsible loess type I – thickness of the collapsible zone 6-8 m, δ_{col3}=0,025 under p=3.10⁵ Pa, consistency semi-plastic, E=135.10⁵ Pa; Dust-sandy clay – thickness 6-12 m, consistency semi-plastic, E=121.10⁵Pa; water level 8-13 m.*

II district - slope processes, collapsible soils type I: *1. Loess-Pliocene complex section (LPC): Collapsible loess type I – thickness of collapsible zone 8-10 m, δ_{col3}=0,023 under p=3.10⁵ Pa, E=150.10⁵ Pa; Water level - 5-10 m. 2. Pliocene complex section (PC): Non-collapsing loess - thickness 3-5 m, δ_{col3}=0,012 under p=3.10⁵ Pa; Clays and limestone clays - thickness 45 m, consistency semi-solid, E=200.10⁵ Pa; Water level 5-10 m; Potential danger for development of shallow landslides and slope creeping occurrence.*

III district - collapsible soils type II: *1. Loess complex section (LC): collapsible zone 21 m, total collapsing 75 cm, δ_{colY}=0,035 under p_Y (geological load), E=150.10⁵ Pa, water level 37 m. 2. Reduced loess complex section (LC^i) – thickness of the collapsible zone 6-21 m, E=150.10⁵ Pa.*

Other indications: OAL – old abrasive level; S - slope; T_0 – low terrace

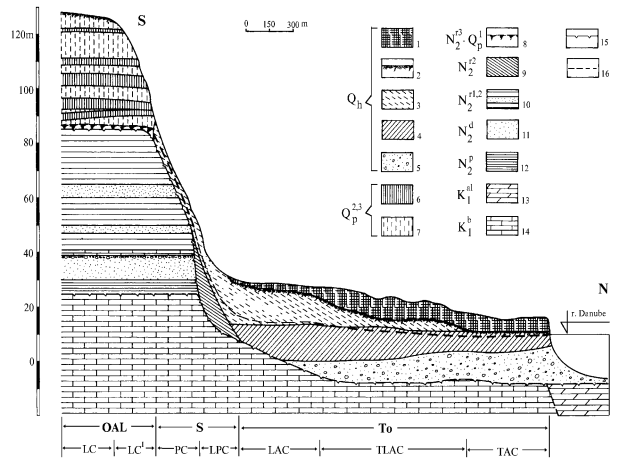

Figure. 2. Geological profile I-I

1 - technogenetic embankment; 2 -clay with organic substances (contemporary soil); 3 - clayey loess (delluvial); 4 - dust-sandy clay (alluvial); 5 - coarse gravel with sand filling (alluvial); 6 - loess-like clay (fossil soil); 7 - dust-sandy loess (eolic); 8 - sandy clay, brick-red (weathering layer); 9 - clay with grey nuts and lens sand (delluvial); 10 - alternation from clays, calcareous clays and sandy layers (lacustrine); 11 - fine to mean sand (lacustrine); 12 - dust-sandy clay, layered (lacustrine); 13 - sandy marls; 14 - limestones; 15 - erosive or abrasive surface; 16 - water level; Others: OAL - old abrasive level; S - slope; T_0 - low floodplain terrace; LC - Loess complex; LC¹ - reduced loess complex;PC - Pliocene complex; LPC - Loess Pliocene complex; LAC - Loess alluvial complex; TLAC - technogenetic loess alluvial complex; TAC - technogenetic alluvial complex; Q_h - Holocene; $Q_p^{2,3}$ - Middle and Upper Pleistocene; N_2^{r3}-Q_p^1 - Upper Roman Lower Pleistocene; N_2^{r2} - Middle Roman; $N_2^{r1,2}$ - Lower and Middle Roman; N_2^d - Dacian; N_1^p - Upper Pontian; K_1^{al} - Alb; K_1^b - Barem

1. In case of shallow moistening and presence of additional load from buildings there would be realized collapsing only in the active zone of the foundations - type I; 2. In case of moistening in depth collapsing could be provoked from geologic load only - type II; 3. In case of full water saturation of the collapsible layer both types of collapsing would be realized.

Loess horizons are built of dust-sandy loess and buried soils - of loess-like clays according to their granularity. The mean - average values of the physic-mechanical indices for collapsible zone are the following w_n=16,8 %, ρ_s=2,74 g/cm³, ρ_n=1,68 g/cm³, ρ_d=1,44 g/cm³, n=47,4 %, δ_{colY}=0,035 under p_Y (geologic load), Sr=0,6; E=150.10⁵ Pa.

Sandy marls. They fill the crest-like forms in the river course and the forehead of the terrace. Their thickness varies from several to 72 m. The physic-mechanical indices have the following values: ρ_s=2,67 g/cm³, ρ_n=2,00 g/cm³, ρ_d=1,65 g/cm³, porosity index e=0,62, angle of internal friction φ=25˚, cohesion c=2,25.10⁵ Pa, E_0=1400.10⁵ Pa.

Limestone. It occurs at absolute elevation - 6 to - 8 m in the low terrace and at absolute elevation 25 m in the slope and loess plateau. Limestone here is dense, porcelain-like, strong, light-brown to white - colored, non-uniform carstified. It is stronger carstified in its upper part, and the cavities and caverns are hollow or filled with sand and red clay. Limestone has the following physical-mechanical indices: ρ_s=2,70 g/cm³, ρ_n=2,60 g/cm³, ρ_d=2,50 g/cm³, e=0,08 and strenght indices φ=33˚, c=40,0.10⁵ Pa.

Table 1. Mean average values of physicomechanical characteristics of lithological varieties.

District	Section	Soil description	Tickness	Number of samples	Water content	Density	Dry density	Porosity	Degree of saturation	Plasticity index	Consistency index	Modulus of deformation
	-	-	m	-	W_n,%	ρ_n, g/cm³	ρ_d, g/cm³	n, %	Sr, -	I_p, -	I_c, -	E, .10⁵ Pa
1	2	3	4	5	6	7	8	9	10	11	12	13
I district – technogenetic, collapsible and alluvial soils	TAC	technogenetic embankment	4,0-9,0	3	26,5	1,79	1,42	48,6	0,93	15,1	0,58	80
		dust-sandy clay	10,0-16,0	19	25,5	1,93	1,54	43,6	0,90	15,7	0,60	121
		gravlel with sandy filling	5,0-13,0	-	-	-	1,90	28,3	-	-	-	600
	TLAC	technogenetic embankment	3,0-7,0	3	25,9	1,66	1,32	51,3	0,66	14,8	0,83	60
		clayey loess (non-collapsible)	3,0-9,0	29	22,6	1,81	1,48	45,8	0,73	15,5	0,76	-
		dust-sandy clay	9,0-13,0	19	25,5	1,93	1,54	43,6	0,90	15,7	0,60	121
		gravlel with sandy filling	7,0-11,0	-	-	-	1,90	28,3	-	-	-	600
	LAC	clayey loess (collapsible type I)	6,0-8,0	17	21,5	1,85	1,52	44,3	0,74	15,8	0,71	135
		dust-sandy clay	6,0-12,0	19	25,5	1,93	1,54	43,6	0,90	15,7	0,60	121
II district - development of slope processes, collapsible soils type I	LPC	clayey loess (collapsible type I)	8,0-10,0	13	18,3	1,72	1,45	46,9	0,56	-	-	114
	PC	clayey loess (non-collapsible)	3,0-5,0	3	14,9	1,82	1,58	42,5	0,54	-	-	-
		clay and calcareous clay	45,0	9	17,6	1,98	1,68	38,5	0,77	16,9	1,12	200
III district - collapsible soilstype II	LC[I]	dust-sandy loess (type II)	6,0-21,0	8	16,3	1,68	1,44	47,4	0,50	12,5	0,95	150
	LC	dust-sandy loess (type II)	21,0	18	16,8	1,68	1,44	47,4	0,60	-	-	150

HYDROGEOLOGICAL CONDITIONS

The ground waters in Silistra region are cavern-carstic and porous-gained waters.

Cavern-carstic waters. They are accumulated in limestone complex, at the age of Barem (The suite of Razgrad). The lower aquifer consists of Lower Cretaceous argillaceous limestones and marls from the suites of Gornaoriahovitsa and Razgrad. The ground waters are formed in carst hollows and caverns of limestone. The formed unconfined underground aquifer has general flow strike to the North. Infiltration from precipitated and surface water feed the aquifer. In Silistra region natural sources of draining are absent, with the exception of Srebarna lake, feed from carst waters of Barem aquifer. Viewing from qualitative aspect the waters are hydrocarbonic-magnesium-calcium according to their chemical composition and neutral (pH=7-8). Their mineralization is 0.4-0.8 g/l in general and rarely at about 1 g/l.

Porous waters. They are accumulated in alluvial of the floodplain terrace, slope delluvial and Pliocene sandy layers.

Alluvial aquifer is two-layered, its lower part have higher water permeability (sands and gravel) and the upper part have lower water permeability (sandy clays). The waters formed in the aquifer are semi-confined and unconfined one. The fluctuation of the water table depends on the water level in the Danube River bed. It is characterized with rich water quantity. The values of conductivity are between 250 and more than 1000 m²/d. Highest values characterize the West Industrial zone of the town. Water feeding of the aquifer comes from high waters of the Danube River, Lower Cretaceous aquifer and from rainwater flowing in from the slope (slope waters) and accumulated above the Pliocene clays. It is drained away from the Danube River during mean and low water level and from existing water extracting equipment. The mineralization of alluvial aquifer is under 1 g/l, waters have hydrocarbonic, calcium and calcium-magnesium characteristics. The water table is at 4-6 m in depth in the forehead of the terrace. The presence of technogenetic embankment and shallow ground waters results in significant difficulties for foundation works of buildings and constructions in this part of the town. The water table is at 8 to 13 m depth in the center of the floodplain terrace. The water table is higher at the backside of the terrace due to feeding from rain water, flowing in from the slope (slope waters).The aquifer of the slope is fed from infiltrated surface waters and sandy layers of the Pliocene. The aquiclude of the aquifer consists of Pliocene clay. The slope waters are accumulated at the interface between Pliocene clays and loess delluvial. They occur at depth 5-7 m at the abrupt slope and 5-10 m depth at its low part.

HAZARDOUS PHYSICAL-GEOLOGICAL PROCESSES AND PHENOMENA

Endogenetic, exogenetic and technogenetic hazardous physico-geological processes and phenomena endanger the territory and infrastructure of Silistra. Endogenetic processes are earthquakes - Silistra is situated among three seismic epicenters - Shabla, Gorna Oriahovitsa and Vrancha. Exogenetic hazardous processes are the potential dangerous shallow earth creep, slope creeping, erosion of the Danube river bank, shallow ground waters, surface erosion, flooding and marsh occurring. Technogenetic hazardous processes are the occurrence of loess soils collapsing, generation of thick embankments and terrain violation by stone-pits.

Endogenetic processes

Earthquakes. According to the macroseismic districts in Bulgaria, Silistra belongs to a region with high seismicity - VIII grade of intensity under MSK and seismic coefficient k_c=0,15. The town has experienced powerful earthquakes and bore damages on the buildings: from Vrancha earthquake with magnitude 7.2 in 1977, again from Vrancha earthquake M=6.7 and 6.1 in 1990 and from the earthquake with Strajitsa epicenter M=5.3 in 1986. The earthquake in 1990 damages 16 objects, including 7 public buildings, and the rest of them have been residential blocks. The first ones are buildings above 50 years of age, built up in the central part of the town, having damages on supporting walls and partitions. The second ones are 4-5 storeyed buildings with steel-concrete frames, built up in the central and south part of the town. The damages were a result of not effective construction design, combined with unfavourable engineering-geologic conditions (Karachorov, Evlogiev, Glavcheva, 1992).

Exogenetic processes

Landslides. Potential dangers of occurrence of shallow earth creeping exist in the extent of the abrupt slope. Slope waters at depth 5-7 m are accumulated at the interface between Pliocene clays and delluvial loess. The terrain is not built up, but future excavating works could create conditions about formation of shallow landslides.

Slope creeping. It occurs in the region of the Pedagogic Institute, constructed at the abrupt slope. The building covers wide area, the foundations are on Pliocene clays and loess delluvial with shallow ground waters. The deformations on the construction of the building are due to worsen of soil consistency and occurrence of unabating creeping of the ground. Not constructed vertical planning of the building gives unfavourable impact.

River erosion. The course of the River Danube is formed in alluvial deposits of the floodplain terrace. This fact makes easier the development of erosive processes. They recruit in April and May, when the water level in the river reach up to 670 cm above the pegel (6,5 m). The biggest part of the Danube bank is erosion protected by supporting wall. The only exception is the west part, where the bank is exposed to active undermine and dilution.

Shallow groundwaters. Shallow ones are porous alluvial waters, accumulated in the sediments of the floodplain terrace. They occur at depth 4-6 m at the north part of the terrace and originate difficulties at the foundation of buildings and constructions.

Surface erosion. It is developed in the slope section of the town. During Holocene in result of surface erosion loess complex was deluted and was deposited secondary as delluvial clayey loess, showing the biggest thickness in the low part of the slanting slope. The absence of contemporary soil gives evidence that this process continues until today.

Floodings. The top water levels registered in th eDanube River are 740 cm above the pegel (in 1942), i.e. 13.9 m absolute elevation. Danube riverbank is at 15 m absolute elevation in the central and eastern parts of the town and it is sheltered by supporting walls. Flooding endanger west industrial zone, where there are sections with lower level at the riverside. Flooding from storm water do not endanger the territory of the town.

Marsh occurring. Occuring of temporary marshlands are observed in Aidemir lowland, on the west of Silistra. They are formed in the negative lowerings as a result of shallow ground water yielding, hydraulically tied to the Danube waters. The water is retained long time in the marshlands in result of colmatage of the negative formed beds.

Carst phenomena. Barem limestones are non-uniform carstified. Cavern carstic aquifer is formed in carst formations and caverns. The caverns are hollow or filled with sand, rarely filled with red clays. Carstifying in the upper layer of the carbonate horizon is intensive.

Technogenetic processes

Collapsibility. Loess soils are distinctive with their non-firming structure and structural non-stableness. They are inclined to collapsing under self-load and additional loads if moistened.

Technogenetic moistening have caused deformations of terrain and buildings in Kalipetrovo district, built at loess plateau - type II loess base. Constructing of industrial structures is assured by anti-collapsible preparation of the loess base when the collapsibility of the terrain is type II - most-frequently by heavy beetle and improving foundation conditions by deep excavations and realization of concrete-soil pillows. The foundation of the TV tower Silistra is accomplished in the following order: realization of 7.7 m deep excavation; densification with heavy beetle; constructing of concrete-soil pillow and foundation on it at elevation 119.30 m. Water protection measures have been taken at the end of constructing.

Deformations from technogenetic moistening could occur only in the active zone of the foundations of buildings and structures at the regions with type I loess base. Such deformations are registered in the south part of Silistra.

The seismic influences are "operating mechanism" for occurrence of collapsibility if a technigenetic moistening of loess ground are present.

Teechnogenetic embankment. Larger part of Silistra territory is constructed on technogenetic embankments. At the towns center they reach 9 m depth. The embankment is non-girm and it performed unfavorable soil ground for foundation purposes. The embankment is flooding by the ground waters at high waters in the north part of the town. Under these circumstances building construction at the embankment results in deformation of these building. The new building construction is implemented with deep excavations. If the embankment overcoming is not possible, then a pile foundation is implemented.

Violation on the terrain from clay-pits. Deep excavating works in the southern part of the town have been done for the needs of the Bricks factory in the slope section. A vertical angle of friction is formed 25 m in height. There exists a danger from gravitational sliding down of the ground massive from the slope.

PRELIMINARY DATA FOR ENGINEERING-GEOLOGICAL DISTRICTS DEFINING

It is developed preliminary engineering-geological districts defining on the territory of Silistra based on the determined geomorphologic-lythostratigraphical, engineering-geological and hydrogeological conditions and the hazardous physicogeological processes and phenomena that are caused. We call it preliminary because it is foreseen including of new areas (West industrial zone and Kalipetrovo district), thickening of drillings and increasing the number of tested soil samples. Here are defined three districts, according to engineering-geological conditions and geodynamic processes occurrence. The districts are sub-divided into 2 or 3 sections, according to defined differences in engineering-geological varieties (Fig. 1):

I district – technogenetic, collapsible and alluvial soils

It covers the territory of the town, situated within the bounds of the low floodplain terrace. It is built of collapsible loess, technogenetic embankment and alluvial deposits. Hazardous geological processes for this district are earthquakes, loess collapsibility (type I), thick technogenetic embankments, shallow ground waters, river-bank erosion, flooding, marsh occurring and carst. Three sections are separated at district I:

Technogenetic-alluvial complex section (TAC). It is situated in the northern part of the town, at the forehead of the floodplain terrace. It is built of non-firmed technogenetic embankment up to 9 m thick and alluvial deposits (dust-sandy clays and coarse gravel with sandy filling). The ground waters are shallow and occur at 4-6 m depth. The conditions for engineer structuring are difficult in the TAC section. The foundation is realized at high depth, and in case of impossible embankment overcoming, then a pile foundation is implemented. The shallow ground waters worsen the seismic conditions.

Technogenetic-loess-alluvial complex section (TLAC). It covers the central part of the floodplain terrace. It is also built of non-firm embankment 2-7 m thick. Underneath non-collapsible loess occurs, with thickness from 3 to 9 m and alluvial deposits. Loess is in the range of subsurface waters at high water in the river Danube. It is non-collapsible under additional load. The ground water table is settled at 8-13 m depth.

Loess-alluvial complex section (LAC). It covers the back part of the floodplain terrace. The technogenetic embankment has low thickness (up to 3 m), wherefore it is does not cause problems to foundation process of buildings and constructions. The LAC section is built of collapsible loess type I (7-12 m) and alluvial deposits. The loess does not collapse under geological load and moistening. It shows collapsible properties under additional load, in the active foundation zone of buildings and constructions only. For the collapsing layer the initial collapsing load in higher than the geological load ($p_{ini}>p_Y$). Ground waters are accumulated in delluvial loess - at depth 8-13 m. In occurrence of technogenetic moisture-overladen loess ground seismic influence provoke collapse development.

II district - development of slope processes, collapsible soils type I

It covers the slanting and abrupt slope between the floodplain terrace and loess plateau. It is built of non-collapsible loess, collapsible loess type I and Pliocene sediments. Porous slope waters are accumulated at the interface. Hazardous geological processes for the II district are earthquakes, landslides, slope creeping, collapsibility, shallow groundwaters, surface erosion and violation on the geological environment from clay-pit excavations. Based on differences in the engineering-geological conditions and geodynamic processes the district is divided into two sections:

Loess-Pliocene complex section (LPC). It is situated within the bounds of slanting slope. Its surface layer is built of collapsible loess type I, 11-16 m thick. The loess do not collapse under geological load and moistening. It shows collapsible properties under additional load. The initial load for the collapsible layer is higher than the geological load ($p_{ini}>p_Y$). The loess covers Pliocene clays and sands. The ground waters occur at 5-10 m.

Pliocene complex section (PC). This is the abrupt slope section. The loess cover is thin, non-collapsible and occurs on Pliocene clays, limestone clays and sandy layers.The ground waters are accumulated at the interface. In fulfillment of constructional or excavating works exist conditions for development of shallow landslides and slope creeping occurrence.

III district - collapsible soils type II

It covers the loess plateau territory. The loess has well defined collapsible properties. The most dangerous geological processes for the district are collapsibility and earthquakes. Two sections are defined depending on the thickness of the collapsible zone:

Loess complex section (LC). The loess complex is with its full litho-stratigraphy. The thickness of the collapsible zone is 21 m. The total collapsing under geological load is up to 75 cm. The initial load for the collapsible layer is lower than the geological load ($p_{ini}<p_Y$). The indices for load-bearing will reduce three times in case of accidental moistening of the loess ground. The ground waters are accumulated above the Pliocene clays (37 m).

Reduced loess complex section (LC^I). The LC thickness is reduced. Collapsible zone is 6 - 21 m thick.

CONCLUSION

Engineering-geological conditions of the Silistra town are complicated on the average. The soil ground of the town is built of thick technogenetic embankments, collapsible loess, alluvial clays and gravel, Pliocene clays and sands and rocky underplate from Barem limestone and Alb marls. Collapsible and technogenetic soils, causing the basic difficulties in building and constructions foundation, cover the most of the studied area. The porous waters are shallow. They are accumulated in the caverns of quaternary and Pliocene deposits and additionally complicate the geotechnical conditions. The determined engineering-geological conditions combined with geomorphologic terrain particularity are precondition for occurrence of particular geodynamic processes. The territory of Silistra is endangered from endogenetic (earthquakes), exogenetic (shallow earth creeping, slope creeping, erosion of Danube riverbank, shallow ground waters, surface erosion, flooding and marsh occurrence) and technogenetic (loess soils collapse, embankment settlement, stone-pit excavations) hazardous physico-geological phenomena and processes. Based on this geological environment the territory of Silistra is divided into three engineering-geological districts, subdivided into 2 or 3 sections each.

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REINFORCED WALLS OF NATURAL REINFORCED SOIL

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ABSTRACT
When excavations are picked, especially in more depth excavations, often is necessary to reinforce the slopes. The well known technologies are applied – slurry walls, pilots, sheets, etc. In recent years another type reinforcement is being used, which consist in driving the steal rods in slopes at definite angle on determined intervals and with determined lengths. A result is a conditional reinforced wall of natural reinforced soil, which can provide considerable depths of excavations in vertical or low-pitched slopes. The theory of determination of static diagram of the walls is based on the theory of earth pressure, but with alternations that admit the specific of interaction between walls of reinforced soil and surrounding massif. The most important part of these alternations is inclusion of cohesion between soil of the wall and soil massif. This interaction is not considered in classical theory of Coulomb and leads to considerable reduction of soil pressure to values, that could be taken by the walls of reinforced soil. Assumptions and methods of determination of corrected values of earth pressure in such type walls and peculiarities of their accomplishment are given in the report.

When excavations are picked, especially excavations with greater depth, it is not always possible to carry out the reinforcement of slopes in compliance to geo-technology requirements. This applies mostly where construction in built-up city areas is performed and a number of restrictions arises, due to the existence of roads and underground communications such as water supply systems, electrical and phone cables, etc. in close proximity. An important requirement is not to disturb the transport and life cycle in the areas surrounding building sites. In all these occasions reinforcement of the slopes, especially for relatively deep hollows is needed. This reinforcement is carried out by well-known technologies such as slurry walls, pilots (usually borehole), short passive or deep pre-stressed anchors, sheets, etc. In recent years a new type of reinforcement, comprising of driving steel rods with a certain length into slopes at defined intervals, is implemented (fig. 1). As a result a conditional reinforced wall of natural reinforced soil, which can provide for considerable depth of excavations in vertical or light slopes is created.

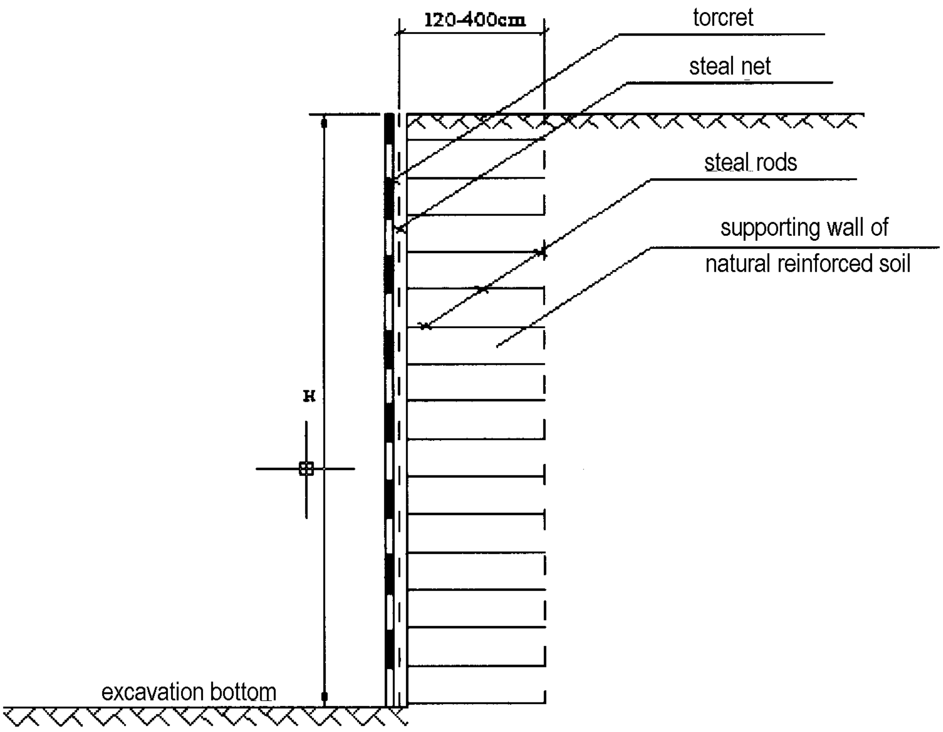

Fig. 1

The theory for determination of the static diagram of such walls of natural reinforced soil is based on the earth pressure theory, but with alternations, taking into consideration the specific character of the interaction between reinforced soil walls and the surrounding massif. An essential part of these alternations is the provision for of cohesion between the soil of the thus constructed walls and the rest of the soil massif. This interaction is not accounted for in Coulomb's classical theory and leads to significant reduction in the soil pressure quantity to a value that could be supported by reinforced soil walls.

In the classical theory on earth pressure, created by Coulomb (in 1773), and prerequisites sufficiently quoted in specialised literature, /the soil volumetric mass and the internal friction angle are homogeneous, earth pressure is a result of the soil wedge sliding along the plane, the bridging over the shearing strength takes place simultaneously along the entire failure plane, and there is no soil cohesion/ (fig.2), earth pressure is calculated by dependence [1]:

$$E = \frac{G \sin(\upsilon_a - \varphi)}{\sin(\theta + \delta + \varphi - \upsilon_a)} \tag{1}$$

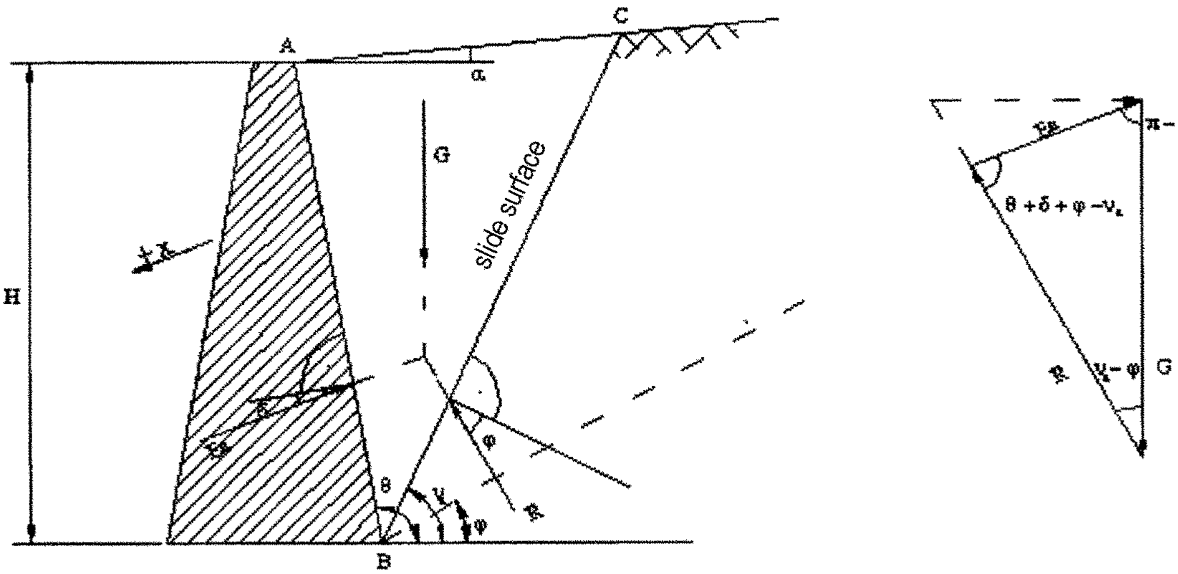

Fig. 2 Calculation scheme of the active earth pressure

The meaning of separate values is presented in the figure.

One of the essential problems is related to determination of the slope angle of the sliding surface - ν_a. According to theory this angle is determined by the condition for obtaining the peak of active earth pressure, an element of the theory for peak value of a function. Following performance of the specific operations, which shall not be subject of this study, an angle value ν_a is reached. It is a complex function of ground slope's angle, the wall's rise, the angle of the soil's internal friction and the friction angle between wall and soil [1]. By substitution of the value reached for ν_a by formula (1), the final value of the earth pressure E_a is calculated.

In dimensioning the scale of reinforcing constructions of excavations of significant depth, dependencies are reduces by admitting for horizontal ground and vertical back wall of the reinforcing works - α=0, θ=π/2. In more accurate calculations the angle of friction between wall and soil - δ is accounted for, and in some more specific cases – the rise of the back of the wall $\theta \neq \pi 2$ is also accounted for. In analytical expressions for determining the horizontal component of active earth pressure the following formula is applied:

$$E_a = ½.\gamma.H^2 \tag{2}$$

Where: γ is the average volumetric mass of soil in the soil wedge sliding along the sliding surface, H is the wall height, and K_a is the side earth pressure factor. K_a is calculated by formulas, presented in specialized literature, such as formula [1].

In more typical cases the inclusion of friction between soil and wall may lead to a reduction of earth pressure by 20 or more than 20 %. If this friction, as well as the influence of the back of the wall's rise are disregarded, as is the normal practice in construction, the formula for calculation of the side earth pressure factor is reduced and the classical type of Rankin's minimum state of tension is reached:

$$K_a = tg^2\left(45 - \frac{\varphi}{2}\right) \tag{3}$$

Cohesion is not included in all the above mentioned formulas. The cohesion influence is taken in consideration also on the basis of Rankin's state of tension, where the constant speed P_c is eliminated from the earth pressure diagram:

$$P_c = 2c\sqrt{K_a} \tag{4}$$

Cohesion, despite its changing value, has a significant influence on earth pressure, therefore it should be accounted for, especially for temporary constructions, such as reinforcing constructions of excavations of greater depth, because following construction of the underground parts of buildings their interaction in the static diagram of buildings is usually disregarded. Cohesion may be directly accounted for in the earth pressure values by directly including its interaction in the sliding surface of the soil wedge. In the case of reinforced walls of natural soil, the cohesion influence may be taken into consideration also in the interaction between wall and soil, because for such walls, due to their nature, there is always adhesion between conditional reinforced soil wall and the rest of the soil massif.

In order to account for this influence, the force triangle in fig. 2 is considered. The effect of tilting earth pressure to the angle of friction between soil and wall may be accounted for approximately by the figure, where its vector is determined to be horizontal. If the cohesion action is included, which has not been done previously, another force, that is approximately vertical and for one linear meter of the wall length has a value of:

$$C = cH \qquad (5)$$

should be included in the force triangle, where c is the cohesion value, and H is the wall height. The inclusion of the force C may be synonymous, due to the fact that the direction of the force R is known, as well as the direction of the earth pressure E_a. Following recording of the force C, the force polygon is of the type presented in fig.3. Obviously this leads to significant reduction of earth pressure and this fact makes it possible to understand the way walls thick 1.2 m to 2.0 m may hold in vertical slopes with a height of up to 7 – 8 m.

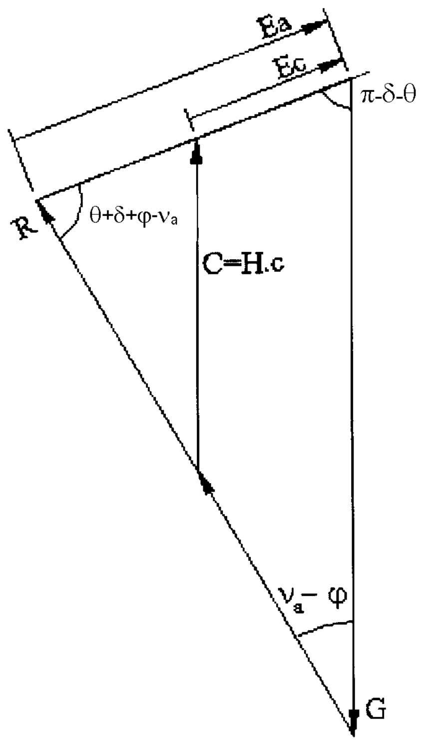

Fig. 3

The determination of the new corrected value of earth pressure may be carried out by general dependencies, known from trigonometry, by using all other dependencies and quantities, known from classic solutions. By applying the prerequisite that forces G and C are parallel, where the backs of walls are vertical and approximately parallel in all other cases, the dependencies for similar triangles, presented in fig.3, may be applied. The weight of soil prism G is easy to calculate due to the fact that the slope angle of the sliding surface is known. The value of earth pressure is also calculated by classic methods. The corrected value of the earth pressure by including the action of soil cohesion in the back surface of the soil wall E_c is calculated by the equation:

$$\frac{cH}{G} = \frac{E_a - E_C}{E_a} \qquad (6)$$

Or more clearly, the value of E_c may be calculated by the formula:

$$E_C = E_a\left(1 - \frac{cH}{G}\right) \qquad (7)$$

Following reduction, the formula may be presented as:

$$E_C = E_a K_c \qquad (8)$$

where K_c may be defined as factor of reduction of earth pressure by reporting cohesion between the reinforced soil wall and the surrounding ground. This factor is in all cases lower than 1. An additional prerequisite is $c.H \le G$.

This formula can be applied for all cases of earth pressure, for random values of the quantities, included in the formulas for its determination. The question for additional inclusion of cohesion, in compliance to Rankin's postulates, by elimination of the value of P_c from the earth pressure diagram determined by formula (4), still poses a problem. It is based on the same reasoning, as the basis for its performance, independent of the reading of the angle of friction between the soil and the reinforced wall.

The effect of inclusion of cohesion between soil massif and the wall of natural reinforced soil may be easily determined. This determination is carried out by implementing the most widely used of Rankin's examples for determination of earth pressure under the condition that the back of the wall is vertical, the ground is horizontal and the friction angle between soil and wall is $\delta = 0$. In this case the sliding surface of the soil wedge is rising to the horizon under an angle of $\upsilon_a = \frac{\pi}{4} + \frac{\varphi}{2}$, the weight of the soil prism is, as follows:

$$G = 1/2H^2\gamma tg\left(\frac{\pi}{4} - \frac{\varphi}{2}\right) \qquad (9)$$

and the active earth pressure E_a is calculated by the formula:

$$E_a = 1/2\gamma H^2 tg^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right) \qquad (10)$$

The factor of reduction of earth pressure as a result of reporting the cohesion between wall and soil shall be:

$$K_c = 1 - \frac{2c}{\gamma H tg^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right)} \qquad (11)$$

Numeric example:

Determine the earth pressure on a wall of natural reinforced soil using the following values:

Excavation depth (height of slope)	H=6 m
Angle of internal friction of the soil	φ=22°
Soil cohesion	c=15 kPa
Volumetric mass of the soil	γ=20 kN/m^3

The earth pressure, determined by the classic method shall be:

$$E_a = 1/2.20.6^2\, tg^2\left(45 - \frac{22}{2}\right) = 163,79 \text{ kN/m}$$

The factor of reduction of earth pressure, as a result of reporting the cohesion between soil and wall shall be, as follows:

$$K_c = 1 - \frac{2.15}{20.6.tg^2\left(45 - \frac{22}{2}\right)} = 0,45$$

The corrected value of earth pressure is as follows:

E_c = 163,79.0,45 = 73,7 kN/m

The reduction of earth pressure is 55%, which is significant.

In other cases this reduction may be different, but most often it is significant, as may be seen from the numeric example. In all cases the solving must be carried out carefully, using reduced cohesion values, for example reduced 2 – 2.5 times, in order not to calculate a drastic and unrealistic value of the corrected earth pressure, despite the correct postulate of the theoretical solution.

After calculation of the earth pressure, the same procedure shall be followed in the dimensioning of the reinforced wall, as with all other walls. The diagram of earth pressure shall be constructed, reduction as a result of the cohesion action – Rankin's example and control of the wall for tensions in the base plane, sliding and conversion shall be used.

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GEOECOLOGICAL RISK OF EROSION PROCESSES IN THE BULGARIAN PART OF THE DANUBE

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ABSTRACT

The river bad is subject of permanent reversible and not reversible changes in nature conditions. The reversible deformations depend on the nature of the river flow and opportunity to support correspondence between quantity of moving sediments, transport capacity of the river flow and granulometric contents of the river bad sediments.

The not reversible deformations in the upper part of the river flow are manifested in river bad erosion, and in the low part of the river flow – in sediment accumulation.On the base of multiple studies are determined the "critical section" of Bulgarian part of Dunabe river. The analyze of the existing erosion processes in Danube River shows that it is necessary to be done a systematical study works and full mapping

The erosion processes in Dunabe River are element of the river bad processes. In this report we do not discuss the Dunabe River hydrological regime in our section. The existing observations clearly show that the period of reduced river flow depending most of all from the global planet warming up. The changes of river bad processes during last years in terms of erosion increasing are caused by setting up of hydrotechnical junctions "Jelezni vrata 1 and 2". These facilities detain huge quantity moving sediments and almost all river bad sediments. This is the reason for increasing of river bad erosion and riverbanks erosion. The river bad processes in Bulgarian section had been object of repeatedly studies. The first study made comparison of the existing maps from 1908, 1936 and 1966. This study gives the erosion processes in nature conditions.

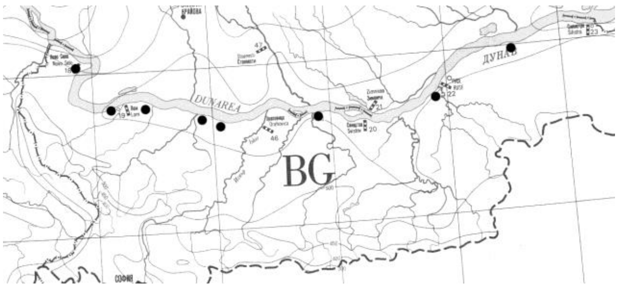

Figure 1. Risk points in the Bulgarian part of the Danube river

Later were made studies for river bad erosion processes by General Staff ,Troian and Russe and Transproekt /1998/.

On the base of this information are determined the following "critical sections":

803 – 805 /Timok – Slanotran/ – the river bank is stable – the bad is eroded and "paved" - as far as fine river bad sediments are taken out and only the bigger sediments are remained. There is riverbank erosion where the riverbank is composed of clay fractions.

803 – 791 /Slanotran – Vidin/ The section is before Vidin' valley. The erosion processes affecting the river bad and bank continue. Considerable quantities of filling agents are taken out. First critical section required protecting facilities and detailed observations.

791 – 723 /Vidin – Staneva/. From km 789 – 770 existing some erosion. From 776 – 774 the river bank erosion is strong and have to be made detailed observations and some protection.

723 –713 /Stanevo – G. Tziber/. This is a critical section according to all indexes. The section borders on danger river bank landslides / 715 km/. This is the second critical section who required strengthening.

713 – 634 /G. Tzibar – Iskar/. In section 657 – 655 exists strong erosion. There is erosion in some sub-sections too. Additional studies have to be made.

634 – 604 /Iskar – Olt/ This section is before Karaboazka vaelly. There are several sections with comparatively light erosion and one section /609 km/ with strong erosion. This section is with active River bank erosion. There is river shoots in km 616, where dragged activities are made. This is the third critical section, requiring engineer protection.

604 – 540 /Olt – Yantra/. Here in the past was marked active erosion. Now the active erosion is observed in section 567 – 559 /in section of shoots Belene II/.

540 – 530 /Yantra – Batin/. The erosion exists from km 539 – 537. This is fourth critical section. The strengthening activities were made from "Transproekt'.

530 – 489 /Batin – Russe/. The river bank is stable.

489 – 479 /Ruse – Sandrovo/. There are active river bad processes. Regardless of the strengthening measures in Marten, the river bank erosion is observed in km 487 – 484. This is the fifth critical section. In all sections have to be made additionally studies. There are some measures taken by Romanian part /shoots in channel of island Marten, steering facilities before Gjurgevo bridge and ets./.

479 – 457 /Sandrovo – Oriahovo/. The section is before Brashlanska vaelly. The erosion in this section is not very well studied.

457 – 438 /Oriahovo – Tutrakan/ - The sixth critical section. The midstream is changed his position around the islands Goliam Brashlian and Vajetaria. Supporting of both shoots impact to the river bad processes.

438 – 408 /Tutrakan – Popina/. Data show active erosion. An additional study is necessary.

408- 398 /Popina – Vetren/. Seventh critical section. The location of midstream, the existing of river shoots and geological type of river bad create conditions for active erosion. The engineer protection here is indispensable.

398 – 375 /Vetren – Silistra/. Eight critical region from 391 – 382 km. The section has to be studied and the dynamic of the processes should be seen.

The river bad is subject of permanent reversible and not reversible changes in nature conditions. The reversible deformations depend on the nature of the river flow and opportunity to support correspondence between quantity of moving sediments, transport capacity of the river flow and granulometric contents of the river bad sediments.

The not reversible deformations in the upper part of the river flow are manifested in river bad erosion, and in the low part of the river flow – in sediment accumulation.

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On the base of multiple studies are determined the “critical section” of Bulgarian part of Dunabe river. The analyze of the existing erosion processes in Danube River shows that it is necessary to be done a systematical study works and full mapping, together with Romania for our part of Danube river

The study on the river flow and comparison of the new mapping with the existing has to be made. Only such kind of approach may give an security for the necessary measures for protection of river bank and river bad. Such mapping is necessary as well for determining the river midstream and boundary line between Bulgaria and Romania. The fourth mapping documents for Dunabe river is being late. The new bridge “Danube 2” may create some problems without existing of such kind of documents. We have not forgotten, that the biggest changes in Danube river in our section are after the Danube bridge I.

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PECULIARITIES IN THE BLACK SEA WATER QUALITY FORMATION AROUND THE SOZOPOL BAY AND STRANDJA REGION

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ABSTRACT
The water volume of the Black Sea is formed by continental water, precipitations and water from the Seas of Marmora and Azov. Among the continental fresh waters the most significant are the rivers Danube, Dneper, Dnester and Buk. 70% from the all water discharge inflowing into the sea is from the Danube river catchment area. Southward the Sozopol town the rivers Ropotamo, Diavolska and Veleka rivers register some local influence on the shore water. The assessment of the Black Sea water quality is done on the base of hydrographic, geological and hydrochemical characteristics of the studied region. The geological structure of the shore part is examined, especially in the region of the mouths of the main rivers. The water quality in the shore part is estimated. The assessment is carried out according the main standard water quality parameters concerning the oxygen regime, organic pollution, mineral content (including salinity), biogenic elements.

CHARACTERISTICS OF THE REGION

The water volume of the Black Sea is formed by continental water, and water from the Seas of Marmora and Azov. Among the continental waters the most significant are the rivers Danube, Dnester and Buk. 70% from the whole water discharge that flows into the sea is formed by the Danube river. Regarding the interaction between the shore and sea waters at the Bulgarian part some quantitative idea gives the annual discharge of the Bulgarian Black sea rivers which now is about 2 km^3 yearly. More than one third of it is from the Kamchia river. The seawater inflow into the oversalted lakes is about 0,3 km^3 yearly. The seawaters that enter the limans and the mouth parts of the river basically are flowing back into the sea. The direct industrial input in the Bulgarian southern part of the Black Sea has a small quantity, but shows a certain influence of the quality of the sea water in the regions close to the river mouths. The influence of the Bulgarian shore waters to the waters of the Black Sea has a local character- mostly in the mouths of the bigger rivers and in the gulfs, because the total length of the Bulgarian seashores about 9% of the seashore of the Black sea and the water discharge from the rivers inflowing from Bulgarian territory is 0,7% from the water discharge of all Back Sea tributaries.

The salinity of the Black Sea water in this region is 17-18 ‰. The specific hydrological regime forms two basic layers – upper (shallow) with dept of 150-180 meters, which contains the poisonous gas, which is deprived from any living organisms. The full exchange of the seawaters is performed for 590 years.

In the ecological condition of the Black Sea there are four periods, which are characterized with considerable modifications in its hydro-chemical regime.

◄ 1st period of comparatively clean sea (up to 1965)
◄ 2nd period of the gradual accumulation of the contamination of organic and inorganic origin (from 1065-1972)
◄ 3rd period of intensive eutrofication (1973-1999)
◄ 4th period of slow rehabilitation (after 1991)

CHEMICAL COMPOSITION

The information about the chemical composition of the shore waters in the Sozopol gulf and the Strangian seacoast is from the regional chemical lab of NIMH -BAS based in Burgas town. The information, which is used, is from expedition results for the period of May 1999 up to October 2002. The samples are taken from docks at about 30 m distance from the seashore and are current about the condition of the seawaters in the region.

Main ions

The main ions of which depends the level of salinity are the (Cl^-), (SO_4^{2-}), (HCO_3^-), (Na^{2+}), (Mg^{2+}), (Ca^{2+}), (K^+). The alterations of these ions concentrations for the period 1999-2002 for the months May - October are shown in the figures 1, 2, 3, 4.

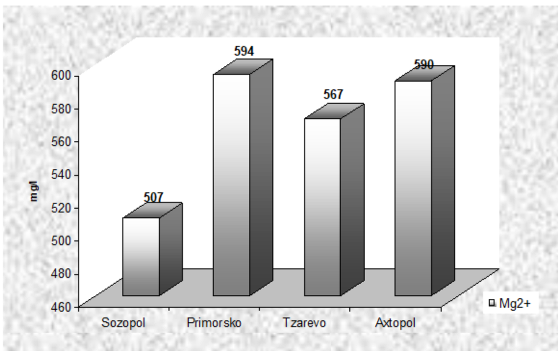

Figure 1. The alteration of concentrations of Mg^{2+} ion for the period May-October 1999–2002.

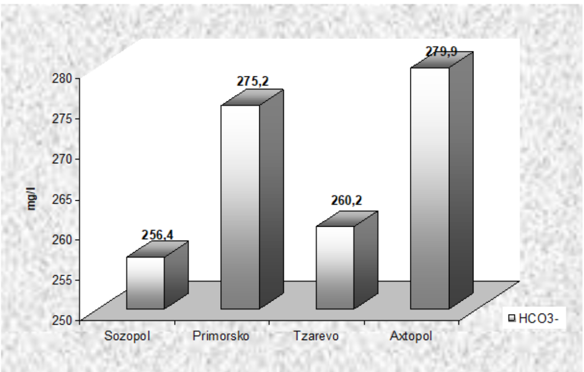

Figure 2. The alteration of concentrations of HCO_3^- ion for the period May-October 1999–2002.

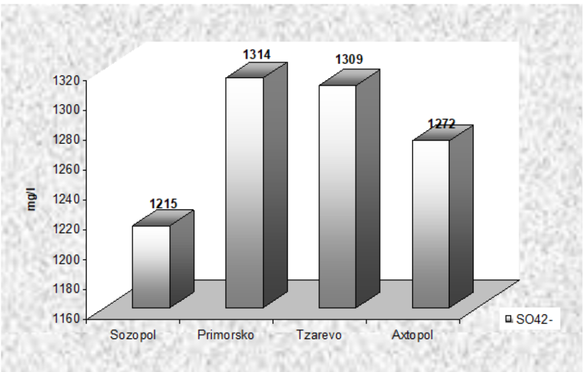

Figure 3. The alteration of concentrations of SO_4^{2-} ions for the period May-October 1999–2002.

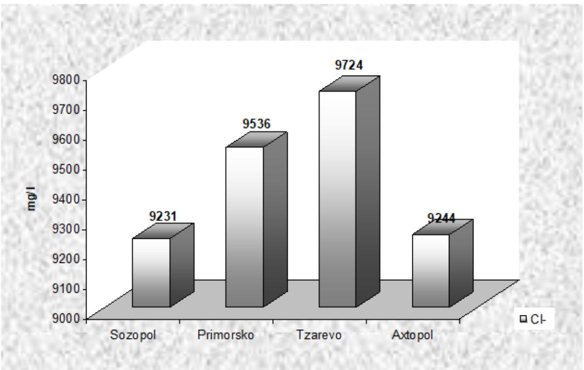

Figure 4. The alteration of concentrations of Cl^- ion for the period May-October 1999–2002.

Biogenic elements

The biogenic elements are of big importance to every ecosystem. The variability of biogenic elements concentrations is shown in table 1.

Table 1. The biogenic elements concentration variability for the summer months for the period 1999-2002

Element	concentrations, mg/l	
	Max	min
NO_3	0.803	0.00
NO_2	0.800	0.00
PO_4	0.660	0.12

Indicators for the oxygen regime

Dissolved oxygen (O_2). The alteration of the concentrations of this important parameter is shown in figure 5.

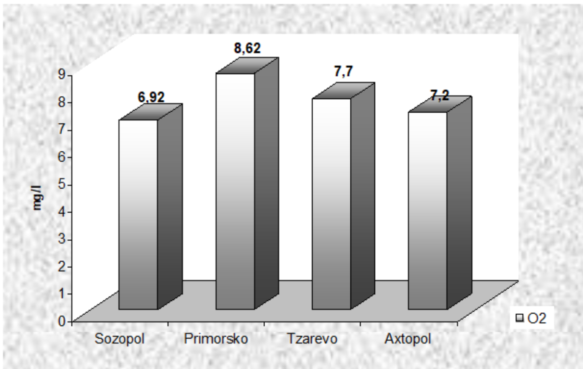

Figure 5. The alteration of concentrations of dissolved oxygen for the period May-October 1999–2002.

Oxidation. The average values of permanganate oxidation in the Sozopol gulf and the Strangian seacoast are shown in figure 6.

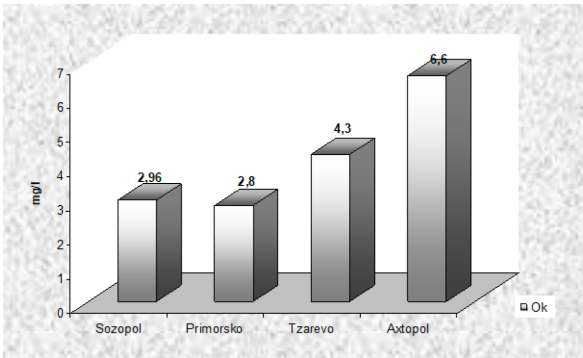

Fig. 6. The alteration of permanganate oxidation for the period May-October 1999–2002.

On the base of the gathered information for the quality of the Black sea waters to the south of Sozopol town, near Bulgarian Turkish boundary we may conclude that waters in this region are not contaminated. The rivers that flow into the sea are the Diavolska river, Ropotamo river and Veleka river. Their role in the forming the Black Sea water chemical composition is small and has a local character. It is of big importance to continue the quality control activities concerning inflowing industrial and domestic water.

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ECOLOGICAL RATING OF GEOCHEMICAL ANOMALIES (RESEARCH, CRITERION OF A RATING, ECOLOGICALLY-GEOLOGICAL MAPPING)

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The region of researches is dated for the maiden patch of the Crimean Mountains (Eastern Crimea). Pursuant to the biogeochemical geographical demarcation the given terrain falls into to the Crimea-Caucasian mountain zone [3].

The detail researches are made in a field season of 2003 year in limits of Sudak synclinorium (Eastern Crimea). The structure of Sudak´s synclinorium is derivated potent (not less than 3500—4000 m), strata Bathonian, Callovian, Oxfordian, Kimmeridgian and Titonian structural stages (more ancient deposits not eroded). A composition of deposits participating in a constitution of synclinorium, basically terrigene-clay (often these deposits have nature of flysch). In a constitution of a western part of synclinorium the relevant role belongs to to reef massive limestones of oxford, and in Toklucs range and on a peninsula of Meganomas — of Titonian´s conglomerates. Fissile neotectonical raising predetermine vigorous erosion, geologic youth of landscapes [1, 6].

Characteristic of the given terrain is the underdeveloped edaphic profile, prevail soils of rock debris referred. Specifity of mountain terrains is the high power engineering of a relief conditioned its strong ruggedness, large difference of altitudes, that slows down intensity of pedogenic processes [2].

The vegetation is scanty, herbage prevails with mean density of projective cover less than 50 %. Arbors and the bushes have focal distribution. On declines of mountains grows more often stunted shiblyak. The repeated attempts of simulated landings of pines on declines of mountains have failed. The researches of scientists, conducted on the initiative Sudak´s silvics have shown, absence of the depredators, both in an assemblage of rootlets of arbors, and in stock part of plantations.

In this connection by the purpose of researches was the analysis of a spectrum ecologically-geochemical of the factors conditioning depressing of phytocenosises as a whole and the arboreal forms of plants personally.

For achievement of an object in view a number of problems is resolved:

1) In a field season of 2003 year in limits of Sudak´s synclinorium are made complex test of a system: "rocks - soil-vegetation";

2) In cameral season is carried out quantifying a humus in soils (on a Tyurin´s method);

3) The contents of carbonates in soils, degree them salinity is determined, is studied грансостав (on standard methods);

4) In rocks, soils, green on the basis of semiquantitative spectral analysis the contents of a number biophil elements and elements of 1-3 classes of rick is estimated.

As a whole migration is characteristic gentle for the nature of Crimea at outwash of soils. Elements of accumulation in a landscape are Cs, Cr, Co, Ag, Sr. To category of technogenic elements collecting in landscapes, concern Be, Ni and Cr.

The chemical barriers in the data landscapes are expressed is gentle, the major value among them has a biogeochemical barrier - accumulation of trace substances in humic horizon. The smaller role is played sorbate by a barrier.

The biological reactions, reference for the given region are miscellaneous and are determined by mutable concentration and ratio of many chemical elements, lack of iodine (95%) and sometimes by lack of a cobalt (31%), copper (28%), zinc (24%), excess in some cases of molybdenum, cobalt, copper, lead, zinc, strontium and other chemical elements [3]. The excess entails any of a chemical member in biogeocenose of a different kind morphological and physiological deviations in development of alive organisms including for plants.

Within the limits of an studied standard site in field routes changes for arbors repeatedly were fixed. For pages of an ouk were watched spots of chloroz, the needle of pines had yellow tint.

The key sites are dated for regions of development of rocks of a different structure and age. 40 key sites in general were gobed up, from which one 144 samples on lithogeochemical and biogeochemical researches [4, 5, 7] are selected.

The analysis of a degree of security of soils by a humus has shown, that within the limits of a mining part the majority of the studied edaphic differences are characterized under the contents of a humus as not sufficial provided, the exception is made by soils of apron plains and girders, it is conventional - used for an agricultural production.

The degree of soils salinity is in direct relation to remoteness from the sea. To a category very much hardly - salt (8.7 %) are referred soils the peninsulas, selected from coast of Meganomas (50 m from a water boundary).

The analysis of distribution of trace substances in rocks, soils and green has shown their close intercoupling, that visually it is visible on fig. 1.1.-1.3.

The confrontation of the obtained data on a microelement structure of soils with a clarke of rock sphere, has shown, that the oxford limestones contain in a condition of dissipation, i.e. the clarke of concentration is lower 1.

In concentrations near the clark the members in Callovian and Kimmeridgian sandstones and titon conglomerates (fig.2.2) are contained, exception make lead, chromium, vanadium having spacecrafts > 1.

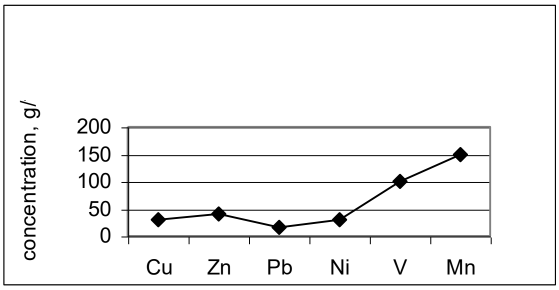

Figure 1.1. Content of microelements in Callovian sandstones, point 6.

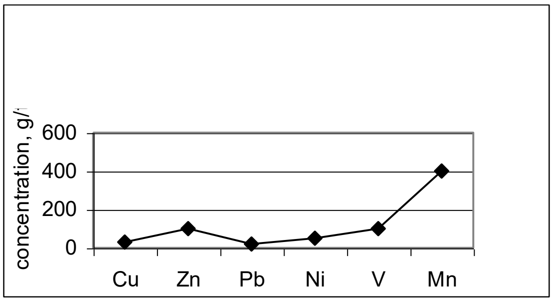

Figure 1.2. Content of microelements in soil, point 6

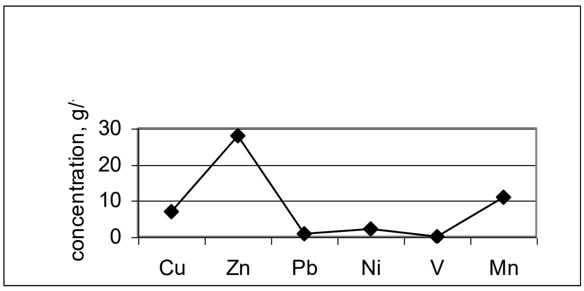

Figure 1.3. Content of microelements in foliage of oak, point 6

The maximum values of clarkes of concentrations of the spacecraft > 1 have titon sandstones, Kimmeridgian and Barremian-Aptian clays for copper, zinc, lead, nickel, cobalt, chromium, vanadium and molybdenum.

As it is visible from the data presented on figures 1.2, 2.2. in soils of general tendencies are inherited from a structure of pedogenic rocks, that is conditioned by low power of an edaphic cover, gentle intensity of processes of pedogenesis, low contents of a humus.

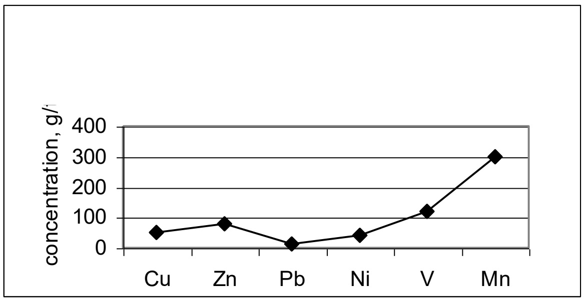

Figure 2.1. Content of microelements in Titonian conglomerates, point 11

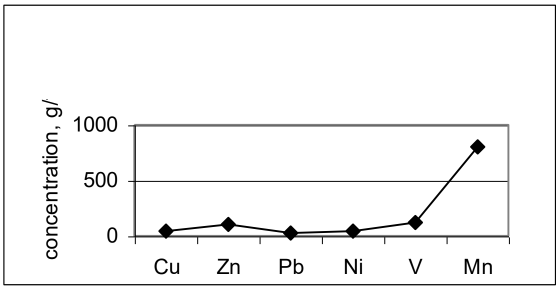

Figure 2.2. Content of microelements in soil, point 11

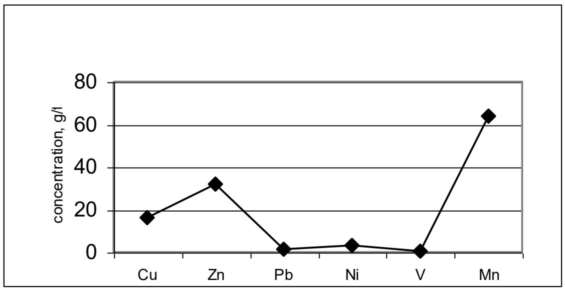

Figure 2.3. Content of microelements in foliage of oak, point 11

In a collocation of information of a microelement structure of soils with values of maximum allowable concentrations (MAC), the factors of concentrations on MAC (Kmac) were counted. The estimation of a category of pollution of soils was executed with allowance for of class of danger of a chemical element.
The general tendency of the heightened contents in soils of association from three members is detected: a nickel, cobalt, chromium.

In soils developed above Titonian sandstones and conglomerates, and Kimmeridgian sandstones and clays paddingly capture heightened concentrations of cuprum and zinc. On set of the obtained data the majority studied is model from key sites 1-3 classes of danger are referred to a category moderately dangerously - contaminated by elements.

On technogenic landscapes in a structure of bottom sediments the intensive accumulation - zinc and nickel is captured.

As it is visible from the presented data (fig.1.3; 2.3) in pages of arbors of general regularity of distribution of members detected in lithogenic substratum, are inherited and in a structure of green. That in a complex with the low contents of a humus, heightened contents toxicants in soils and pedogenic rocks, alongside with the detected tendencies to a salification of soils and in a complex instigates depressing the arboreal forms.

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HYDRO CHEMICAL REGIME OF THE KARST SPRINGS ON THE MOUNT SUVA PLANINA IN EAST SERBIA

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ABSTRACT
The paper presents the results of the research of physical-chemical properties of groundwater from karst aquifer formed within the carbonate rock complex of the massif Suva Planina. Groundwater from this aquifer is drained through powerful karst springs that appear on the hillsides of the massif. With regard to geology, researched area distinguishes with compound geological fabric and compound tectonic relations that predisposed certain hydrogeological properties of the terrain.
Key words: massif, karst, aquifer, chemism

INTRODUCTION

Suva Planina belongs to mountainous area of southern Serbia. With the altitude over 1800 m.a.s.l., it is one of the highest mountains in this area. It is characterized with indented relief, distinguished erosion processes that are conditioned by geological feature of the terrain. It is surrounded by Zaplanje`s and Koritnicko-Babusnica`s depressions along which flow the Koritnica and the Luznica. The altitudes of these depressions range between 400 and 500 m.a.s.l. Apart from some local roads Suva Planina is hardly passable (figure 1).

Figure 1. The landscape of Suva Planina

Basic Geologic-Tectonic Properties of the Terrain

The area of Suva Planina distinguishes with compound geological fabric and compound tectonic relations. Rock complex from Paleozoic distinguishes as the oldest litho-stratigraphic unit. It is represented by the series of schists, conglomerate, sandstone, diabase, sillstone, and chales. Rock complex from Mesozoic is represented by Triassic, Jurassic, and Cretaceous. The most prevailing are Cretaceous sediments. They consist of rock complex made of limestone, and dolomite as well as of flysch series made of conglomerate, sandstone, and sillstone. Jurassic sediments are much more spread than Triassic ones, especially in the region of both anticlines of Suva Planina. They are represented by heterogeneous clastics sediments and carbonate sediments. Triassic sediments occupy little space and are discovered only on the wings of anticlines of the mountain. They are represented by conglomerate, sandstone and limestone. Hillsides of the massif are made of Neogenic strata such as Paleocene, Miocene and Pliocene sediments. Zaplanje`s and Korito-Babusnica`s depressions are made of this complex, which consists of send, clay, pebble, marl, conglomerate and sandstone. With regard to the tectonics, the massif distinguishes with compound tectonic relationships that are characterized with numerous faults of different directions of ranging. The dominant structural form is the anticline that ranges from northeast towards southeast. Its length along the axis amounts 30 km. All the same, it is one of the longest anticlines in eastern Serbia. Its core is made of formations from Paleozoic of middle Jurassic, while its wings are made of formations from upper Jurassic and lower Cretaceous. Overall, it is deformed by longitudinal and lateral faults. Regarding geotectonics, the area of Suva Planina belongs mostly to Carpathian-Balkan range and partly to Rodop i.e. Serbian-Macedonian mass made of crystal schist.

Hydrogeological Properties of the Terrain

Basic rock complex of Suva Planina is made of carbonate complex of Jurassic and Cretaceous ages, which is mostly tectonically damaged. All the same, from the aspect of drainage and accumulation of groundwaters, it is the most significant complex. It is taken by deep processes of karstification resulting in the dissolution fracture porosity formed within. Such intensively developed system of porosity enables forming of one powerful karst aquifer with significant amounts of groundwaters. The resources of these waters are in function of hydrological agency, which affects the regime of their effluence. According to the data from the nearest meteorological station, middle term average precipitation for this area amounts 850 mm. Precipitations infiltrate over the whole surface of the massif, whic hrepresents one open hydrogeological structure providing good conditions for water exchange. In this way are formed dynamic reserves whose intensities of effluence are the greatest in spring and autumn. The occurrences of springs are bound to the lowest erosion parts of the terrain and they appear on the contact of water permeable karst and water impermeable nonkarst rock complexes. In this case, it applies to flisch complex from Paleozoic or Neogene that are predisposed by certain structural elements, first by faults along which appeared effluence of the ground flow (figure 2). The strongest drainage of the karst massif of Suva Planina generates through the springs Mokra, Divljana and Ljuberadja. Their middle term average discharge amounts 0.4 – 0.9 m^3/s. With regard to the way of emerging, they are of spillway type. When solving the problem of municipal water supply these springs are of extraordinary significance.

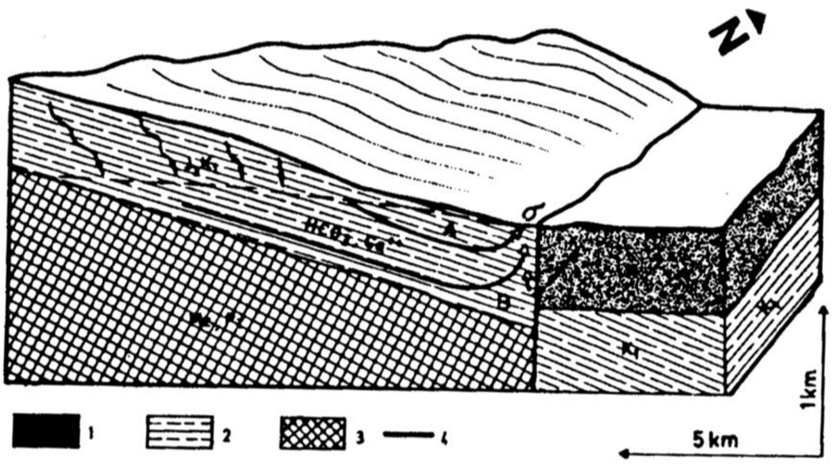

Figure 2. Hydrogeological model of the area

Physical – Chemical Properties of the Waters from Karst Springs and Their Regime

Researches of physical- chemical properties of the waters from karst springs were carried out at the springs Mokra, Divljana and Ljuberadja. Their sum results during one hydrogeological year are shown in semi-logarithm diagram (figure 3). According to the content of anions and cations (table 1), analyzed waters from these springs belong to HCO_3-Ca type of water which refers to already presented conclusion that they are formed in carbonate rock complex (figure 4). Their temperature regime is unstable and is liable to seasonal changes. Average annual temperature of the water amounts 11.4 – 15.2°C at the air temperature of 11 – 17.5°C. Such a temperature ratio points out the existence of deeper shallow waterbearing layers of the aquifer within the frames of faster and weaker water exchange.

According to the content of Ph ions which amounts 7.3 – 7.4, the waters from analyzed springs are of neutral character. Evaluated E.C. is 385 – 404 s/cm, while Eh is 452 – 487 mV. The content of dissolved O_2 is 8.4 – 10.2 mg/l. According to the degree of hardness, which amounts 12.6 – 15 dH, these waters belong to very hard waters (after Klut). As for other chemical elements, heavy metals were followed and only Cu and Zn were registered in traces. The content of organic ingredients was registered in negligible concentration, which characterizes very pure waters. Carried out analyzes and followed chemical regime of mentioned springs clearly point out that waters from these karst springs can be utilized for municipal water supply of population and settlements that gravitate in this area. All the same, they can be bottled as natural stone waters. Their ecological environment proved such a statement.

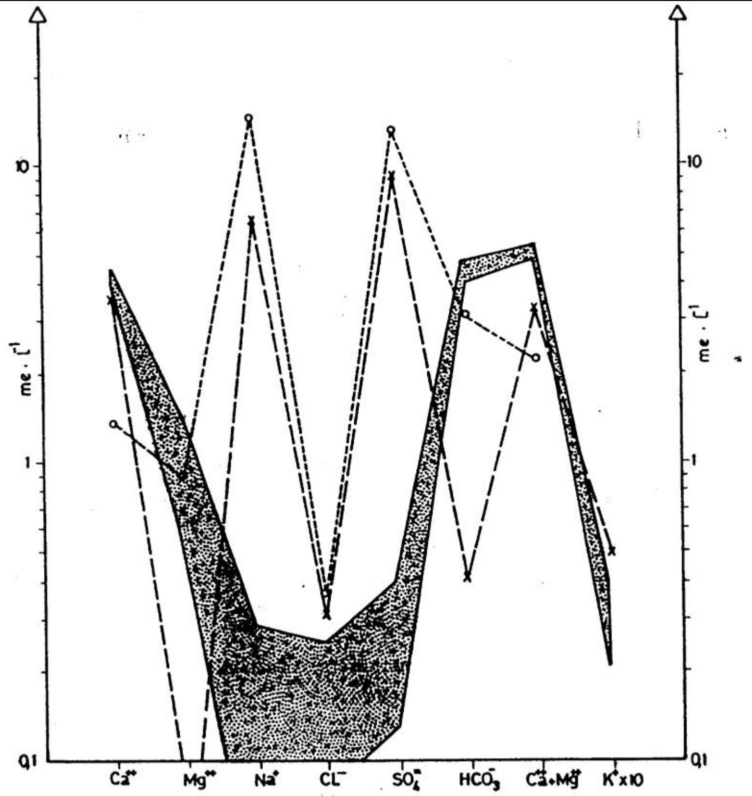

Figure 3. Semi-logarithmic diagram of hydrochemical analyses of karst springs: Mokra, Divljana and Ljuberadja

Table 1. The content of the anions and cations in karst springs (mg/l)

Spring	HCO_3	Cl	SO_4	Ca	Mg	K	Na
Mokra	335.3	5.2	10.7	90.5	7.0	0.7	3.2
Divljana	291.0	3.5	8.4	85.0	5.3	0.7	1.2
Ljuberadja	337.3	5.3	12.8	91.4	8.3	0.7	5.2

Figure 4. The rock complex of Suva Planina

CONCLUSION

Karst aquifers of the massif Suva Planina represent an accumulation of groundwaters whose reserves incessantly recharge. It empties through springs and wells that exist at the bottom of the Massif. One-year research of the quality of chosen springs proved that the quality of their waters was very suitable for human's utilization, which is contributed by ecologically saved environment.

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RESULTS OBTAINED IN SOME AGRO SYSTEMS ESTABLISHED ON DAMAGED SOIL FROM ROVINARI MINING ZONE

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ABSTRACT
This study presents the production result obtained in some agro systems established on degraded soil from Rovinari mining zone in a period of 25 years. From obtained results we can take the conclusions that on degraded soil from waste dump we can create diversified cultivations which normal productions with condition to assure a agronomic background in concordance with cultivation species, in special fertilizer manure and increased dose of N, P, K. the best results are obtained on trees, vine, pea, oat, maize and forage cultivations.

1. THE RESEARCH PURPOSE

An important aspect of ecological balance deterioration is soil pollution. One of the most aggressive forms of soil destruction is the damage made by the surface mining activity.

As a result of coal exploitation the ecological balance is highly affected by the ground water layer modification, the mix of different geological layers, natural migration of chemical elements into the depth, the acceleration of soil erosion, destruction of micro flora and organic matter (Humus) from soil, in fact the destruction of the most important property of the soil: natural fertility.

Soils recovered after surface coal exploitation and biological recultivation, are called by some authors "Technologically created soils".

The purpose of the researches made by SCPP TG-JIU, started in 1969 on technological created soil from Rovinari Mining Zone, is to reinsert the area into agricultural use – ecological and economical speaking.

2. LOCATION AND CONDITIONS OF THE RESEARCH

The experiments were carried on technologically created soil from Rovinari Mining Zone, more precise at Cicani waste dump. The area reserved for the experiment, consist of a heterogeneous mixture of sand, clay, gravel, coal, with poor physical, chemical and biological properties, as a result of dumped earth found between layers of coal.

3. STUDIED FACTORS

Studied factors are the ones mentioned in the lower tables and they represent a collection of results on a period of 25 years, starting with 1971-1972, with biological and production data obtained in studied agro systems – vine, apple trees, plum trees, cherry trees, nut trees, hazel nut trees and cereals, established on technologically created soil.

RESULTS OBTAINED

4.1. Fruit trees

4.1.1. Tests on tree species. Along the years a great number of species had been tested: apples, plums, cherries, hazels and nuts.

Trees were planted in 1970-1971. They had been treated in normal conditions. We have gathered the results on a period of 25 years in table No.1.

From that data we can see that the apple trees with a production of 24,9 t/he and the plum trees with a production of 8,2 t/he are most fitted for this kind of soil.

An interesting plant revealed to be the hazel tree, which was planted on the edges of the embankments which stopped soil erosion.

The trees should be planted on dumps, 10 to 15 years after their soil had been physical and chemical improved, followed by biological cultivation with annual plants species for a minimal period of 5 years.

4.1.2. Establishing fertilizing systems. The experiment was mented to improve the hydro physical, chemical and biological properties of the dumps, by using green fertilizer (simple or mixed with chemical fertilizers based on N, P, K manure) on a plum tree culture, the Stanley variety.

As a "green" fertilizer we used different weed crops with 8.5 to/he of biomass without fertilizer and 30.0 to/he of biomass with $N_{16}P_{160}K_{120}$ fertilizer. These crops were left to decompose on the ground, increasing the humus level.

The determinations were made between 1987-1993 on dump site Gârla-Rovinari and the alternatives are the ones mentioned in table No.2.

The data obtained between 1987-1993 reveal the soil need of chemical and organic fertilizers.

So, the main biometric data determened shows a proportional growth with the chemical fertilizer dosage, but also with the organic fertilizer used.

It all came up in the first important production, 6 years after the trees were planted, when the researches revealed significant increases in the alternative ways of fertilization.

The highest level of production was revealed with the V9 variant, when were used 40 t/he of manure + $N_{160}P_{160}K_{120}$ Kilo/he, about 6.04 t/he plums, which means an increased percentage of 59% compared with the unfertilized soil.

Table No.1. Average multiannual production and main biometrical data recorded on fruit trees on recovered dumping sites (25 years)

Studied Species	Roaling percentage	Trunk thickness after 25 years		Average offshoot growth	Multiannual average production	
		Total	Annually		Kilo/tree	T/he
Apple	99	13.7	1.1	54	39.8	24.9
Plum	97	13.2	1.2	37	24.8	8.2
Sweet Cherry	69	16.5	1.5	18	17.0	4.1
Cherry	65	12.1	1.1	13	11.5	3.8
Nut	68	9.5	0.9	14	6.2	0.6
Hazel nut	89	4.0	0.3	7	0.5	0.3

Table No.2. The fertilization influence on main biometric data on the plum culture

Variant	Trunk's diameter-cm		Annual growth of offshoots –cm			Productions t/he	
	1987-1993	Annual growth	Average 1987-1993	% Compared to the unfertilized soil	Importance	At 6 year old	%
V1-unfertilized soil	2.9	2.0	66	100	X	3.8	100
V2-green fertilizer	3.0	2.0	74	112	XX	4.2	123
V3-green fertilizer+ $N_{80}P_{180}K_{40}$	4.4	3.5	102	155	XXX	4.20	135
V4- green fertilizer+ $N_{120}P_{120}K_{80}$	4.5	3.6	109	165	XXX	4.35	135
V5- green fertilizer+ $N_{160}P_{160}K_{120}$	5.5	4.1	112	170	XXX	3.90	140
V6-manure 40 t/he	5.0	3.0	107	162	XXX	4.20	125
V7-manure 40 t/he + $N_{80}P_{80}K_{40}$	5.2	3.9	115	174	XXX	4.70	135
V8- manure 40 t/he + $N_{120}P_{120}K_{80}$	5.2	4.5	121	183	XXX	4.92	152
V9 manure 40 t/he + $N_{160}P_{160}K_{120}$	5.6	4.6	127	192	XXX	6.04	159

4.2. Vine culture

In the same experiment we also researched the vine culture. For proving this we present the most representative data from 1988-1992.

During the period of study, were analyzed and determined a series of factors (soil moisturing/humidity, green fertilizers biomass, green fertilizers content in N, P, K, wood mass), which linked together have contributed to the difference of production related to the applied treatment. The studied variety was Pinot Noir, guided as a two-way, medium height stemp (70 cm).

From the shown data can be seen that increased production was obtained with green and chemical fertilizers ($N_{160}P_{160}K_{160}$ Kilo/he) with a production of about 7.27 t/he, comparing with 4.59 t/he without fertilization, followed by the V3 way with 40 t/he of manure + $N_{40}P_{40}K_{40}$ kilo/he.

Table No.3. Fertilizing system influence on grapes production on dumped site Gârla-Rovinari

Variant	Obtained production		Sugars g/l	Acidity g/l H_2SO_4
	Kilo/vine	To/he		
V1 – US + NPK 160 kilo/he	1,50	6,82	210,8	4,99
V2 – US + NPK 40 kilo/he	1,27	5,77	216,2	4,98
V3 – US + manure 40 to/he + NPK 40 kilo/he	1,58	7,18	207,7	4,75
V4 – GF + NPK 100 kilo/he	1,54	7,00	206,7	4,92
V5 - GF + NPK 40 kilo/he	1,42	6,50	202,5	4,87
V6 - GF + manure 40 to/he + NPK 160 kilo/he	1,60	7,27	206,4	5,19
V7 - US	1,01	4,59	223,7	4,42

US – unfertilized soil

4.3. Cereal crops

Other plants studied during the experiment were cereals (maize, oat, barley) and other plants (potatoes, pea).

In table No.4 is shown the energetical level of main studied species.

The soil was found to be less suited for potato and spring barley crops, but also for unfertilized or little fertilized maize crop.

Table No.4. Energetical level of several crops – annual average 1990 – 1998 MJ/he physical, chemical and biological properties.

Culture	Fertilizing level					Average	%
	N_oP_o	$N_{44}P_{44}$	$N_{100}P_{100}$	$N_{132}P_{132}$	$N_{176}P_{176}$		
Potato	19794	24517	32677	36044	53637	3334	51
Maize	22021	40868	68363	80902	104475	63326	97
Oat	30346	57920	77870	83774	98853	71753	110
Pa	30197	58118	92152	107066	123368	82180	126
Barley	20294	46329	57783	76758	80611	56355	86
Wheat	25100	43755	75800	101507	117560	72744	111
	22715	49538	102782	114429	135614	85016	130
Average per variant	24228	46215	71938	84829	99426	65327	100
Percentage %	37	71	110	130	152	100	

5. Conclusions

Soil that was technologically created on mining dumps can be used for agricultural purpose just like normal ones, with the condition to insure proper organic and chemical fertilization, in order to enhance the soil's physical, chemical and biological properties.

We can creat ecological agro systems consisting of annual cultures, fruit trees and vine by respecting their growth needs

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INVESTIGATION ON THE REGIME OF PCHELINSKI BANI MINERAL WATER OCCURRENCE AND CURRENT ASSESSMENT OF ITS EXPLOITATION RESOURCES

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ABSTRACT
Pchelinski Bani mineral water occurrence is located in the north part of Dolna Banya thermal water basin. The terrain of the investigated area is built up by the granodiorites of the Gucal pluton. Thermal springs that have appeared in the zone of intersection of two faults were captured in general shaft. Two of the drilled wells are reserved – one as a duplicate exploitation water source and second – as a seismohydrogeological observation point. Up-to now the only operating water source is the thermal spring intake Pchelin. Thermal water is sulfate sodium by composition, with mineralization of 9.94 g/l, silicic, fluoric, radonic,hyperthermal (73 °C).
This mineral water occurrence is seismohydrogeological phenomenon – there is a manifested change in spring discharge after strong earthquakes occurring both in Bulgaria and its neighboring states.
The regime of thermal spring is investigated by the authors. The data obtained from regime observations on the discharge of the Pchelin captation for a period 1937-2003 is used. Up to 1990 the average spring discharge is 11.71 l/s and after (up to date) falls to 8.83 l/s. The prognostication assessment of the exploitation resources of mineral water and geothermal energy is made up to 2013, by processing the regression analysis of data for 1990-2003 period. According to this assessment the resources, at the end of prognostic period, will amount respectively to 8.76 l/s and 2092 kJ/s.

INTRODUCTION

Pchelinski Bani mineral water occurrence is located in the central west part of Bulgaria, 8 km to the north-east from the Kostenets town. Its mineral water is characterized with high temperature (73°) and valuable balneotherapeutic properties - it is good for treatment of the locomotory system, the peripheral nervous system as well as of gynecological, skin and other diseases.

The first information of most general character concerning the geology of this region is given by A. Boue. Later on, the region has been survived by G. Zlatarski, G. Bonchev and others. The results from the geological mapping of the region are summarized by Iliev and Katskov (1990, 1993) in Geologic map of Bulgaria in M 1: 100 000 – map sheet Ihtiman. N. Dobrev (1905) carried out the first investigations on mineral waters composition, followed by those of Azmanov (1929, 1940).

The Catchment of the springs has been made under the guidance of minimg engeneer G. Vasilev in 1937. During the 1965-1967 period the Enterprise for Geological Explorations in Sofia conducted well-and-hydrogeological survey in the region of the mineral water occurrence. The occurrence is studied by K. Shterev (1964) and P. St. Petrov et al. (1970). Full hydrogeological characteristic of the mineral water occurrences in the hydrothermal basin of Dolna Banya, including also that of Pchelinski Bani, has been made in the paper of P. Penhev et al. (2003).

The purpose of the present work is to investigate the mineral water regime and to develop a prognostication model for assessment of its exploitation resources of mineral water and geothermal energy. Pointed are also the main prerequisites for its treatment as a seismohydrogeologic phenomenon, which is of scientific interest to the studies on the seismic activity in this country and in the other Balkan states.

DESCRIPTION OF THE MINERAL WATER OCCURRENCE

Pchelinski Bani mineral water occurence is located in the northern part of Dolna Banya thermal water basin. It is revealed in the southern slope of Cherni Rid, which belongs to the Ihtiman Sredna Gora mountain. The relief proceeds from low to medium-high mountainous and is characterized by well-expressed unevenness.

In a regional plan, the mineral water occurence falls into the catchment area of Maritsa river, the region immediately around it being drained by the small river Zhezhkata voda.

The climate is temperate continental of submountain character. The summer is hot and the winter is moderately cold. The average annual temperature is 8.8 °C. Precipitations as a basic factor in the formation of underground waters, is about 685 mm.

On the territory of the investigated region Paleozoic, Mezozoic and Neozoic formations are found. The geological structure of the region is shown in Fig. 1. Basic collector of thermal water are the granodiorites of the Gucal pluton ($gu\gamma\delta K_2$), which reveals itself within the region of Gucal and Pchelin villages, to the west from the village Momin prohod. Pluton is built of large-grain granodiorite, leuco – to mesocratic with massive texture whose mineral composition includes plagioclase, pottassium feldspath, quartz, amphibole, biotite, apatite, titanite, sericite, epidot. By their chemistry the rocks belong to the normal granodiorites from the potassium-sodium series. The pluton age is determined to 72.5 million years (Katskov, 1993).

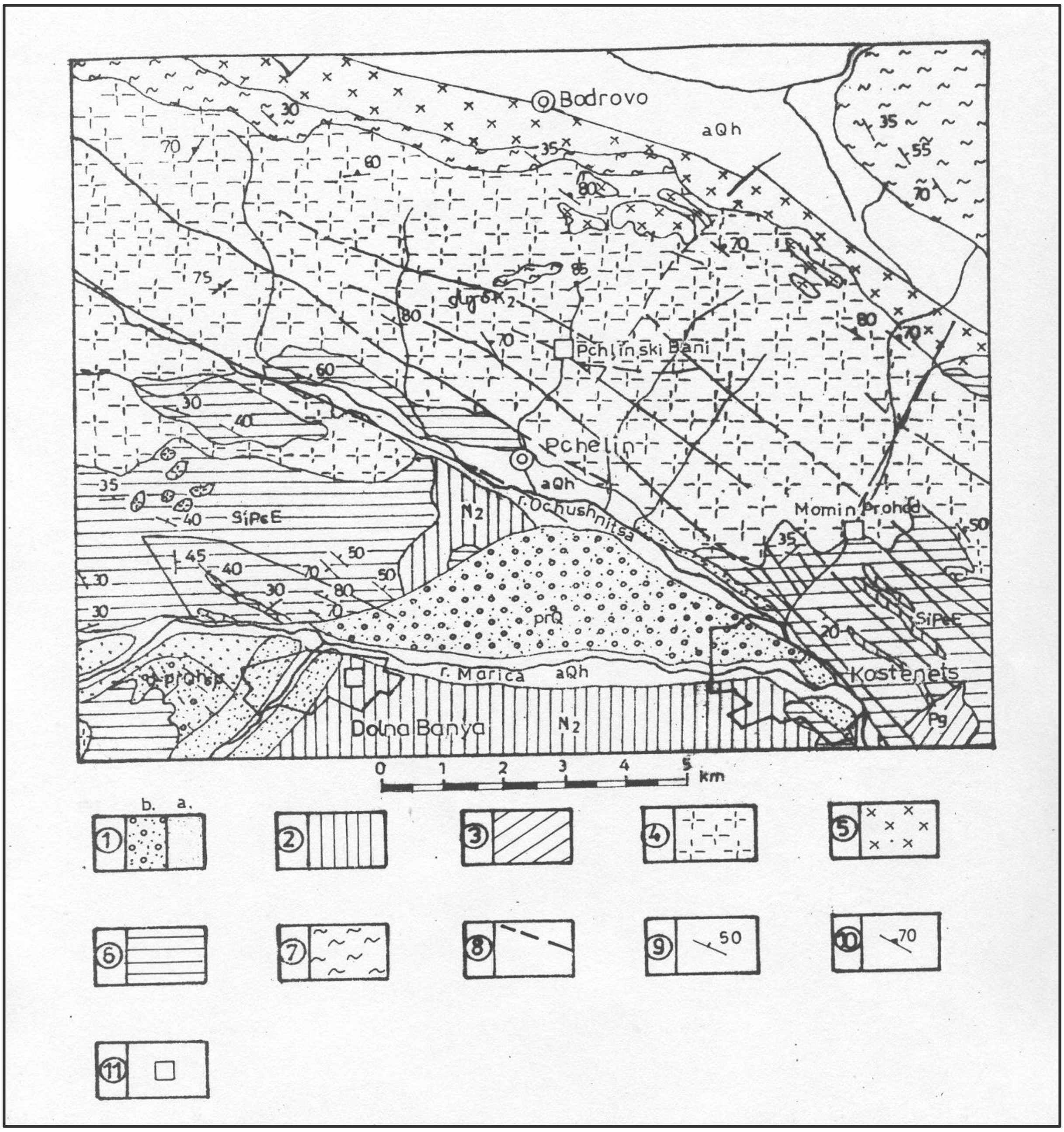

Figure 1. Geological map of the region and the vicinities of Pchelinski Bani mineral water occurrence (by Iliev, Katskov, 1990; Dimitrova, Katskov, 1990).
1- a) Alluvium and prolluvium (Holocene), b) Alluvium, delluvium and prolluvium (Pleistocene); 2 – Brecca-conglomerate-sandstone formation (Upper Pleistocene – Eopleistocene); 3 - Conglomerate-sandstone formation (Lower Oligocene); 4 - Gucal pluton – granodiorites (Upper Cretaceous); 5 – Varshilo pluton – granites (Paleozoic); 6 – Sitovo formation – gneiss-shales, shales, leptinites, gneissis (Lower Proterozoic); 7 – Prarodopska formation – migmatized gneisses, gneisses and gneiss-shales (Archean – Lower Proterozoic); 8 – fault; 9 – bedding; 10 – plane structures in magmatic rocks; 9 – the mineral water occurrence

Pchelinski Bani mineral water occurence reveals itself in the eastern part of the Gucal pluton. Before the catchment the mineral water has been drained by several small springs at an elevation of 632.6 m coming out from a 3 to 10 m wide fault of east-west direction and steep incline to the south. The springs have appeared at the place where the fault is intersected by transverse tectonic fissures of northeast orientation. The open part of the fault is filled with cavernous tectonic breccia from granodiorite fragments (pieces) that are intensively changed, covered and fused by ferrous hydroxides, zeolites and other materials, deposited by thermal waters.

The springs were intaked in a general captation shaft in 1937. Their total discharge before captation ammounted to 11.17 l/s and then to 11.7 l/s at temperature of the water 73 ^{o}C. Three hydrogeological boreholes - Wells №№ 1, 2 and 3 were drilled in the region of the reservoir during the 1965-1967 period by the Enterprise for Geological Exploration – Sofia. Their depths are respectively – 497 m, 348.9 m and 350.3 m, passing entirely into granodiorites. In the course of the hydrogeologic studies, experimental tests of the wells have been made, no artesian flow being obtained as a result. Water from Well № 1has been pumped for a short time and by intervals. A discharge also of 0.161 l/s has been obtained and also drawdown of 9.20 m in the well at statical water leve (SWL) 6.68 m under the terrain. Wells №№ 2 and 3 have been pumped one in a time or as a group at three stages with total duration 25 days without reaching stabilization. From wells №№ 2 and 3, when singly pumped, maximum discharge have been achieved, respectively 30.0 and 27.7 l/s, at drawdown of 1.26 and 3.25 m. The temperature of pumped water was 73 °C.

The data obtained from the group pumping of Wells №№ 2 and 3 are summarized in Table 1. The course of water level recoveries in the wells after the end of the pumping is shown on Fig. 2.

Table 1. Results from the group pumping of wells №№ 2 and3, during the 20-25.08.1968.

Stage	Duration, h	Total discharge at the end of stage Q, l/s	Drawdown at the end of stage, m	
			Well №2	Well №3
I	30	54.8	2.00	4.10
II	37	49.7	1.90	2.18
III	32	34.4	1.82	1.48

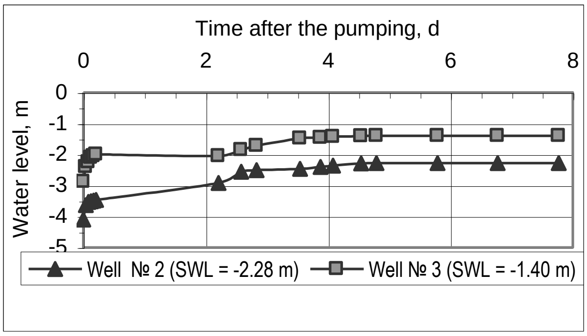

Figure 2. Diagram of the water level recovery in Well №№ 2 and 3 after their group pumping during 20-25.08.1968.

During the experimental water pumping the discharge in the spring intake has declined and at their end the spring has completely dried up. Appearance of artesian flow from the captation occurred 84 h (3.5 d) after the completion of the pumping while the discharge reached its initial values following a period of a month and a half. This process is shown on Fig 3.

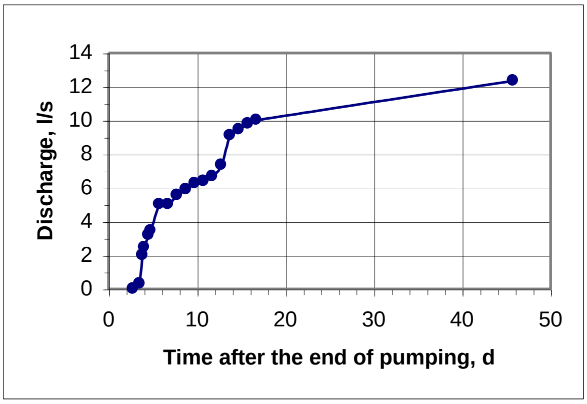

Figure 3. Diagram of the thermal spring discharge recovery after the end of the group pumping in Wells №№ 2 and 3.

The reaction of the spring shows that the yield of groundwater during the pumping has exceeded the natural resources of the reservoir as a result of which part of its elastic resources has been taken away.

Well №1 has been liquidated after the end of the surveying works. Well №2 has been equipped with a hydrograph as a seismohydrogeological observation point by the Main Board of Hydrology and Meteorology at the Bulgarian Academy of Sciences, but at present no daily observations are made. Data from previous observations will have to be found and interpreted. Well № 3 is adapted for pumping exploitation. For the time being it is not used since the discharge of intaked spring supplies the water amount required for satisfying the needs of consumers (Balneotherapeutic unit, greenhouses, etc.).

Now the only operating water source is the intaked spring known as Pchelin captation. Mineral water flows out at an elevation of 632.9 m, the spring discharge varying around 8.8 l/s.

The physical-and-chemical composition of Pchelinski bani mineral water has been repeatedly investigated, the values of the macrocomponents fluctuating within comparatively narrow limits, while the water temperature remains unchanged, being in the range of 72-73 °C. Present-day physical and-chemical , as well as radiologic analyses of the water from the reservoir were made in 2002. The data obtained are given in Table 1.

Table 1 Macrochemical composition of mineral water

Date	Tempe-rature, °C	pH	Chemical compounds, mg/l							Minerali-zation, g/l	Total β-activity Bq/l
			Na + K	Ca	HCO_3	SO_4	Cl	F	H_2SiO_3		
25.02.2002	73	7.20	259.2	27.6	82.4	483.1	22.1	9.0	103.4	0.987	0.347

On the basis of the comparative analysis of all investigations made up to now (1904-2002), the mineral water of the Pchelinski bani is determined as fresh - with mineralization 0.92 – 0.98 g/l, hyperthermal (72.8 °C), sulfate sodium by composition with slightly alkaline reaction (pH up to 8.0) The content of metasilic acid is 95 – 112 mg/l, which characterizes the water as silicic. By content of fluoride - 8÷10 mg/l the water is strongly fluoric. The content of radon in the water reaches 110 ÷ 120 Em (407 ÷ 444 Bq/l), which characterized it as slightly radonic. Nitrogen dominates among the gases diluted in the water - 96.7 volume %, followed by argon (1.7 vol.%) and helium (0.25 vol.%).

FACTUAL MATERIAL AND METHODS OF INVESTIGATION

The investigation on the mineral water regime have been carried out on the basis of an analysis of data obtained from regime observations on the discharge of the spring intake for a period of 66 years (1937 – 2003).

The first observation was made in 1930 before the catchment of the springs when a discharge of 11.17 l/s was measured. After captation the discharge of the spring reached 11.67 l/s and the water was 72.8 – 73 ^{o}C (Azmanov, 1940). There are preserved data from regime observations for the 1958-1969 period (Segmenski, 1968). Regular regime observations have been made by the Specialized Hospital for Rehabilitations in Momin prohod in the course of the 1977-2000 period. They have been carried out with changing frequency, no measurements at all being made during some periods and only sporadic ones in other periods.

Up-to-date measurements of the discharge of Pchelin thermal spring were made by the authors in August 2001 and March 2003. The results from the regime observations for the 1937-2003 period are visualized in Fig.4.

The assessment of the exploitation resources of mineral water is made empirically – by processing data from long-year regime observations. As a result of analyzing all available data, two periods have been differentiated that are characterized with different values of the discharge. The discharge values for each of the periods are processed by the method of the regression analysis - through selection of various functions (linear, logarithmic, exponential, etc.). A linear trend that ensures best approximation of the data obtained from regime observations is chosen.

The second period of observation is used for appraisal of the mineral water exploitation resources excluding those values of the discharge, which have been affected by earthquakes. The regression model obtained, by its essence represents a model for prognostication, used in the assessment of the exploitation resources $Q_{exp.}$ This assessment concerns a period of 10 years – up to 2013, in the course of which, new regime observations will be made with the purpose of calibrating the model.

The appraisal of the exploitation resources of geothermal energy (GTE) which represent the admissible and possible average annual yield of heat from the thermal spring has been carried out according to the well-known formula (Gulabov et al. 1999):

$$G_e = Q_e \, . \, C_B . \Delta T$$

where: *Ge* is the heat power, kJ/s; Q_e is the prognosticated exploitation resources of mineral water; C_B is the volume heat capacity of water, C_B = 4,19MJ/m^3. K; $\Delta T = T_{av} - T_o$ is the temperature difference; T_{av} is the average temperature of the thermal water; T_o is temperature of the thermal water after its cooling.

RESULTS AND DISCUSSION

Investigation of the thermal spring regime and assessment of its mineral water and geothermal energy resources.

The diagram of regime observations presented in Fig. 4 shows that two periods may be differentiated in the flow of the Pchelinski Bani thermal spring. The first period includes the time from the catchment of the spring in 1937 to 1989 (on Fig. 4 it is marked as "□") and the second one is from 1990 to 2003 ("○").

During the first period the discharge of the spring varies around the average weigh value of 11.71 l/s. The beginning of the second period sets in 1990 when there occurs a sharp fall in the discharge of tehrmal spring with nearly 3 l/s. From that time on the discharge average weight value amounting to 8.83 l/s. Since the thermal spring is the only operating water source in the mineral water occurence and its exploitation is effected by artesian flow on a fixed elevation, the authors assume that the sharp fall of the discharge after 1990 is due to a technogenic influence which probably still persists.

From the graphical interpretation of regime observations made in Fig.4 it can be seen that the averaged lines show trends toward lowering of the discharges for both periods. Their comparison shows that the trend toward lowering the first period is more abrupt. The trend-line approximating the data from the second period is nearly parallel to the absciss axis, which is an indicator for relative stabilization of the artesian flow from the thermal spring

The prognostication assessment of the exploitation mineral water resources from Pchelinski banii mineral water occurence has been made by using data from the 1990-2003 period, since it shows the current state of the thermal spring regime. The established linear trend (Fig 3) for alteration in the spring discharge (Q) within time (t) has been used and a prognostication period – up to 2013 has been determined:

$$Q_{екс} = 8{,}78 - 4.10^{-7}. t \quad ,$$

where: Q_{exp} is the prognostic value of the exploitation resources, l/s; *t* is the time from 1900,d.

The straight line of the regression approximates only those data that are shown as circules in Fig. 3. The remaining data from the discussed period, which are not taken into account at the approximation, are visualized with the sign "x". The exploitation mineral resources in the reservoir toward the end of the prognosticated period (01.07.2013) are assessed to:

$$Q_{екс} = 8{,}76 \, l / s \quad .$$

The exploitation resources of geothermal energy are determined by the amount of the thermal water obtained and the degree of its cooling when being used. In the specific case they are calculated at T_o = 15 ^{o}C:

$$G_e = 8{,}76\,.\,4{,}19\,.\,57 = 2092\ kJ/s\,.$$

Seismogenic effects on the mineral water regime

Pchelinski bani mineral water occurrence is characterized with an expressed postseismic response, which is manifested in the sharp fall in its discharge immediately after strong earthquakes occurring both in this country and in its neighboring states. In separate cases a full stop of the artesian flow from the spring captation occurs and the mineral water there appears only after one or several days. The first well-known example in this respect are the destructive earthquakes in Gorna Trakija within the period 14-19.04.1928 when the springs suddenly dried up and appeared again only several days later. Analogic is the response of the reservoir observed after the earthquake on 18. 03. 1953.

The diagrame of regime observations presented in Fig. 4 shows that there were several extremely low values of the spring discharge during the 1937-2003 period. On the basis of the study conducted in this respect it was established that those values were measured immediately after stronger earthquake shocks occurring in Bulgaria or in its neighboring countries. Such wererespectively the earthquakes in 1977 – Romania (Vrantcha); 1999 – West Turkey; 2001 – Romania; 2002 – Macedonia (Skopie) and Kosovo.

After these falls the discharge usually restores its values up to the limits typical for it under normal conditions. This is also confirmed by the current measurementsmade by the authors in 2001. A series of earth tremors and activation of Etna volcano were registered at the end of July and at the beginning og August (20.07 – 03.08. 2001). On 03.08.2001 a discharge of 5.22 l/s was measured while the measurements made afterwards were already within the range - 7.59 /s (10.08.2001) and 9.42 l/s (23.08.2001).

The last postseismic responses of the spring were observed on 24 and 29.04.2002, when a series of earth tremors had been registered in Macedonia (Skopie) and Kosovo (Gnilyane) with a magnitude reaching between 5.3 and 4.5 accorging to the Richter scale. The discharge of the spring showed a sharp fall and stopping entirelly after the last stronger tremor. On 30.04.2002 the discharge restored its value up to about 6.5 l/s (measurements were made by workers in the Specialized Hospital for Rehabilitation in Momin prohod).

All stated above substantiates the dependance between anomaliesin the thermal water discharge and the earthquakes in Bulgaria and its neighbouring states. Imperfection in the study on these phenomenon is the lack of observation on the behavior of the spring immediately before the beginning of the seismic activity. In this connection it is necessary to renovate the regular observations over the changes in the water level in Well № 2 which is 44 m from the captataed spring in a south-easterly direction.

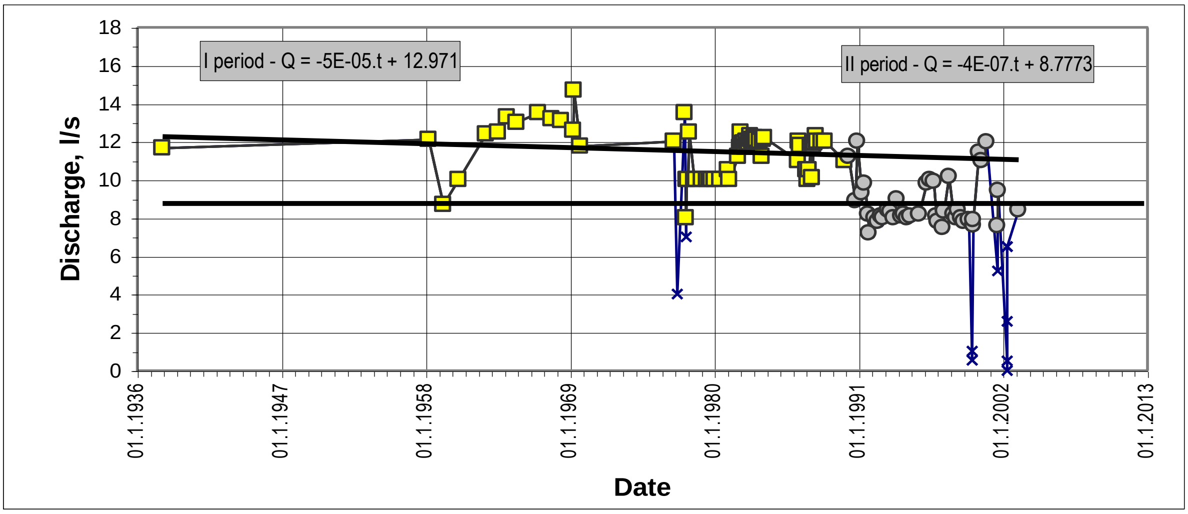

Figure4. Visualization of data, obtained from regime observations on the discharge of thermal spring for 1937-1989 and 1990 – 2003 periods.

CONCLUSION

As a hydrogeological object of a fissure-vein type, the occurrence of mineral water Pchelinski banii may be used as a model for investigation of similar structures with the purpose of elucidating the factors affecting the regime of mineral water – climatic, seismic and technogenic.

A prognostication assessment of the resources of mineral water is made for a period of 10 years according to which at the end of the prognosticated period (2013) the discharge would amount to 8.76 l/s. The resources of geothermal energy at cooling from 72 ^oC to 15 ^oC are evaluated to 2092 kJ/s. Under the regime of exploitation established that way – at artesian flow from the Pchelin captation and at permanent environmental conditions, no essential changes in the thermal spring resources are envisaged.

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ASSESSMENT OF LOESS COMPOSITION AND STRUCTURE IN CONNECTION WITH RADIOACTIVE WASTE DISPOSAL

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ABSTRACT

Investigations have been carried out on the composition and structure of loess in the vicinity of the Kozloduy Nuclear Power Plant in connection with the long-term disposal of radioactive waste. The thickness of loess in the investigated region is in the range from 10 to 40 m. The loess grain-size composition is characterised by predominating silty fraction reaching up to 80%. The clayey fraction content varies from 10 to 20%. The silty and sandy fractions contain mainly quartz, feldspar, mica and carbonates and the clayey fraction – mainly chlorite and smectite. The most important components of the chemical composition of loess are SiO_2, Al_2O_3, Fe_2O_3 and FeO, CaO and MgO. The amount of the water-soluble salts, presented mainly by carbonates (bicarbonates), sulphates and chlorides, is low. The sorption capacity is about 6 meq/100 g. According to the classification of Minkov the loess structure is granular or aggregate-granular, its basic property being the incomplete consolidation and collapsibility. The dry density is about or less than 1.4 g/cm^3, and the degree of water saturation is S_r = 0.30-0.55. The volume of macropores under loading of 0.3 MPa is 6.5 – 7.0%. The filtration coefficient varies from 2.10 $^{-5}$ to 5.10 $^{-6}$ m/s. The properties of loess are considered in the present report from the viewpoint of safety of both existing and future repositories. The main conclusion of the investigations is that regardless of some suitable qualities, loess in its natural state cannot be an efficient barrier against radionuclide migration. It is necessary to apply methods for its compacting and strengthening. In Bulgaria there is experience in the successful application of such methods, as proved by the operation of the Kozloduy NPP.

INTRODUCTION

The beginning of nuclear power generation in Bulgaria dates back to 1974 with the launching of the first reactor of Kozloduy Nuclear Power Plant, as other 5 reactors have sequentially been put into operation till 1991. In compliance with the international practice, the low and intermediate level radioactive waste (LILRAW) released during the plant operation should be subjected to final disposal in surface repositories after their temporary storage. As a result of the whole period of operation of the Kozloduy NPP, the closing of its first two reactors and the eventual operation of the Belene NPP, it is expected that the LILRAW volume in the conditioned state will amount to about 100 000 m^3. These wastes are stored at present in temporary storages on the plant territory and it is envisaged to construct a permanent repository. In this context it is very important that a suitable geological environment for its construction should be selected. The investigations carried out so far both in the country and abroad (Hungary and Romania), prove that loess could be considered as a prospective medium for storing low and intermediate level radioactive waste. This geological medium together with the engineering structure (the repository) plays the role of a barrier against the radionuclide migration and is a basic factor for the long-term stability of the future repository system. The assessment performed further on refers also to the existing repositories on loess at the plant site.

Loess was deposited in an aeolian way during the Quaternary and covered in a mantle manner the existing Pliocene relief. The formed loess horizons alternate with fossil soils (paleosoils), thus forming a common "loess complex". The number of horizons in the studied region reaches up to six, separated by five fossil soils. The following geomorphological forms are outlined: loess plateaux, where loess reaches the thickness of up to 30 –40 m; loess slopes; wadies "inheriting" old dried riverbeds, where the loess cover becomes thinner, as well as loess plates situated in the plateaux. The complex is characterised by the following specific features: changes in the facial composition in both horizontal and vertical direction – from sandy to clayey loess from the north to the south. A similar transition is also observed from the plateaux to the slopes. The loess structure and composition on the wady slopes are altered, the loess being generally more dense and clayey in comparison with the loess of the terraces. Another specific feature is the increased content of clay in the more deeply situated horizons. The upper ones in the region of Kozloduy are classified as sandy or silty (typical) loess while the bottom horizons fall within the group of clayey loess.

Loess composition and structure influence to a great extent its engineering geological properties and especially its behaviour as a soil base. The study of loess composition and structure has several aspects with respect to radioactive waste disposal, namely:

- stability of loess minerals and structure under the influence of climatic factors and groundwater in the course of a long time period;
- effect exerted by the properties and structure on the long-term stability of the soil base of a LILRAW repository;
- presence and effect of chemical compounds in loess, which are aggressive towards concrete, steel and other building materials;
- possibilities for improving loess structure by means of methods for strengthening and compacting.

On the basis of the above mentioned aspects an assessment will be made for the composition and structure of loess in the

Kozloduy NPP proximity form the viewpoint of an eventual medium for LILRAW long-term disposal.

COMPOSITION AND PROPERTIES OF LOESS

Grain-size distribution and plasticity limits

The silty fraction is the basic one in loess. It reaches up to 80% in sandy, silty (typical) and clayey loess, up to 50% - in loess-like sands and up to 60% - in loess-like clays. A clearly expressed trend is observed for the increase of the clayey fraction in both the redeposited loess and in the fossil soils as a result of long-term weathering processes.

The changes in the quantity of the clayey fraction (< 0.005 mm) are used as a criterion in loess classification (Minkov, 1968): loess-like sand and sandy loess, containing up to 10% of clayey fraction; silty loess – up to 20%; clayey loess – up to 30% and loess-like clay - >30%.

The considered region is characterised by sandy and mainly silty loess, to a smaller extent – by clayey loess and to a much smaller degree – by loess-like sand, which is observed along the bank of the Danube River. Redeposited loess has been established too. For this reason, samples of sandy and typical loess from the region of the Kozloduy NPP have been investigated. The tested sandy loess samples (according to the Bulgarian State Standard BDS 2762-75) showed the following composition: 10% of sandy fraction, 84% of silty fraction and 6% of clayey fraction. The fraction larger than 2 mm (Table 1) is absent in sandy loess. One variety of silty loess has been investigated, yielding the following composition – 11% of sandy fraction, 68% of silty fraction and 17% of clayey fraction. The amount of the fraction >2 mm is 4%. The silty fraction is the dominating one in both facial varieties but its share is relatively lower in the tipical loess at the expense of the clayey fraction. The uniformity coefficient $u=d_{60}/d_{10}$ is 7.06 and 15.00 respectively. The typical loess possesses higher uniformity coefficient, i.e. it is characterised by complete granulometric curve, which is favourable with respect to loess compaction. The two samples are defined as silty clayey sand according to BDS 676-85.

Mineral composition

Loess contains a great number of minerals, irregularly distributed in the different fractions. The available data from the studies carried out so far (Minkov, 1968; Petrussenko, 1973; Antonov, 2002) are analysed further on.

The predominating minerals in loess are quartz, feldspar, mica and carbonates. The DSC curves of the loess samples from the region are complicated because the reflections of many minerals overlap with each other. Regardless of this fact, strong reflexes are observed for: quartz at 0.333 nm, 0.424 nm, 0.1812 nm and 0.1815 nm, 0.1537, 0.137 nm; calcite – at 0.302 nm; dolomite – at 0.288 nm (dominating quantitatively the calcite in the silty loess); micas – at 0.989 nm and 0.983 nm, 0.496-0.498 nm; feldspars – at 0.319-0.322 nm and 0.318-0.323, with plagioclase being mainly the dominating species and with traces of potassium feldspar, the latter being in a greater amount in the sandy loess sample; clayey minerals – at 0.53 nm, 0.705 nm (chlorite), 0.352 nm and 0.701 nm; smectite (montmorillonite) – at 1.403 nm.
The granulometric fractions of loess are characterised by the following composition:

Fraction >2 mm. It is represented mainly by quartz, single muscovite and biotite scales and single feldspar grains (the light part of the fraction). Bigger carbonate and clayey-carbonate concretion, known as loess dolls, are encountered too. Single grains of amphibole, epidote and ore minerals are seldom observed as representatives of the heavy part of the fraction.

Fraction 2 – 0.01 mm. The greater part of the loess mass falls within this fraction. The light part of the fraction contains mainly quartz, micas – muscovite and biotite, feldspars and carbonates.

Quartz is the basic mineral (more than 50-60%) and is represented by rounded transparent grains of irregular shape.

The micas – muscovite and biotite, occupy the second place after quartz. The muscovite amount exceeds the biotite one from 4 to 8 times and is usually represented by thin colourless platelets. Its content in the total loess mass varies from 15 to 30%. The biotite is observed in the form of small scales and not so often – of oval shaped platelets.

Feldspars occupy the third place but sometimes their quantity might exceed that of micas.

Table 1. Classification indices of the used samples

Loess variety	Particle-size distribution [%]				Solid density	Plasticity			Uniformity coefficient
	> 2 mm	2 - 0,1 mm	0,1 - 0,005 mm	< 0,005 mm	ρ_s g/cm³	w_L %	w_P %	I_P %	u [-]
Sandy loess	0	10	84	6	2,74	28,0	25,3	2,7	7,06
Typical loess	4	11	68	17	2,72	25,5	20,0	5,5	15,00

They are encountered either as weathered or quite fresh particles of angular, slightly rounded or oval shape. In principle, the feldspars in fossil soils are strongly weathered and their quantity is two to three times lower than in the loess horizons. Orthoclase and seldom microcline are found as representatives of potassium feldspar and albite and oligoclase – of plagioclase.

All these minerals are resistant to the action of the atmospheric factors and eventual infiltrates that might be released by the conditioned RAW.

The carbonate content of loess varies within a broad range both in horizontal and vertical direction – from 3-4% in leached loess to 30% in the carbonate horizons of the paleosoils. This variation can be used as a natural analogue considering migration properties of some radionuclides. A trend of changing the carbonate content in horizontal direction is observed: in loess-like sands – average of 18%, in sandy loess – about 15%, in silty loess – to 17% and in clayey loess – to 13-14%. The present investigations have shown a carbonate content of 22.9% for sandy loess and 16.32% for silty loess (Table 2). The carbonates are represented by calcite and by a very small amount (1-2%) of dolomite. Carbonates are minerals subjected to destruction under the continuous action of atmospheric water, which is displayed by the presence of thick carbonate zones in the buried soils. Their dissolution is increased in acidic medium. The light fraction comprises also the secondarily formed highly water-resistant clayey-carbonate, iron- or magnesium-carbonate aggregates, ferromanganese salts, etc., which are irregularly distributed and in negligible quantities.

The amount of the heavy fraction is smaller and is represented by about 20 minerals, the quantity of the non-transparent minerals being the highest.

Fraction 0.01 - 0.005 mm. According to the microscopic investigations the particles with sizes from 0.01 to 0.005 mm are represented by quartz, altered feldspars and micas, calcite, rarely by single small crystals of heavy minerals and clayey aggregates.

Fraction <0.005 mm (clay). This fraction consists mainly of kaolinite, hydromicas and montmorillonite. Dispersed quartz and dispersed carbonates are also observed. The following trends have been established for the changes of the clayey minerals in horizontal and vertical direction: the finely dispersed fraction of the contemporary soil (loess chernosem) consists of minerals with three-layered crystal lattices, mainly montmorillonite; the clayey fraction of loess contains predominantly minerals of the group of hydromicas (mainly illite) and of montmorillonite; the hydromicas are predominant in sandy loess; montmorillonite is predominant, hydromicas decrease and kaolinite is almost negligible in the direction towards loess-like clay and fossil soils. The samples investigated by us showed the presence of chlorite, kaolinite and montmorillonite (traces).

Humus content – loess always contains a certain amount of humus (0.1 – 0.6%), which is usually included in the clayey fraction. The humus content of the investigated samples is 0.22 and 0.67% (Table 2). The highest humus quantity is observed in the fossil soils. Two types of humus are distinguished – primary and secondary. The primary humus is encountered as a fine incrustation on the phytogenic macropores. The post-sedimentation humus generation is contained in the soils in the form of diverse aggregates.

Chemical composition

The chemical compounds contained in loess can be distinguished in three main groups: of major importance (primary) – SiO_2, Al_2O_3, Fe_2O_3, FeO; of secondary importance – CaO and MgO, and less important – all the rest compounds.

The chemical composition of loess is in accordance with its mineral composition. The quantity of SiO_2 dominates all the other components in all loess varieties and horizons. The silica amount in loess changes within relatively narrow limits – from 58 to 51%, decreasing gradually from the sandy to the clayey facies. The amount of Al_2O_3 + Fe_2O_3 changes in the opposite direction from that of SiO_2, moreover within a significant range – from 13.0% in sandy loess to 19.0% in loess-like clay. The quantities in the buried soils are higher.

The amounts of the earth alkaline oxides (CaO and MgO) change in the reverse direction with increasing the distance from the Danube River – CaO is increased while MgO is decreased. This is in good agreement with the reduction of mica and magnesium carbonate amounts in clayey loess. The sum CaO + MgO in the buried soils is lower due to the leaching of carbonates.

At the same time the soils have lower alkaline oxide (Na_2O + K_2O) amounts and a higher TiO_2 content.

The following data (Minkov, 1968) might be used as an illustration of the chemical composition of the clayey fraction.

Table 2. Chemical and physico-chemical data of the used samples

Loess variety	Aqueous extract 1:10 - 24 h meq/100g							Carbonate content	Humus content	Sorption capacity
	HCO_3^-	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	dry residium [%]	pH	[%]	[%]	[meq/100g]
Sandy loess	0,976	1,0	0,4	0,27	0,17	0,12	8,1	22,4	0,22	5,88
Typical loess	1,31	1,0	1,0	0,11	0,15	0,12	8,0	16,32	0,67	6,20

Three loess samples, collected sequentially from a depth of 0.60, 2.10 and 10.0 m, exhibit the following chemical composition of this fraction (% of the silicate mass without the ignition losses): SiO_2 – 46.44 to 51.08; Al_2O_3 – 20.99 to 15.49; Fe_2O_3 – 12.44 to 19.77; P_2O_5 – 0.48 to 0.24; TiO_2 – 0.74 to 1.18; CaO – 2.44 to 1.52; MgO – 3.42 to 3.35. The SiO_2 content is about 20% lower and the sum R_2O_3 is about 18-20% higher than that in the total loess mass. The quantity of Al_2O_3 is increased significantly in comparison with Fe_2O_3, and the MgO amount exceeds the CaO one.

Water soluble compounds. The total content of the easily soluble and average and hardly dissolved salts determines the type and degree of loess salinity. The loess in the investigated region contains, although in rather small amounts, the three water soluble compounds – carbonates (bicarbonates), sulphates and chlorides (Table 2).

The carbonate (bicarbonate) quantities are the highest. In about 80% of the samples HCO_3^- amounts to more than 60% of the total anion sum. This determines the exclusively carbonate type of salinity. Only the loess-like sands and some sandy loess samples exhibit slightly expressed carbonate-sulphate salinity. The HCO_3^- amount in the first, second and third loess horizon slightly increases from sandy to clayey loess in parallel with the increasing finely dispersed carbonates. The carbonate content is the highest in the Lom district both in loess (up to 4.08 meq/100 g) and in buried soils (up to 9.54 meq/100 g). The carbonate amounts gradually decrease to the east. The HCO_3^- quantity near Kozloduy is 0.976 meq/100 g for sandy loess and 1.31 meq/100 g for typical loess. The loess in the sections of our sampling exhibits also a carbonate type of salinity. The bicarbonate quantity is more than 69% of the total anion sum for the sandy loess sample and more than 83% for the typical loess sample. In general, the chemical composition of the samples is within the framework of the expected values for the region of the Kozloduy NPP.

Sulphates occupy the second place. Their quantity is higher only in sandy loess. Their amounts decrease in eastern and southern the direction and do not exceed 30% of the anion sum for about 80% of the samples. In contrast to carbonates, they decrease in the fossil soils and exhibits maximums at a certain depth below them. The sulphate content in the samples investigated by us is lower, respectively 0.17 meq/100 g for sandy and 0.15 meq/100 g for typical loess (Table 2), which could be considered as a favourable circumstance with respect to the long-term stability of the RAW barriers, using Portland cement.

The chloride content is lower but it is most constant. It does not exceed 0.74 meq/100 g.

The total amount of water-soluble salts (anion sum) in loess does not exceed 6.50 meq/100 g. In 85 – 90% of the cases it is between 2 ad 4 meq/100 g. The pH value fluctuates from 7.1 to 9.6 (pH about 8 for our samples), i.e. it varies within a relatively narrow interval, so that loess exhibits neutral to slightly alkaline reaction.

Sorption capacity. This parameter shows what part of the cations in the soil could be exchanged by an equivalent quantity of other cations introduced from the outside. Its value depends on the dispersity, on the fine fraction mineral composition and especially on pH of the medium. The sorption capacity of a soil – a host medium for a RAW repository, is one of the important criteria for evaluating its qualities as a natural barrier for radionuclide retention.

It is known that under other equal conditions the bentonite (montmorillonite) clays exhibit the highest exchange capacity (80-100 meq/100 g) compared to other clays due to their specific structure. It is considerably lower in the case of illite (40-20 meq/100 g) and goes down to 15 and 3 meq/100 g. The organic substances increase strongly the exchange capacity. The exchanging complex consists of Ca^{2+}; Mg^{2+}; Na^{+} and K^{+}. The sorption capacity of loess changes from 5 to 15 meq/100 g. It is closer to the lower limit (Table 2) – 5.88 meq/100 g for the sandy loess sample investigated by us and 6.20 meq/100 g for the silty loess sample.

The sorption capacity increases to the south in the fossil soils too, which is connected with the higher clay content and with its higher degree of montmorillonitization. The sandy and silty loess possess lower exchange capacity compared to the clayey varieties. The determined sorption capacity is typical for the loess in the studied region. Its value is not high, which means that the natural barriers should be combined with artificial ones in order to minimise the radionuclide migration in the geosphere.

Structure of loess

The structure of loess is formed under the influence of its specific aeolian origin, its mineral and chemical composition, the dry climate during its deposition as well as of the diagenetic processes. As a result of all this loess had acquired insufficiently compacted and porous structure, its most important specific feature being the instability of structural bonds under the action of water.

The basic building elements of the loess structure are the elementary particles (mono-grains) and the aggregates, connected with inter-particulate and inter-aggregate bonds of colloid, condensation and crystallisation type. According to Minkov (1968) the structure can be granular, aggregate and transitional (aggregate-granular and granular-aggregate) depending on the degree of aggregation, the quantitative criterion being the percent composition of the fraction <0.005 mm, obtained after 20 minutes of mixing.

The loess structure can be represented in other ways too – for example, by the two-dimensional structural model of loess based on a simplified version of the “Monte Carlo” method (Smalley, 1978) or the so-called “masonry” model, representing the building elements of loess in the form of differently arranged bricks (Shen & Hu, 2000). The described structural models are based on various principles and rather complement than exclude each other.

In the present study the structural model of Minkov has been accepted as most suitable for the aspect of consideration. The loess in the investigated region has a granular and transitional structure with the following characteristics:

The granular structure is characterised by deficiency of clayey substance and as a result the latter realises mainly single contacts between the grains of the sandy and silty fraction. The colloidal clay (<0.001 mm) is observed mainly in the form of incrustation of clayey-carbonate substance on the quartz grain surface. In some cases these incrustations (micro patina) serve as a “binder” between the single mono-grains. The total amount of aggregates is small and the predominating ones possess bonds of the condensation and crystallisation type. The granular structure is weak because of the small number and brittleness of the bonds (mainly of carbonate substance) and it collapses spontaneously under conditions of water saturation.

The aggregate-granular and granular-aggregate structure, called generally “transitional” types of structure, are characterised by the fact that the particles of the sandy and silty fraction are not in contact between themselves but “float” in the rest of the silty mass still looking as single grains. The percent of the clayey substance increases in comparison with the former structural type (remaining however still low as an absolute value, especially for the aggregate-granular type) and the number of contacts is increased. The relative number of the structural bonds is low because this structure is characterised by high super-porosity. The aggregates with coagulation and crypto-crystallisation type of bonds are predominating. The structure possesses (similarly to the former type) a low strength in the water-saturated state. Another specific feature of this structure is the regular (isomorphic) distribution of the building elements and structural bonds.

DEPENDENCE OF THE GEOTECHNICAL PROPERTIES ON THE COMPOSITION AND STRUCTURE

A clearly expressed relationship exists between the geotechnical properties of loess and its composition and structure. The main unfavourable property of loess – its collapsibility, is due to the insufficient compaction of the above-described structures and the presence of weak unstable to water action bonds between the sandy and silty grains. These specific features determine the great differences in the strength and deformation properties of loess in the natural and in the water-saturated state.

Average values of the physical and mechanical parameters of loess in the NPP zone (Table 3) are presented here. The loess varieties exhibit low dry density (ρ_d=1.39 – 1.42 g/cm^3) due to their not compacted structure.

The angle of internal friction of the different varieties changes from 27^0 to 30^0, the cohesion – from 10 to 15 kPa, and the modulus of compressibility determined by a stamp is between 14 and 16 MPa for the loess in the natural state. However, this modulus can be reduced to 5 MPa after additional moistening due to weakening of the structural bonds.

From the viewpoint of the considered task, the volume of macropores is of greatest interest. Under vertical loading of 0.3 MPa, which is close to the load transferred to the base of a RAW repository, the volume changes from 4.5 to 6.5%. In some cases the values of this coefficient can exceed considerably the values shown in Table 3. For example, they can exceed 10% for typical loess. This means that the collapse of a massif with a thickness of 10 m can be more than 100 cm. Such big collapse has been observed in irrigation systems to the south of the NPP. This proves categorically that the RAW repository in loess soils cannot be built without preliminary improvement of the soil base. The whole equipment of the Kozloduy NPP has been built on loess after such improvement (Minkov and Evstatiev, 1975), so that significant experience has been accumulated in this respect.

The natural loess represents an unsaturated medium with a low degree of water saturation Sr = 0.30-0.55. This fact presents a number of advantages with respect of RAW disposal – the velocity of radionuclide migration is much lower in an unsaturated medium than in a saturated one. In this connection, the existence of three horizons in the loess massif according to the water content and the moisture fluctuations should be mentioned (Minkov, 1968):

- upper (“impulse horizon”) – with a thickness from 3 to 5 m, whose water content is influenced by the seasonal climatic changes;
- medium (“dead horizon”) – with a thickness from 5 to 30 m, where mainly century-old moisture fluctuations take place;
- lower (“zone of capillary rising”) – connected with the aquifer in the gravel embedded in the base of the loess complex. The height of the capillary rising reaches up to 2.5 m.

The water movement in the two upper horizons proceeds by the moisture movement from thicker to thinner water envelopes, mainly in descending direction. Hence, here the filtration in the sense of Darcy cannot be considered, although the laboratory investigations are carried out with water saturated samples.

Table 3. Average values of physical and mechanical indices of the loess in the Kozloduy NPP zone (by Antonov, 2002)

Loess variety	Solid density	Moisture content	Dry density	Plasticity index	Degree of water saturation	Angle of internal friction	Cohe-sion	Modulus of compressibility	Volume of the macro-pores
	ρ_s [g/cm^3]	W [%]	ρ_d [g/cm^3]	I_P [%]	S_r [-]	φ [degree]	c [MPa]	M [MPa]	% (at 0,3 MPa)
Sandy loess	2,74	11,1	1,42	6,4	0,30	30	0,010	16	4,5
Typical loess	2,72	14,2	1,39	10	0,45	27	0,015	14	6,5

The filtration properties of loess depend on its composition and structure. The sandy loess with its granular structure is more water permeable compared with the typical one due to the increased clayey content and changes to the granular-aggregate structure of the latter. It could be assumed for preliminary assessments that the filtration coefficient in the region of an eventual site near the Kozloduy NPP varies between 1.7x10^{-5} and 5.0x10^{-6} m/s.

CONCLUSIONS

Stable minerals participate in the mineral composition of loess, which would not be subjected to unfavourable diagenetic changes in the course of a several centuries long period – the operation term of the repositories for low and intermediate level radioactive waste disposal. The water-soluble chemical compounds represent a small percent of the total mass and it is not expected that they would exhibit aggressiveness towards the building materials.

The existence of the described type of salinity, the displayed slightly alkaline reaction as well as the low humus content are good prerequisites for the effective interaction between the solid (mineral) phase of loess with the strengthening agents. No corrosion processes in concrete and the other building materials of the eventual repository could take place due to the alkaline medium.

Loess possesses a certain sorption capacity, which is favourable from the point of view of its role as a protective barrier but it is necessary to investigate its sorption with respect to the radioactive isotopes expected to be released by the eventual RAW repository.

The unfavourable specific feature of the loess structure is its collapsibility and high degree of subsidence. However, this feature is prone to control and management due to the granulometric, mineral and chemical composition of loess in the region of Kozloduy.

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SPECTROMETRIC MEASUREMENTS OF GRANITES AND STUDY SURFACE EFFECTS

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ABSTRACT
Spectrometric measurements are a part of remote sensing. They study reflected, emitted or scattered from real land cover light as a function of wavelength. According to main experimental problem obtained spectral reflectance characteristics of different land surfaces have been analyzed. The goal of present paper is the study of petrographic samples with natural roughness and with different mineral grain size and than to do analysis of study surface effects in spectrometric measurements. In this paper granites as a mixed class of their rock-forming minerals are measured. If more than one class is found within the studied surface it is called a mixed class. Laboratory spectral reflectance measurements in range (0.4 - 1.1 μm) of granites are performed. Spectral reflectance characteristics of samples with natural roughness and with different mineral grain size are compared. The study surface effects in spectrometric measurements of granites are discussed.

INTRODUCTION

Spectrometric measurements are a part of remote sensing. They study the light as a function of wavelength. If more than one class is found within the studied surface it is called a mixed class. In this case studied granites are two sub-classes of one and the same class (group) of granite and rhyolite (Маринов, 1989). In other words, the granites are mixed class of their rock-forming minerals.

The goal of present paper is the study of petrographic samples with natural roughness and with different mineral grain size and than to do analysis of study surface effects in spectrometric measurements.

MATERIALS AND METHODS

It is known that the specific reflectance, absorption and emission of solar radiation by land covers is the basis of remote sensing, of spectrometric measurements in particular (Мишев *и др*., 1987).

At the root of spectrometric studies lies the fact that the reflected by the object radiation contains information about surface structure and roughness. This information is carried by the specific spectral distribution of the reflected solar radiation, i.e. by the reflectance coefficients $r(\lambda_i)$. These coefficients form the spectral reflectance characteristic $R\{r(\lambda_i)\}$ and are spectral informational features of the studied object. According to similarity of objects spectral reflectance characteristics different classes could be formed.

The parameters of studied object using measured spectral reflectance $R\{r(\lambda_i)\}$ are defined, i.e. inverse task is to be solved. A basis for the purpose provides the dependence of the reflectance features on the type and properties of the object. This dependence actually determines the informational content of spectral features.

The amount of light scattered and absorbed by a grain is dependent on grain size (Clark and Roush, 1984; Hapke, 1993). In Clark, *et al*., 1993 have been measured reflectance spectra of pyroxene as a function of grain size. As the grain size becomes larger, more light is absorbed and the reflectance drops. The reflectance decreases as the grain size increases.

Made literature review shows that previous investigations aim at analyzed mineral samples. In present paper a try to examined and analyzed obtained results from petrographic samples as mixed class of their rock-forming minerals is to be done.

The studied objects surface structure is of particular importance. It determines the distribution of reflected from surface radiation. Four type of surfaces could be group.

<u>Orthtropic surfaces</u> diffusely or evently reflect the incident flux in all directions. <u>Specular surfaces</u> reflect the incident radiation mainly in the incident beam plane at an angle equal to the angle if incidence. Dry stony surfaces and denudated rock soils have this type of reflectance within the visible range. <u>Anti-specular surfaces</u> reflect to a maximum of the direction of the emision source. <u>Combined surfaces</u> have two reflectance maxima of the incident radiation – specular and anti-specular.

Mentioned above group have to be include in results interpretation. If a priori information is not enough it could be bring a lot of omissions in interpretation. It is important to know technical parameters of used apparatuses and experimental conditions.

The studied petrographic samples are with natural roughness and with different mineral grain size. The aim is approximation of laboratory spectrometric measurements to natural one. As another confusing factor in spectrometric measurements is cut or polished sample. Polished and mirror surfaces could be make a change in spectral reflectance coefficients value.

Laboratory spectral reflectance measurements in range (0.4 - 1.1 μm) with Δλ=20 nm of granites (10 samples) were performed. It was used spectrometric system for remote sensing SPM-1, made in STIL-BAS (Илиев, 2000).

RESULTS AND DISCUSION

Figure 1 shows spectral reflectance characteristics of studied granites. Obtained values of spectral reflectance coefficient depend on mineral grain size, i.e. on petrographic structure. Reflectance feature of coarse-grained granites is almost horizontal or with a small angle (0-15), of medium-grained the angle is 15-30 and of fine-grained the slope is over 30 .

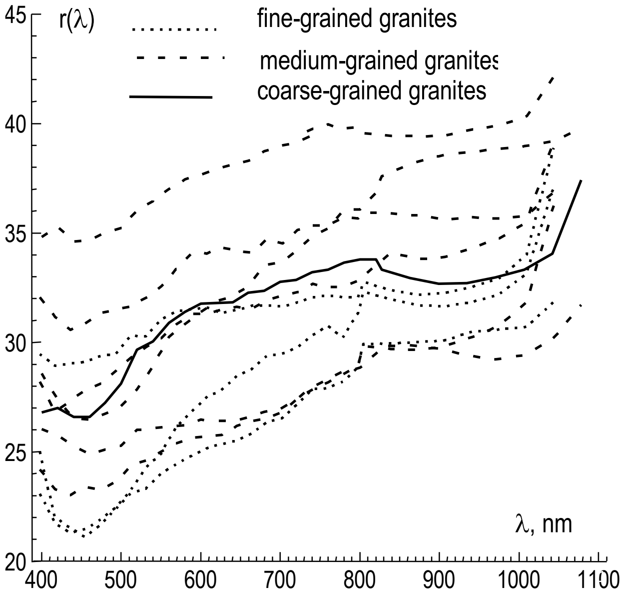

Figure 1. Spectral reflectance of granites with different structure.

Conventionally numerical symbols for three types structure are: 1 – for fine-grained granites; 2 – for medium-grained granites and 3 – for coarse-grained granites. The aim fo this substitution is possibility to analyzed grain size effects in spectrometric measurements.

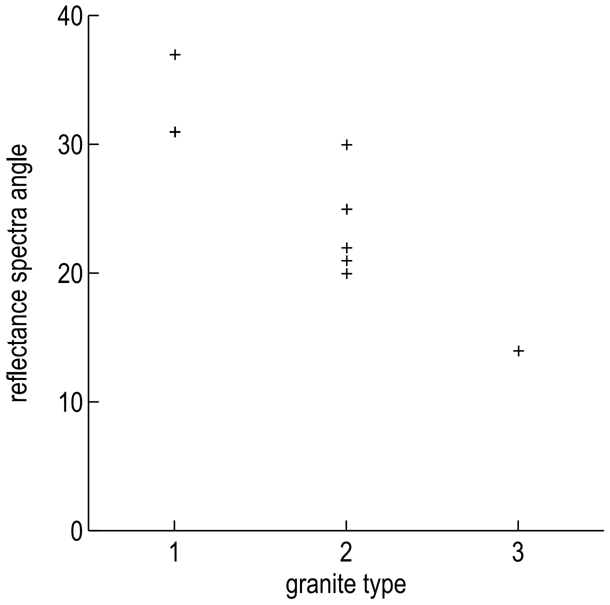

Figure 2. Relationships between granite type structure and reflectance spectra angle.

In advance it was done petrographic analysis on mineral composition, percentage mineral contents, structure and roughness of granites. Figure 2 shows relationships between granite type structure and reflectance spectra angle. It can be seen that the reflectance angle decreases as the grain size increases, i.e. the structure is changed from fine-grained to coarse-grained.

Table 1. Compare structural description.

N	Name	Structure in Figure 1	Structure in determination
1	Granite	Fine-grained	Medium-grained
2	Porphyry granite	Medium-grained	Medium-grained, K-felspar porphyries
3	Porphyry granite	Coarse-grained	Coarse-grained, Plagioclase porphyries
4	Two-mica granite	Medium-grained	Medium-grained
5	Porphyry granodiorite	Medium-grained	fine-grained, K-felspar porphyries
6	Granite	Medium- to Coarse-grained	Medium-grained
7	Granite	Medium-grained	Fine- to Medium-grained
8	Granite	Medium-grained	Fine- to Medium-grained
9	Granite	Fine-grained	Fine- to Medium-grained
10	Granite	Medium-grained	Fine- to Medium-grained

In Table 1 is present the structural description of studied granites in petrographic analysis and in spectral reflectance characteristics. The comparision shows good coincidence of structural description in two used way.

Roughness is another factor which spectral reflectance characteristics of granites depend on. It was registrated (Spiridonov, *et al.*,1980; Борисова, 1996) that polished and smooth rock surfaces increase spectral reflectance coefficients. In present experiment only two samples are with almost smooth surface. It can be seen (Figure 1) in higher spectral reflectance coefficient values.

CONCLUSIONS

An advantage of spectrometric investigations is a lot of information including in obtained results. This allowed their use as decodal indication for type classification of studied objects.

Analysed spectral relfectance characteristics content a complex information. Their type depend on set of factors (color, determined by proportion in mixed class granites of salic and mafic rock-forming minerals; structure and roughness of the samples). We can conclude that study surface effects in spectrometric measurements are:

- reflectance spectra angle of granites;
- higher spectral reflectance coefficients values obtained from more smooth granites.

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BLACK SEA GAS SEEPAGE AND VENTING STRUCTURES AND THEIR CONTRIBUTION TO ATMOSPHERIC METHANE

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ABSTRACT

Only recently the international scientific community started to pay more attention of such natural, geological sources as submarine gas seepages and mud volcanoes and realized that they are significant sources of atmospheric methane. In this work the Black Sea is considered to be one of the most prolific areas in the World. Here we present a detail overview of the gas seepage areas documented offshore along the Bulgarian coastline, on the Georgian, Russian, Ukrainian and Turkish shelves as well as seabed gas venting structures as pockmarks, mud volcanoes, methane derived carbonate chimneys etc. Some speculations about massive gas outburst due to destabilization of gas hydrates are commented. The attempt to evaluate the annual quantities of gas methane venting from the seafloor, passing trough the water column and entering the atmosphere from gas seepage and venting structures shows values form 1.5 to 5.5 Tg (2.0-6.0x10^{9} m^{3}) released from the Black Sea area, an area no exceeding one percent of the World Ocean aquatory.

INTRODUCTION

Greenland and especially Vostok (Antarctica) ice core records for the last few hundred thousands of years clearly show the saw-shaped character of changing in atmospheric methane concentrations with rapid increasing to peaks higher than today one and extend irregular restoring to about the initial values with similar but short lagging temperature curve (Chappellaz *et al.,* 1993; Petit *et al.,* 1999). These indicate that Global warming and Global cooling are mutually depended natural processes repeated already several times during the Late Quaternary, which unknown mechanisms are waiting to be revealed. The authors believe that the present ongoing Global warming is the subsequent climbing to the next fang of the saw, dramatically accelerated by the human activities since the industrial age.

The data also evidenced that the past changes of atmospheric methane concentrations of magnitude more than 400 ppbv happened without any anthropogenic influences, which force scientists to look for natural sources of not only methane but all the greenhouse gases and the pathways of their escape. Only recently the international scientific community started to pay more attention of such natural, geological sources as submarine gas seepages and mud volcanoes and realized that they are significant sources of atmospheric methane. The few existing estimations of global atmospheric methane flux from these "minor" sources vary from a few terra grams (1 Tg = 1x10^{12} grams) (Lacroix, 1993; Cranston, 1994; Judd, 2000) to 65 Tg CH_4 (Hovland *et al.,* 1993) per year coming from submarine gas seepage and from 5.1 Tg (Dimitrov, 2002) to 30.5 Tg CH_4 (Milkov *et al*., 2002) from mud volcanoes world vide.

Among the great number of publications describing individual gas seep sites and related seabed features offshore the Black Sea countries, mud volcanoes in the deep basin and number of gas hydrate discovering there are only two of them devoted on quantification of methane flux in the Black Sea (Tkelashvili, *et al.,* 1998; Dimitrov, 2002). Both papers present regional estimations of the flux from gas seepage only for Georgian and Bulgarian shelves, respectively and do not include other gas venting features, as mud volcanoes etc.

The purpose of this paper is to evaluate the annual quantities of gas methane venting from the seafloor, passing trough the water column and entering the atmosphere from gas seepage and venting structures on the seabed from whole area of the Black Sea including some terrestrial mud volcano areas as Kerch and Taman peninsulas and wetlands in the mouth of Danube delta.

GENERAL GEOLOGY OF THE BLACK SEA

The Black Sea is large semi - enclosed marine basin having area of 423,000 km^{2}, volume of 534,000 km^{3}, and maximum depth of 2,248 m. It is connected to the Mediterranean Sea via Bosporus, a narrow strait that has a sill depth of about 50 m. At the same time the Black Sea has a gigantic catchment basin which includes the river discharge of half of Europe and part of Asia, its drainage area of 2,290,200 km^{2} exceeds by more than 5 times the area of the Black Sea basin itself.

Geologically, the Black Sea is located to the south of the European craton and occupies a complex position on several structural zones. It is surrounded to the north, north-east, south and south-west by Alpine folded systems of Crimea, Caucasus, East and West Pontides and Southern Balkans. To the north and north-west it is bordered by the epihercynian, Mesozoic and Cenozoic formations, the Moesian and Scytian platforms. The deep Black Sea basin itself is formed by two basins separated by a ridge (the Mid-Black Sea Ridge) andrepresents a large depression infilled by up to 16 km thick, sedimentary series burying the pre-existing relief (Finetti *et al.*, 1988). The little-disturbed sedimentary strata lie almost horizontally in the whole deep basin. The basin fill consists of very thick from (3 to 5 km) Paleogene, mainly Eocene sediments, followed by Oligocene (about 3.5-4 km thick), covered by more than 2 km Miocene sediments. Pliocene and Quaternary are characterized by thick Danube fan deposits. The present sediment distribution pattern is a mixture of terrigenous sediments along the shelf and flanks of the basin, turbidites in the basin apron, and biogenic carbonates in the deep portion of the basin.

There are various views on the reason and timing of the formation of the Black Sea; area of resent oceanization, remnant part of Paleo Thetis ocean etc. From the view of plate tectonics the Black Sea may represent a remnant of back-arc marginal basin (Finneti *et al.,* 1988). According to this, during the geodynamic process, initiated in the upper part of Lower Cretaceous and terminated at the end of Paleocene (110-55 million years BP.), the opening of the Black Sea took place as a consequence of the formation of two back-arc basins behind the W and E - Pontides. The W-basin evolved to the stage of complete crustal opening with a basaltic basement, while E-basin evolved to the stage of a very thin continental crust affected by numerous listric faults and tilted blocks. In the Middle Eocene, the first compressive tectonic phase occurred and generated most of the orogenic belts surrounding the Black Sea. These compressive movements with overthrust deformation continue to the present day on the offshore Caucasus, and in the Crimea.

With respect to the water body, until the late Miocene the Black Sea was a shallow marine basin which, but subsidence during the latest Miocene to earliest Pliocene time (5 million years BP) transformed it into a deep marine basin. Since then, during the eustatic sea-level changes and because of the very narrow and shallow sill, the Black Sea became connected with or disconnected from its marine source. Thus it changed back and forth from marine to brackish to freshwater environment. During the last glacial period the Black Sea was a deep isolated fresh water lake. As the sea level rose at the end of the glacial the high salinity and dense waters from Marmara Sea were introduced into the Black Sea (about 7,000 years ago). Thus stratified the water column which caused the bottom waters to became anoxic.

GAS SEEPAGE AND VENTING STRUCTURES

Data on shallow gas, mud volcanoes, gas seepage and related seabed features suggest that the Black Sea may be is one of the most prolific areas in the World. Here we will present a short review on all these features based on published information and own data. Most of the information is summarized on figure two illustrated with the major and most spectacular findings in the Black Sea area.

Evidences of shallow gas occurrences have been found almost everywhere within the Black Sea basin: from around the nearshore, shelf, especially the shelf breaks, continental slopes and abyssal plain. They include both geophysical (echo-sounder, seismic, subbottom profilers and side-scan sonar records) and (geo) chemical data.

The huge terigenous flux with relatively high content of fresh organic matter derived in the Black Sea is an excellent source for methane generation. There are two main patterns for discharging of this material. The first one, working in the largest NW and Western Black Sea shelf is the South density current - the major lythodinamic factor in this part of the sea. This anti clockwise current carry the terigenous material derived from Danube, Dneper and Dnester rivers (almost 80% of the total Black Sea flux) and discharge it mainly on the Bulgarian shelf. The second way is the discharging of the material derived from all other rivers. Because of very narrow shelf as in the southern par (all Turkish shelf), as in the Crimea region, as well as whole eastern part of the sea, the sediments are loaded directly at the slope base and abyssal plain passing the shelf and slope. This pattern have been valid many times for all Black Sea basin in the past, when the sea level have been about 100 m below present, because of eustatic changes. During that times have been deposited a series of organic rich sapropel layers, because of dramatic, sharp change of the living environment. Because of these, the scale of generating and retaining of "shallow gas" are larger in the Holocene muds of the shelf due to the relatively high content of fresh organic matter, and in the Pleistocene sediments in the deep waters.

Gas seepages

The seepage of natural gas is known to be widespread in both land and marine environments (Hovland & Judd, 1988). Gas seeps are known to be associated with leakage from gas reservoirs and shallow gas accumulations, and from gas hydrates; consequently, they occur in all the oceanic environments: coastal environments of deposition (bays, estuaries etc.); major deltas; hydrocarbon-bearing sedimentary basins on the continental shelf and slope etc.

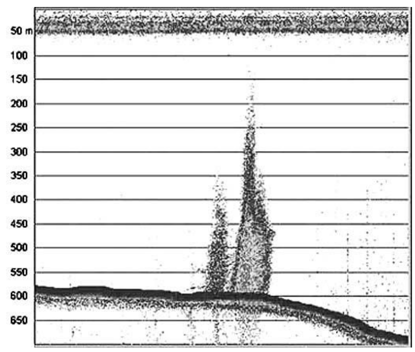

Figure 1. A SIMRAD EK - 500 echogramm of double-seep, nicknamed "Two Captains" in the NW Black Sea at a depth of 593.5 m. The plume rises some 400 m into the water column (courtesy of V. Egorov/S. Gulin, Sevastopol, Ukraine)

50 long existing gas seepage areas are described in Bulgarian coastal waters with more than 6,000 individual seeps and 482 water column targets representing gas seeps are identified offshore Bulgaria (Dimitrov, 2002a). Some ten thousand of seepage are reported to exist within the Georgian shelf (Tkelashvili *et al.,* 1998). Several areas of active gas venting are also known in Romanian (modern Danube delta preferably), Ukrainian (Geodekyan *et al.,* 1991) and Turkish waters as well as oil seeps (Iztan, 1996). More than 500 gas

plumes are documented by echo-sounding (fig. 1) along the shelf break of the Western and North-Western part of the Black Sea (Shnukov *et al*., 1999). Abundant gas seepage have been found around the edge of the basin in water depth down to 800 m along the shelf break and active faults in the shelf areas, especially along the frontal lines of Balkanides, Crimea and Great Caucasus, in the NW shelf where several oil and gas fields in the Ukrainian and Romanian shelves are exploiting, in the area of the Danube, as well as other delta and submarine fan complexes.

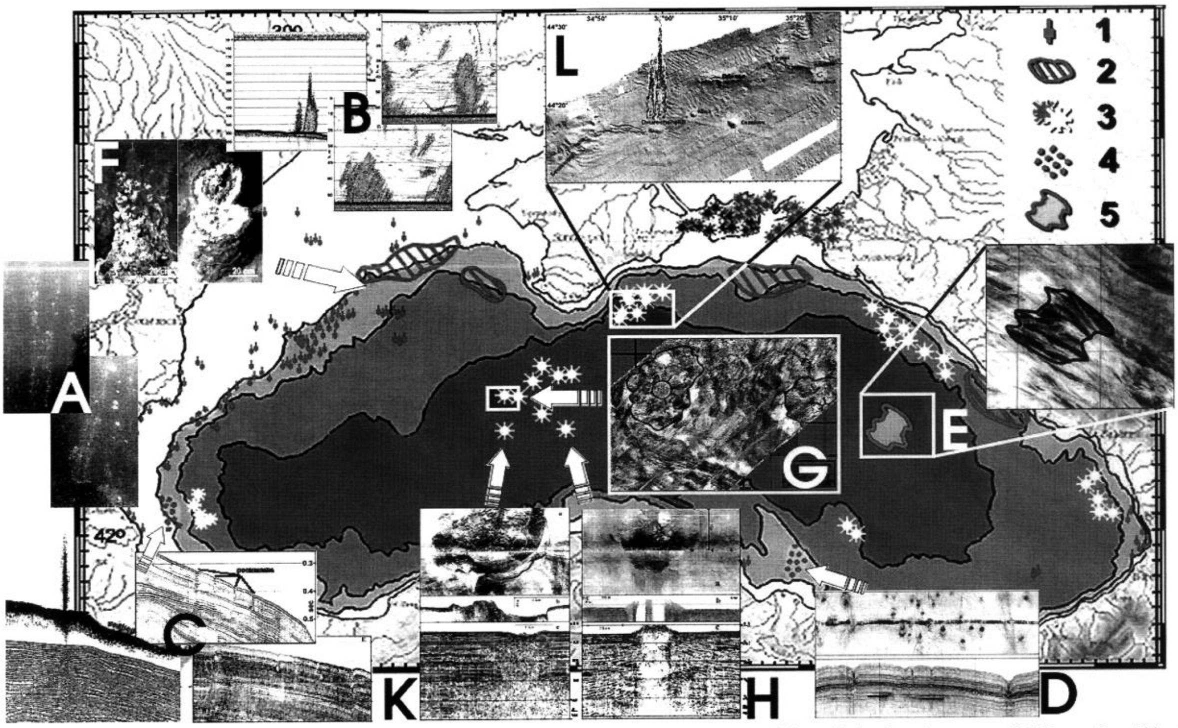

Figure 2. Map of the documented Black Sea gas seepage, seabed venting structures and mud volcanoes. 1. Gas seepage or venting sites; 2. Areas with abundance of gas seepage; 3. Offshore and terrestrial mud volcanoes; 4. Seabed pockmarks; 5. Area of seafloor gas boiling swamp. A – Pictures of gas seepages offshore Bulgaria; B – Echograms of gas plumes from shelf break in the NW part of the Black Sea; C – Sparker profiles showing seabed pockmarks offshore Southern Bulgaria; D – Side-scan sonar image and corresponding subbottom profiler section with pockmarks on the uppermost Turkish slope; E – Deep tow side-scan sonar mosaic with the area of seafloor gas boiling swamp; F – Methane derived carbonate chimneys at water depth of about 250 m in the Northern Danube deep sea fan; G - Deep tow side-scan sonar mosaic of the MSU and Yuzhmorgeologia mud volcanoes; H – Composite Image (sonogram above, profiler and seismic sections bellow) of the Malishev mud volcano in the Black Sea abyssal plain; K – The same of the TREDMAR mud volcano; L – Swath bathymetry of the seafloor in the Sorokin trough wit several mud volcanoes and high intensity double vents on Dvurechenski mud volcano

Seabed gas venting structures

Except, plumes from free gas bubbles in the water column, there are prominent features on the seafloor originated by the escape of the gas from seabed, i.e. pockmarks, carbonate chimneys, cold reefs, “boiling seafloor swamp” etc.

Pockmarks include isometric cone to saucer shaped depressions on the seafloor varying in size from a meter to more than a few hundred meters across with depths of less than one to more than ten meters. They were described and named for the first time in 1970 as morphological features formed on the continental shelf off Nova Scotia, Canada, (King & MacLean, 1970) and then observed and reported in many places all over the world ocean (e.g. Hovland & Judd, 1988). They occur in areas of fluid discharge, and need fine-grained sediments to support their structure and long existence. Nowadays it is widely accepted that pockmarks originated by expulsion of gas from over-pressured shallow gas pockets, dispersing the sediment into the water column (Hovland and Judd, 1988) or by intensive continuous fluid discharge hindering sediment deposition around the seep. Pockmarks may stay active, calmly seeping gas for long periods, or lie dormant between episodic eruptions.

In 1988 pockmarks were discovered for first time in the Black Sea along the Southern Bulgarian shelf break described by Dimitrov and Doncheva (1994). After then other two pockmark areas have been found in the peripheral shelf terrace south-east of cape Kaliakra (Dimitrov, 1998) and on the uppermost eastern Turkish continental slope (Kruglaykova *et al*., 2002)

The first area embraces about 100 km² zone with length of more than 41 km and wide from 2 to 5 km at water depths from 160-240 m to 230-350 m (fig. 2C). There are 305 documented pockmarks within it part of which active.

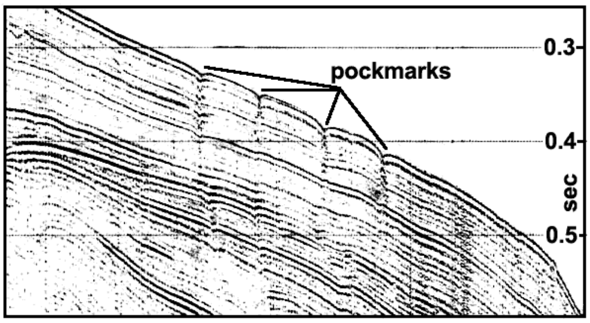

Figure 3. A high-resolution sparker section from the upper part of southern Bulgarian continental slope on which V-shaped pockmarks are clearly visible

The second one near cape Kaliakra is also elongated along the shelf break and more then 160 pockmarks are observed (fig. 3). The last one were localized during pipeline survey on the “Blue Stream” project in 1996. It is situated at water depths of 220-400 m (fig. 2D) and a lot of gas jets are observed coming out from the mouths of the pockmarks suggesting their present high activity.

Other evidences for gas leaking from the seabed are so called methane derived carbonate buildups. These are formed around gas migration path where occurs methane oxidation by methanotrophic bacteria inducing precipitation of carbonate which litifies the sediment. Cementation goes on around the methane pathway, fills channel and the pillar structure grows from outside.

Some areas with number of methane derived carbonate buildups big up to 3.5 m in height are discovered on the seafloor in the upper parts of north and north-western continental slopes – fig. 2F (Gevorkyan *et al.,* 1991; Treude *et al.,* 2002) as well as carbonate crusts in several places in the Sorokin Trough.

Recently a very interesting phenomenon named seafloor "boiling sediment swamp" was discovered in the Eastern Deep Black Sea Basin by the Russian team form Yuzhmorgeologiya, Gelendzhik (Kruglyakova *et al*., 2002). A large spot of high intensity backscattering is observed on the swath bathymetry mosaic of about 3,600 km^2 (fig. 2E). The more detail look on the area by deep towed side-scan sonar MAK-1 with profiler system shows that the seabed sediment in the area is highly gas charged and seafloor is very hummocky by abundance of small griphones – isometric hills about 5-6 m in diameter and near two metres of height, continuously venting gas.

Mud volcanoes

Mud volcanoes are geological structures formed as a result of the emission of argillaceous material on the Earth's surface or the sea floor. Sufficient water and gas is incorporated within this fine-grain muddy sediment to make it semi-liquid and to force it up through long narrow openings or fissures in the crust to produce an outflowing mass of so called mud breccia on the surface. The main driving force for mud volcano formation, discussed in detail by Hedberg (1980), Brown (1990) and Dimitrov (2002), is abnormally high-pore fluid pressure caused by a combination of rapid sedimentation, *in situ* gas generation and structural or tectonic compression. Depending of the activity of the mud volcanoes, they sporadically or continuously emit considerable volumes of gas to the atmosphere and it is mainly methane – up to 99% (Dimitrov, 2002).

There are 46 mud volcanoes on the easternmost part of Kerch peninsula and 42 on the Taman peninsula and more than 50 in adjacent shallow waters of Azov and Black Seas (Dimitrov, 2002) many of them presently active.

The presence of mud volcanoes in the central Black Sea abyssal plain has been supposed since the end of 1970s, when a set of multichannel seismic data was obtained by "Yuzhmorgeologia" - Gelendzhik, Russia.

The Black Sea mud volcanoes are randomly distributed at water depths below 2 km in an area of 6,500 km^2 south of Crimean Peninsula known as Central abyssal mud volcano area. Since 1988 to several expeditions was carried out by international teams in this area and 9 large mud volcanoes were studied in detail (Ivanov *et al.,* 1989)

Belts of clay diapirs and mud volcanoes are situated along the continental slope south-east of East Crimea in the Sorokin Trough where 11 exposed on the seafloor mud volcanoes are localized (Bouriak & Akhmetjanov, 1998; Bhorman *et al*., 2002). Several mud volcanoes have been found on the continental slope in the north-west Caucasian margin (Korsakov *et al.,* 1989.), southern Bulgaria part and in eastern Turkish continental slope. All these belts are connected with overthrust zones and with the development of Oligocene-Miocene basins in which 2 – 5 km thick fine-grained sediments of Maicopian Formation have been deposited. These sediments are believed to be the root of mud volcanoes, just as in the Kerch and Taman mud volcano areas.

Recently, tow big gas flares have been recorded by echo-sounder at the vicinity of Dvurechenski mud volcano in the Sorokin Trough rising some 700 m above the seafloor (fig. 2L). Judging by the measured high geothermal gradients and presence of gas hydrates in the bottom sediments other mud volcanoes are inferred to be active today as TREDMAR, Odessa, Vassoevich, Malishev (fig. 4) etc.

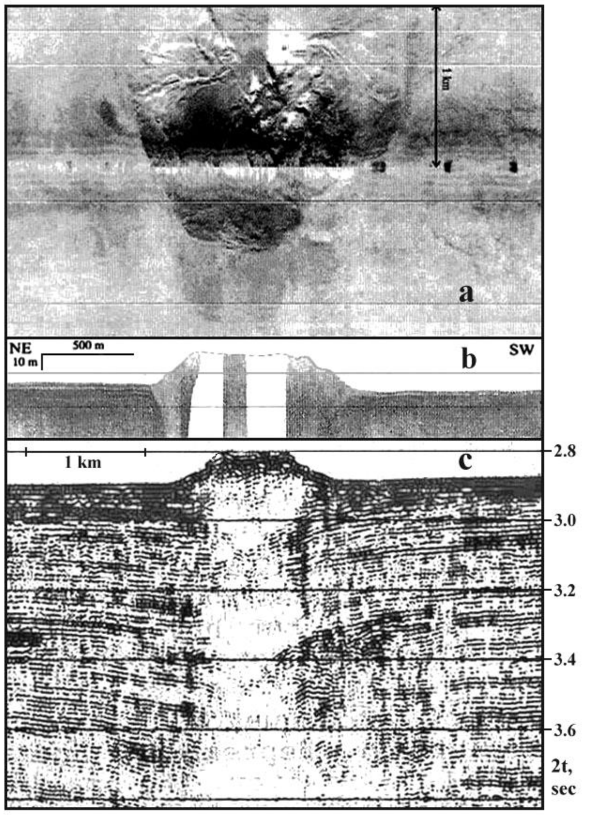

Figure 4. The Malishev mud volcano (fig. 2F). a) MAK-1 deep tow sidescan sonar image with its corresponding subbottom profiler line (b) and seismic section (c). The well developed dome-like structure of the mud volcano is clearly seen as well as mud flow patches on the sonogram and several bright spots around the well delineated feeder channel on the seismic section

CONTRIBUTION TO ATMOSPHERIC METHANE

The previous estimations made by L. Dimitrov (2002) for the Bulgarian continental shelf suggest an annual gas flux at the sea-surface running from about 3,600 m^3 per km^2 to more than 18,000 m^3/km^2; the evaluation of Egorov and co-workers (2002) for an area abundance of high-intensity gas seepage set up these values between 9,100 m^3/km^2 and 630,000 m^3/km^2 (about 90,000 m^3/km^2 on average); and the extreme values form about 400,000 m^3/km^2 to 1,225,000 m^3/km^2 calculated for the Georgian shelf (Tkeshelashvili *et al*., 1997). If take an average conservative flux of about 10,000 m^3/km^2 than the quantity escaping to the atmosphere from the whole shelf area of the Black Sea (about 132,200 km^2) can be estimated on about $1.3x10^9$ m^3 or near one Tg.

The diffusive flux and low intensity gas venting from mud volcanoes in deep water environments are not taken into account also because gas is partially converted into hydrate (as much as 10 %), partially consumed by bacteria or oxidized in the near bottom sediments, other parts are captured in a hydrate form directly on the seafloor or consumed by diversity of species in a chemosynthetic communities, and the amount of the gases left dissolve totally in the sea water. The only gas able to enter the atmosphere from deep water environment is from very high-intensity plumes or blow-outs during the eruption of mud volcanoes.

The total contribution to atmospheric methane by mud volcanoes have been evaluated to be from 5.1 - 30.5 Tg per year commimg from near 1,900 individuals (Dimitrov 2002; Milkov *et al.*, 2002). There are about 200 mud volcanoes in the Black Sea and surrounding land areas, hence they should emit 10% of the world total as a minimum which give about 0.5 – 3.0 Tg (0.7-4.2x10^9 m^3) of methane annually.

CONCLUSIONS

This short review evidenced that shallow gas, gas seepage and seabed gas venting structures are very common in the whole Black Sea area, which add another unique characteristic of the basin - the diversity and abundance of the shallow gas events.

The evaluation of the quantity of the gas released trough all these features shows that they are one of the significant natural, geological sources of atmospheric carbon and particularly gas methane. The total annual amount emitted trough them is estimated in the range 1.5 to 5.5 Tg (2.0-6.0x10^9 m^3) methane enter the atmosphere every year from gas vents of the Black Sea – an area no exceeding one percent of the World Ocean aquatory shelves and what about inland gas seepage and venting structures?

The released methane from the Black Sea area is comparable with the totals of other “minor” natural sources (Judd *et al.*, 1993) as natural coal seam fires (~1 Tg CH_4 yr^{-1}), hydrothermal sources (2.3$\pm$1.4 Tg CH_4 yr^{-1}) and are as significant as the anthropogenic emissions from total Industrial sources (9.1 Tg CH_4 yr^{-1}) (Judd *et al.*, 1993) or petrochemicals, petroleum refining and combustion of fossil fuels all together (11.1$\pm$1.9 Tg CH_4 yr^{-1}) (Lacroix, 1993).

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MAGNETIC CHARACTERISTICS OF THE RHYOLITES IN THE RHODOPE MASSIF

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ABSTRACT
The rhyolite formation in the Rhodope massif is presented by Tertiary extrusive and effusive lava in the Western and Central Rhodopes.
Data from measurements performed by the Department of Applied Geophysics, University of Mining and Geology, Sofia and other organizations are summarized. Magnetic characteristics – the magnetic susceptibility and the value of the remanent magnetization vector, are studied on samples from different areas of the Rodope massif – the Bratsigovo-Dospat depression, the Dospat anticline, the Southern Rhodope syncline, the Northern Rhodope syncline, the Smolyan depression and other more local structures as the Kovachevo syncline, the Batak syncline, the Vacha uplift, the Lyaskovo uplift and the Hvoina graben-syncline.
Statistical analysis is applied for estimating the characteristics of sample packs from one and the same region, as well as for estimating the characteristics of the total set of available data. The surface distribution of the magnetic susceptibility is studied for several local outcrops, using the available data from detailed parametric measurements.
The compound analysis of the magnetic susceptibility and the remanent magnetization of the rhyolites in the Western and Central Rhodopes is proving that the detailed mapping according to magnetic characteristics can efficiently enrich the information obtained by the traditional geological mapping.

INTRODUCTION

The rhyolite formation in the Rhodope massif is presented by Tertiary extrusive and effusive lava in the Western and Central Rhodopes and is most completely studied in the Bratsigovo-Dospat structure (Bahneva *et al.* 1978 ; Bojkov *et al.* 1978). It is composed by biotite and amphibole-containing rhyolites up to rhyodacites. In the northern part of the Bratsigovo-Dospat volcanogenic structure they form one elongated in subequatorial direction zone (Bahneva *et al.* 1978). In the rhyolite zone can be isolated several elementary volcano-structures. The authors state that each of these structures is built by several close in age, in structural-morphologic peculiarities and in magnetic characteristics extrusives, as well as by the connected to them effusive lava flows. For the extrusives is established the presence of remanent magnetization.

I.Bojkov *et al.* (1978) confirm that in the Bratsigovo-Dospat depression the rhyolite covers have frequent occurrence and are characterized by a well-expressed almost horizontal surface parallelism – angle of dip of about 12^o. Extrusive rhyolite bodies intersecting the rhyolite covers are located in the western part of the depression. These extrusive bodies are normally determining the contrast in the relief.

The presented study is based upon data from measurements performed by the Department of Applied Geophysics, University of Mining and Geology, Sofia and other organizations. Magnetic characteristics – the magnetic susceptibility and the value of the remanent magnetization vector, are studied on samples from different areas of the Rodope massif – the Bratsigovo-Dospat depression, the Dospat anticline, the Southern Rhodope syncline, the Northern Rhodope syncline, the Smolyan depression and other more local structures as the Kovachevo syncline, the Batak syncline, the Vacha uplift, the Lyaskovo uplift and the Hvoina graben-syncline.

The magnetic susceptibility is studied according to data from laboratory measurements on rock samples of outcrop and drill core (973 samples) and according to parametric measurements on outcrop surface. The value of the remanent magnetization vector is determined on 536 rock samples of outcrop and drill core.

Statistical analysis is applied for estimating the characteristics of sample packs from one and the same region, as well as for estimating the characteristics of the total set of available data. The surface distribution of the magnetic susceptibility is studied for several local outcrops, using the available data from detailed parametric measurements.

MAGNETIC SUSCEPTIBILITY OF THE RHYOLITES IN THE RHODOPE MASSIF

In a regional plan, the rhyolites in the Rhodope massif have low to middle magnetic characteristics. The magnetic susceptibility measured on 973 rock samples of outcrop or drill core varies in a wide range - from 0 up to 1800.10^{-5} SI, and for some samples it goes even higher. In many cases the values of the studied parameter are quite different in the boundaries of one and the same relatively small area. For example, in the area of Dospat, the pink-coloured rhyolites have magnetic susceptibility of 600-900.10^{-5} SI, and the gray rhyolites, intruded on separate places among the pink-coloured, are characterized by a magnetic susceptibility of 1400-2000.10^{-5} SI. For part of the samples the magnetic susceptibility is relatively low (æ< 500.10^{-5} SI). Obviously in such cases there is a presence of secondary hydrothermal-metasomatic and hypergenic processes leading to destruction or oxidation of the primary ferromagnetic minerals and to formation of non-magnetic or low-magnetic varieties. It can be summarized that the well-expressed local variations of the rhyolites magnetic susceptibility are due to the effect of two major factors – the differentiation according to the studied parameter of the types of distinct phases and the influence of secondary hydrothermal-metasomatic and hypergenic processes.

In Table 1 are systematized the main statistical characteristics of the values distribution for the magnetic susceptibility and in Fig.1 is shown a histogram of the parameter distribution for the main group of rhyolites – only about 4% of the samples having relatively high values (æ>1800.10^{-5} SI) are excluded.

Table 1. Main statistical characteristics of the magnetic susceptibility of the rhyolites in the Rhodope massif (the magnetic susceptibility values are in SI)

Region	Count	æ^{min}.10^5 / æ^{max}.10^5	Average æ.10^5 SI	Standard deviation	Skewness	Kurtosis
Western Rhodope Block	174	0 / 3634	821	652	6	10
Bratsigovo-Dospat Depression	416	0 / 5940	967	704	17	51
Dospat Anticline	92	0 / 3189	734	595	5	9
Southern Rhodope Syncline	106	0 / 2384	520	624	3	2
Northern Rhodope Syncline	48	183 / 1629	1012	378	0	0
Smolyan Structural Depression	79	0 / 1448	393	421	2	0
Total	973	0 / 5940	834	666	19	51

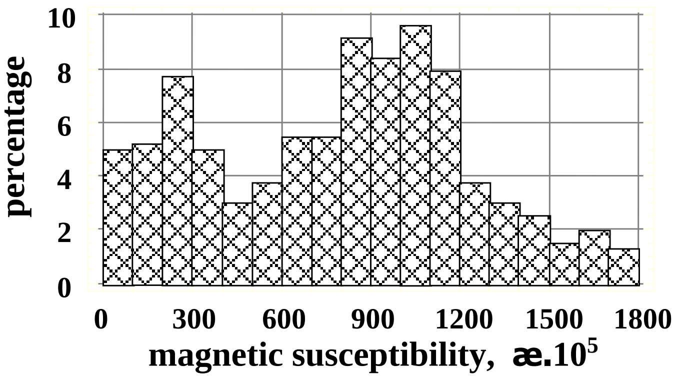

Figure 1. Histogram of the magnetic susceptibility distribution of the main group of rhyolites in the Rhodope massif.

The compound analysis of the illustrated histogram and the histograms elaborated for the different regions is showing that two main groups are well pronounced in the magnetic susceptibility distribution. The first group is including samples having magnetic susceptibility within the limits of 0-500.10^{-5}SI, and the second one is containing samples having magnetic susceptibility within the limits of 500-1800.10^{-5}SI. A limited number of samples (about 5%) has a zero magnetic susceptibility and almost the same number of samples (about 4%) has high parameter values (æ>1800.10^{-5} SI) reaching up to 6000.10^{-5} SI.

The Bratsigovo-Dospat depression is represented by the greatest number of samples and the magnetic susceptibility distribution for this region has predominant influence on the illustrated histogram of the parameter distribution for the main group of rhyolites samples (about 96% of the total set). Almost identical is the distribution for the Dospat anticline and the Western Rhodope block. Insignificant differences are observed for the rest of the studied regions.

It should be accepted, that the group having æ<500.10^{-5}SI is reflecting mainly the influence of the secondary hydrothermal-metasomatic and hypergenic processes. In the group having magnetic susceptibility 500.10^{-5} < æ < 1500.10^{-5} SI are included samples from the predominating rhyolite zone, and the samples having relatively high values (æ > 1500.10^{-5} SI) are related to extrusive formations.

The surface distribution of the magnetic susceptibility is presented in Fig.2. The Bratsigovo-Dospat depression is generally characterized by increased values for the magnetic susceptibility. For the entire territory, on the background of the rhyolite zone having magnetic susceptibility of about up to 1500.10^{-5} SI, can be separated areas having increased parameter values that are mapping the presence of extrusive formations.

The data from laboratory measurements of the magnetic susceptibility on rock samples of Rhodope massif rhyolites are enriched substantially by the performed parametric measurements on outcrop surfaces. These measurements are confirming the very wide range of parameter variation and are proving that this fact is valid within the boundaries of relatively small areas. Special studies are carried to determine the regulations in the local zonal distribution of the rhyolites magnetic susceptibility in the boundaries of separate outcrops.

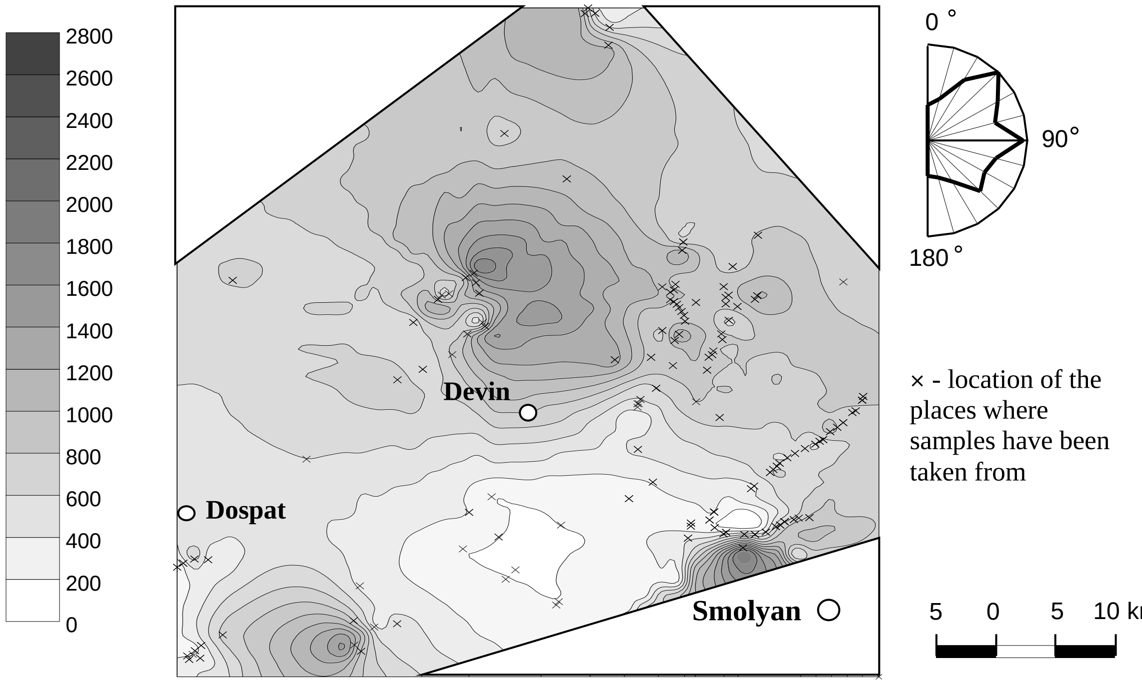

Figure 2. Scheme of the magnetic susceptibility surface distribution of the rhyolites in the Western and Central Rhodopes region and a rose-diagram of the isolines orientation.
The zoning is performed in æ.10^5 SI.

Parametrical measurements of the magnetic susceptibility are performed by a field kappa-meter and along a regular net of 10x10m. Four outcrops of rhyolites in the Smolyan area are studied – “Orlov kamak”, “Chervenata skala”, “Torlouka” and “Perelik”.

In order to avoid the influence of the microstructure non-uniformity, five measurements are done around each station on an area of 1m^2. The differences between the measured values are in the limits of 3-10%. Samples for a laboratory analysis are taken from about 30% of the stations studied during the parametrical measurements. The magnetic susceptibility data of the laboratory analysis and the field measurements are comparable with a precision of 5-15%, so the differences are in the limits of the variations during the parametrical measurements in each station.

In Fig.3, Fig.4 and Fig.5 are illustrated the parameter surface distributions for three of the studied outcrops.

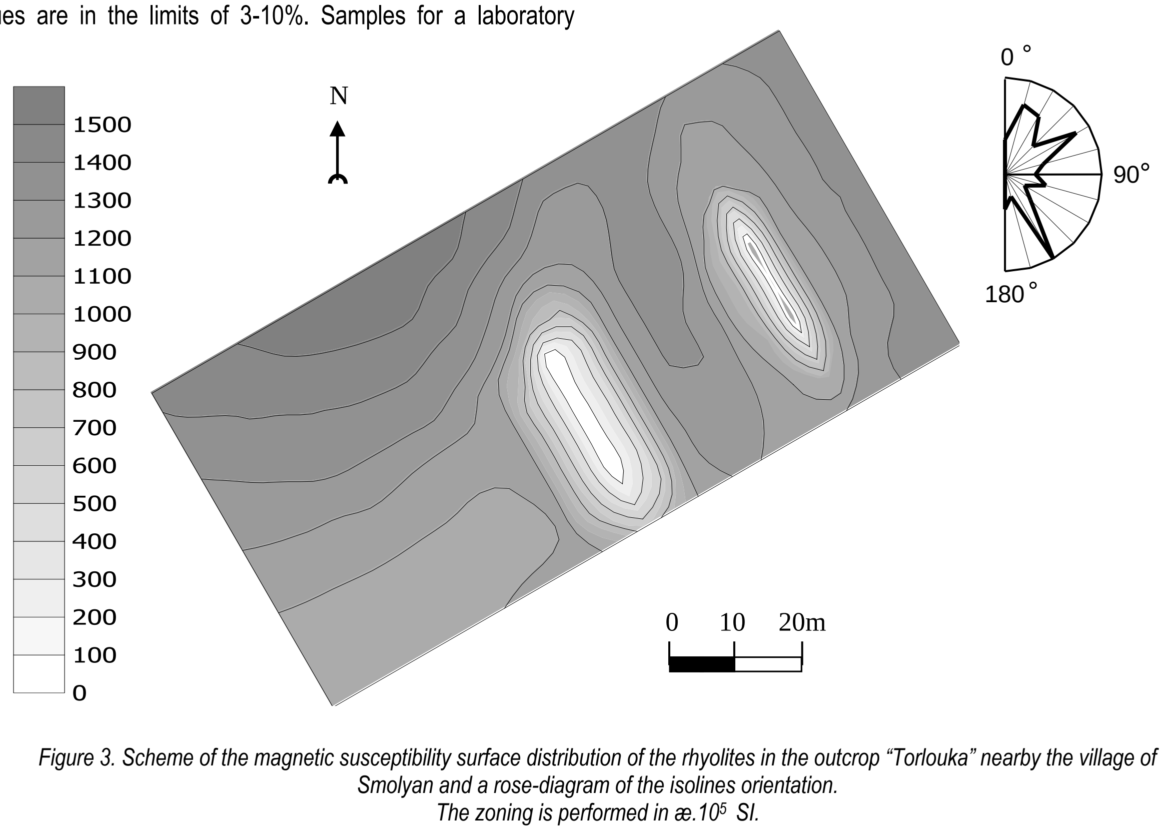

Figure 3. Scheme of the magnetic susceptibility surface distribution of the rhyolites in the outcrop “Torlouka” nearby the village of Smolyan and a rose-diagram of the isolines orientation.
The zoning is performed in æ.10^5 SI.

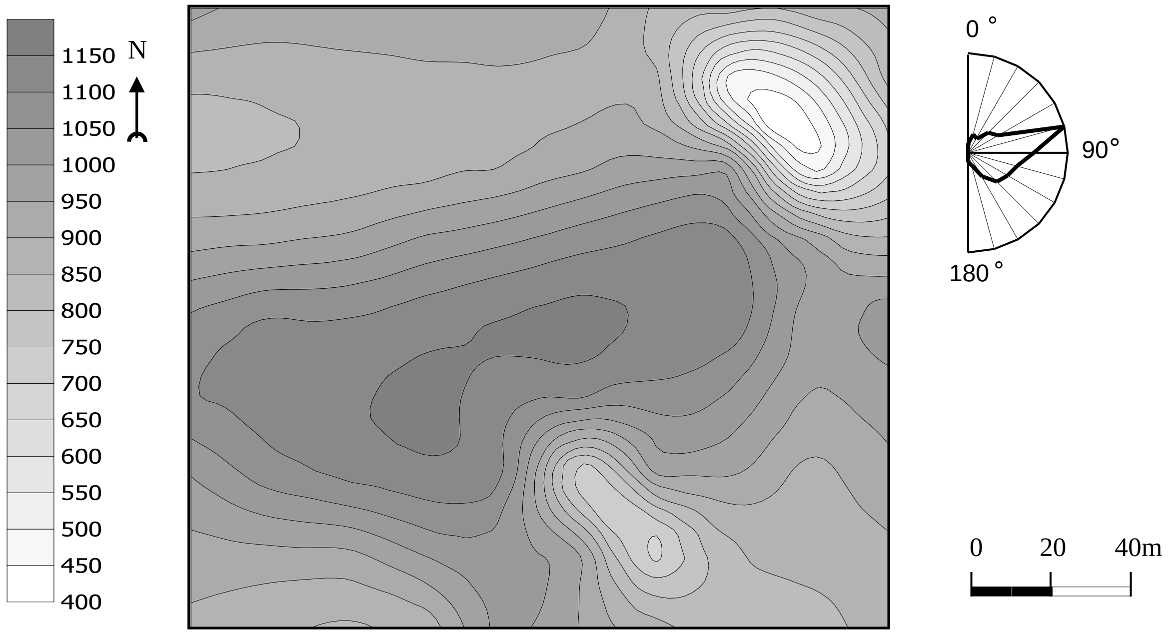

Figure 4. Scheme of the magnetic susceptibility surface distribution of the rhyolites in the outcrop "Orlov Kamak" nearby the village of Smolyan and a rose-diagram of the isolines orientation.
The zoning is performed in æ.10⁵ SI.

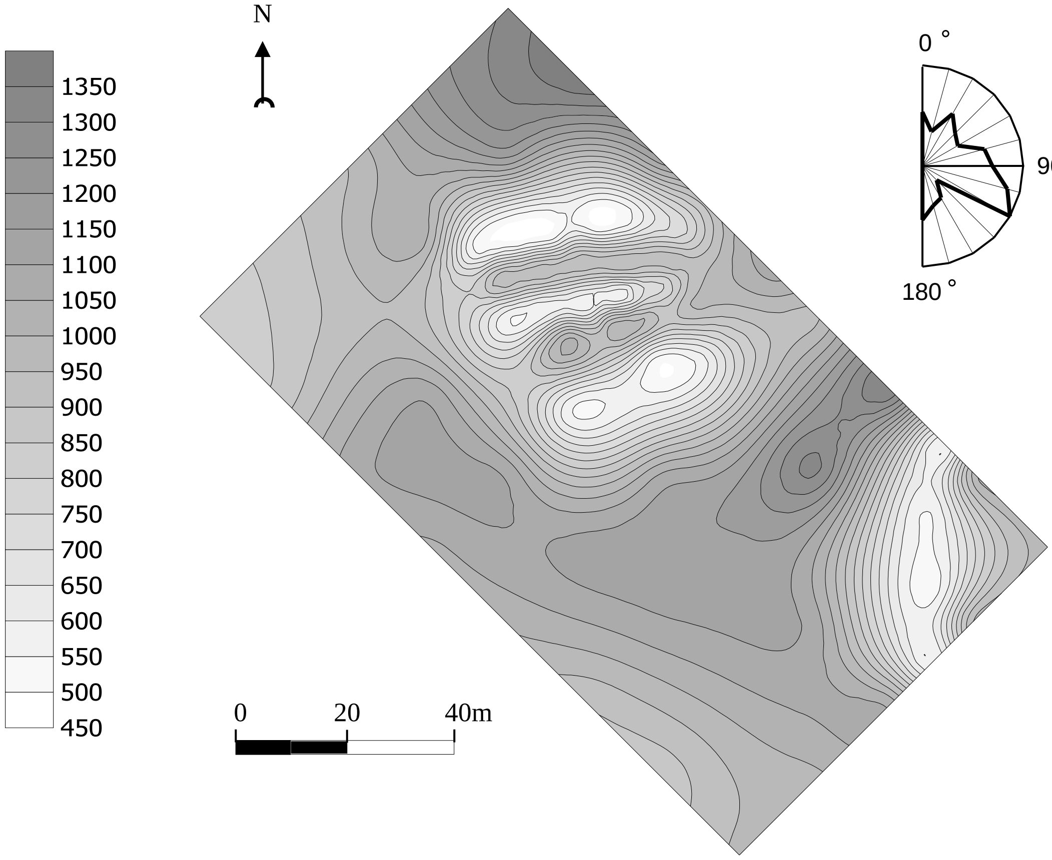

Figure 5. Scheme of the magnetic susceptibility surface distribution of the rhyolites in the outcrop "Chervenata skala" nearby the village of Smolyan and a rose-diagram of the isolines orientation.
The zoning is performed in æ.10⁵ SI.

The compound analysis is showing that in all outcrops subject to detailed study on the background of magnetic susceptibility values in the range of 900-1700.10^{-5} SI, one can easily detect peculiar stations having relatively very low magnetic susceptibility (down to 50.10^{-5} SI).

Rose-diagrams are composed using the developed method for quantity estimation of the isolines surface distribution of the geophysical fields isolines (Dimovski 1999). They are tracing very well the microtectonic destructions. The main directions of these destructions in all studied outcrops are comparable. The predominant trends appear to fall into two groups, striking NE-SW and NW-SE with bearings 75-80^{o} and 150-165^{o} respectively.

REMANENT MAGNETIZATION OF THE RHYOLITES IN THE RHODOPE MASSIF

The absolute value of the remanent magnetization vector is determined on 536 rock samples of outcrop and drill core of the rhyolites in the Rhodope massif. It is established that the parameter varies in a very wide range – from 0 up to about 3000.10^{-3} A/m, with some samples reaching even higher values. In Table 2 are systematized the main statistical characteristics of the values distribution for the remanent magnetization and in Fig.6 is shown a histogram of the parameter distribution for the main group of rhyolites – only about 6% of the samples having relatively high values (Jn >700.10^{-3} A/m) are excluded.

Table 2. Main statistical characteristics of the remanent magnetization of the rhyolites in the Rhodope massif (the remanent magnetization values are in A/m)

Region	Count	$Jn^{min}.10^3$ / $Jn^{max}.10^3$	Average $Jn.10^3$	Standard deviation	Skewness	Kurtosis
Western Rhodope Block	78	0 / 988	304	218	5	6
Bratsigovo-Dospat Depression	184	0 / 6786	354	662	35	14
Dospat Anticline	43	0 / 901	158	214	6	7
Southern Rhodope Syncline	46	0 / 3694	439	935	8	9
Northern Rhodope Syncline	48	29 / 1587	426	405	4	3
Smolyan Structural Depression	79	0 / 290	52	72	6	7
Total	536	0 / 6768	319	603	34	12

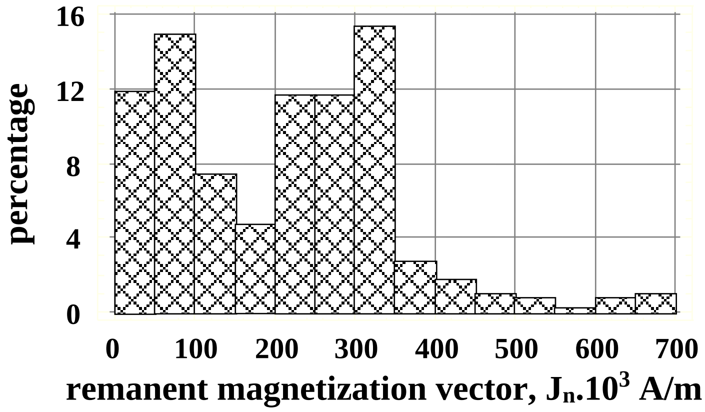

Figure 6. Histogram of the remanent magnetization vector distribution of the main group of rhyolites in the Rhodope massif

The compound analysis of the illustrated histogram and the histograms elaborated for the different regions is showing that we have the same picture as in the case of the magnetic susceptibility - two main groups are well pronounced in the remanent magnetization distribution. The first group is including samples having remanent magnetization within the limits of 0-200. 10^{-3} A/m, and the second one is containing samples having remanent magnetization within the limits of 200-500.10^{-3} A/m. A limited number of samples (about 5%) has a zero remanent magnetization and almost the same number of samples (about 6%) has high parameter values (Jn > 700.10^{-3} A/m) reaching up to 6500.10^{-3} A/m.

In the case of the remanent magnetization it should be accepted once again, that the group having Jn < 200.10^{-3} A/m is reflecting mainly the influence of the secondary hydrothermal-metasomatic and hypergenic processes. In the group having 200.10^{-3} < Jn < 500.10^{-3} A/m are included samples from the predominating rhyolite zone, and the samples having relatively high parameter values (Jn > 500.10^{-3} A/m) are related to extrusive formations.

The surface distribution of the remanent magnetization in the Western and Central Rhodopes is presented in Fig.7. For the entire territory, on the background of the rhyolite zone having remanent magnetization of about up to 400.10^{-3} A/m, can be separated areas having increased parameter values that are mapping the presence of extrusive formations.

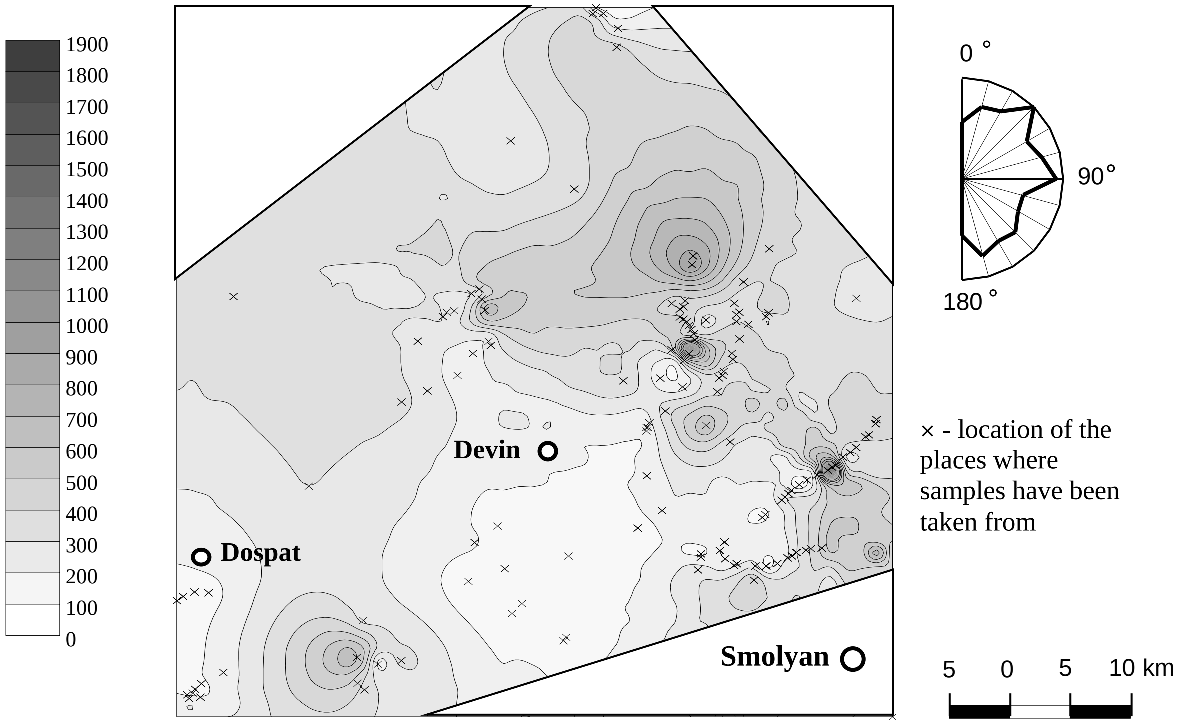

Figure 7. Scheme of the remanent magnetization surface distribution of the rhyolites in the Western and Central Rhodopes region and a rose-diagram of the isolines orientation. The zoning is performed in Jn.10^{3} A/m.

DISTRIBUTION OF THE RHYOLITES IN THE RHODOPE MASSSIF ACCORDING TO THEIR MAGNETIC PARAMETERS

The correlation analysis between the magnetic susceptibility data and the remanent magnetization of all rock samples of rhyolites in the Rhodope massif (536 samples) shows the absence of a well-expressed correlation tie. The only regularity is that all samples (24 by number) having æ=0, have also Jn=0. These are the samples where secondary hydrothermal-metasomatic and hypergenic processes have lead to destruction or oxidation of the primary ferromagnetic minerals and to formation of non-magnetic or low-magnetic varieties. The summarized trend towards plane correlation can be observed in the visual comparison between the magnetic susceptibility surface distribution scheme (Fig.2) and the remanent magnetization one (Fig.7).

Different cluster analysis methods have been tried. The best results were obtained using the Ward's method, City-Block distance metric and classifying the data into 4 clusters. In Table 3 are presented the centroids values for the magnetic susceptibility and the remanent magnetization of the separated clusters and In Fig.8 are illustrated the 2-D cluster scatterplot (a) and the dendrogram (b) of the performed grouping.

Table 3. Centroids values for the magnetic susceptibility and the remanent magnetization of the separated 4 groups after applying cluster analysis using the Ward's method, City-Block distance metric

Cluster number	Samples		Centroids values for the magnetic susceptibility æ	Centroids values for the remanent magnetization Jn
	Count	%		
1	128	31	170.10^{-5} SI	71.10^{-3} A/m
2	214	52	899.10^{-5} SI	233.10^{-3} A/m
3	149	12	1692.10^{-5} SI	317.10^{-3} A/m
4	21	5	1357.10^{-5} SI	1798.10^{-3} A/m

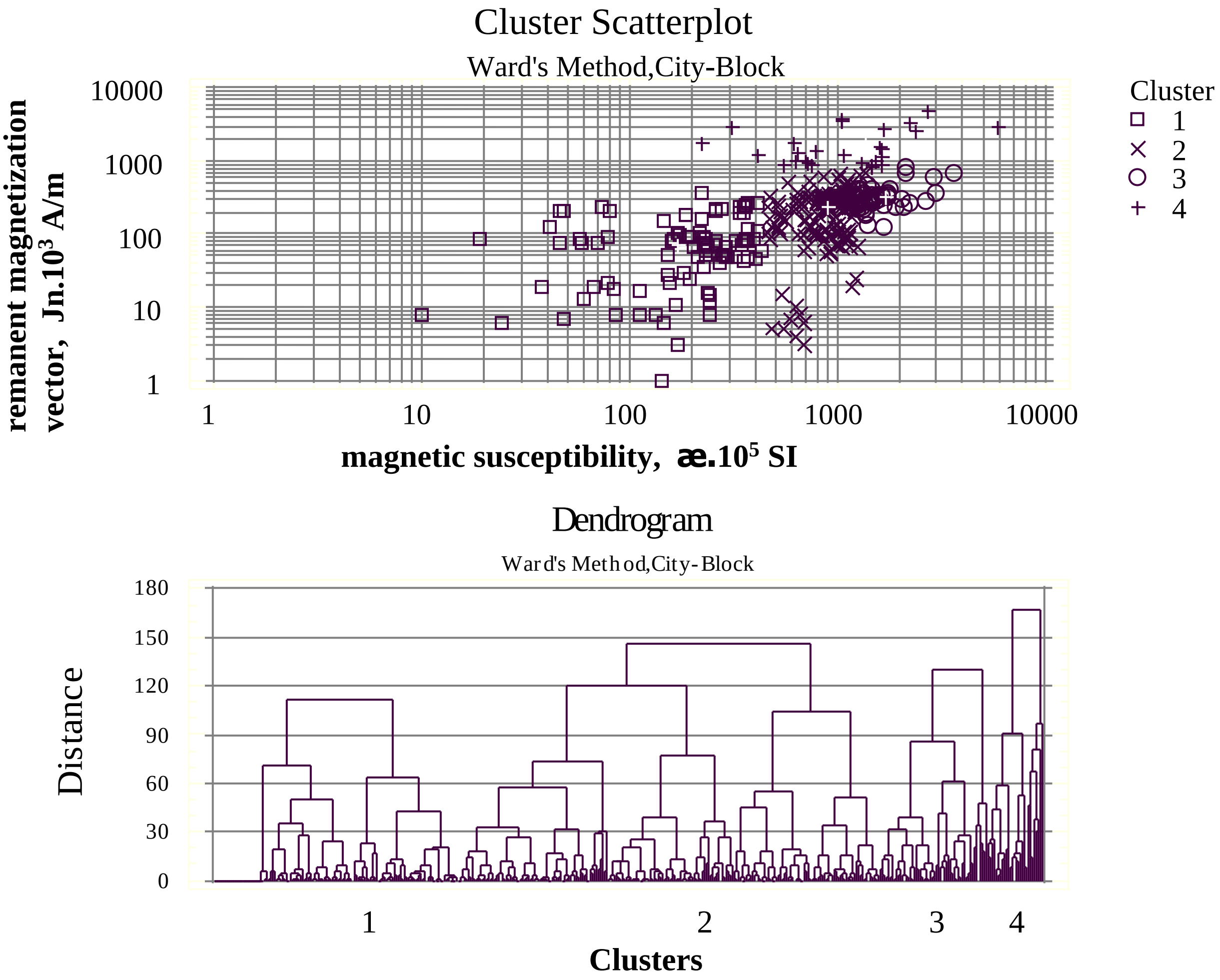

Figure 8. Results from the performed cluster analysis : 2-D cluster scatterplot (a) and dendrogram (b) of the performed grouping

The first three groups are including the major volume of samples – 95%. They are representing the main riolite zone and the centroids values for the magnetic susceptibility and the remanent magnetization of these three clusters have a coefficient of correlation 0,98. The last fourth group is representing the rhyolite samples from the extrusive formations. They are characterized by relatively high average magnetic susceptibility and by very high average remanent magnetization.

CONCLUSIONS

- The magnetic susceptibility of the rhyolites in the Rhodope massif varies in a wide range - from 0 up to 1800.10^{-5} SI, and for some samples it goes even higher. Two main groups are well pronounced in the magnetic susceptibility distribution. The first group is including samples having magnetic susceptibility within the limits of $0\text{-}500.10^{-5}$SI, and the second one is containing samples having magnetic susceptibility within the limits of $500\text{-}1800.10^{-5}$SI. The group having $æ<500.10^{-5}$SI is reflecting mainly the influence of the secondary hydrothermal-metasomatic and hypergenic processes. In the group having magnetic susceptibility $500.10^{-5} < æ < 1500.10^{-5}$ SI are included samples from the predominating rhyolite zone, and the samples having relatively high parameter values ($æ > 1500.10^{-5}$ SI) are related to extrusive formations.
- The detailed parametrical measurements of the magnetic susceptibility are showing that on the background of magnetic susceptibility values in the range of $900\text{-}1700.10^{-5}$ SI, one can easily detect peculiar stations having relatively very low magnetic susceptibility (down to 50.10^{-5} SI). They are tracing very well the microtectonic destructions. The main directions of these destructions in all studied outcrops are comparable. The predominant trends appear to fall into two groups, striking NE-SW and NW-SE with bearings $75\text{-}80^{o}$ and $150\text{-}165^{o}$ respectively.
- The rhyolites remanent magnetization varies in a very wide range – from 0 up to about 3000.10^{-3} A/m, with some samples reaching even higher values. We have the same picture as in the case of the magnetic susceptibility - two main groups are well pronounced in the remanent magnetization distribution. It should be accepted once again, that the group having $Jn < 200.10^{-3}$ A/m is reflecting mainly the influence of the secondary hydrothermal-metasomatic and hypergenic processes. In the group having $200.10^{-3} < Jn < 500.10^{-3}$ A/m are included samples from the predominating rhyolite zone, and the samples having relatively high parameter values ($Jn > 500.10^{-3}$ A/m) are related to extrusive formations.

- The surface distributions of the magnetic susceptibility and the remanent magnetization in the Western and Central Rhodopes are generally comparable. For the entire territory, on the background of the rhyolite zone having relatively low values for the magnetic parameters can be separated areas having increased values that are mapping the presence of the extrusive formations.
- After applying a cluster analysis the rhyolite samples were classified into four groups. The first three groups are including the major volume of samples – 95%. They are representing the main riolite zone and the centroids values for the magnetic susceptibility and the remanent magnetization of these three clusters have a coefficient of correlation 0,98. The last fourth group is representing the rhyolite samples from the extrusive formations. They are characterized by relatively high average magnetic susceptibility and by very high average remanent magnetization.
- The compound analysis of the magnetic susceptibility and the remanent magnetization of the rhyolites in the Western and Central Rhodopes is proving that the detailed mapping according to magnetic characteristics can efficiently enrich the information obtained by the traditional geological mapping.

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AN INTEGRATED GEOPHYSICAL TOOL FOR LOCATING Au-Ag DEPOSITS IN NEOGENE VOLCANICS IN ROMANIA

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ABSTRACT
Gravity and ground & airborne magnetics have been widely used in the last decades in Romania covering large areas with Neogene volcanics aiming at revealing their main structural and petrographic features. The main targets were represented by fault/fracture systems and intrusive magmatic bodies hidden to direct geological observation. Sectors of metallogenic interest, such as hydrothermal haloes, breccia bodies or mineralized veins were generally surveyed using electrometry or/and geochemistry.

Airborne and ground gamma ray spectrometry measurements, originally performed for U and Th accumulations, have been used in studying Neogene volcanic and subvolcanic structures, due to the close spatial association of hydrothermal minerals rich in potassium (K^{40}) (sericite, adularia) with metallogenic features (veins or mineralised breccias). Adularia proved to be associated in most cases with gold, pyrite and quartz.

Mercurometry (Hg spectrometry), as a method based on the high volatility and mobility of Hg, that is able to migrate vertically through thick sequences of rocks and overburden, is considered to represent a direct indicator for hydrothermal Au-Ag accumulations. The migration of Hg toward the surface is continuous, enabling this method to reveal even the presence of "blind" ore deposits, buried beneath younger geological formations or simply Quaternary deposits.

These methods have been lately integrated in an exploration tool (Ioane, 1999), designed to perform a complete study of Neogene magmatic structures and locate Au-Ag hydrothermal accumulations.

GEOLOGICAL SETTING OF NEOGENE VOLCANICS IN ROMANIA

Neogene volcanism developed on large areas in the East Carpathians and Apuseni Mountains, this magmatic activity being considered as a result of subduction processes (Radulescu, Sandulescu, 1973), of tectonic compressions following a continent-continent collision, or of a discontinuous subduction, that generated a volcanic arc during Neogene-Quaternary (Seghedi et al., 1995).

In the Apuseni Mountains, Neogene volcanics (Badenian-Pliocene) outcrop in the Metaliferi, Drocea and Codru Mts., the magmatic processes developing mainly along NW-SE tectonic lineaments north of an E-W crustal fault (Mures Valley), that is considered to represent a subduction plane (Borcos et al., 1980). The volcanic activity started in the Lower Badenian, these processes resuming during Pontian-Upper Pliocene. The magmatic products are represented by volcanic edifices, necks, lava flows, breccias and subvolcanic bodies, most of them intensely eroded. The hydrothermal alterations of the Neogene magmatic rocks have been controlled by intrusive bodies and tectono-magmatic fracture systems. The most important mineralizations are associated with the hydrothermal haloes developed within the "Golden Quadrilateral" in the Metaliferi Mts., and contain Au-Ag and base metal sulphides.

The north-western end of East Carpathians in Romania includes important areas with Neogene volcanics within the Oas-Gutai-Tibles Mts. The magmatic rocks are considered to result from subduction processes (Bleahu et al., 1973) and develop along two crustal fractures, trending E-W and NW-SE. The volcanism migrated in space and time from west to east, and from south to north, during Badenian-Dacian (Seghedi et al., 1995). The magmatic products are quite similar to those emplaced within the Apuseni Mountains, including stratovolcanoes, necks, lava flows, subvolcanic bodies and volcano-sedimentary formations. Due to intense hydrothermal alterations, the structure of the volcanic edifices and tectono-volcanic lineaments can be hardly observed. The metallogenic products (Au-Ag and base metal sulphides) associated with hydrothermal haloes develop mainly in veins trending NNE-SSW, rarely W-E and NW-SE.

HYDROTHERMAL ALTERATIONS

The hydrothermal alteration processes yielded propylite, chlorite, adularia, sericite, clayey and carbonate rocks, a succession which is not always complete within the transformed magmatic rocks or/and sedimentary formations. The argillization-silicification hydrothermal processes affecting the Neogene magmatic rocks induced the substitution of the accessory magnetite with iron sulphides. The argillization-sericitization process is considered as an important stage of hydrothermal alterations, being controlled by tectono-volcanic fracture systems. Potassium rich solutions involved in these processes determined significant mineralogical modifications within the host rocks, the newly formed minerals including adularia and sericite being closely situated with respect to the fractures, veins or breccia bodies. Considering the relationships noticed between hydrothermal alterations and metallogenic products, many times adularia haloes are associated with epithermal Au-Ag mineralizations, while sericite haloes are correlated mainly with mesothermal base metal sulphides.

PETROPHYSICAL AND GEOPHYSICAL DATA

Variations in the rocks density observed within the volcanic products are mainly due to differences in mineralogical composition, structure, type and degree of hydrothermal alterations. They may determine in many cases important density contrasts that enable gravity surveys to locate volcanic and subvolcanic bodies by either high or low gravity anomalies, depending on the specific geological environment. Fault systems that are often involved in metallogenic processes may be also depicted on Bouguer maps as lineaments of rapid variations in gravity. Within the hydrothermal haloes, where the argillization processes affected strongly the magmatic rocks, density may decrease significantly, high accuracy gravity data being able to reveal breccia bodies or important vein systems. In Fig. 1 is displayed such a situation, density measurements on andesitic rocks hosting an Au-Ag vein in the Metaliferi Mts being situated on a profile that crosses half of the associated hydrothermal halo. The density variation of 0.16 g/cm^3 on quite a short distance displays significant differences between unaltered and highly argillized rocks (the latter being sampled in the very vicinity of the auriferous vein) (Ioane, 1999).

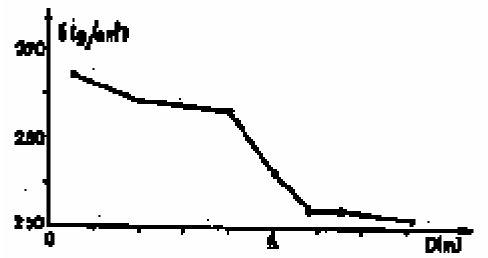

Figure 1. Density measurements on an Au-Ag vein in the Metaliferi Mts (Romania)

The magnetic properties of Neogene volcanics in Romania have been largely investigated, early geophysical studies performed within the Metaliferi Mts (Romanescu, 1963; Calota and Romanescu, 1963) emphasizing good possibilities for magnetic surveys to outline the hydrothermal alteration areas, affected by argillization, sericitization, silicification or pyritization processes. This is due mainly to the substitution of the accessory magnetite with newly formed paramagnetic minerals. Recent petromagnetic and magnetic studies (Ioane and Andrei, 1993; Ioane, 1999) extended such researches in all regions with Neogene volcanism in Romania and found a good applicability for high accuracy magnetic surveys in locating hydrothermal haloes and even metallogenic products, especially when integrated with other geophysical information. In Fig. 2 are displayed the results of continuous measurements of magnetic susceptibility across the studied auriferous vein in the Metaliferi Mts. Two aspects were considered as significant when analysing this picture: a) the abrupt attenuation of the magnetic properties at the outer limits of the hydrothermal halo; b) the absence of any magnetic variations over the mineralized sector. Obviously, in such areas, high accuracy and detailed magnetic maps may display in good conditions the location and development of fracture systems involved in postmagmatic hydrothermal processes.

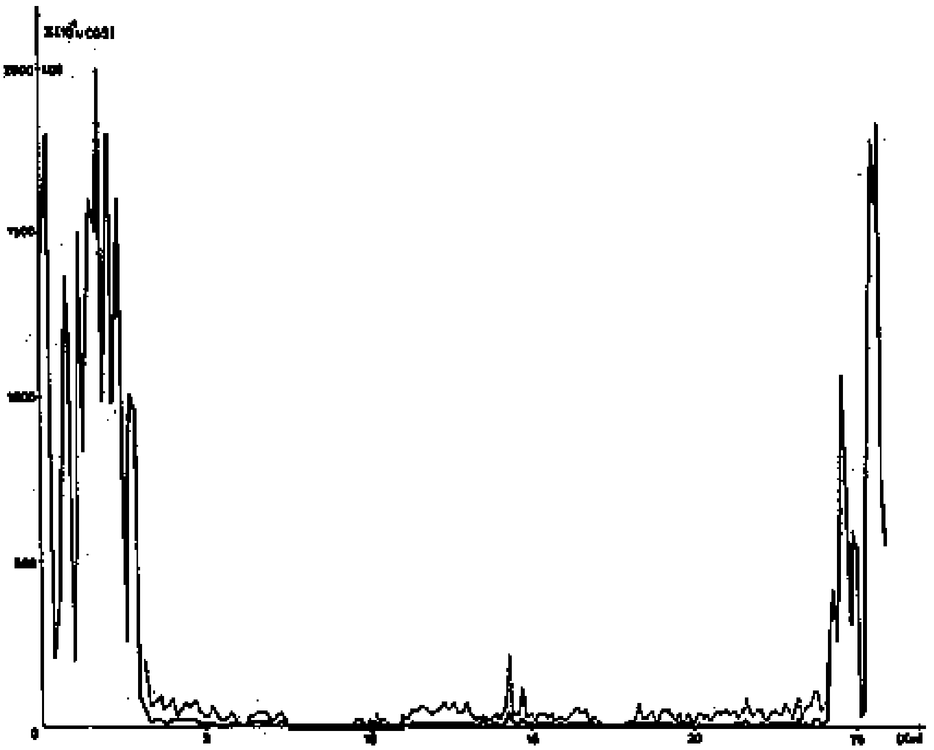

Figure 2. Magnetic susceptibility measurements across the Au-Ag vein in the Metaliferi Mts (Romania)

The hydrothermal haloes cover large areas in regions characterised by Neogene magmatic rocks and consequently their contouring using gravity and/or magnetic information proved to be not sufficient in many cases when trying to locate Au-Ag accumulations and/or base metal sulphides. Detailed mineralogical studies (Udubasa et al., 1976) showed that hydrothermal mineralizations are closely linked spatially with products of a potassium metasomatosis (adularia, sericite, illite). Laboratory determinations of U, Th and K concentrations on samples of Neogene volcanics displayed significant differences between various petrotypes, enabling gamma ray spectrometry (both ground and airborne) to successfully mapping magmatic structures and/or potassium rich hydrothermal haloes.

Such analyses performed on Neogene andesites and dacites sampled in Romania showed good possibilities of discrimination using information on the U, Th and K contents. For example, amphibole andesites may be characterised by mean values of 1.5 ppm for U and 4.0 ppm for Th, while quartz bearing andesites may contain 1.5 to 3.0 ppm U and 6 to 10 ppm Th. High potassium contents in Neogene volcanics, ranging from 2.5 % to 10.0 %, are many times due to hydrothermal sericite and adularia contents (Ioane and Andrei, 1993; Ioane, 1999).

In Fig. 3 are displayed gamma ray spectrometry data (measurements with shielded detector) and laboratory results on potassium contents in rocks sampled across the same auriferous vein situated in the Metaliferi Mts, Romania (Ioane, 1999). The high potassium anomaly over the sector located closely to the vein is easily observed, both on the geophysical profile and on the K contents obtained on samples of andesitic rocks, affected by variable potassium metasomatosis (adularia, sericite, illite).

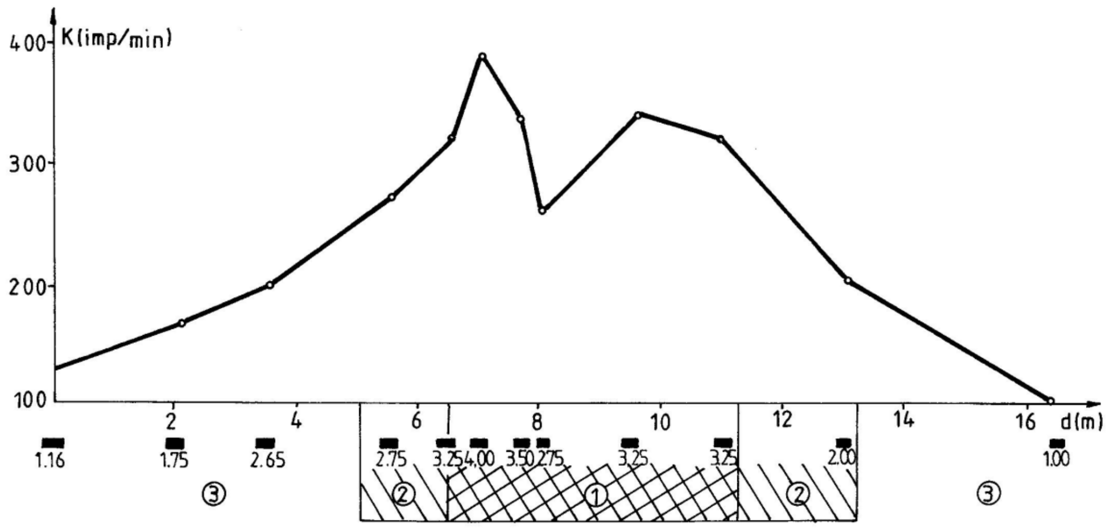

Figure 3. Potassium anomaly and K content in rocks sampled across the Au-Ag vein (Metaliferi Mts, Romania)

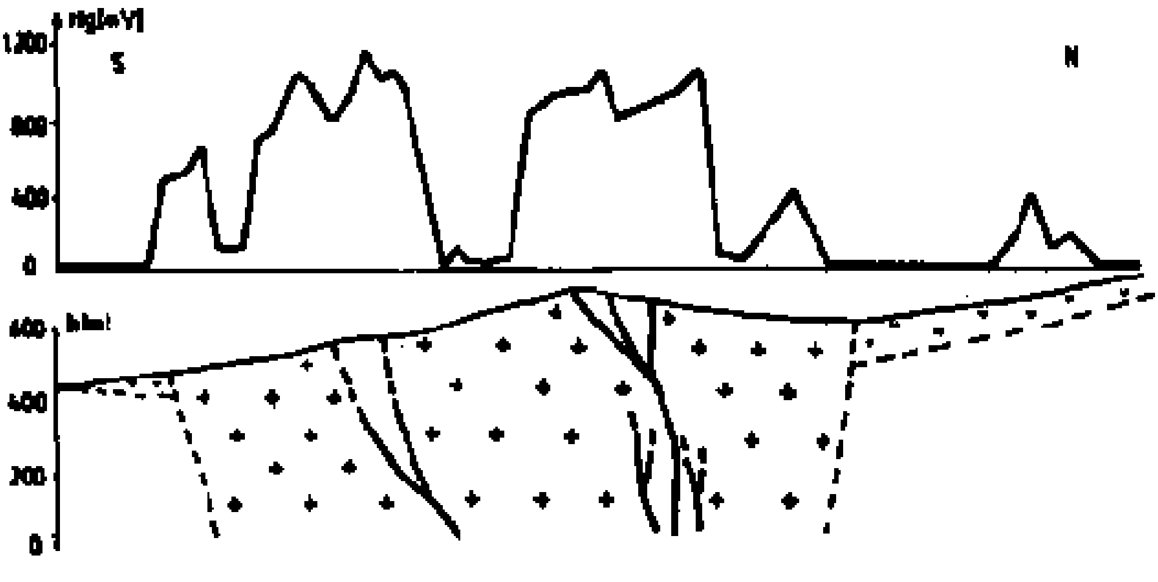

Figure 4. Mercurometric anomalies across the Baia Sprie Au-Ag ore deposit (Gutai Mts, East Carpathians, Romania)

GEOPHYSICAL TOOL FOR LOCATING AU-AG MINERALIZATIONS IN NEOGENE VOLCANICS IN ROMANIA

The applicability already proved by the geophysical methods considered in this paper (gravity, magnetics, gamma ray spectrometry) in studying Neogene magmatic structures in Romania, as well as some of their valuable metallogenic products (Au-Ag mineralizations), led lately to the integration of their specific capabilities. The following main tasks are envisaged when using these methods:

- the Bouguer gravity data, adequately processed, may be especially exploited for getting information on the structural frame of the studied areas (location of Neogene intrusive bodies, development of fault systems or breccia columns);
- the magnetic data (both ΔZ or ΔT) may offer two main categories of information: a) location of hidden magmatic bodies, especially when they are unaltered or slightly altered; b) contouring hydrothermal haloes and fracture systems involved in postmagmatic processes;
- the gamma ray spectrometric data, as anomalies of high content in potassium or as high values of the K/Th and K/U ratios, are able to restrict the hydrothermal haloes contoured by magnetics to sectors closely related to the metallogenic features, such as veins or breccias. An important information brought by the radiometric data refers to the main potassium mineral that is developed within the hydrothermal halo. The highest potassium anomalies, corresponding to K content in rocks over 4%, reflect the presence of important adularization processes, many times associated with Au-Ag, quartz and pyrite.

At this stage of the investigation, the processing and interpretation of the above mentioned geophysical data may provide information on the presence of intrusive bodies, hydrothermal haloes, fracture systems that controlled hydrothermal processes and areas rich in potassium minerals (adularia, sericite), closely associated with metallogenic features (veins, breccia bodies). The next important stage of such a study is dedicated to investigations that might provide information on the presence of Au-Ag mineralizations within the magmatic structure. The usual option is represented by electrometric surveys, either induced polarization or electromagnetic. They may prove suitable in numerous situations, but they are quite costly, difficult to perform in rough topography and may lead to ambiguous interpretations when the target mineralizations are enclosed in pyritization haloes. The alternative to electrometry, that is integrated in this geophysical tool, is represented by mercury spectrometry, or mercurometry. This method is based on the association of Hg with low temperature hydrothermal mineralizations (including Au-Ag) and on its high mobility, which enables mercury to penetrate thick sequences of rocks and overburden toward the surface. Such studies that have been carried out in Romania, mainly in Neogene volcanics, showed that mercury anomalies may be related in many cases to the location of the mineralizations, especially epithermal ones. In Fig 4 is presented a mercurometric profile crossing the Baia Sprie Au-Ag ore deposit (Gutai Mts, East Carpathians), the important Hg high content anomalies being nicely correlated with the main veins bearing rich Au-Ag mineralisations (Ioane, 1999).

CONCLUSIONS

An integrated geophysical tool for locating Au-Ag mineralizations was tested in Neogene volcanics in Romania. It consists of gravity, magnetics, gamma ray spectrometry and Hg spectrometry, in most cases the measurements being performed in a synergistic mode.

The gravity data provide the structural frame of the studied area, the magnetics being employed to get petrographical and metallogenic information (argillization haloes and fracture systems). The potassium high anomalies may restrict such large haloes to areas closely situated to the mineralized sectors. The mercury high anomalies are usually located within the potassium high haloes, indicating in favourable situations the presence of hydrothermal mineralisations.

Good possibilities of locating Au-Ag mineralizations using this complex geophysical tool are offered by correlating potassium high anomalies determined by zones rich in adularia and mercury high anomalies, determined mostly by epithermal metallogenic products.

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MAIN PRINCIPLES IN VEGETATION SPECTROMETRIC STUDIES

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ABSTRACT
Characterictic peculiarities of vegetation covers as objects of remote sensing are summarized and the associated with them sources of variation of spectral reflectance data. The resulting main principles which should be observed for correct data interpretation and implementation are discussed. Some requirements to the conditions of reflectance measuremets and their spectral-biophysical modeling are analized.

An essential application of remote sensing with significant importance for practice is vegetation monitoring. In agriculture for instance regular and timely information is needed about crop state and development, about the occurrence of stress situations for undertaking of respective measures, and etc. This paper has the goal to summarize issues related to vegetation peculiarities as a biological system and as an object of spectrometric studies, and on this ground to analize a number of specific problems typical in vegetation monitoring, to point out some difficulties that data interpretation runs on, to suggest some approaches for their overcoming. Spectral reflectance specifics of the soil-vegetation cover as a dynamical system and a mixed class is scrutinized, the use of reflectance properties as an indicator of plant state is substantiated basing on their adequate relationship with plant bioparameters.

Sun radiation interaction with vegetation covers is a complicated process, which depends on vegetation optical properties and a great number of factors discussed below. Short-wave radiation transmission, absorption and reflectance are selective i.e. depend on the wavelength. That's why sun radiation transference in vegetation covers changes its spectral and energy distribution. This fact determines the informative abilities of measured reflectance, as it is a function of vegetation biostructural parameters, which are associated with plant type and status.

Crop status assessment is an important task of agriculture remote sensing monitoring (Kuusk, 1991; Yoder and Waring, 1994). Regression models are used relating reflectance features to plant phytoparameters (Curran, *et al*., 1992; Кънчева, 1999). In such studies the following vegetation peculiarities lying in the root of a number of methodological issues and determining the approaches of experiments performing, data processins and interpreting should be considered.

- Vegetation diversity with its physiological and morphological specifics does not allow the extrapolation of spectral-biophysical models developed for a certain soil-vegetation cover upon different vegetation types.
- Meteorological, soil and agricultural growth conditions are the reason of spatial and temporal crop development and spectral reflectance variance.
- Vegetation is a compound object whose elements in their entity (leaves, stems, reproductive organs) determine crop structure which has essential influence on spectral reflectance features.
- Spectrometric data are multiple function of a number of phytoparameters that characterize plant status.
- Vegetation covers can not be treated without taking in view soil background, which participates in the forming of integral reflectance characteristics of soil-vegetation mixtures.
- Soil effect on vegetation spectral reflectance is not determined but varies due to different soil types and properties.
- Agricultural species are dynamic systems whose parameters change during plant development. The respective reflectance changes impose spectral-biophysical modeling to be performed for different phenological stages.
- Bioparameters determine plant status and at the same time are factors of the reflectance ability. Their effect is simultaneous that causes data interpretation ambiguity.
- Plant growth is a process, which depends on external factors (meteorological conditions) whose input to prognostic models is impeded by their stochastic nature.
- The development of models describing crop status requires considering of anthropogenic impacts such as fertilization, soil toxic contamination, etc.

As a result of these peculiarities, some difficulties follow for achieving precise and faithful results. The main reasons are the dynamic and stochastic nature of processes in biosystems; variety of environmental and agricultural conditions; different data registration conditions (atmospheric, measurement devices); large number of factors (noise and informational) that influence soil-vegetation spectral reflectance; incomplete ground-true data, etc. The following shortcomings in vegetation studies can be mentioned: limited use of multitemporal data throughout plant growing period; lack of experiment repetition and evaluation of models prognostic accuracy and reliability; insufficient studies of anthropogenic factors impact.

Considering all this, some conditions can be recommended in regard to spectrometric data registration, processing and applyment. These recommendations are supposed to decrease data multifactor innderminateness and results ambiguity. Some main principles will be discussed that are of importance for proper investigation performance and spectral data analysis.

The process from registration to tematic interpretation of spectral data contains elements of innderminateness. In regard to plant bioparameters it is caused by vegetation diversity and natural variations within a given agrosystem, as well as by plant status changes (phenological growth, stress impacts). Reflectance features innderminateness is due to varying measurement conditions (view, illumination), surrunding background, object non-homogenety, different parameters of measurement devices. Concerning data analysis the reasons are incomplete apriori information, model errors, etc.

It is very important the factors to be divided into two groups: ● external factors which have no relation to useful information and are noise, ● internal factors which have relation to useful information and are signal. The first group characterizes the conditions of the experiment - measurement device (number of channels, wavelengths, spectral resolution, view angle); measurement conditions (height, direction); illumination (zenith and azimuth solar angles, atmospheric conditions, topography, direct to scattered irradiance ratio); surrounding background effects. The second group is relevant to biophysical parameters. For the effiective implementation of reflectance data elimination of noise factors influence on spectral features is needed. This is achieved to some extent by observing certain requirements as far as data acquisition is concerned.

The dependence of spectral features on external factors is the reason relative reflectance to be preferably measured which decerase noise factors influence. For instance, slow atmospheric changes do not considerably effect reflectance coefficients as far as the object and the reference surface are under the same illumination conditions. Relative measurements, containing information about the object, have also the advantage of being comparable in temporal studies and thus used for monitoring of object status changes.

The variance of angle coordinates, i.e. view and incident light directions, effects soil-vegetation reflectance even when the optical properties of the mixture components, plant canopy morphology and soil parameters are constant. The reason is the anisotropic backscattering (especially in chlorophyll absorption spectral bands) and the varying proportion of shadowed and illuminated elements. Needed elimination is achieved by adhering to full or partial (sufficient for the experiment) constancy of these factors, for instance, measurements during noon hours when the sun zenith angle does not change considerably.

The dependence of reflectance features on illumination conditions includes also the ratio of direct to diffuse solar radiation following from which is the requirement measurements to be evaded under changing illumination (variable cloudiness).

A basic problem of remote sensing measurements in the optical spectral band are atmospheric effects. Registrated data depends not only on the reflected by the object radiation but also on the atmospheric conditions (aerosol particles, gas content) which determine the process of incident light transformation (absorption, scattering) and the atmospheric background. The proplem of atmospheric corrections does not stay in the case of field or low-heihgt airborne measurements. This is a ground for their use in modeling studies.

The necessity of ground-based experiments is dictaded also by a number of methodological issues which are worked out through such experiments and consider: data representativity, regularity and optimal time of data acquisition (depending on the studied object and the task to be solved), different spectral bands and spectral transformations informativity, multiple dependence of reflectance on a variety of properties (type, status), and other factors (anthropogenic) and their combinations, apriory information content.

For achieving of reliable results it is important to use comparable data acquired under similar geometric and radiance conditions as well as by spectrometric devices with identical or close characteristics (spectral resolution, view angle, etc.). High spectral resolution helps the establishment of subtle biochemical changes that serve as an early indicator of structural and functioning changes.

Some of the ways for decreasing unwanted influences refer to data processing methods. A lot of radiometric problems can be resolved using ratios of the registrated signal in two or more channels or other transformations of measured reflectance.

Observing the requirements for minimizing 'noise' variations of reflectance data only relevant to the solved task factors will be taken into account when evaluating the accuracy of the results. Such are the natural variations of soil-vegetation spectral and biophysical featuters and the inherent erros of data analysis methods.

Information-containing factors that influence soil-vegetation spectral reflectance include: biotic features (type, phenological stage, pigment concentration, water content, biomass amount), architectonics parameters (canopy coverage, density, height, orientation of phytoelements), soil properties (type, mineral composition, water and organic matter content, microrelief, degradation processes – erosion, salinity). Here stays the question of proper choise of crop state diagnostic parameters which at the same time determine plant reflectance ability as well as the choise of spectral bands and the development of spectral indices that give most reliable information for plant parameters estimation.

Soil-vegetation objects are most common example of mixed classes. It's especially typical for agricultural species which during their development pass through the stages of bare soil to full-cover plant canopy. It's obligatory to have in view that soil and vegetation form an undivided system both physiologically and as far as spectral reflectance is concerned. The latter depends on mixture component type, properties and portion participation (canopy coverage). Considering soil background effects on vegetation reflectance is of essential importance for proper interpretation of spectral data. To minimize the influence of varying soil parameters (humidity) spectral transformations (ratios, sums, normalized differences, derivatives) are used called vegetation indices (Chappelle, *et al.*, 1992; Gamon, *et al.,* 1992; Thenkabail, *et al.*, 1994).

An expressed seasonal dynamics is inherent for agricultural crops manifesting itself in vegetation physiological and morphological changes during ontogenesis. As spectral reflectance depends on plant status changes due to phenological development (or stress anomaly), the modeling of the relationships between spectral and biometric features should be performed for given phenological stages. The same refers to remote sensing data implementation.

Besides, spectral reflectance temporal variance often contain the needed information. They are useful for registration of plant status changes and revieling of data acquisition optimal periods. The availability of temporal data and spectral multidimensional presenting in different moments increases the spectral separability of land covers and classification accuracy.

An essential approach is the use of spectral features temporal behaviour during the whole growth period. They are applied for vegetation classification (Badhwar, 1985), phenological stage assessment (Gallo and Flesch,1989), yield prediction (Кънчева и Георгиев, 2000).

Besides soil-vegetation diversity a reason for spectral reflectance variance are anthropogenic factors. That is why actual and necessary are studies devoted to plant growing conditions (fertilization (Penuelas, *et al.*, 1994), contamination (Kancheva, *et al.*, 1992; Kancheva, *et al.*, 2001; Mehandjiev, *et al.*, 2000)), and aiming at stress impact identification. The necessity of aspriori information should be pointed out here because of similar plant reflectance changes due to different impacts (for instance water and nutrient deficit (Penuelas, *et al.*, 1994; Shibayama, *et al.*, 1993)).

Summarizing all this we shall mention briefly some main requirements to vegetation spectrometric studies performance: ● identical conditions of reflectance data registration; ● minimizing atmospheric effects; ● taking into account soil-vegetation diversity; ● high spectral resolution; ● development of informative spectral indices; ● a priori information (needed for spectral data analyses and interpretation); ● temporal data acquisition (for assessment of plant status changes, development trend monitoring and stress situations identification); ● considering plant growth conditions (environmental, ecological, agricultural); ● repeated experiments imposed by the stochastic nature of bioprocesses (for data representativeness and statistical analysis); ● evaluation of the prognostic accuracy of spectral-biophysical models, their reliability and usage limitations.

In conclusion we shall poin out again that vegetation cover spectral reflectance is a multiple function of many variables. This determines on one hand the high informativity of spectrometric data but on the other hand is the reason for their ambiguity. That is why different factors, which are temporally and spatially varying, and effect plant spectral features in various combinations should be taken into account. This imposes the necessity experiment conditions to be known and considered for evading significant errors and wrong results.

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INFORMATIONAL POTENTIAL OF VEGETATION SPECTRAL REFLECTANCE IN ANTHROPOGENIC IMPACT STUDIES

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ABSTRACT
The serious ecological problems relevant to the anthropogenic impact on the environment, and first of all on the biosphere, impose the necessity of methods for assessing these effects especially on vegetation land covers. In agriculture the possibility for timely identification of abnormal crop state is of particular importance. This paper is devoted to the implementation of reflectance spectra as informational featute about plant status as well as for the assessment of anthropogenic factors impact on plant development. Some results from ground-based reflectance measurements of plants grown up under different conditions (nutrient regime, heavy metal pollution) are presented.

The special attention paid to ecological problems associated with the anthropogenic impact on the environment, and first of all on vegetation, determines the importance of studies directed towards the development of efficient means for early phytodiagnostics. The identification of abnormal plant state (Kancheva, *et al*., 1992; Shibayama *et al*., 1993 Кънчева *и др*., 1996) caused by various stress factors such as soil toxic contamination is of particular interest. Remote sensing has proved abilities in this respect.

The goal of the this paper is to illustrate the use of spectral reflectance data for crop monitoring when anthropogenic factors are applied, represented here by nitrogen fertilization and soil heavy metal pollution.

The specific reflectance, absorption and emission of solar radiation by land covers is the basis of multispectral remote sensing. Widely used in soil and vegetation monitoring is the visible and near infrared (0.4-1.3 μm) spectral range due to some its advantages, such as: concentrates the largest portion of solar energy, covers the biologically active spectra, requires relatively simple technical devices, shows significant sensitivity to plant parameters variations.

At the root of spectrometric studies lies the fact that the reflected by the object radiation contains information about its biophysical properties. This information is carried by the specific spectral and energy distribution of the reflected solar radiation, i.e. by the reflectance coefficients $r(\lambda_i)$ which form the spectral reflectance characteristic $R\{r(\lambda_i)\}$ and are spectral informational features of the studied object, its 'spectral image'. Vegetation covers are characterized by a composition of biomorphological parameters Φk which are their 'substantial features'.

The so called 'inverse task' is to be solved that means to estimate the parameters Φk using measured spectral reflectance $R\{r(\lambda_i)\}$. A basis for the purpose provides the dependence of the reflectance features on the kind, properties and current state of the object. This dependence actually determines the informational content of spectral features. Vegetation reflectance for instance is a function of a number of bioparameters such as density, height, biomass, leaf area, chlorophyll, etc. This means that plant parameters variation cause reflectance spectra changes, i.e. between the radiometric and biophysical properties there exist adequate relationships $R\{r(\lambda_i)\}=f(\Phi k)$ which not only determine the informational content of spectral data but attaches to it quantitative expression.

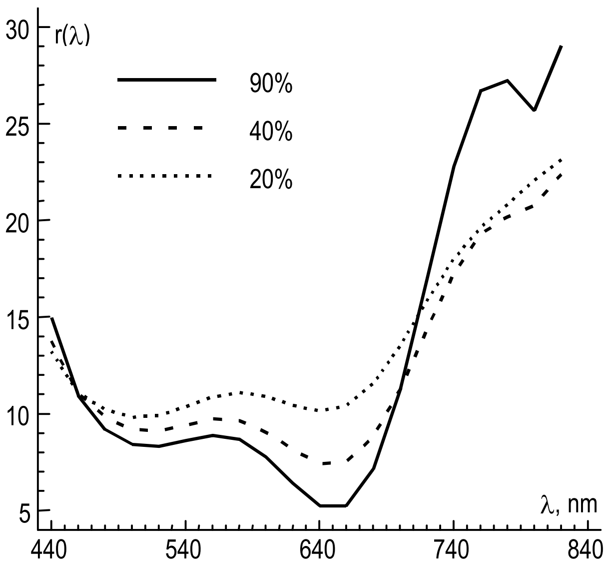


Figure 1. Spectral reflectance of spring barley plots with different plant canopy coverage.

Fig.1 shows the obvious difference of spring barley reflectance ability due to canopy coverage variance (the proportion of vegetation within the pixel area).

Crop bioparameters being an expression of morphological changes are indicators of plant state as a result of the growth process and of the impact of various factors including anthropogenic influences Fr. Along with the natural physiological development stress factors cause statistically significant variations of plant reflectance (Bammel and Birnie, 1994; Kancheva, *et al*., 1992; McMurtey, *et al*., 1994; Кънчева, 1995) because of their affect on chlorophyll content, biomass amount, etc. This is illustrated very well by Fig.2 where the spectral characteristics $R\{r(\lambda_i)\}$ of spring barley during the whole vegetation period are presented for the case of unpolluted (a) and 400 mg/kg Ni-polluted soil (b).

Statistical methods are used for data processing, including preliminarily correlation and regression analyses, the models being later applied for biophysical interpretation of spectrometric data. A peculiarity and wide spread practice in vegetation studies is the use of spectral transformations called vegetation indices (VI). They are various combinations of the measured reflectance coefficients $r(\lambda_i)$ at two or more wavelengths λ_i and have the form of ratios, weighted sums, normalized differences, etc. Some of the considerations for doing so are: the large data amounts are being reduced, the signal to noise ratio is being improved by minimizing the effects of 'noise' factors (such as varying illumination conditions, topography, etc.), spectral differences become more pronounced and the sensitivity to estimated variables is being increased, thus achieving better accuracy and reliability of the results. All this is aimed at improving the spectral data informativity.

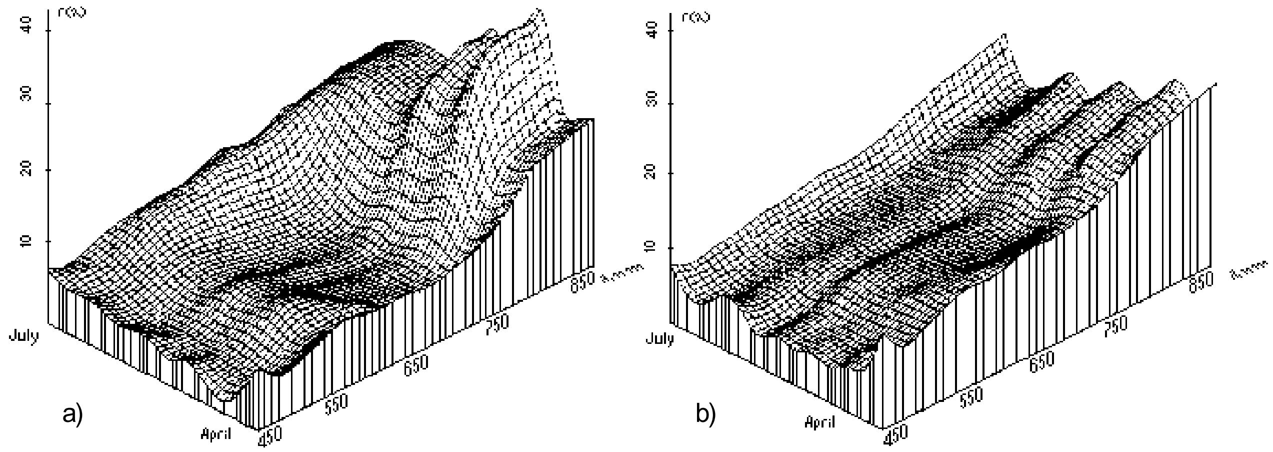
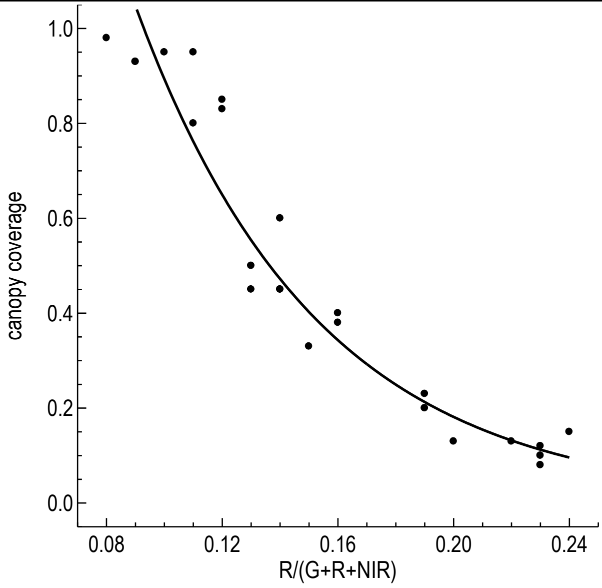


Figure 2. Barley spectral reflectance throughout the growing season for unpolluted (a) and Ni-polluted plots (b).

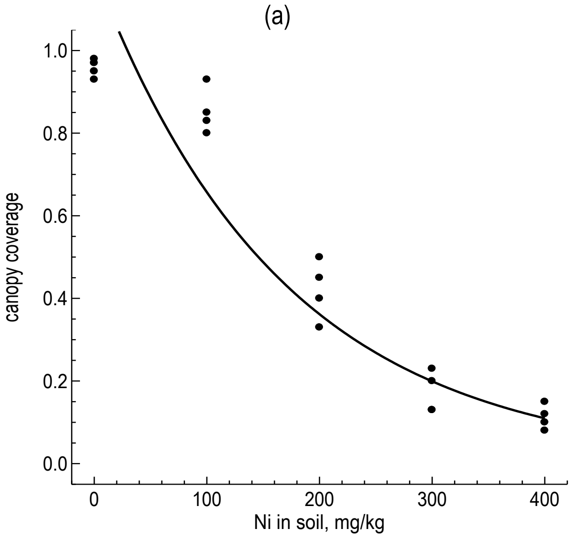
Thus spectral reflectance variations are a function of plant state which in return depends on growth conditions. The relation 'growth conditions → plant state → reflectance ability' determines the informational potential of vegetation spectral data and provides ground for vegetation abnormal status identification caused by stress factors. The aim is to extract the informational content which means plant bioparameters Φk to be estimated and anthropogenic influences Fr to be assessed using crop multispectral data $R\{r(\lambda_i)\}$. This is possible on the basis of empirical relationships derived from experimental data. The task is to establish quantitative dependences between reflectance features, bioparameters and anthropogenic factors: $R\{r(\lambda_i)\}=f(\Phi k)$, $\Phi k=f(Fr)$, $R\{r(\lambda_i)\}=f(Fr)$.

Vegetation indices are used as input variables in regression models for crop state and anthropogenic impact evaluation. More often these are indices formed in specific for vegetation spectral bands (see also Fig.1) of intensive reflectance and absorption of the incident light: green (G– 550 nm), red (R – 670 nm), near infrared (NIR – 800 nm) and the R-NIR region (700-780 nm) of sharp reflectance increase.

Examples are presented below illustrating some spectral-biophysical models. In Fig.3 the relationships between spring barley vegetation index R/(G+R+NIR), plant canopy coverage and Ni concentration in soil are shown (a, b, c) as well as the simultaneous change of the spectral and biometrical variables as functions of the pollution (d).



(a)



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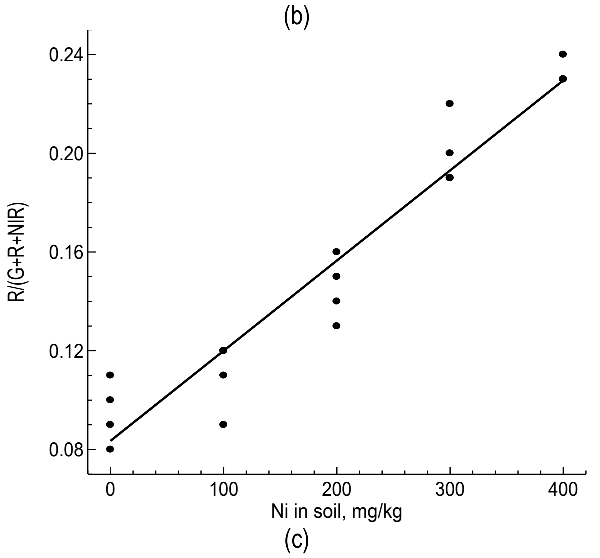
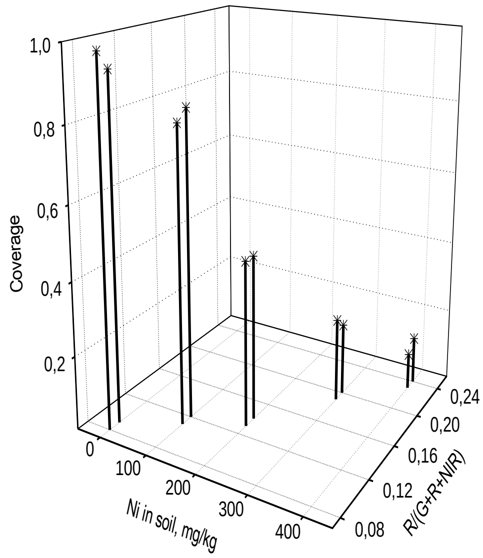


(c)



(d)

Figure 3. Relationships between barley vegetation index R/(G+R+NIR), plant canopy coverage and Ni concentration in soil.

Such empirical models when high correlations are observed allow plant parameters to be estimated using multispectral data as well as the impact of stress factors on crop development to be evaluated.

Should be mentioned also that special attention is being paid to data temporal aspect (Samson, 1993; Shibayama and Akiyama, 1989; Кънчева и Георгиев, 2000). The study of spectral features temporal behaviour during plant development is a condition for crop state periodical assessment, growth process forecasting and early identification of stress situations. The dependence VIj=f(t) called spectral-temporal profile carries information about the current and previous plant status and shows development trends. Temporal spectral data is indicative as well of plant state differences caused by anthropogenic factors. An example is Fig.4 where the temporal behaviour of r(λ=670nm)/r(λ=700nm) vegetation indices for Ni-polluted spring barley plots are shown.

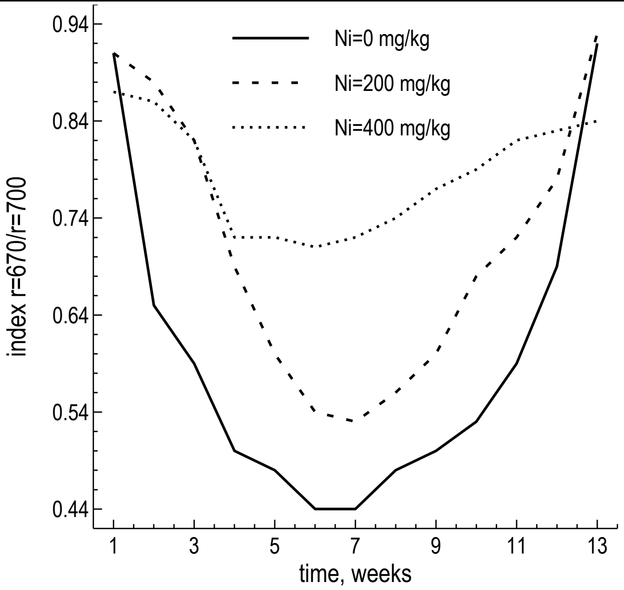
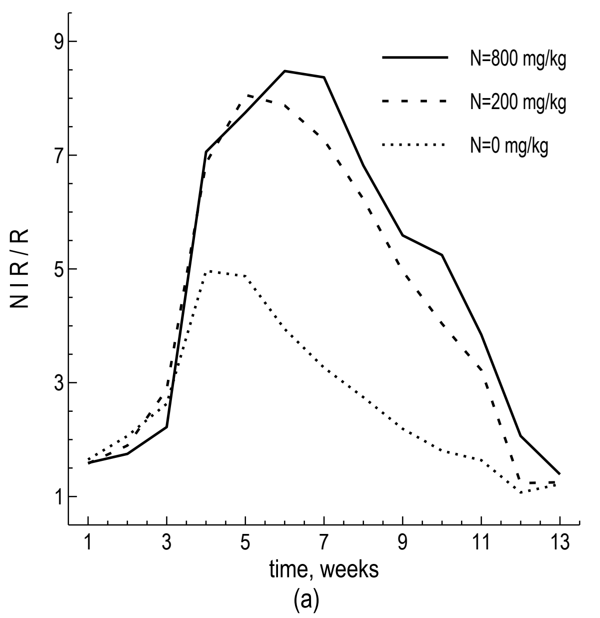


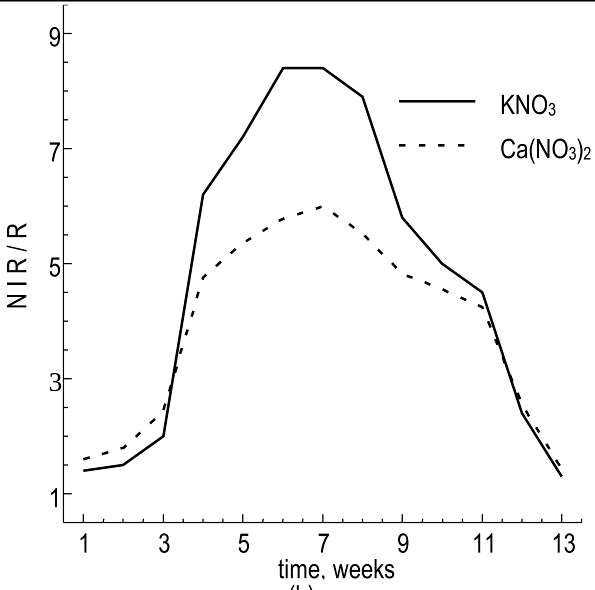
Figure 4. Temporal behaviour of r(λ=670 nm)/r(λ=700 nm) vegetation indices for spring barley plots with different Ni pollution.

It should be pointed out that the dependence of plant spectral reflectance on the heavy metal concentration in soil is observed almost throughout the whole vegetation period. This fact permits crop early diagnostics.

A stress factor can be also the nutrient deficit. Already at layering and tube-forming stages cereals manifest the insufficient nitrogen supply. Nitrogen fertilization effects plant growth bioparameters (height, biomass amount, canopy coverage, chlorophyll content) that leads to pronounced differences of reflectance features comparing to nutrient suffering vegetation. Fig.5a is an example of NIR/R index for spring barley plots with different nitrogen concentration in soil (the fertilizer is NH_4NO_3). It is interesting to point out that spectral differences are observed also in relation to fertilizer compound. This is seen in Fig.5b where the nitrogen content in soil is equal for all treatments (800 mg/kg) but the spectral-temporal profiles differ due to the fertilizer compound.



(a)



(b)

Figure 5. Temporal behaviour of barley NIR/R vegetation index depending on nitrogen amount (a) and fertilizer compound (b).

Summarizing the results of experimental studies, part of which are presented here, we draw the conclusion that reflectance spectra temporal behaviour and regression models relating plant reflectance features to bioparameters and growth conditions can be used for quantitative assessment of plant state and stress factors impact.

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RECOGNITION OF NATURAL OBJECTS ALONG A TRACE OF EARTH'S SURFACE BY SPECTRAL REFLECTANCE CHARACTERISTICS AND PHOTOIMAGES

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ABSTRACT
On the basis of remote sensing data of reflected by natural formations solar radiation in the visible and near infrared (NIR) ranges of the electromagnetic spectrum and accompanying photographic images, there are recognised the classes of objects, which are located along ~ 20 km long trace of the Earth's surface passing through the mountain of Sarnena Sredna Gora. The measurements are made onboard the manned space station 'MIR' with the help of the multichannel spectrometric system 'Spectrum 256' developed in STIL-B.A.S. The spectral reflectance characteristics (SRC) of the natural formations are obtained in the spectral range 450 ÷ 830 nm using the spectrometric system in the 128 spectral channel mode of operation. The SRC are linked to the underlie cover by means of accompanying photo images made with the built in the system photographic camera as well as with additional topographic data. Statistical methods are applied to verify the reliability of the main classes of objects and their subclasses delimited by the spectral methods.

INTRODUCTION

Among the main objectives of remote sensing of Earth from Space in the visible and near infrared (NIR) spectral ranges is to verify the adequacy of the different types of natural formations and their states with the information based upon the reflected by them electromagnetic radiation. Such investigations are of great scientific interest because of providing description of the objects through objective physical characteristics reflecting changes in their physical and chemical, and biological parameters.

To the research related with studies of spectral reflectance characteristics (SRC) of natural objects and phenomena it was assigned a significant part in the Scientific Research Program developed in connection with the flight of the second Bulgarian cosmonaut onboard the manned space station 'MIR'. A number of remote sensing experiments were carried out with the help of the multichannel spectrometric system 'Spectrum 256' developed by scientists and specialists of STIL – BAS and being operated for more than 12 years onboard the orbital station 'MIR' (Mishev, 1988). They were directed mainly to investigation of the various types of natural formations and their states by means of their spectral reflectance characteristics, the dynamics of their colour coordinates, the influence of the conditions in carrying the experiments out (atmospheric conditions, zenith angle of Sun, and others) on the reflection power of the objects, the optical properties, structure and dynamics of Earth's atmosphere (Mishev *et al*., 1989; Mishev *et al*., 1999; Krezhova *et al*., 1998).

The amount of information that is obtained by multichannel spectrometers and scanners mounted on aerospace carriers is increasing continuously but the data accumulated are of practical importance only in case of being quickly and effectively converted into information necessary for decision making or developing a strategy of behaviour. The modern methods, through the machine interpretation of data, ensure completely automated treatment and analysis of data in real time. In the practice a wide range of application and development find the qualitative methods for treatment of aerospace data among which is the method for recognition of natural formations by their spectral reflectance characteristics. The essentials of this method are in relating (classification) the SRC of the studied object to one of the classes of objects determined on the basis of accumulated databases of SCR (Swain and Davis, 1983). Therefore, it is necessary to know in depth the spectral characteristics of the classes of natural formations and the factors that exert influence upon them because they are a basic means of the remote sensing methods for recognition of natural formations on the Earth's surface.

In interpreting images obtained from Space the spatial indications are often very important in identifying the objects but in applying the algorithms for image recognition they are of no so effective use as the spectral indications.

The present paper is aimed to report on results from recognition of natural objects along a land trace of the Earth's surface by means of their SRC and accompanying photo images acquired under space conditions by means of 'Spectrum 256'. A priori information about the reflection power of the main classes of objects accumulated under ground conditions (field and laboratory measurements) in the visible and NIR ranges of the electromagnetic spectrum, and topographic data are used. The efficiency of the used instrumentation and method for carrying out continuous monitoring of natural formations is also shown.

EXPERIMENT AND DATA

In accomplishing the program for remote sensing utilising the system 'Spectrum 256' onboard the manned station 'MIR' there was obtained a large amount of spectral data and linked to them accompanying photo images taken with the built in the system photographic camera operating in automated mode. The measurements with 'Spectrum 256' were carried out through the MIR' station illuminators 'by fixing it by means of a special console. The latter is a mechanical device of circular design with graduated scales (nonius) for reading of the angle of rotation and positioning of the spectrometric system with respect to the illuminator, which allows for three-dimensional orientation of the direction of measurements. By means of the viewfinder of the photo camera the spectrometer is directed to the object selected for observation.

In our present study we used the spectral data accumulated during the passage of the 'MIR' station in one of its orbits above the territory of Bulgaria. The trace of the Earth's surface subjected to spectrometry is with a length of ~420 km in Southwest - Northwest orientation and crosses the towns of Razlog, Pazardzhik, Targovishte, and Tervel. The system 'Spectrum 256' has been operated in an operational mode with 128 spectral channels, each of 3nm halfwidth and spatial resolution 70x170 m at the 'MIR' station altitude of ~300 km.

The data are recorded within he spectral range 450 ÷ 830 nm in digital form (codes of the analogue to digital converter). For each session of recording (of about of 2 minutes duration) in the 128 channel operational mode of the system there is generated a set of data containing 2048 SRCs. In the course of each one of the registration sessions the corresponding dark current is recorded as well.

By applying a specialised program package the recorded spectral data are subjected to a preliminary treatment that includes the extraction of a given number of spectra with the possibility for printing and saving of a particular file, averaging and elimination of the dark current, and radiometric linkage. In the essence of the radiometric linkage is to account for the sensitivity of every one of the spectral channels by means of the calibration factors determined while carrying out the calibration of the system 'Spectrum 256' on absolute scale. After eliminating the dark current followed by performing the radiometric linkage, the real data for the radiance *L* of natural formations is obtained in absolute units [$\mu W/cm^2$ sr nm].

The radiance *L* of a particular natural formation at a given wavelength λ, i.e. the flux emitted into a unit solid angle by a non point – like source in a given direction from a unit projected area of this source in the same direction, is dependent of the flux density of incident radiation $E_0(\lambda)$ and the reflection properties of the object $r(\lambda)$ (Mishev, 1985)

$$L(\lambda_i, \theta, \varphi) = f[E_0(\lambda_i, \theta_0, \varphi_0), r(\lambda)], \quad (1)$$

where: θ_0 и φ_0 – zenith and azimuth angles of Sun, which condition the illumination of the natural formation; λ_i – wavelength; θ, φ - direction of the reflected radiation.

The radiance L recorded by means of the spectrometric block of the system 'Spectrum 256' is determined by (Mishev, 1985)

$$L(\lambda) = \frac{1}{\pi}\sin h \int_{\lambda_{min}}^{\lambda_{max}} E_h(\lambda)P_h(\lambda, H)P(H)r(\lambda)R(\lambda)d\lambda, \quad (2)$$

where: $P(H)$ - atmospheric transfer coefficient in direction to the sensor; $R(\lambda)$ - spectral characteristic of a given channel of the spectrometric system, $r(\lambda)$ - reflection power of the object under study, $E_0(\lambda, \theta_0, \varphi_0)$ - spectral density of the flux of solar radiation incident on the upper borders of the atmosphere; $P_h(\lambda, H)$ - transfer coefficient of the atmosphere at a wavelength λ, dependent of the Sun's height and its corresponding air mass *H.*

By means of a specialised software package the spectral reflectance characteristics in absolute units are subjected to a preliminary analysis. It includes: visualisation of the spectral reflectance characteristics obtained after the radiometric calibration; histogram and 3D analyses; diagrams of the data on channels along the whole measured trace or for particular sections of it.

METHOD AND RESULTS

The recognition of natural formations on the basis of the spectral data and accompanying photo images has been carried out by several steps.

First, on the photo frames representing sectors from earth surface with a size of 25 x 25 km it was determined the location of the river Struma. By using the reference marks printed on each photo frame the line of the spectrally measured trace was laid, and the Struma River has been taken as reference. On a map of Bulgaria drawn to a scale of 1: 500 000 the whole trace subjected to spectrometry was also protracted. On the Bulgarian territory the starting point was chosen at the village of Mikrevo, which is a few kilometres Southwest from the Struma River, and the town of Tervel was taken as the last point. The measurements with the spectrometric system 'Spectrum 256' along this trace have been carried out in the beginning of June and low clouds are observed to obscure some sections of the land trace. Therefore, after reviewing the photo images with taking into account the meteorological conditions along the particular land trace it was selected a section of it situated in the Mountain of Sarnena Sredna Gora. On the topographic map used, the chart K-9-37, 38 drawn to a scale of 1:100 000, the corresponding part of the land trace was protracted. From the photo images and the accurate topographic chart used it was determined the distance of the chosen section (southest with respect to the trace, at 1km far from the village of Ivan Vazovo and 157, 5 km far from the Struma River.

The topographic symbols on charts K–9-37,38 (A, B, C, D) drawn to a scale of 1:50 000 define the types of objects spread on this part 20.8 km long of the trace to be pieces of land with gardens planted with fruit trees, meadows, arable lands (fields), and forests of broad-leaved trees.

After reviewing the spectral data and their spatial link to the photo images the spectral characteristics corresponding to the Struma River was identified on the basis of the typical features of spectral reflectance characteristics of watery objects. (Cracknel, 1984).

The next step is by the spectral reflectance characteristics to carry out the recognition the objects specified from the topographic data to be located along the studied section of the trace. On the basis of SRC features the whole set of SRC data was decomposed into subsets. Then, the types of objects determined from SRC and topographic data were linked one to another with taking into account the spatial resolution of 'Spectrum 256' (one SRC corresponds to 170 m of land trace) and the photo images (one SRC per 1,1 mm of the photo frame).

Using the spectral data there were delimited three regions of Sredna Gora Mountain occupied with deciduous forests. Their distance with respect to the starting point of the studied section (Ivan Vazovo village), the number of corresponding SRC, and the change in altitude within the boundaries of one region, are presented in Table 1. The averaged SRC of these sets of data are shown in Figure 1.

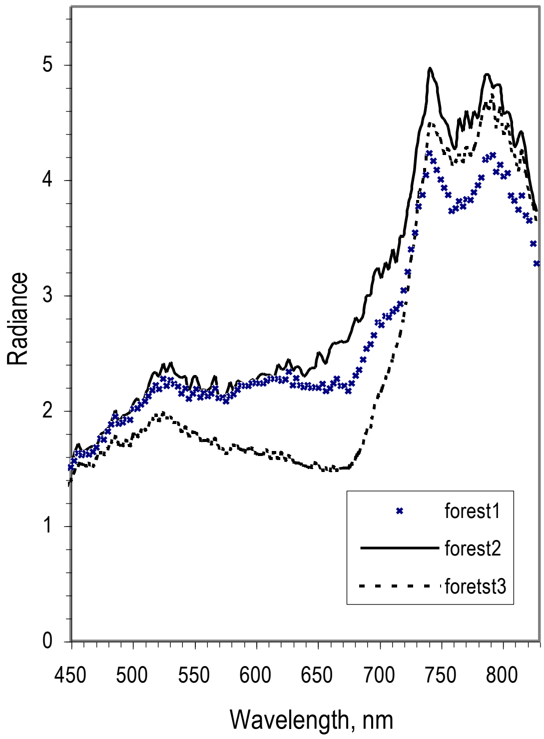

Figure 1. Averaged SRC of the three forest canopies

More substantial differences of the three types of spectral reflectance characteristics are observed in the NIR spectral range (741 ÷ 820 nm) wherein the reflection power of green vegetation is the highest and in the region of about 650 nm (maximum absorption of solar radiation. They are reasoned by the diversity of types of broad-leaves trees falling within one pixel, the possibility of presence of a mixed spectral class in one pixel, and difference in altitude.

By spectrometric data there were delimited also four sectors of arable land located as follows. The first one of 1,5 km in length is in the beginning of the section of the land race, in the region of Ivan Vazovo. The second sector with a length of 1.2 km is at a distance of about 2.4 km far from the starting point, and the third and fourth ones are located at a distance of 4,2 km and 12.3 km and are 2 km and 1.9 km long, respectively. Figure 2 shows the averaged SRC of these sectors of land. There are observed strongly pronounced differences in the values of SRC mainly in the visible range of the spectrum (450 ÷ 700 nm). This is due to the diversity of cultures grown and presence of mixed spectral classes within the boundaries of one pixel.

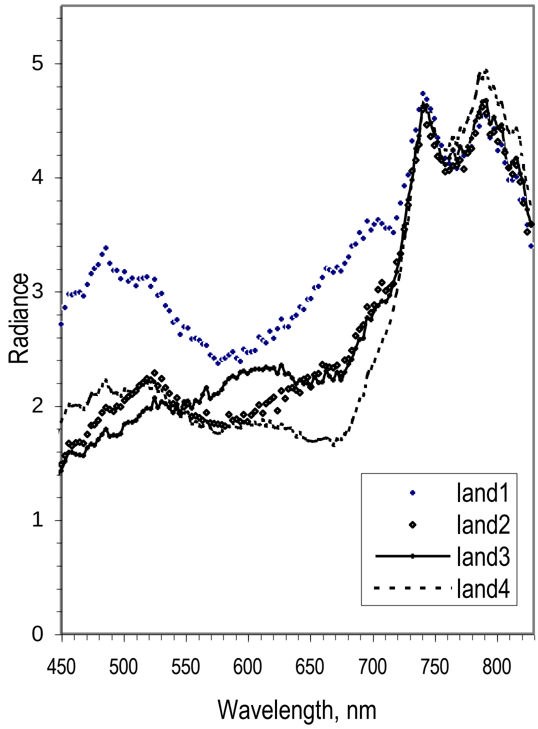

Figure 2. Averaged SRC of the four fields

Based on their spectral reflectance characteristics in these sectors of land there were delimited by several types of sub-regions with different green plantations. In Figure 3 are displayed the averaged spectral reflectance characteristics of the subclasses of objects, which form the averaged SRC of the first sector of arable lands. The course of SRC indicates the presence of two mixed spectral classes (subclass 1 and subclass 2). The SRC of the latter are significantly different from the typical spectral characteristics of green vegetation in the spectral range studied.

In the process of recognition of natural formations it was established the presence of another two classes of objects. The first one is orchards and occupies a sector with a length of 900 m, which is located at a distance of 1.6 km far from the Ivan Vazovo village. The other one is meadows (1.5 km long along the trace) at a distance of 5 km from the village. Figure 4 shows that the spectral reflectance of meadows is smaller throughout the whole spectral range studied.

Table 1. Distance, height above sea level, and ordinal number of SRC of the three forest canopies

Object	Distance, km		Height above sea level, m		SRC, №	
	from	to	from	to	from	to
Forest 1	3.6	4.30	300	320	946	949
Forest 2	7.6	11.3	423.7	495.4	970	995
Forest 3	14.3	20.8	466	654	1008	1045

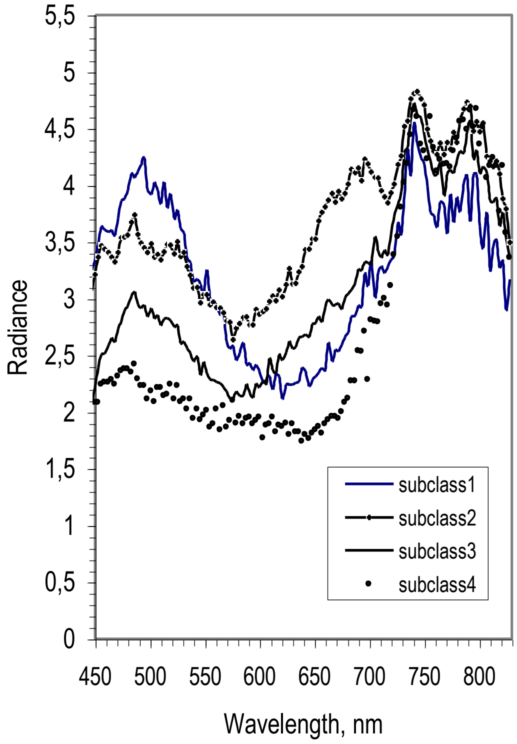

Figure 3. Averaged SRC of the subclasses of arable land 1

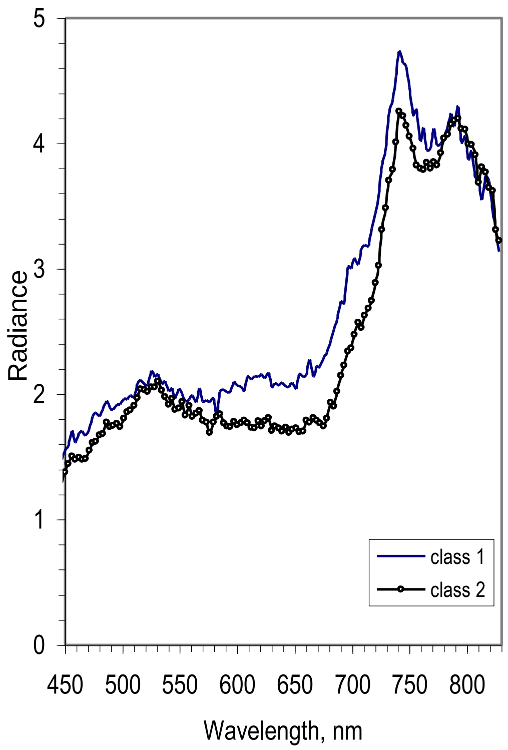

Figure 4. Averaged SRC of the two pieces of land – orchards (class 1) and meadows (class 2)

To confirm the likeness or unlikeness of the types and subclasses of objects determined by SRC it was applied a cluster analysis of the spectral data for the characteristic wavelengths λ_1 = 525 nm and λ_2 = 744 nm at which SRC reaches its maximum in the visible and near-infrared spectral regions, respectively. Figure 5 illustrates the results for the distribution of the reflection power at λ_1 with respect to the reflection power at λ_2 for the three broad-leaves forests. The spectral data of the three broad-leaves forest canopies are distinctly grouped into three clearly pronounced clusters.

The results presented show that the multichannel spectrometric system ‘Spectrum 256’ and the method developed and implemented for recognition of natural objects by spectral data, photo images and additional topographic data allow for the operative monitoring of natural formations by spectral indications.

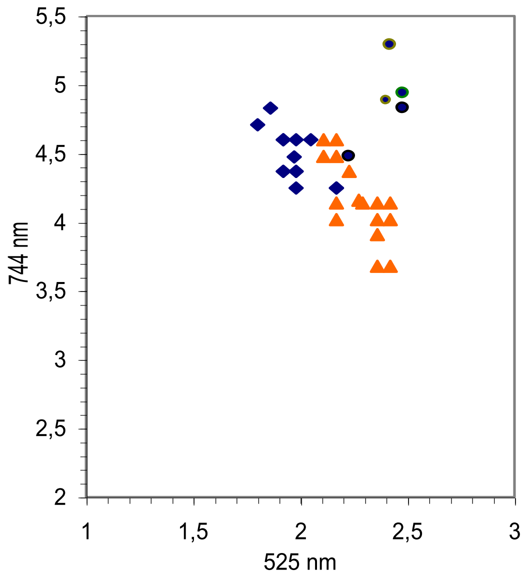

Figure 5. Cluster analysis of the SRC of 3 deciduous forests

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SPECTRAL REFLECTANCE OF MAGMATIC AND METAMORPHIC ROCKS IN THE VISIBLE AND NEAR INFRARED RANGES

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ABSRACT

The investigation of reflected by natural formations solar radiation within the visible and near infrared ranges (NIR) of the electromagnetic spectrum and occurring changes in its spectral distribution under the action of various environmental factors is a well established technique for aerospace and ground remote sensing, which finds broad areas of application in geology, applied geophysics, ecology and others. In this report we present results from investigations of the spectral reflectance characteristics (SRC) of rock formations (magmatic and metamorphic rocks) with different genesis and chemical composition and contrasting mineral constituents in the spectral range 480 ÷ 810 *nm*. The spectral data were obtained using the multichannel spectrometric system 'Spectrum 256' developed in STIL-B.A.S., which has been operated for many years onboard the manned orbital space station 'MIR'. The studies of SRC were carried out under laboratory conditions on samples of ultramaphic (pyroxenite) and basic (gabbro) magmatic rocks, granitoids (granites, alkaline type granites) as well as regional metamorphic rocks – serpentinite, gneiss, garnet bearing amphibolite and kyanite schist. On the basis of the spectral data and implemented statistical methods the texture of the rock types was analysed and for some of them there were identified spectral subclass objects belonging to a common spectral class in accordance with their mineral composition.

INTRODUCTION

The spectrometric measurements of reflected by natural formations solar radiation in the visible and near infrared (NIR) ranges of the electromagnetic spectrum provide an express and reliable information for the objectives of cosmic and ground remote sensing and for various areas of science (geology, applied geology, ecology, etc.). At a high spectral and spatial resolution featured by the apparatus in use, the spectral data provide for the possibility to recognise main classes of objects, to identify their diversity and states, and to establish the presence of subclasses of objects within the frames of a single spectral class.

One of the applications of data from remote sensing of natural objects is the recognition of geological structures and formations. Already with coming into light of the aerocosmic photos and emerging methods for their usage, the interrelated decoding indications of the geological objects were separated into direct, involving the radiation of the objects themselves, and indirect, related to corresponding salient features of landscape. This was done on the basis of the geological objectives formulated (Trifonov and Schulz, 1986; Moralev and Cheschihina, 1989; Wood and Laserre, 1990; Salisbury *et al*, 1992). The division of the decoding indications into optical and geometrical is of basic importance, because of differences in the methods applied for their use for recognition of geological formations. The optical spectral signs are most informative and characterise the brightness of radiation from the surface of the geological formations in the electromagnetic spectrum. The geometrical signs characterise the structure and the texture of the spatial distribution of signals with different brightness and in the recognition of geological formations it is of no importance if they manifest themselves as direct or indirect.

Depending upon the objectives to be achieved by the particular experiments being carried out, there is a variety of the ground (laboratory and field) remote sensing investigations but two main groups could be specified. A part of them is oriented to ascertain qualitative relationships between the parameters of the natural formations and phenomena on one side and the information provided for the latter by the aerospace remote sensing on the other side. Another part is aimed to reveal the mutual relation between the different components and states of the objects and phenomena, and the factors which exert an influence upon them. The laboratory spectrometric measurements in the visible and NIR spectral ranges show that the spectral characteristics of the elementary natural species are strictly individual (Mishev *et al*., 1989; Salisbury and D'Aria, 1994; Mishev *et al*. 1999). They can easily be subjected to treatment and identified which determines their leading place in the general strategy for recognition of natural formations based on data from aerospace measurements. Because of this, the knowledge of SRC of particular characteristic objects located on the Earth's surface (soils, rocks, water, forest and agricultural vegetation, etc.) is of primary importance for the correct and accurate interpretation of the data from remote sensing.

The aim of the present work is to report on results from laboratory investigations of spectral reflectance characteristics of different rock formations in the visible and near infrared ranges of the electromagnetic spectrum and their applicability for recognition of main types of rocks and their variety by texture and mineral composition.

MATERIALS AND METHODS

Petrographic characteristic of the rock specimens under investigation

The objects under study in the present report are representative specimens of magmatic and metamorphic rocks. The spectrometric measurements were carried out on five basic types of magmatic and four types of metamorphic rocks with different genesis and chemical composition and contrasting mineral constituents.

Magmatic rocks: The rock specimens of magmatic rocks belonged to five main classification groups: ultramaphic rocks (pyroxenite); basic rocks (gabbro); mediumbasic rocks (diorite); acidic rocks (granite) and alkaline rocks (alkaline granite-diorite).

Pyroxenite is a coarse-grained rock of massive texture and coloured in dark green to black. It was built mainly of pyroxene (up to 90%). Small portions in the rock were single grains of olivine and ore minerals.

Gabbro (Figure 1) is a medium-grained rock of massive texture, dark greyish-green of colour. The basic rock forming minerals were plagioclase and amphibole in a ratio of 1 : 2, which determines macroscopically the mesocratic character of the rock and its classification as amphibolic gabbro.

Figure 1. The measured surface of gabbro

Diorite is with a medium up to fine-grained structure, dark greyish-green coloured, with a massive, locally taxite texture. Single epidote veins cut the specimen. Its mineral composition is of primary rock forming minerals – medium plagioclase and amphibole (up to 90%), and minority minerals – single grains, mainly of pyroxene, biotite and quartz. The colour index (M) of the rock was of about 40 ÷ 45 %.

Granite is an unevenly grained (fine to medium-grained), light grey of colour, with a massive texture and a mineral composition of primary rock forming minerals – acidic plagioclase, K - feldspar, quartz and biotite, and minority minerals - amphibole. Because of the unevenly grained character of the granite the spectrometric measurements were performed on two specimens poor in the femic component with an index M up to 7%, and both cases could be specified as leucogranites. The first specimen was with a fine-grained structure, while the second one featured a more coarse-grained up to pegmatite-like texture.

Alkaline granodiorite – dark-coloured reddish-rose rock with a massive texture of locally spotted character. Mineral composition: K-feldspar (main), acidic plagioclase, quartz, biotite, amphibole.

Matemorphic rocks: Specimens of regional metamorphic rocks were studied, as follows: serpentinite, amphibolite, gneiss, and kyanite schist.

Serpentinite (metaultramaphit) – a greyish-green of colour dense rock built of minerals from the serpentinite group, chlorite, talc, ore minerals, and sporadic relicts of olivine and pyroxen. The surface upon which the measurements were taken was textured mainly of talc-chlorite-serpentinite products.

Amphibolite (metabasit) – dark green, fine-grained, with a massive up to locally unclear stripe texture, and mineral composition: amphibole (60 ÷ 65%), garnet (up to 5%), acidic plagioclase (20%), quartz, epidote, and titanate. Macroscopically, the porphyryblastic character of the garnet was clearly visible.

Gneiss (metagranite) – biotite gneiss with an augen-layered texture and mineral composition: plagioclase, quartz (primary rock forming minerals), and muscovite and K-feldspar (minority minerals). The rock is with clear signs of tectonic treatment and features local indications of blastomylonitisation.

Kyanite schist (metapellite) – fine-grained rose-brownish of colour schistose rock with a mineral composition of kyanite (modified into sericite-muscovite), biotite, granite, and quartz. The rock exhibits a strong mineral linearity and a porphyryblastic texture by the mineral kyanite. Two specimens were measured with surfaces of different texture. The surface of the first one (Figure 2) is schistose and with presence of kyanitic porphyryblasts, whereas the surface of the other specimen is pronouncedly cracked and with lacking kyanite porphyryblasts.

Spectrometric measurements of the rock specimens – experimental set up and methods

The SRC of the rock specimens studied were measured using the multichannel spectrometric system 'Spectrum 256'. This system was developed by scientists and specialists of STIL – BAS in connection with the implementation of the scientific program of the second Bulgarian cosmonaut, and for more than 12 years was operated successfully onboard the manned orbital space station 'MIR' (Mishev and Kovachev, 1988; Mishev *et al*, 1990). 'Spectrum 256' consists of two blocks - a spectrometric block and a block for data registration. The spectrometric block contains a built-in photographic camera, which is optically linked to it and is operating in an automatic mode. By means of this photo camera it is achieved the link between the spectral data recorded and the objects under study.

For the measurements under laboratory conditions it was used a special experimental set up. Besides the multichannel spectrometric system it incorporates an optical bench, an optical table, a standard white screen, a movable platform for fixing and adjustment of the specimens, and a light source of high stability (three halogen lamps each one energised by an individual regulated power supply). The white screen is a disk with a diameter of 32 *cm*, covered with barium sulphate, and featuring linear spectral characteristics in the visible and NIR spectral ranges. The spectrometric system MS is fixed with horizontally aligned optical axis on the optical table which allows for fine and smooth displacement about X and Y axes in order to realise the scanning of the studied objects. The white screen and the investigated surface of the rock specimens are adjusted perpendicular to the optical axis of the objective of 'Spectrum 256'.

Figure 2. The measured surface of kyanite schist (Specimen 1)

The spectrometric measurements of rock specimens were carried out with 'Spectrum 256' used in an operational mode with 128 spectral channels, each of 2.6 *nm* halfwidth at a spatial resolution of 2 mm^2. Each second the system is recording 40 spectra in the spectral range 480 ÷ 810 *nm*.

The measuring method includes: determination of the optimum conditions for illumination of the specimen studied, so that the recorded reflected radiation to possess a sufficiently high dynamic range in the visible and NIR spectral ranges; determination of the optimum area of the specimens for carrying out the spectrometric measurements; determination of the minimum number of areas (pixels), which is necessary to be spectrally measured, so that the SRCs obtained to yield with a sufficiently high reliability the averaged SRC of the object, considered as being a spectral class

Based on preliminary experiments we have carried out the measurements of the rock specimens under study in 25-30 points (pixels) on average in dependence on the particular texture, chosen adjacent in the horizontal direction. For every rock specimen there are recorded the dark current; the reflected radiation by the investigated area within a given number of pixels; the reflected radiation by the diffuse white screen, and the spectral reflectivity coefficients are determined. For each spectrally measured area there are recorded by 60 spectra on average, and for the white screen and the dark current - by 120.

Every natural object reflects in a specific way the incident upon it radiation, and this determines to be informative the radiance in absolute units or the spectral reflectivity coefficient in relative units. These quantities are multiple-factor photometric functions, being dependent of physical and chemical properties and biological properties of the objects.

The spectral reflectivity coefficient r $(\lambda_i, \theta_o, \varphi_o, \theta, \varphi)$ characterises the structure of the reflected by the natural formation radiation by both wavelength and conditions of illumination. Under conditions of illumination (θ_o, φ_o), in the direction of the recording system (θ, φ) and range of wavelengths λ_i, $\lambda_i+\Delta\lambda$, the spectral reflectivity coefficient is determined by

$$r(\lambda_i, \theta_o, \varphi_o, \theta, \varphi) = L(\lambda_i, \theta, \varphi) / L_o(\lambda_i, \theta_o, \varphi_o), \quad (1)$$

where $L(\lambda_i, \theta, \varphi)$ is the radiance of a given object in direction (θ, φ) at wavelength λ_i, $L_o(\lambda_i, \theta_o, \varphi_o)$ is the radiance of an orthotropic fully reflecting surface under identical conditions of illumination.

For determination of the spectral reflectivity coefficients the spectral data recorded by the system 'Spectrum 256' are subjected to a preliminary treatment. It includes averaging of the data of one area spectrally measured, accounting for the dark current, averaging of the data of the standard screen, averaging of the data of all areas being spectrally measured for each rock specimen.

RESULTS AND DISCUSSION

Figure 3 shows the averaged SRCs obtained for the investigated surfaces of the 11 rock specimens. Three clearly displayed groups of SRC can be separated. The most numerous group brings together magmatic rocks with ultrabasic (pyroxenite), basic (gabbro) and medium basic (diorite) constitution and one basic metamorphic rock (amphibolite). The lowest values of the spectral reflection coefficient are associated with the specimens of amphibolite (curve 10) and pyroxenite (curve 11). These rocks are the darkest of colour and feature a massive texture. They are built of various femic minerals, which is manifested by the differences in the spectral reflection coefficient values in the spectral range 480 ÷ 650 *nm*. This conclusion is confirmed also by the result from the correlation analysis of the averaged SRC of these two rock specimens. Figure 4 illustrates the low degree of correlation in a part of the spectral range.

The averaged SRC curves of the serpentinite (curve 7) and diorite (curve 8) exhibit a roughly similar course with a difference in the value of SRC of about 0.07 relative units in the whole spectral range studied. The averaged SRC (curve 6) of the measured area from the surface of gabbro shown in Figure 1 has a rather smooth behaviour and for that group of SRC reaches the highest values. A special note deserves the behaviour of SRC of the alkaline granodiorite (curve 9). It is of particular interest because the averaged spectral reflection coefficient values of this group of spectral characteristics is featuring the highest dynamic range, 0.15 ÷ 0.23 relative units.

The second group of SRC comprises the granites (curves 4 and 5) and gneiss (curve 3), the latter being a metamorphosed granite. The difference in the reflection power of the surface of the two granites studied is related with their different texture (coarse or fine-grained) and the different proportion of femic and ore minerals.

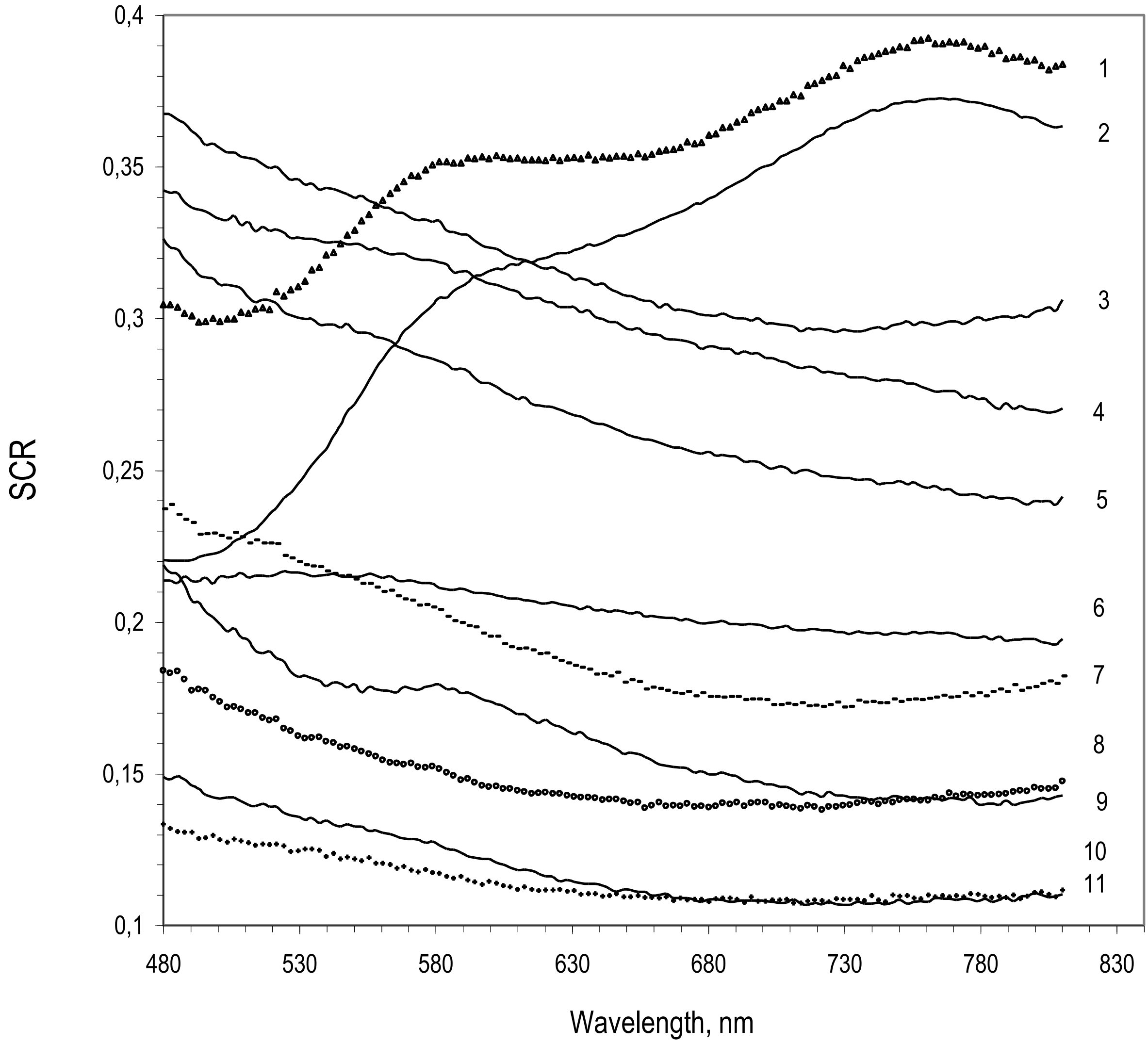

Figure 3. Average SRC of the rock specimens: 1) kyanite schist (specimen 1); 2) kyanite schist (specimen 2); 3) gneiss; 4) granite (specimen1); 5) granite (specimen2); 6) gabbro; 7) serpentinite; 8) diorite; 9) alkaline grnodiorite; 10) amphibolite; 11) pyroxenite

The correlation analysis of the averaged SRCs of the two specimens of granite confirmed the similarity of their constitution, irrespectively of the uneven grain size. This is illustrated in Figure 7.

In the third group of SRC fall the kyanite schist's (curves 1, and 2). The two averaged SRCs have a roughly identical behaviour. The surface of one of the specimens was schistose with presence of large greyish-blue crystals of kyanite and its reflective power is higher (curve 1) than that (curve 2) of the surface of the other representative of this type of rocks where crystals of kyanite were absent. Figure 5 shows the averaged SRC of 27 studied areas, measured on the cracked surface of the secon specimen. The spectral reflectance characteristics form a single spectral class. Figure 6 displays the averaged SRC of 25 areas of sample 1 of the kyanite schist. The spectral characteristics are clearly differentiated into two spectral subclasses. Their presence reflects the differences in the texture of the surfaces due to the kyanite porphiryblasts and the fine-grained quartz-bioite body, respectively.

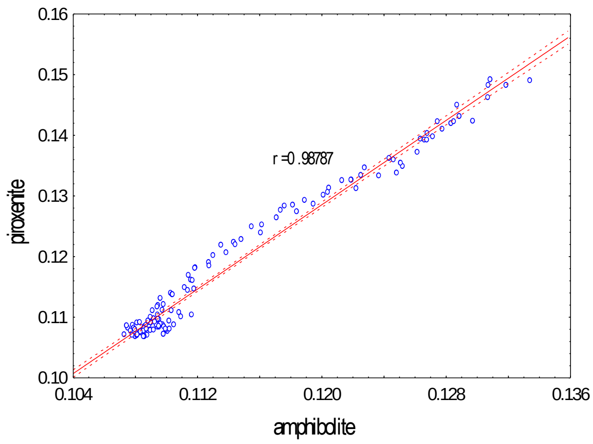

Figure 4. Correlation analysis of SRC of amphibolite and pyroxenite

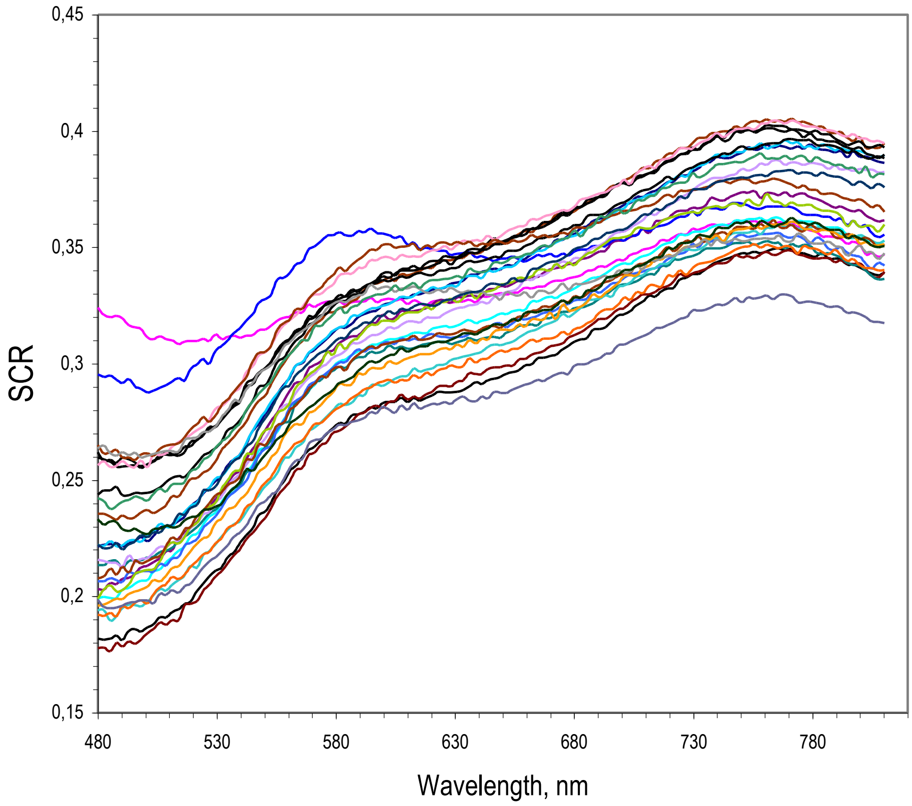

Figure 5. Averaged SRC of the measured areas of the kyanite schist (specimen 2)

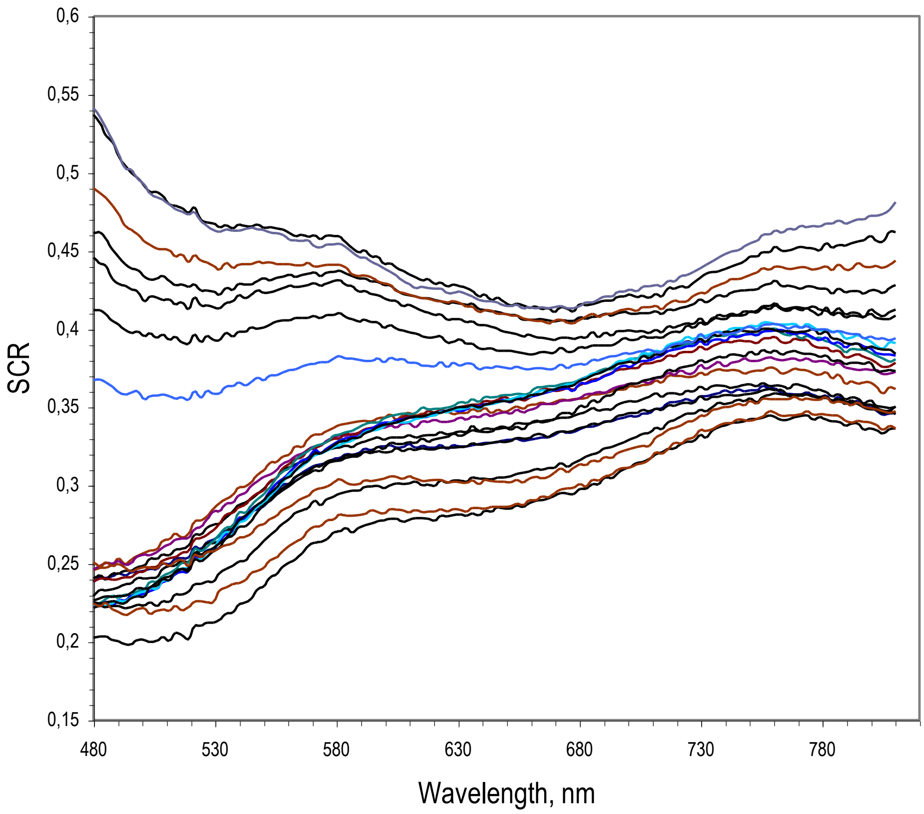

Figure 6. Averaged SRC of the measured areas of the kyanite schist (specimen 1)

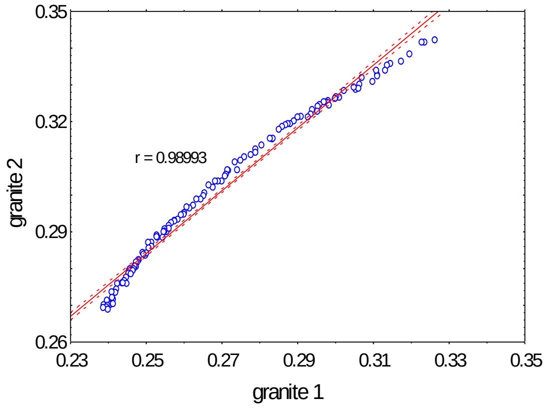

Figure 7. Correlation analysis of SRC of two granite specimens

Figure 8 presents the averaged SRCs of the two subclasses. The results from the cluster analysis of the SRC of the two subclasses are illustrated in Figure 9, where the case of carrying out such analysis for the wavelengths 500 *nm* and 779 *nm* is given as an example.

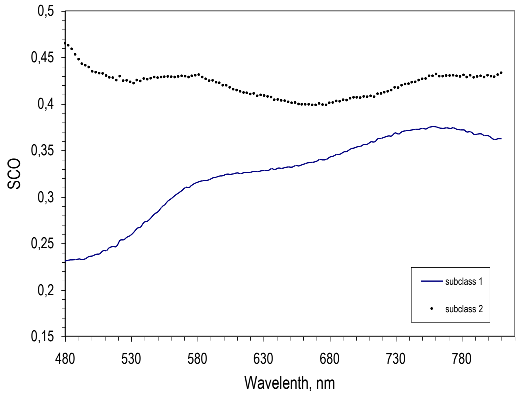

Figure 8. Averaged SRC of the two subclasses of specimen 1 of the kyanite schist

Concluding, we shall note that the spectral reflectance characteristics of studied rock formations give information for their texture features and contribute to the ground remote sensing database necessary for aerospace geological research by spectral indications.

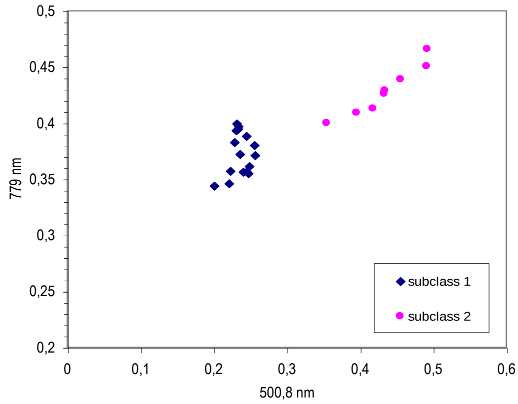

Figure 9. Cluster analysis of the two subclasses of specimen 1of the kyanite schist

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IMPROVEMENTS AND INNOVATIONS IN REGISTERING THE GEOMAGNETIC FIELD PARAMETERS

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ABSTRACT
The paper discusses the improvements and innovations made in the classical registration of the geomagnetic field (GMF). Complex equipment for automatic measurement and registration of the GMF horizontal component and automatic digital registration of the four basic parameters of that field – declination D, horizontal intensity H, vertical intensity Z and total vector F is considered. The shortcomings of the classical analog photographic registration used until now and the positive effect of implementing the new methods and equipment are manifested. Some of these are being used at the Panagyurishte Geomagnetic Observatory of the Geophysical Institute of the Bulgarian Academy of Sciences and others are to be introduced there as well. The methods and equipment have been patented.

At present tens of geomagnetic observatories round the world use the classical methods and equipment for analog photographic registration of the geomagnetic field parameters (Gauss, 1952; Penkevich, 1948). These include a number of manual test operations requiring a long time without providing the same conditions for the various experiments and allowing for high probability of errors. The data obtained from these tests are not suitable for direct computer processing or transmission through a telemetric channel.

Complex equipment for measuring the absolute value of the GMF horizontal component H_T and automatic digital registration of the basic parameters of that field has been developed to eliminate these shortcomings and in particular, to increase considerably the accuracy, cur down a number of labour-consuming manual operations, reduce practically to zero the time required to obtain the results, automate the measuring and calculating process as well as perform some additional functions.

1. COMPLEX EQUIPMENT FOR MEASURING THE GMF HORIZONTAL COMPONENT

Complex equipment for measuring the GMF horizontal component was proposed and designed. A basic unit in the complex equipment is the precise periodometer. Such a precise periodometer – PPM-MO (Mardirossian et al, 1988) was designed especially for implementation at the Panagyurishte Geomagnetic Observatory (GMO).

Fig. 1 illustrates schematically the PPM-MO operation. The light beam from collimator 2, reflected from the mirror-polished part of the oscillating permanent reference magnet 3, is periodically incident on the photo conversion unit (PCU) mounted on the zero line where the beam velocity is maximum - V_{max}. This ensures minimum error in reading the times between each beam incidence on the PCU. The electric signal generated during each beam incidence is transmitted to the PPM-MO.

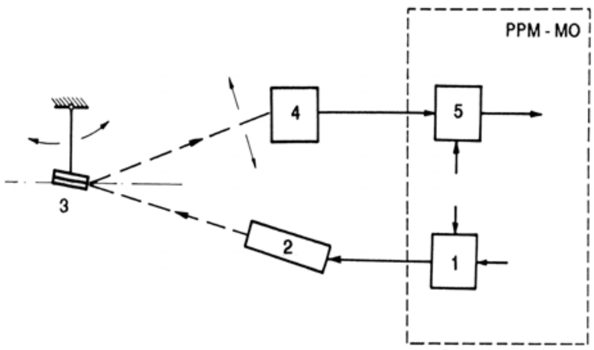

Figure 1.

The method and implementation were patented (Mardirossian, Fratev, 1989) and the main PPM-MO design-performance characteristics are given in Mardirossian et al (1988).

Since the permanent reference magnet oscillates not in vacuum but in a real air environment, minimum error and maximum reliability in comparing the individual measurements can be obtained for all these measurements only if it is possible to make sure that they are performed under magnet oscillations of equal amplitude. However, this cannot be controlled by the visual method used so far.

In Penkevich (1946) for the value of the difference between the oscillation periods with and without attenuation we have $\Delta T \approx$ 0.00006, i.e. the influence occurs in the 4[th] or 5[th] decimal place. If until now it was negligible given the methods and equipment that registered the period T to an accuracy of up to three decimal places, with the introduction of the new methodology and equipment capable of reading within an accuracy of up to six decimal places, this negligence is now considered incorrect.

Methods have been created to control automatically within high accuracy the oscillation amplitudes *a* of the magnet and the amplitudes A_i of the light spot reflected by it during the measuring process, respectively. After initial oscillation of the magnet, an optoelectronic circuit traces the oscillation amplitudes and upon reaching the assumed initial (maximum) value A_{max}, it switches on the PPM-MO. Upon reaching the determined finite (minimum) value A_{min} the device is switched off.

The implementation of the proposed method is based on a model TSL-215 opto sensor with an amplitude resolution of 0.125 mm, i.e. the angle can be controlled within an accuracy of the order of 0.5^0. Thus amplitudes A_i corresponding to the measured periods T_i, are entered directly in the computer. In addition, it is possible to control to what extent the deviation amplitudes on both sides of the meridian are similar thereby judging about the mechanical parameters of the oscillation system.

A digital signal is transmitted to the computer by an EW (east-west oriented) seismometer mounted in the basement of the Panagyurishte GMO. It is possible to analyse and search for a correlation of inaccuracies between the individual measured periods and the microseismic vibrations. When such a correlation is established, the measurement (or reading of already measured periods) is carried out only at a microseismic noise level lower than the determined threshold level for non-discredited measurements. For the particular case the lab has assumed a threshold of $2A_{MN} \leq 0.05$ mm in the frequency domain 0.3 Nz $\leq f \leq$ 60 Hz.

Fig. 2 shows a block diagram of the complex equipment for measuring the GMF horizontal component. The respective units are 1 – periodometer, 2 – amplitude control unit, 3 – hygrometer, 4 – thermometer, 5 – seismometer, 6 – computer.

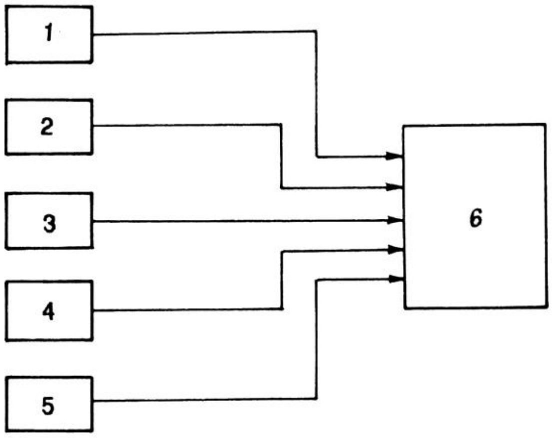

Figure 2.

As it is normal to expect, the increase in the equipment accuracy by two orders raised some methodological problems. In the first place, it is the fluctuation of the 4th decimal place where a unit equals approximately 10 *nT*. It was necessary to give an answer to the question of what this fluctuation, reaching up to one to three units in the 4th decimal place, is due to. The problem is essential because it is known that the accuracy of the other GMF elements depends on the accuracy of determining the horizontal intensity *H* (Cholakov, 1989).

The main external disturbing and interfering factor in the high accuracy measurements is the change in the geophysical parameters, in this particular case the humidity, temperature, atmospheric pressure and microseismic vibrations. At stationary observatories like the Panagyurishte GMO it is normal that measures should have been taken to minimise their impact. The effect of these measures is different for the different geophysical factors but their complete avoidance is practically impossible.

The effects of external and internal factors are divided conditionally and considered separately. The external factors are temperature, humidity and atmospheric pressure. The experiments performed to cause artificial changes in the temperature and humidity showed that such changes would not affect the values of period *T* at least up to the 4th decimal place. Similarly, it is shown that the atmospheric pressure variations reaching up to approx. 10hPa/3 h have no effect on the accuracy of measurement.

The effect of the microseismic vibrations on the accuracy of measuring the absolute value of the GMF horizontal component *H* was studied. The microseismic vibrations within the frequency range of 3-4 to 50-60 Hz are most strongly expressed and commonly have maximum amplitudes of several to several tens of μm. These short-period vibrations of the Earth's surface in relation to the permanent magnet oscillations can affect both the instantaneous spatial position of the collimator (C), magnet (M) and photo sensor (PS) and directly the permanent magnet oscillations. The analysis of all possible situations, bearing in mind the amplitudes, frequency and phase characteristics of the microseismic noise as well as the mass and elastic parameters of resonance frequencies of the mechanical elements of the complex equipment is very complicated. Therefore, we restricted our analysis only to considering the two simplified boundary cases:

a) The instantaneous vibration of the collimator C and photo sensor PS (units 2 and 4 in Fig. 1, respectively) is synchronous and co-phase.

b) The instantaneous vibration of C and PS is in antiphase.

The second case has practically a very low degree of probability as the collimator and the photo sensors are mounted on a common foundation. For the assumed mean value of the amplitudes of the microseismic vibrations of the order of 1.0 μm and for the most unsuitable instantaneous position of the collimator and photo sensor, the maximum error in measuring the period T_x can be of the order of $10^{-5} - 10^{-6}$, i.e. in the 5th and 6th decimal place of the results obtained.

Of special interest is the error obtained from possible changes in the luminance, focusing, geometry and spectral composition of the light beam incident on the PS during the measuring process. Eventually, the change in these parameters can sooner or later lead to illumination, and consequently, actuation of the PS thus causing readings of shorter or longer periods than the actual ones T_x. Bearing in mind the invariable state of the optical details it was found that possible variations of the current in the collimators of the order of $\Delta I \approx 2 \div 3$ mA can cause a change in the luminance of the order of $\Delta B \approx 0,3$ mW/m^2 (Mardirossian, 1999), which could not give rise to luminance, geometric and spectral changes in the beam incident on the PS that can have a relevant influence on the accuracy of measuring the period T_x.

With the aim of checking in situ the theoretical assessments of effect of the microseismic vibrations on the accuracy of measuring the GMF horizontal component, a real experiment was conducted at the Panagyurishte GMO. Simultaneously with measuring T_x, were measured the three components (displacement x, velocity $\dot{x}$ and acceleration $\ddot{x}$) of the horizontal microseismic movements of the foundation on which the oscillating system of the permanent reference magnet is mounted. The processing and analysis of the results obtained shows that there is no correlation between the maximum fluctuations of T_x and the amplitudes of the microseismic vibrations. Furthermore, it was found that in the range of 0,3 ÷ 0,4 Hz, corresponding to the natural periods of oscillation of the two reference magnets there are not seismic vibrations with amplitudes exceeding the average amplitude for the entire studied spectrum. A similar conclusion can be drawn about the range of the third harmonics (0.9 ÷ 12 Hz). Therefore, the vibrations of the foundation on which the permanent reference magnets are mounted, caused by the local microseisms do not introduce changes in the measured periods T_x within the measurement error.

The analysis of the telemetric registration at the National Operative Telemetric System for Seismological Data (NOTSSD) (Samardjiev et al, 1980) for the period April 1998 to August 1999, obtained by the vertical seismometer S-13 (Operation and..., 1989) mounted in the basement of the Panagyurishte GMO at a distance of 20 m from the horizontal intensity *H* measuring equipment did not show any presence of macroseismic events or an anomalous high level of microseismic noise during these measurements.

The nearly 10-year operation of the complex equipment for measuring the GMF horizontal component enabled us to obtain the following relevant results and make the respective conclusions (Mardirossian, 2001):
- the accuracy of the results obtained increased by at least two orders;
- the time for obtaining the result is practically zero;
- obtaining the value of T_x directly in a digital form allows for its further automated primary processing, registration by modern methods, telemetric transmission, etc.

There are technical and technological reserves (better circuit technique, more reliable electronic components, increasing the optical arm of the light beam, using a differential PS, etc.), which, if realised, can lead to increasing the accuracy of measurement by at least one more order. This can be done naturally if such accuracy is considered to be necessary and applicable in the geomagnetic theory and practice including studies on anomalous and disastrous natural phenomena and processes.

2. DIGITAL REGISTRATION OF THE GEOMAGNETIC FIELD PARAMETERS

A method has been developed for automatic digital registration of the four basic GMF parameters – declination *D*, horizontal intensity *H*, vertical intensity *Z* and total vector *F*. It consists in using part of the light beams by which the analog photo registration is accomplished to obtain a digital electric signal corresponding to that registration. The general functional diagram of implementing the method is shown in Fig. 3. A photodiode ruler 1 is mounted on diaphragm 2 of photo recorder 3. The ruler is composite and consists of four separate rulers located in relation to the diaphragm 2 as follows: 1^{I} and 1^{III} immediately above it, and 1^{II} and 1^{IV} below it. Such an array cancels their inactive side parts and produces a practically continuous photodiode ruler along the entire length of the diaphragm. The light beams from the collimators 5, reflected by sensors 9, are focused on the diaphragm 2 in the form of a line. The middle parts of these

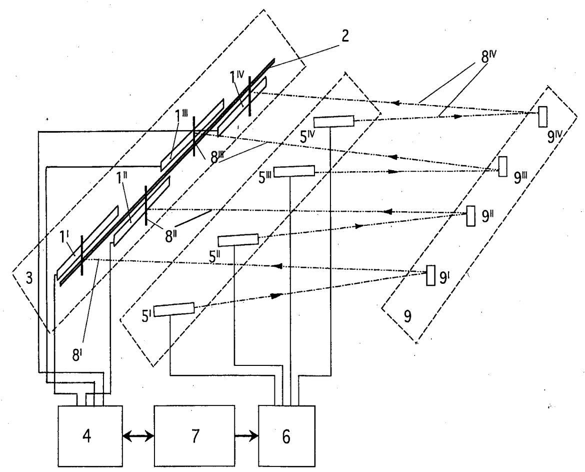

Figure 3.

beams perform the analog photo recording. The unused parts (for 8^{I} and 8^{III} – the upper ones, and for 8^{II} and 8^{IV} – the lower ones) are incident on the respective photodiode rulers 1. The outputs of 1 are connected to a unit for preliminary processing of the signals 4, which has a two-directional connection with the microprocessor system (computer).

Having in mind the geometric, optical and other design-performance characteristics of the analog magnetic photo recorder, it is most expedient to use an integrated photo sensor model TSL-218 of the TEXAS INSTRUMENTS Co. (Intelligent..., 1995). Four TSL-218 sensors, mounted on the diaphragm of the photo recorder (see Fig. 3), cover with some reserve the width of the diaphragm and the photo-paper tape, which is 200 mm. Consequently, this method of digital registration will allow to record deviation from the GMF parameters by approx. 25% higher amplitudes. The existing practice at the GMO has shown that during a geomagnetic storm the registograms of some GMF components come out of the diaphragm limits, i.e. there is no recording.

A basic problem is the identification of the recording traces of the separate components during a geomagnetic storm. This problem is solved here in the following manner. The collimators are not supplied continuously but according to a special cyclogram. In the initial version cyclograms shown in Fig. 4 and Table 5 were used.

As can be seen, in the registration of each GMF component there is an interruption of 50 s, which given the standard registration rate of the magnetic photo recorders *V* = 20 mm/h is expressed as an interruption of the analog registration trace by $\Delta t \approx 0,28$ mm. On the one hand, for such a short time the GMF practically does not change and, on the other, such an interruption on the analog registration is practically unnoticeable. Therefore, we cannot speak of loss of recording or information.

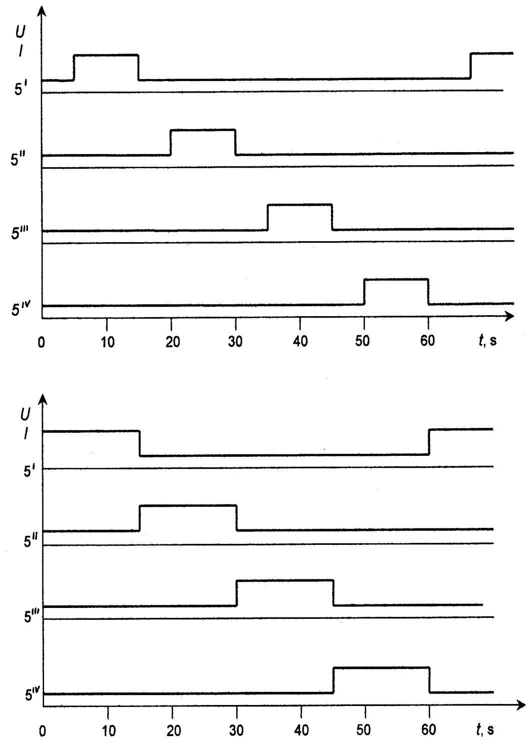

Figure 4.

At present the Panagyurishte GMO obtains data by the standard “mean hourly values”. With implementing the proposed method and equipment for registering the values of the GMF components several times per minute, a transition is made to the modern standard “mean minute values”. For this purpose, a cyclogram is introduced by which 5 values of each GMF component are recorded per minute. The collimators are switched on serially for 2 s with an interval of 1 s, i.e. within 1 minute there is a 10 s registration of each component.

Table 3.1.

Time from to s		Voltage supplied to collimator	Registered component of GMF
5	15	5^{I}	*D*
20	30	5^{II}	*H*
35	45	5^{III}	*Z*
50	60	5^{IV}	*F*

There are no technological problems to increase the number of measurements and registrations per minute, e.g. 1.5 s each without pauses, i.e. 10 measurements of each component per minute. The only limitation for an even higher frequency of measurement is the inertia of the illuminating lamps of the collimators. The experiments showed that it is approx. 1 s. In order to decrease this inertia and provide a more favourable operating mode of the lamps, their voltage is not completely cut off, i.e. the current does not become zero but is only reduced (see Fig. 4).

We believe that after a 2-year parallel analog photo registration and digital registration, and establishing its adequacy, the analog photo recording can stop. Besides, it is possible to decrease the optical arm (the distance between collimators – sensors and sensors – photo recorder by approx. 25 – 30% and even more. The number of photodiode rulers will be reduced accordingly since only one of about 50 – 70 mm length will be enough. In the absence of analog photo registration all light beams accomplishing the digital registration of the separate components *D*, *H*, *Z* and *F* are positioned and focused at the same point on that photodiode ruler, e.g. TSL-218 (Fig. 5). Thus the overall dimensions of the equipment are reduced, expensive photographic materials are saved, labour- and time-consuming manual operations are avoided, the equipment becomes cheaper due to the smaller number of photodiode rules, electric power is saved, the lifetime of the collimator lamps is extended, etc.

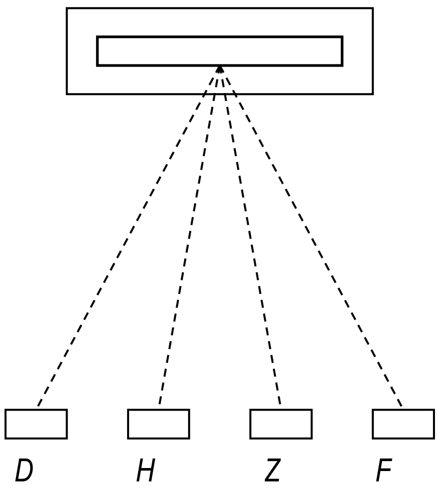

Figure 5.

Being produced by the same sensors, the proposed digital registration is suitable for processing, comparison and interpretation jointly with a long-term analog magnetic registration.

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INVESTIGATIONS ON CLAYS FOR RADIOACTIVE WASTE DISPOSAL

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ABSTRACT

The radioactive wastes (RAW) represent a serious problem for the environment and human health. It is necessary to isolate them from the biosphere in specially constructed repositories, which have to meet special requirements ensuring the safe disposal without the hazard of radiation emissions in the environment.
A great part of the existing or designed RAW repositories in the world are situated on clay terrain. Clays are preferred because of their good isolation properties.
The present report makes a concise summary of foreign experience in the investigations on clays for RAW isolation from environment. The repositories "Centre de l`Aube" (France) and "Mohovtse" (Slovakia) and the underground laboratory "HADES" (Belgium) have been described.
The analysis of this experience will contribute to the investigations on site selection and exploration for a RAW repository in Bulgaria, situated in clays.

INTRODUCTION

Radioactive wastes (RAW) differ from the other types of wastes in their contents of substances emitting ionizing radiation (alpha, beta and gamma rays). This radiation damages living tissues and can be harmful for human health and for the environment. RAW radioactivity diminishes with time but it is necessary to isolate these wastes from the biosphere until its activity is reduced to levels that are not hazardous for human health and environment.

The term of radioactive waste refers to all radioactive materials in the solid, liquid or gaseous state, about which no method for utilization is known or envisaged at the moment and whose level of radioactivity causes inadmissible irradiation in the environment (Commission of the European Communities, 1979).

Radioactive wastes are released during the operation or closing of nuclear power plants, the use of radioactive materials in industry, scientific investigations, medicine, agriculture, etc.

Different criteria are applied for classifying the radioactive wastes: origin, radiological properties, physical properties, chemical properties, biological properties (Safety Series No 111-G-1.1 – Classification of Radioactive Waste, 1994).

Three groups are distinguished according to the degree of RAW activity: very low radioactive (VLLW); low and intermediate radioactive (LILW); high radioactive (HLW) (the spend nuclear fuel refers to this waste too when declared as a waste product). According to the half-live of radionuclides RAW are classified as short-lived (less than 30 years) and long-lived (more than 30 years). According to their physical state RAW are solid, liquid or gaseous.

MANAGEMENT OF RAW

The RAW management includes processing; conditioning; intermediate storage and disposal. All activities related to RAW management are aimed at reaching reasonable admissible minimal level of irradiation of personnel and population, taking under consideration the economic and social factors (the so called "ALARA" principle – "as low as reasonably achievable").

The nine basic principles of RAW management (Safety Series No 111-F - The Principles of Radioactive Waste Management, 1995) are:

1. Protection of human health;
2. Protection of the environment;
3. Protection of people and environment beyond the national borders;
4. Protection of future generations;
5. The problems concerning the wastes should not cause exorbitant troubles for future generations;
6. Development of an effective national legislation structure;
7. Control on the discharged quantities of RAW and adhering to their minimal production;
8. Interrelations between the discharge of RAW and their harmless management;
9. Safety of the equipment intended for RAW management.

DISPOSAL OF RAW

The RAW disposal in specially constructed repositories is an important ingredient part of their long-term management. It provides the possibility of reducing the activities connected with the waste storage, reducing the irradiation doses of the operation personnel and reducing the hazard for the population and the future generations.

There are three types of repositories: surface (built on the surface itself), near-surface (up to 17 m, rarely up to 30 m below the surface) and deep geological repositories (built at a considerable depth).

The envisaged disposal depends on the waste type: VLLW are not disposed; the short-lived LILW are deposited in surface or near-surface repositories; the long-lived LILW and HLW are deposited in deep geological repositories.

The safe operation of the repositories is achieved by ensuring a number of barriers (a multi-barrier principle) restricting the transfer of radioactivity in the biosphere. In this way, the failure of one or more of these barriers will be compensated by the rest of them (Commission of the European Communities, 1979). The barriers are situated in a coaxial manner, i.e. one into another according to the "matrioshkas dolls" principle. Each barrier is made of a different material and resists radiation release in its own specific manner. There are two types of barriers: artificial (engineering) and natural (geological).

In the case of short-lived LILW disposal in surface or near-surface repositories, their protection from human interference and surface or groundwater should be ensured for the time period required for reducing the radioactivity, which is harmless for human health and environment. This protection is usually provided by three basic barriers between the source of radioactivity and the biosphere: a container for RAW; the construction elements of the repository, ensuring the protection of the containers; the particular geological and other natural conditions. The period of institutional control for the LILW repositories is usually between 300 and 1000 years.

In the case of the long-lived LILW and HLW the prevention or impeding of radionuclide transfer is also ensured by barriers. Several engineering barriers are used. The geological barrier is the last one but it is the most important. It is expected to secure the safety of the repository in such a way that even if all engineering barriers are destroyed, conditions should exist, which exclude the possibility of unfavourable effects on the biosphere. The deep geological repositories should isolate RAW in the course of tens, even hundreds of thousands of years.

SELECTION OF SUITABLE REPOSITORY SITE

The selection of a suitable site for a RAW repository is based on considering the geological, hydrogeological and geochemical specific features of the region; the volcanic, tectonic and seismic activity in it; the exo-geodynamic processes; the meteorological and topographic conditions; the anthropogenic activity; the transport of wastes; the land use for agricultural and other purposes; the density of population in the region; the public acceptance, etc.

When selecting a site, the greatest attention is paid to the geological barriers. The most important factors characterising a geological barrier are these, which ensure the biggest obstacle for water movement (a hydrodynamic barrier) and/or for the transfer of leached substances from the wastes (a geochemical barrier). The hydrodynamic barrier is provided by very low permeability, a very low hydraulic gradient and low water content in the host rock. The sorption properties of rocks are most important for the geochemical barrier.

Various rocks have been investigated as a host medium for RAW disposal – clays, salt, granites, marls, basalts, andesites and others, which meet the above mentioned requirements to one degree or another (Witherspoon, 1996; Witherspoon and Bodvarsson, 2001).

Clays are preferred as a host medium for RAW disposal because of their low water permeability, high sorption capacity and the ability of "sealing" the formed cracks. They have been investigated as the soil base or host medium of repositories; as anti-filtration screens; as materials for constructing the cover of surface repositories; for creating artificial barriers in the repositories themselves, etc.

In connection with RAW disposal the clays are subjected to different investigations: lithological-stratigraphic, mineralogical, petrographic, hydrogeological, radiochemical, engineering geological, soil mechanical, etc.

Mineral composition and sorption properties of clays

Clays consist of clayey minerals, non-clayey minerals (quartz, calcite, feldspar and others), organic substances and water-soluble salts.

The physical, physico-chemical (including sorption), mechanical and filtration properties of clayey sediments depend to a great extent on the content of the fraction with d < 0.005 mm. This fraction can consist of one clayey mineral but most often it represents a mixture of several minerals. The clayey minerals represent hydrated alumina silicates with stratified or stratified band-like structure, being to a smaller or greater extent final products of rock weathering. This circumstance is taken into account from the viewpoint of the soil medium stability against radionuclide migration.

With respect to bonds between the structural layers and their mobility, the following clayey minerals are distinguished: with stable, mobile and intermediate crystal lattice. Pursuant to the generally accepted models, the structure of the greater part of the clayey minerals consists of two major structural units – a silica tetrahedron and an alumina octahedron (Grim, 1969). Sometimes the silicon atoms in the tetrahedrons and the aluminium atoms in the octahedrons are replaced by atoms of lower valency. Deficiency of positive charges occurs in the crystal lattice due to such replacements, which affects the important for RAW disposal physico-chemical properties of clays as sorption, plasticity, viscosity, etc.

The basic clay minerals are classified in several groups: smectite minerals (montmorillonite being the most widespread one), illite minerals, the group of clayey minerals with a mixed layered structure and kaolinite minerals.

The group of the smectite minerals offers the most favourable conditions with respect to the isolation qualities. They represent the final product of the weathering processes and under all other equal conditions provide evidence that these processes have lasted for a long time. These minerals possess a mobile crystal lattice with large internal surface reaching up to 700-800 m^2/g and a high sorption capacity of some of the varieties – up to 80-150 meq/100 g. They are also highly plastic and are used most often for the preparation of isolation composites intended for the internal spaces of RAW repositories. The minerals of the illite group possess lower internal surface of 65-100 m^2/g and a sorption capacity within the range of 10 to 40 meq/100 g. The mixed-layered minerals are similar to these of the illite group. The minerals of the kaolinite group are least interesting in the considered aspect, their internal surface being 10-20 m^2/g and their sorption capacity – 3-15 meq/100 g.

FOREIGN EXPERIENCE IN INVESTIGATIONS FOR RAW REPOSITORIES

The management of RAW, including the process of site selection for their disposal, has reached a different level in the countries with developed nuclear power generation. The problem with short-lived RAW disposal has been practically solved in some countries, where greater attention is paid to the long-lived RAW disposal. The process of licensing of sites and repositories is in progress in other countries, while investigations on prospective sites are carried out in third countries.

The state of the repository problem towards the end of the 90ies was the following: 17 sites had been selected for new LILW repositories, some of them being licensed and already under construction, more than 25 sites in 17 countries were investigated.

About 62 % of the LMRAW repositories built so far are engineered near-surface ones (about 10 m below the Earth surface), 18 % are simplified near-surface repositories, 7 % are situated in mine cavities and 4 % represent deep geological repositories (Han et al., 1995).

A great number of near-surface repositories are functioning in the countries with developed nuclear power generation. About 1.3 million m^3 of waste had been deposited in them till 1990, the predominating wastes being with a low period of radionuclide half-live, so that their radioactivity will be diminished within several hundred years to harmless levels.

There are no generally valid criteria in world practice for repository site selection as well as a generally accepted structure and type of repository. This problem is solved in each particular country depending on its natural and social-economic conditions, taking into account the requirements of the International Atomic Energy Agency (IAEA).

With respect to the repository type for final disposal of short-lived LILW, most of the countries (France, the USA, Great Britain, Spain and others) give preference to the structures of the close-to-the-surface type. There are few countries, where these wastes are disposed at a greater depth (Sweden and Finland). The deep geological disposal is preferred in Switzerland and Germany not only for long-lived but also for short-lived radioactive wastes.

A significant part of the world existing or designed RAW repositories are situated on clayey terrain. Investigations on clays in connection with RAW disposal are carried out in Belgium, France, Spain, Switzerland, Argentina, Armenia, Belarus, Chroatia, China, Lithuania, the Netherlands, Slovakia, Slovenia, South Africa and elsewhere (Witherspoon, 1996; Witherspoon and Bovarsson, 2001). Sediments of different age – Mesozoic, Tertiary and Quaternary, have been considered.

The present report analyzes briefly the experience in the research on clays for RAW disposal in three countries – Belgium, France and Slovakia, which might be useful for the exploration of sites intended for a RAW repository in clays in Bulgaria.

The underground research laboratories (URL) mark an extreme progress in the development of research on deep geological disposal of long-lived RAW. They ensure the performing of experiments *in situ* at the depth intended for the waste isolation.

The URL number has been significantly increased during the last years. Only 5 countries had well-developed laboratories in 1996. The number of the countries using URL or being at different stages of planning or development of their laboratories was already 13 towards the end of 2001. Japan and Switzerland develop 2 laboratories each within two different rock types, which provides the possibility of parallel development of the investigations. The first URL in France is being built in argillites and a second one is planned in granites.

URL provide extremely favourable opportunities for the development of international cooperation in the field of RAW disposal. Switzerland can be mentioned as an example in this respect. Nagra and other 17 organizations from 9 countries are involved in the investigations on granites for the construction of URL in Grimsel Test Site (GTS). It is envisaged to continue the cooperation after the completion of the project. In this way GTS will become an international centre for studies on granites as a RAW isolation medium. Nagra also participates together with other partner organizations in the development of the second site, envisaged for URL construction in Mont Terri in Jura Mountains. The initial 7-year long phase of the research on clays (Opalinus Clay) is carried out there.

Another eloquent example for an international cooperation is the Spanish organization ENRESA. It participates in 3 different projects in URL in Sweden (in Äspö), in a number of projects in the two laboratories in Switzerland (Grimsel Test Site and Mont Terri), in projects in the Belgian UIL in Mol Site as well as in the laboratory "Meuse/Haute-Marne" in France.
A high interest has been expressed in clays and granites when rocks are selected as a host medium for URL construction in Europe (Witherspoon and Bovarsson, 2001).

Underground research laboratory "HADES" in Mol Site–Belgium

One of the most advanced in clay investigation URLs is HADES in Belgium, which is functioning for already more than 20 years. It is situated near to the town of Mol Site in Tetriary clays (Boom Clay), the layer being embedded at a depth of 180 ÷ 270 m. HADES is built at a depth of 222 m and has a total length of 39 m and an internal diameter of 3.5 m. The investigations carried out in the laboratory are in different directions: material testing; nuclear technologies;

geosphere transport; safety assessment; geotechnical studies.

The testing of materials consists in investigating the qualities of different materials for RAW conditioning (glass, concrete, bitumen, etc.) or for producing containers for the conditioned wastes (stainless steel, carbon steel and noble alloys). The typical *in situ* experiments study the behaviour of clay in direct contact with material samples. The tests are carried out under different temperature, different gas medium (oxygen, inert gas, etc.) and after different processing of the samples of the tested materials. The experiments show the corrosion of metals and the filtration of clays. At the same time the necessary laboratory tests are carried out too.

The emphasis is laid on the behaviour of the host rock, the structure of the materials for containers and of the conditioned materials under irradiation conditions. A typical experiment is the so-called "radiation-thermal test", when conditions are created that are equivalent to the expected ones after the RAW disposal. Several experiments are carried out in the radiation and thermal field concerning the corrosion, filtration, migration, radiation effects, geochemistry and geomechanics.

The action of the geosphere barriers is considered at the first place according to the nulti-barrier principle of RAW disposal. Regional and local studies, modelling and laboratory experiments are carried out for establishing the barrier qualities.

The regional hydrogeological observation network covering 2 500 km^2 and operating in the course of more than 10 years allows the mapping of the groundwater system in the territory surrounding Mol Site.

The local hydrogeological conditions are investigated in detail by means of a network of piezometers installed in the clayey host rock. The data obtained from them are used in the experimental models for the precise determination of different parameters, as hydraulic gradients and permeability. Other very important characteristics are the sorption properties of the different geological layers and the delay in radionuclide transfer. The data from the investigations are used in migration models.

Various detailed analyses are made for the safety evaluation.

The geotechnical studies are related with the design, construction and operation of the underground engineering structures in the deeply embedded clays (Boom Clay).

The present state of the problem in Bulgaria leads to the higher interest in the experience of the countries, where surface LILW repositories have been constructed in disperse and mainly in clayey soils. Further on, the description of two of them, situated in France and Slovakia, will be made.

LILW repository “Centre de l`Aube” – France

After closing the repository “Centre de la Manche”, a new repository was built in France on the land of several volunteer municipalities in the northeastern part of the country at a distance of 180 km form Paris. The repository site was studied during the 80ies, using a complete set of exploration methods recommended by IAEA. The volume of the exploration works was extremely big, since the repository fell within the eastern part of the important for France Paris hydrogeological basin. Only in the period 1984-1986, 560 boreholes, including deep boreholes, were drilled.

The soil base of the repository is built of alternating clayey and sandy Lower Cretaceous sediments. The foundation was performed in a relatively thin layer of aquifer sands, situated on top of 30-m thick clays. It has been proved that these clays represent a reliable protection against pollution of the numerous more deeply situated aquifers, used for water supply. In the particular case the upper Albian-Aptian aquifer horizon is the most important one. Its hydrogeological parameters have been studied by means of 500 piezometers, 150 water pumpings and other tests and analyses. The following parameters have been established - zones of feeding and draining, direction of water movement, filtration coefficient, resources, level-transfer coefficient, dispersion characteristics and other parameters, necessary for the prediction of radionuclide migration. A significant volume of geotechnical explorations has been carried out. They comprise a considerable depth of the soil base (more than 100 m) because the big sizes of the loaded area and its considerable loading of 300 kN/m^2 (30 t/m^2).

The geological structure of the uppermost part of the soil base is not complicated. The groundwater in the sands (their level is situated several meters under the repository) is drained in the small river flowing in the vicinity. It is assumed that these hydrogeological circumstances facilitate both the prediction of radionuclide migration and the environmental monitoring.

The performed investigations have shown that there is no hazard that exogenic risk processes (landslides, surface erosion, etc.) could occur in the course of the 300-year period of the repository existence. Its region falls within the so-called Ardennes block, where no active faults have been established and the seismic conditions are favourable. The closest earthquake foci are situated at a distance of 60 km to the southeast. On the basis of data for historic and instrumentally measured earthquakes, it has been predicted that the occurrence of one earthquake with intensity of VI degree is probable for a period of 300 years.

The repository “Centre de l`Aube” is situated in a woody area and occupies about 95 ha, 30 ha being the RAW storage areas themselves. The capacity is 1 million cubic meters of conditioned short-lived wastes. This volume will be filled for 30 years. All the expenses for exploration, design and construction of the repository amount to about USD 250 million.

The repository is of the surface type and consists of concrete cells (sizes 21x24 m and a volume of 2200 m^3), in which the barrels with cemented LILW have been placed. The space between the barrels has been filled with concrete mixture or gravel. After filling up, the cell is sealed by polyurethane concrete slab, ensuring the water tightness of the roof. In consequence the space between the cells is filled up with clay. The final cover of the whole repository consists of a clayey layer, a bitumen membrane, a draining layer and a soil layer with herbaceous species.

Galleries have been built under the foundation slab in order to control the eventual transfer of radionuclides in groundwater. They are an effective draining system, which does not allow the rising of groundwater table and the access of lateral water. Water pipes pass through the draining galleries, which discharge rainwater from the repository site into a control collecting pool.

Except for the storage cells, the repository has on its disposal administrative, production and control buildings and equipment.

LILW repository "Mohovtse" - Slovakia

The Slovakian repository is of the same type as the French repository "Centre de l`Aube". It was built between 1986 and 1992 on an area of 11.2 ha and consists of 80 concrete cells, situated in two rows. The volume of each cell is 510 m^3. The total volume of the concrete containers for the 22 000 m^3 of conditioned wastes is 7200 m^3. During the last years the repository was reconstructed and a drainage system was made, which is of the same type and destination as that in the repository of l'Ob.

The soil base is built of Quaternary alluvial and deluvial clays with a thickness from several meters to up to 10 m, situated on top of heterogeneous Neogene sediments of the Panonian basin. The latter contain several aquifer horizons, which are in hydraulic connection between themselves. The upper one is in the sands embedded immediately under the Quaternary clays. Similarly to the French repository, the groundwater table is only several meters under the surface, but an appropriate draining system has been built for preventing the rising of groundwater level and avoiding the contact between the groundwater and the stored wastes.

RAW DISPOSAL IN BULGARIA

The East European countries (including Bulgaria) express their orientation to surface radioactive waste disposal. The greater part of the repositories were built during the 60ies.

Since 1964 a surface LILW repository has been under operation in the country. It is located at a distance of 6 km from Novi Han in the Lozen Mountain. The repository site is situated in thin-layered semi-crystalline clayey and quartz-serritic phyllites (Evstatiev and Kozhukharov, 2001). The surface layer has a thickness of 5-7 m and consists mainly of clayey-sandy fraction. No emergencies and accidents have been recorded during the 35 years of the repository operation that could have led to irradiation of the staff or threats for the health and life of the population.

As already mentioned, there are no generally valid criteria for site selection as well as for a generally accepted repository type and structure in the world practice. This problem is solved in each country depending on its own legislation and its particular geological and social-economic conditions. However, some general requirements exist, as the maximal guarantees for the health of future generations. In the case of LILW the required geological guarantee is 300 years. Another requirement is that the wastes should be stored in a cemented or processed in another appropriate state. The requirements are especially stringent with respect to the safety against groundwater pollution, since groundwater is the main transferring agent to the nutrition chain of man. The basic criteria applied till now in the country for the investigations on repository site selection have been in conformity with the requirements in the more developed countries and reflect the international experience in this aspect. Recently, special attention is paid to the social-economic criteria and especially to the opinion and perception of local population concerning the repository, without which even the performance of any serious explorations is not to be recommended.

About twenty sites have been preliminary allocated as prospective for low and intermediate radioactive waste repositories on Bulgarian territory. They are situated mainly in Northwest and Southeast Bulgaria. The more prospective of them are the areas in Northwest Bulgaria. These are the marl terrains in the Fore Balkan, the loess terrains, the Quaternary clays, the Pliocene clays in the vicinity of the Kozloduy town (Evstatiev and Kozhukharov, 2001).

Investigations on loess around the town of Kozloduy have been carried out during the last years in connection with surface LILW repository site selection, which have proved its suitability for this purpose (Antonov, 2001; Evstatiev et al, 1998).

Investigations have been started in the Geological Institute of the Bulgarian academy of Sciences on the Pliocene clays around the town of Kozloduy. *In situ* tests, borehole, laboratory and other studies have been carried out to determine the qualities of these clays for the construction of a repository for LILW disposal.

CONCLUSIONS

The analysis of the foreign experience proves that clays represent preferred medium for both close-to-the-surface and deep RAW disposal. Considerable experience has been accumulated in the study of the geochemical, radiochemical, geotechnical and other properties of clays, which are relevant to the understanding and elucidation of their insulation qualities for RAW disposal. The results from the tests in the underground investigation laboratories (URL), where the experiments are carried under real conditions, are especially useful. The analysis of the foreign experience, which has been the task of the present report, will contribute to the investigations of clays intended for short-lived LILW disposal in Bulgaria. This research has been started in the last two years and will be continued until all aspects relevant to the protection of environment against radionuclide migration are elucidated. The establishment of multilateral international cooperation would be especially useful since it could accelerate and facilitate the investigations in Bulgaria and increase the confidence in them. All data obtained so far represent the clays in a very positive light as a reliable medium for RAW disposal.

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DENSITY AND POLARIZABILITY COEFFICIENT OF THE RHYOLITES IN THE RHODOPE MASSIF

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ABSTRACT
The rhyolite formation in the Rhodope massif is presented by Tertiary extrusive and effusive lava in the Western and Central Rhodopes.
Data from measurements performed by the Department of Applied Geophysics, University of Mining and Geology, Sofia and other organizations are summarized. The values for the density and the polarizability coefficient are studied on samples from different areas of the Rodope massif – the Bratsigovo-Dospat depression, the Dospat anticline, the Southern Rhodope syncline, the Northern Rhodope syncline, the Smolyan depression and other more local structures as the Kovachevo syncline, the Batak syncline, the Vacha uplift, the Lyaskovo uplift and the Hvoina graben-syncline.
Statistical analysis is applied for estimating the characteristics of sample packs from one and the same region, as well as for estimating the characteristics of the total set of available data. The surface distribution of the analyzed parameters is also studied.
The compound analysis of the values for the density and the polarizability coefficient of the rhyolites in the Western and Central Rhodopes is proving that the detailed mapping according to these characteristics can efficiently enrich the information obtained by the traditional geological mapping.

INTRODUCTION

The rhyolite formation in the Rhodope massif is presented by Tertiary extrusive and effusive lava in the Western and Central Rhodopes and is most completely studied in the Bratsigovo-Dospat structure (Bahneva *et al.* 1978 ; Bojkov *et al.* 1978). It is composed by biotite and amphibole-containing rhyolites up to rhyodacites. In the northern part of the Bratsigovo-Dospat volcanogenic structure they form one elongated in subequatorial direction zone (Bahneva *et al.* 1978). In the rhyolite zone can be isolated several elementary volcano-structures. The authors state that each of these structures is built by several close in age, in structural-morphologic peculiarities and in magnetic characteristics extrusives, as well as by the connected to them effusive lava flows.

I.Bojkov *et al.* (1978) confirm that in the Bratsigovo-Dospat depression the rhyolite covers have frequent occurrence and are characterized by a well-expressed almost horizontal surface parallelism – angle of dip of about 12^o. Extrusive rhyolite bodies intersecting the rhyolite covers are located in the western part of the depression. These extrusive bodies are normally determining the contrast in the relief.

The presented study is based upon data from measurements performed by the Department of Applied Geophysics, University of Mining and Geology, Sofia and other organizations. The values for the density and the polarizability coefficient are studied on samples from different areas of the Rodope massif – the Bratsigovo-Dospat depression, the Dospat anticline, the Southern Rhodope syncline, the Northern Rhodope syncline, the Smolyan depression and other more local structures as the Kovachevo syncline, the Batak syncline, the Vacha uplift, the Lyaskovo uplift and the Hvoina graben-syncline.

The values for the density and the polarizability coefficient are studied according to data from laboratory measurements on rock samples of outcrop and drill core. Statistical analysis is applied for estimating the characteristics of sample packs from one and the same region, as well as for estimating the characteristics of the total set of available data.

DENSITY CHARACTERISTICS OF THE RHYOLITES IN THE RHODOPE MASSIF

The measured on rock samples of outcrop or drill core 973 values for the density vary in a wide range.

In Table 1 are systematized the main statistical characteristics of the values distribution for the density and in figures from 1 to 6 are illustrated the histograms of the parameter distribution for the different regions and for the total set the studied samples.

The compound analysis of the histograms elaborated for the different regions is showing that one main group is well pronounced in the density distribution. This group is including samples having density within the limits of 2,30-2,50 g/cm^3. A second group is also well pronounced. It contains a considerably smaller number of samples (6-14% of the total set). These samples are having relatively low values for the density - within the limits of 2,05-2,30 g/cm^3. The second group is including samples affected by hydrothermal metamorphism. This group is causing the negative values for the skewness of the density distribution for the samples from the Western Rhodope block, the Bratsigovo-Dospat depression, the Dospat anticline and the Smolyan depression, as well as for the total set of samples. Another group is well pronounced for the samples from the Southern Rhodope syncline. It contains about 20% of the samples and is characterized by relatively high values for the density - within the limits of 2,50-2,68 g/cm^3. This group is causing the positive value for the skewness of the density distribution. In the other regions relatively high values for the density are measured only for separate samples.

The density distribution for the total set of samples is characterized by an average value of 2,38 g/cm³, a standard deviation of 0,092 g/cm³, and a wide range of parameter changes – from 2,04 g/cm³ up to 2,68 g/cm³.

Table 1. Main statistical characteristics of the density ρ [g/cm³] of the rhyolites in the Rhodope massif

Region	Count	ρ^{min} / ρ^{max}	Average value	Standard deviation	Skewness	Kurtosis
Western Rhodope Block	174	2,17 / 2,48	2.35	0,072	-2,092	0,008
Bratsigovo-Dospat Depression	416	2,13 / 2,57	2,39	0,074	-6,12	6,6
Dospat Anticline	92	2,04 / 2,64	2,34	0,12	-2,24	2,3
Southern Rhodope Syncline	106	2,15 / 2,68	2,40	0,12	1,23	-0,29
Northern Rhodope Syncline	48	2,23 / 2,53	2,36	0,093	0,83	0,75
Smolyan Structural Depression	79	2,28 / 2,64	2,45	0,071	-1,01	2,11
Total	973	2,04 / 2,68	2,38	0,092	-4,94	7,67

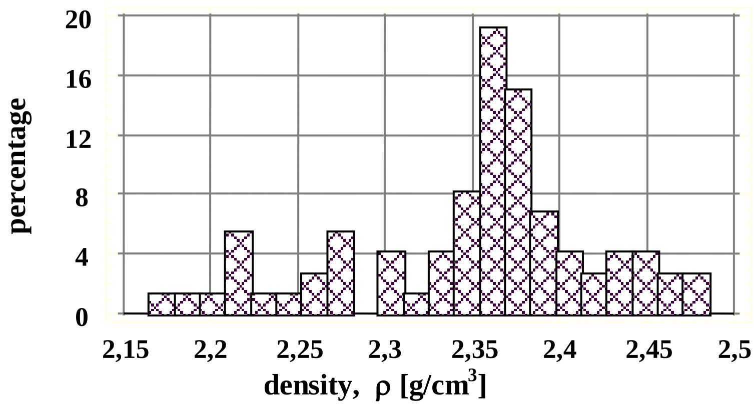

Figure 1. Histogram of the density distribution of the rhyolites in the Western Rhodope block

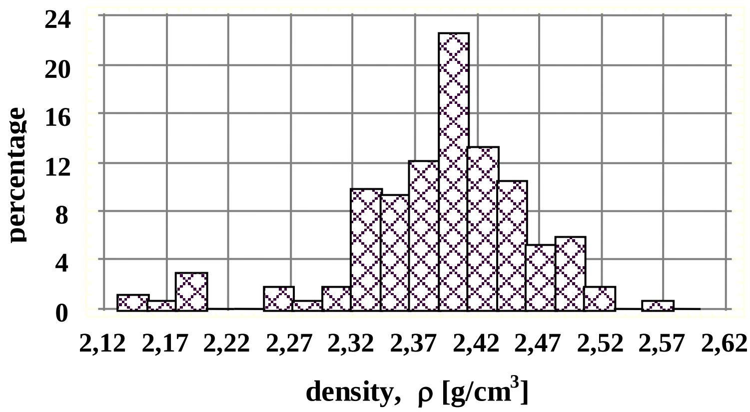

Figure 2. Histogram of the density distribution of the rhyolites in the Bratsigovo-Dospat depression

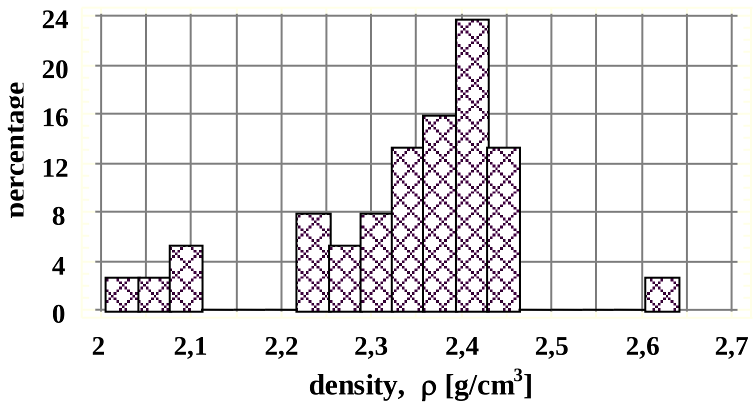

Figure 3. Histogram of the density distribution of the rhyolites in the Dospat anticline

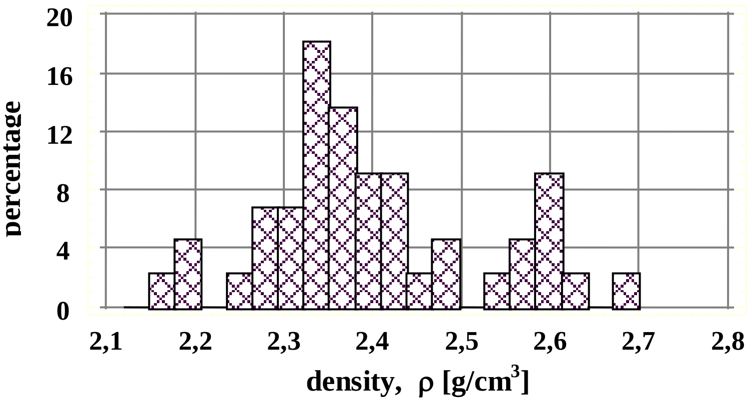

Figure 4. Histogram of the density distribution of the rhyolites in the Southern Rhodope syncline

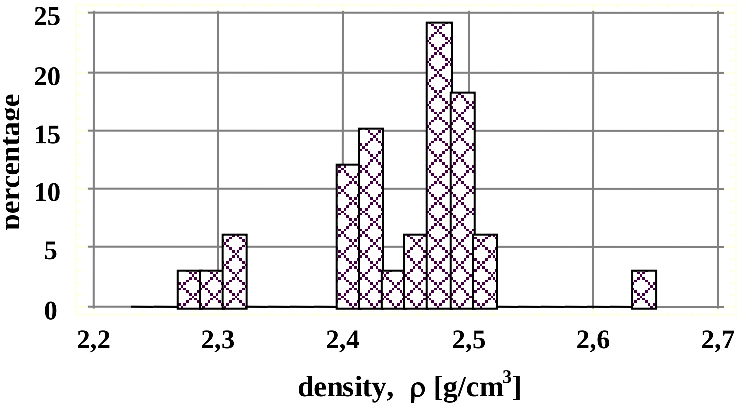

Figure 5. Histogram of the density distribution of the rhyolites in the Smolyan structural depression

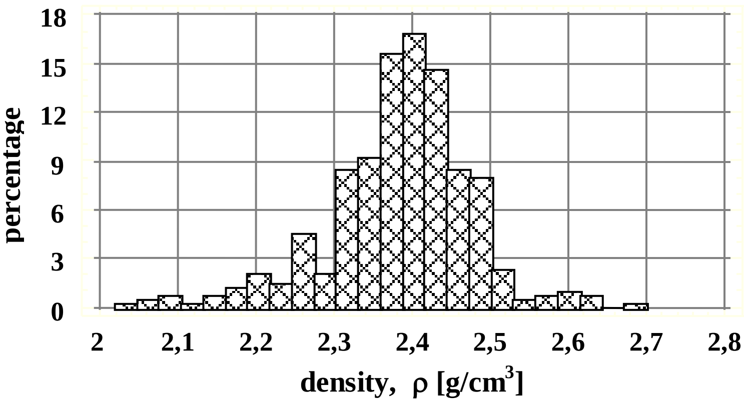

Figure 6. Histogram of the density distribution for the total set of rhyolite samples from the Rhodope massif

Different cluster analysis methods have been tried. The best results were obtained using the Ward's method, City-Block distance metric and classifying the data into 4 subgroups. The first one is including the samples affected highly by the hydrothermal changes. The second and third subgroups are containing about 76% of the total set of samples. The forth subgroup is characterized by relatively high density.

In Table 2 are presented the average values for the density of the separated subgroups and in Fig.7 is illustrated the dendrogram of the performed grouping.

Table 2. Average values for the density of the separated four subgroups after applying cluster analysis using the Ward's method, City-Block distance metric

Subgroup number	Samples		Average values for the density, ρ [g/cm³]
	Count	%	
1	68	7	2,16
2	350	36	2,33
3	389	40	2,41
4	166	17	2,51

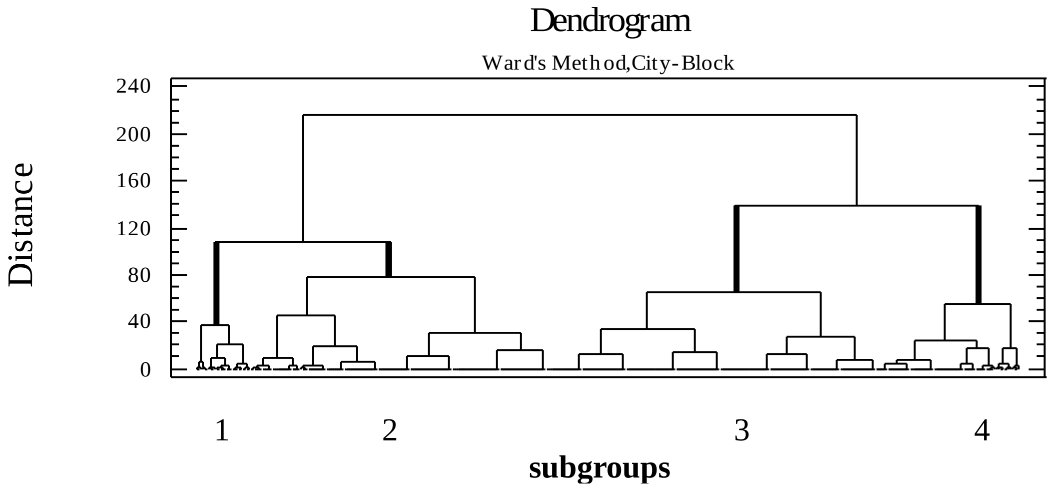

Figure 7. Dendogram of the performed grouping according to the density of the rhyolite samples from the Rhodope massif (four subgroups classified)

The surface distribution of the density of the rhyolites in the Western and Central Rhodopes region is presented in Fig.8. The Bratsigovo-Dospat depression is generally characterized by decreased values for the density. The Southern Rhodope syncline and the Smolyan structural depression are characterized by increased parameter values. The presented rose-diagram is showing no predominant direction of the isolines orientation.

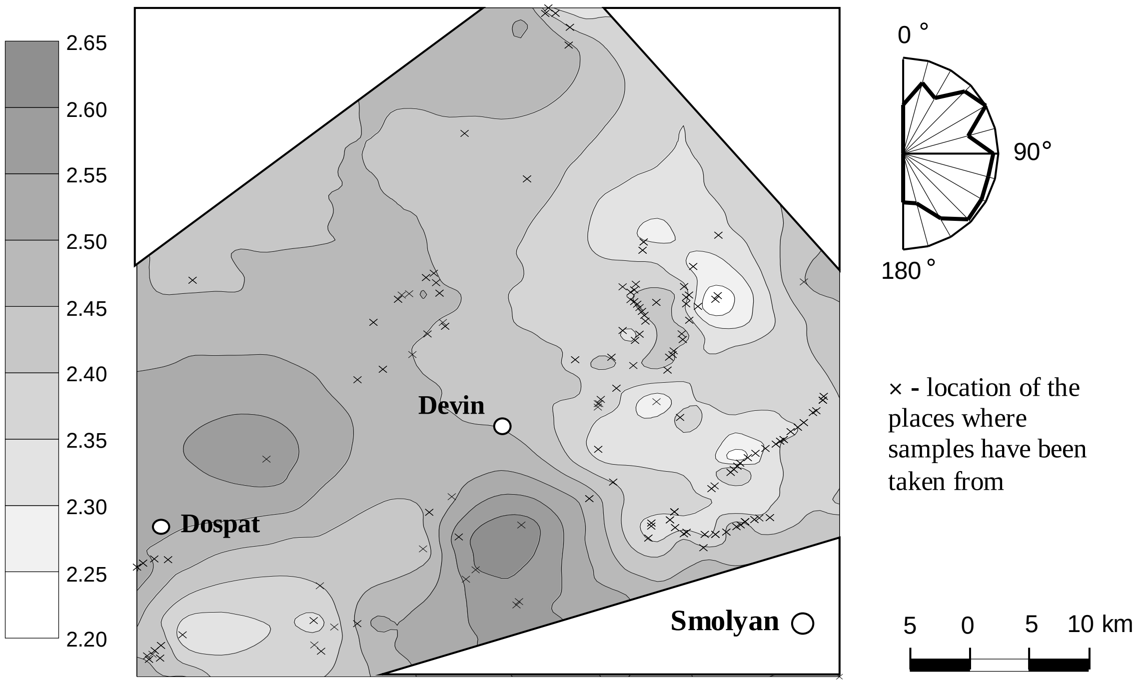

Figure 8. Scheme of the density surface distribution of the rhyolites in the Western and Central Rhodopes region and a rose-diagram of the isolines orientation.
The zoning is performed in g/cm³

POLARIZABILITY COEFFICIENT OF THE RHYOLITES IN THE RHODOPE MASSIF

The measured on rock samples of outcrop or drill core 423 values for the polarizability coefficient vary in a wide range – from 0,22 up to 6,51% with an average value of 1,51%. In Fig.9 is illustrated the histograms of the parameter distribution for the main set of rhyolite samples – excluded are only about 2% of the samples characterized by relatively high polarizability coefficient (η >4,5%). The well-pronounced positive value for the skewness of the parameter distribution is connected to the presence of samples taken from the periphery of ore-bearing zones.

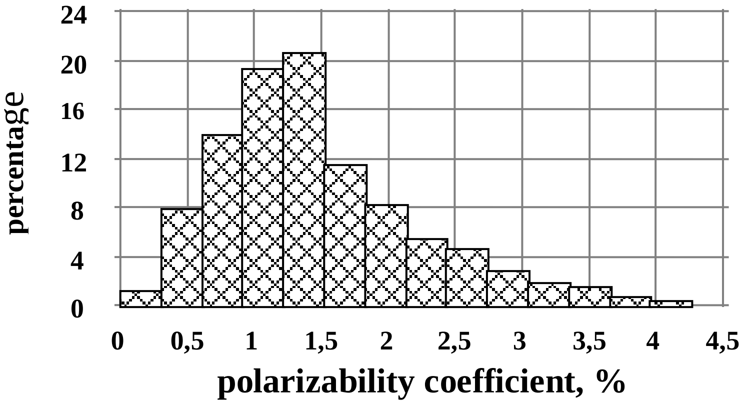

Figure 9. Histogram of the polarizability coefficient for the main set of rhyolite samples from the Rhodope massif

Summary statistics of the total set :
Count = 423; Min / Max = 0,22 / 6,51 %;
Average = 1,51 %;
Standard deviation = 0,85 %;
Skewness = 12,4; Kurtosis = 22.1

Different cluster analysis methods have been tried. The best results were obtained using the Ward's method, City-Block distance metric and classifying the data into 4 subgroups. In Table 3 are presented the average values for the polarizability coefficient of the separated subgroups and in Fig.10 is illustrated the dendrogram of the performed grouping. Very well pronounced is the first subgroup including about 39% of the samples characterized by an average value for the polarizability coefficient of 0,81%. The second and third subgroups are composed on the next level of grouping. They have average parameter values 1,40 and 1,96% respectively and comprise about half of the samples (48%). The forth subgroup has an average value for the polarizability coefficient of 3,14% and is containing about 13% of the total set of samples. It includes samples taken from the periphery of ore-bearing zones. These are the rhyolite samples causing the well-pronounced positive asymmetry of the presented in Fig.9 histogram.

Table 3. Average values for the polarizability coefficient of the separated four subgroups after applying cluster analysis using the Ward's method, City-Block distance metric.

Subgroup number	Samples		Average values for the polarizability coefficient, %
	Брой	%	
1	165	39	0,81
2	114	27	1,40
3	89	21	1,95
4	55	13	3,17

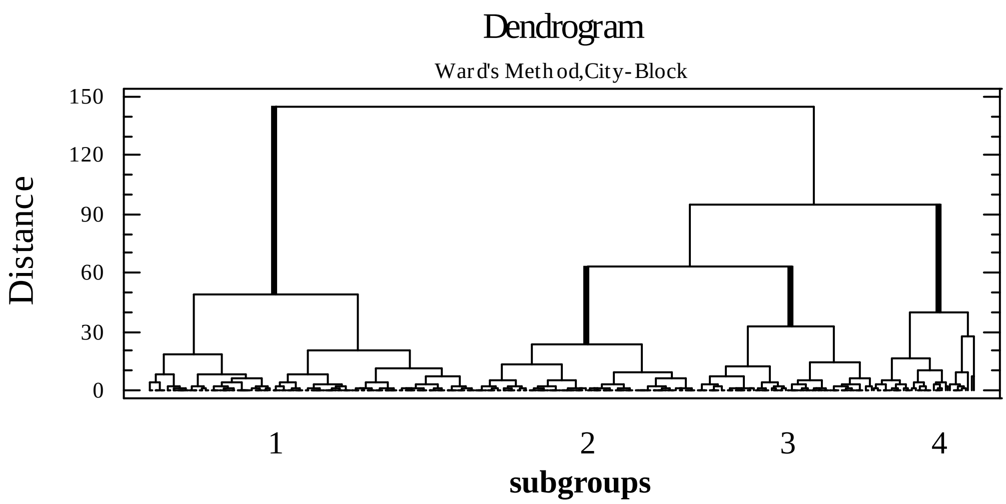

Figure 10. Dendogram of the performed grouping according to the polarizability coefficient of the rhyolite samples from the Rhodope massif (four subgroups classified)

CONCLUSIONS

- The density of the rhyolites in the Rhodope massif varies in a wide range - from 2,05 up to about 2,50 g/cm³. One main group is well pronounced in the density distribution. This group is including samples having density within the limits of 2,30-2,50 g/cm³. A second group is also well pronounced. It contains a considerably smaller number of samples (6-14% of the total set). These samples are having relatively low values for the density - within the limits of 2,05-2,30 g/cm³. The second group is including samples affected by hydrothermal metamorphism. This group is causing the negative values for the skewness of the density distribution for the samples from the Western Rhodope block, the Bratsigovo-Dospat depression, the Dospat anticline and the Smolyan depression, as well as for the total set of samples.
- On the scheme of the surface distribution of the density of the rhyolites in the Western and Central Rhodopes region the Bratsigovo-Dospat depression is mapped by decreased values for the density and the Southern Rhodope syncline and the Smolyan structural depression are located by increased parameter values.
- The polarizability coefficient varies in a wide range – from 0,22 up to 6,51% with an average value of 1,51%. The well-pronounced positive asymmetry in the parameter distribution is connected to the presence of samples taken from the periphery of ore-bearing zones.
- The performed study of the density and the polarizability coefficient of the rhyolites in the Western and Central Rhodopes is enriching the possibilities for effective analysis of geophysical data and more precisely - for interpretation of gravity anomalies and results from the induced polarization method.

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QUANTITATIVE INTERPRETATION OF THE HORIZONTAL GRAVITY GRADIENT FOR SEMI-INFINITE HORIZONTAL SLAB STRUCTURES ACCORDING TO DATA FROM STATISTICAL ANALYSIS

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ABSTRACT

The applied method for quantitative interpretation of the gravitational field caused by semi-infinite horizontal slab structures is based on the horizontal gradient U_{xz} distribution on different levels.

Representative characteristics are chosen, that can be obtained without ambiguity from the data after analysis of the measured gravitational field – the maximum value of the horizontal gradient U_{xz}^{max}, the anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ and the widths of the two branches of the horizontal gradient distribution - $\Delta X_{1/2}^{-}$ and $\Delta X_{1/2}^{+}$.

Subject of the study is the relationship between these characteristics and the main parameters of a semi-infinite edged horizontal slab – the depth h_1 to the slab structure, the thickness of the slab Δh ($\Delta h = h_2 - h_1$) and the angle of the edge α. On the base of statistical studies for a wide range of different model parameters are obtained correlation ties suitable for the aims of the quantitative interpretation.

INTRODUCTION

The semi-infinite edged horizontal slab is one of the most common cases of contact between rocks having different density (W. Telford *et al.*, 1990; Gravity surveying, 1990). In this geometrical model the anomaly forming mass is confined by two horizontal and one dipping planes. In fig.1 is illustrated the traditional 2-D model of a semi-infinite edged horizontal slab, as well as the notation of its basic parameters. The gravitational effect U_z of the edged slab is presented by the following analytical expression:

$$U_z = 2G\Delta\rho \left| h\left(\frac{\pi}{2} + \text{arctg}\frac{h.\text{ctg}\alpha + x}{h}\right) + x.\sin\alpha\left\{\frac{1}{2}\sin\alpha.\ln\frac{1}{\sin^2\alpha}\left[(h + x.\sin\alpha.\cos\alpha)^2 + x^2.\sin^4\alpha\right] - \cos\alpha.\text{arctg}\frac{h + x.\sin\alpha.\cos\alpha}{x.\sin^2\alpha}\right\}\right|_{h_1}^{h_2}$$

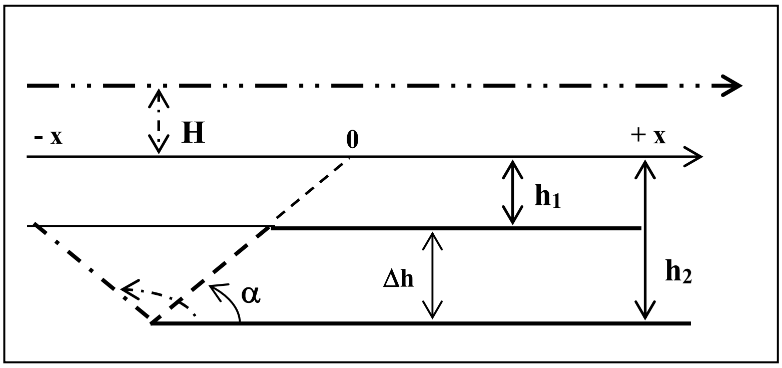

Figure 1. A 2-D model of a semi-infinite edged horizontal slab and notation of its basic parameters

Due to the quite complex expression there are no analytical methods for solving the reverse gravity problem. For that reason a detailed statistical analysis was performed over a wide range of different models solutions not only for the gravitational field, but also for its horizontal U_{xz} and vertical U_{zz} gradients. The aim of the studies is to obtain results for the geometrical parameters of the slab structure after excluding the influence of the density distribution. The analysis of a big volume of statistical data shows that it is most suitable to apply the distribution characteristics of the horizontal gradient U_{xz} on two levels – basic one and upward continuation on height H.

MAIN RESULTS FROM THE STATISTICAL STUDIES

After many statistical studies are selected representative characteristics that can be obtained without ambiguity from the data after analysis of the measured gravitational field – the maximum values of the horizontal gradient on the basic level $U_{xz}^{max,b}$ and on the upward continuation on level H - $U_{xz}^{max,H}$, as well as the difference ΔU_{xz}^{max} between these values; the anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ and the widths of the two branches of the horizontal gradient distribution - $\Delta X_{1/2}^{-}$ and $\Delta X_{1/2}^{+}$ (fig.2).

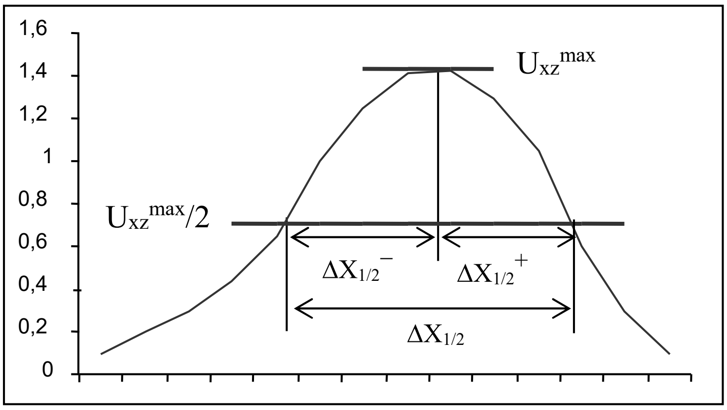

Figure 2. Notation of the parameters utilized in the quantitative interpretation of the horizontal gravity gradient for semi-infinite horizontal slab structures

Subject of the study is the relationship between these characteristics and the main parameters of a semi-infinite edged horizontal slab – the depth h_1 to the slab structure, the thickness of the slab Δh ($\Delta h=h_2-h_1$) and the angle of the edge α (fig.1). All parameters having dimension length are presented in the utilized scale (metres or kilometres).

The analysis of some of the obtained main statistical relations is of definite methodical and practical interest. In all presented cases is applied upward continuation on level H=1 toward the basic level.

In fig.3 is presented the ratio $U_{xz}^{max}{}_{,b}/U_{z,b}$ as function of the depth h_1 towards the slab structure (a) and as function of the slab thickness Δh (b) respectively. The illustrated relations are showing that the ratio $U_{xz}^{max}{}_{,b}/U_{z,b}$ differentiates reasonably well the depth h_1 down to about 4 for slab structures having thickness Δh up to about 5.

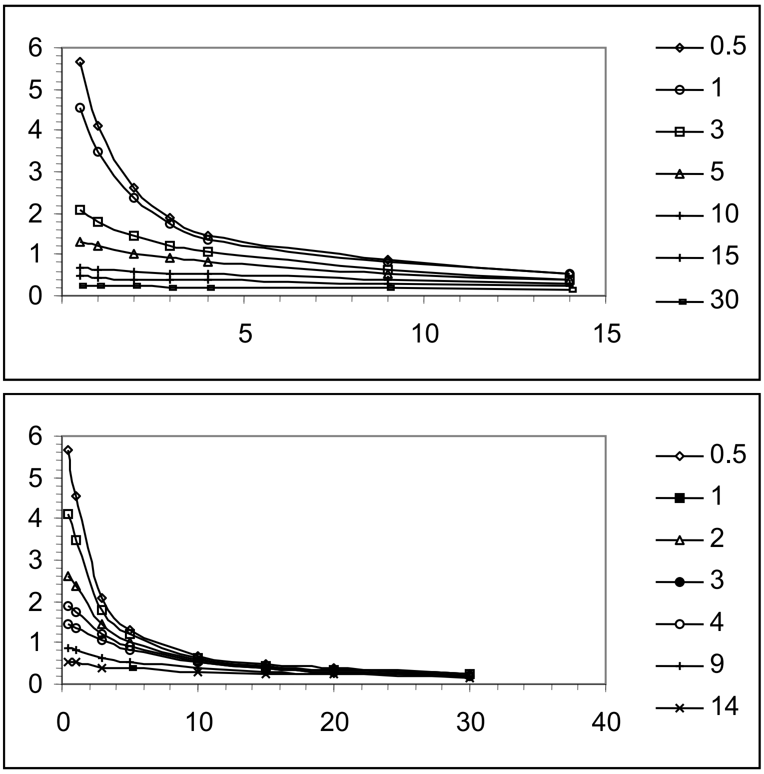

Figure 3. a. The ratio $U_{xz}^{max}{}_{,b}/U_{z,b}$ as function of the depth h_1 towards the slab structure for various slab thicknesses Δh

b. The ratio $U_{xz}^{max}{}_{,b}/U_{z,b}$ as function of the slab thickness Δh for various depths h_1 towards the slab structure

In fig.4 is presented the ratio of the maximum gradient value $U_{xz}^{max}{}_{,b}$ on the basic level towards the difference ΔU_{xz}^{max} between the maximum gradient values on the basic level ($U_{xz}^{max}{}_{,b}$) and on level H=1 ($U_{xz}^{max}{}_{,H=1}$) as function of the depth h_1 towards the slab structure for various angles of the edge α and slab thickness Δh=10.

The compound analysis of the illustrated dependence as well as the similar relations for slab thicknesses Δh in the range

0,1-50 is showing that for depths $h_1>15$ the angle of the edge has practically no influence and that the complex parameter $\Delta U_{xz}^{max}/U_{xz}^{max},_b$ for Δh=const is connected linearly to the depth h_1 towards the slab structure.

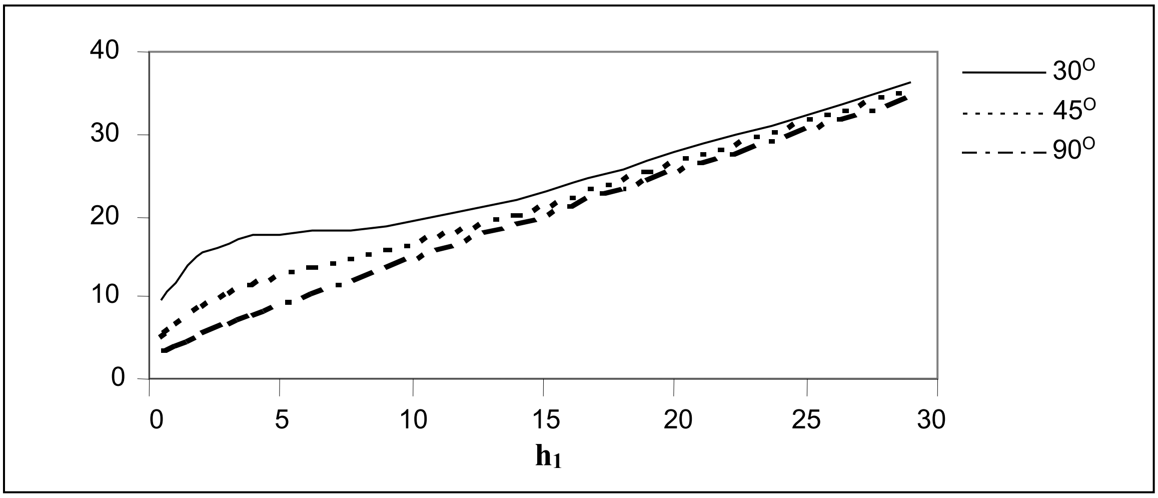

Figure 4. The ratio of the maximum gradient value $U_{xz}^{max},_b$ on the basic level towards the difference ΔU_{xz}^{max} between the maximum gradient values on the basic level ($U_{xz}^{max},_b$) and on level H=1 ($U_{xz}^{max},_{H=1}$) as function of the depth h_1 towards the slab structure for various angles of the edge α and slab thickness Δh = 10

When $h_1<15$ the relationship is showing ambiguity. This is revealed clearly for $\alpha<30^o$ ($\alpha>150^o$ respectively). For example, for depth h_1=10 the values of the ratio $\Delta U_{xz}^{max}/U_{xz}^{max},_b$ for angles 60°, 45° and 30° are 4%, 13% and 23% respectively if compared towards the value for 90°. For depth h_1=20 these values decrease to 2%, 4% and 8% respectively.

In fig.5 is presented the anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ as function of the slab thickness Δh for various depths h_1 towards the slab structure and angles of the edge $\alpha=90^o$ and $\alpha=30^o$ respectively. The analysis of the illustrated dependence as well as the similar relations for other angles of the edge is showing that for h_1=const and α=const the anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ is connected almost linearly to the thickness Δh of the slab structure.

This dependence is detailed in fig.6. There is illustrated the relationship for two angles of the edge and two depths towards the slab structure – 0,5 and 14 respectively. For small values of Δh the angle of the edge has no influence and with the increase of the slab thickness the angle influence is increasing linearly.

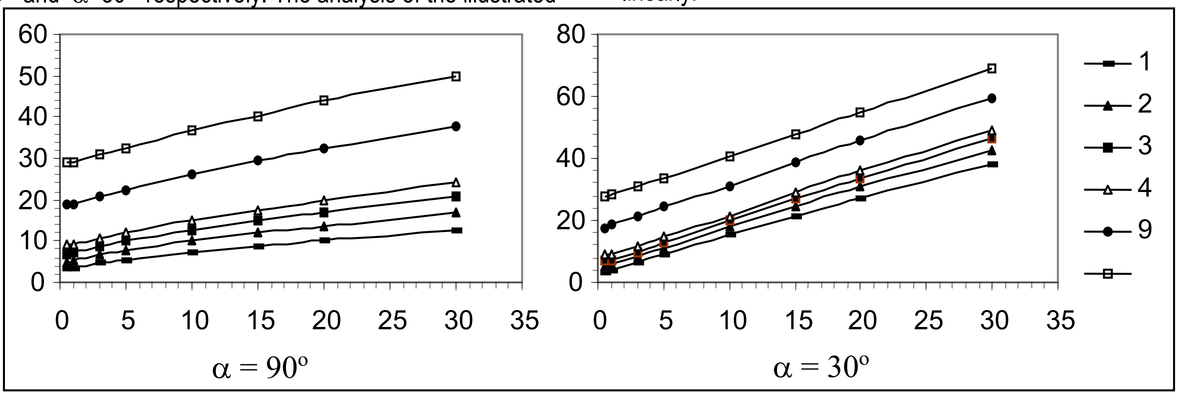

Figure 5. The anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ as function of the slab thickness Δh for various depths h_1 towards the slab structure and angles of the edge α = 90° and α = 30° respectively

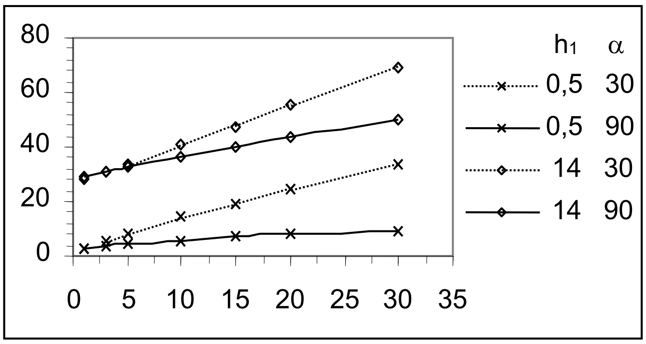

Figure 6. The anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ as function of the slab thickness Δh for depths towards the slab structure h_1 = 0,5 and h_1 = 14, and angles of the edge α = 90° and α = 30° respectively

In fig.7 is presented the anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ as function of the depth h_1 towards the slab structure for various slab thicknesses Δh and angles of the edge α=90° and α=30° respectively. The dependence is showing that the connection is exponential and for depths greater than 5 the tie becomes linear.

The function between the depth h_1 towards the slab structure and the anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ is detailed in fig.8. There is illustrated the relationship for two angles of the edge – 30° and 90°, and two thicknesses of the slab structure – 5 and 30 respectively. On this figure the influence of the angle of the edge and the slab thickness is becoming clearer. For values of Δh smaller than 5 the angle of the edge has no influence. With the increase of the slab thickness the anomaly width $\Delta X_{1/2}$ for angle 30° increases compared to the width for angle 90°. This tendency is decreasing with the increase of the depth towards the slab structure.

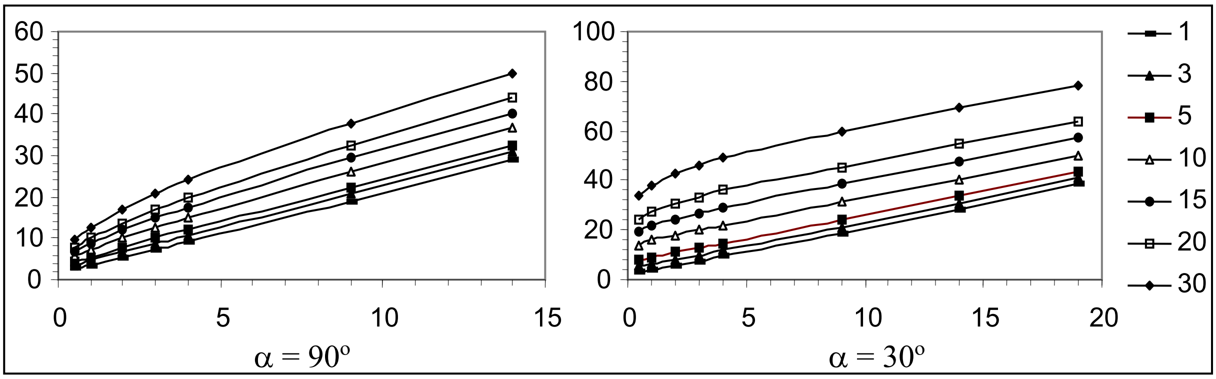

Figure 7. The anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ as function of the depth h_1 towards the slab structure for various slab thicknesses Δh and angles of the edge α = 90° and α = 30° respectively

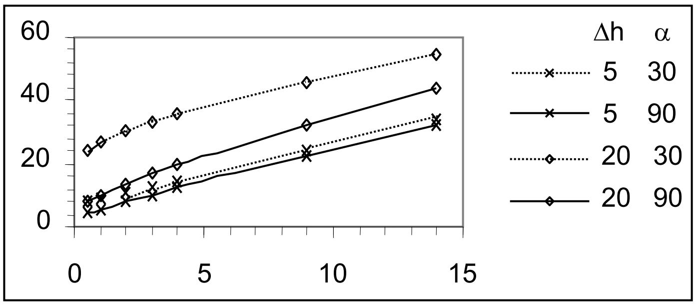

Figure 8. The anomaly width $\Delta X_{1/2}$ for gradient value $U_{xz}^{max}/2$ as function of the depth h_1 towards the slab structure for slab thicknesses Δh = 5 and Δh = 20, and angles of the edge α = 90° and α = 30° respectively

In fig.9 is presented the ratio of the maximum gradient value $U_{xz}^{max}{}_{,b}$ on the basic level towards the difference ΔU_{xz}^{max} between the maximum gradient values on the basic level ($U_{xz}^{max}{}_{,b}$) and on level H=1 ($U_{xz}^{max}{}_{,H=1}$) as function of the depth h_1 towards the slab structure for various slab thicknesses Δh and angle of the edge α=60°. The dependence is showing that the connection is exponential and for depths greater than 5 the tie becomes linear.

In fig.10 is illustrated the ratio of the maximum gradient value $U_{xz}^{max}{}_{,b}$ on the basic level towards the difference ΔU_{xz}^{max} between the maximum gradient values on the basic level ($U_{xz}^{max}{}_{,b}$) and on level H=1 ($U_{xz}^{max}{}_{,H=1}$) as function of the slab thickness Δh for various depths h_1 towards the slab structure and angle of the edge α=60°. The dependence is showing that the connection is exponential as the above-mentioned one.

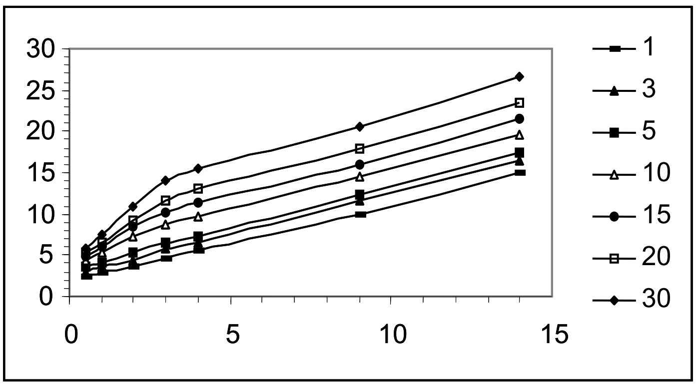

Figure 9. The ratio of the maximum gradient value $U_{xz}^{max}{}_{,b}$ on the basic level towards the difference ΔU_{xz}^{max} between the maximum gradient values on the basic level ($U_{xz}^{max}{}_{,b}$) and on level H=1 ($U_{xz}^{max}{}_{,H=1}$) as function of the depth h_1 towards the slab structure for various thicknesses Δh of the slab and angle of the edge α = 60°

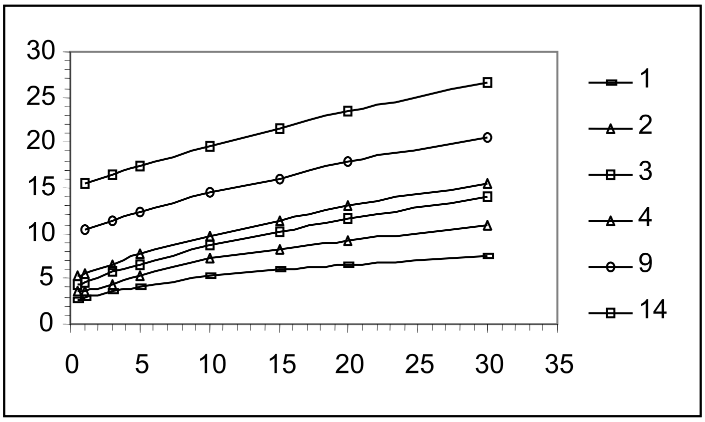

Figure 10. The ratio of the maximum gradient value $U_{xz}^{max,b}$ on the basic level towards the difference ΔU_{xz}^{max} between the maximum gradient values on the basic level ($U_{xz}^{max,b}$) and on level H=1 ($U_{xz}^{max}{}_{,H=1}$) as function of the slab thickness Δh for various depths h_1 towards the slab structure and angle of the edge α = 60°

In fig.11 is illustrated the ratio $\Delta X_{1/2}^{-} / \Delta X_{1/2}^{+}$ as function of the depth h_1 towards the slab structure for various angles of the edge α and slab thickness Δh=10. For values of the depth greater than 7 the ratio inclines towards 1. For smaller depths the ratio is increasing with the decrease in the depth towards the slab structure and for angle α=30° and h_1=0,5 it has a value of about 6.

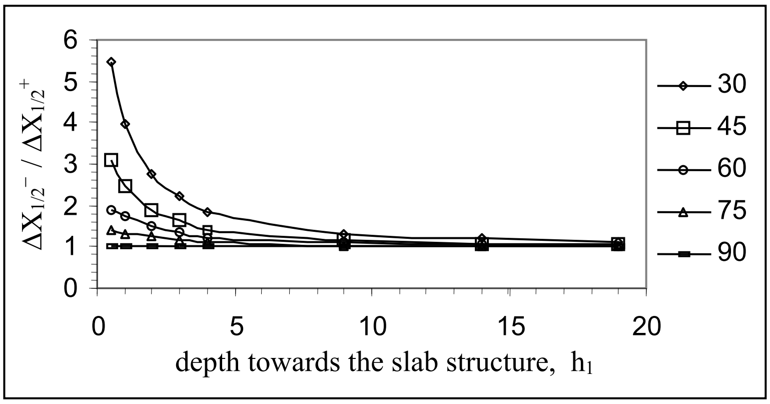

Figure 11. The proportion $\Delta X_{1/2}^{-} / \Delta X_{1/2}^{+}$ as function of the depth h_1 towards the slab structure for various angles of the edge α and slab thickness Δh = 10

In fig.12 is presented the ratio $\Delta X_{1/2}^{-} / \Delta X_{1/2}^{+}$ as function of the angle of the edge α for various depths h_1 towards the slab structure and slab thickness Δh=10. The illustrated relation is showing that the angles of the edge α < 75° (α > 105°) are forming a well-pronounced asymmetry in the case of relatively small values for the depth (h_1 < 7).

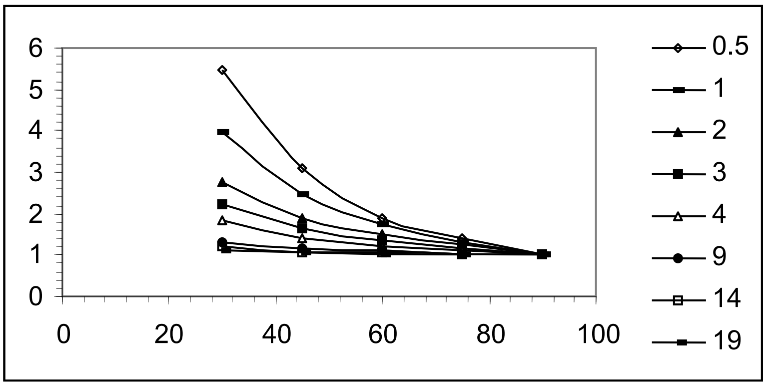

Figure 12. The proportion $\Delta X_{1/2}^{-} / \Delta X_{1/2}^{+}$ as function of the angle of the edge α for various depths h_1 towards the slab structure and slab thickness Δh = 10

Some more detailed information is presented in fig.13. It illustrates the ratio $\Delta X_{1/2}^{-} / \Delta X_{1/2}^{+}$ as function of the depth h_1 towards the slab structure for various slab thicknesses Δh and angle of the edge α=30°. This dependence reveals the quick increase of the asymmetry related to the increase of the slab thickness and the decrease of the depth towards the slab structure.

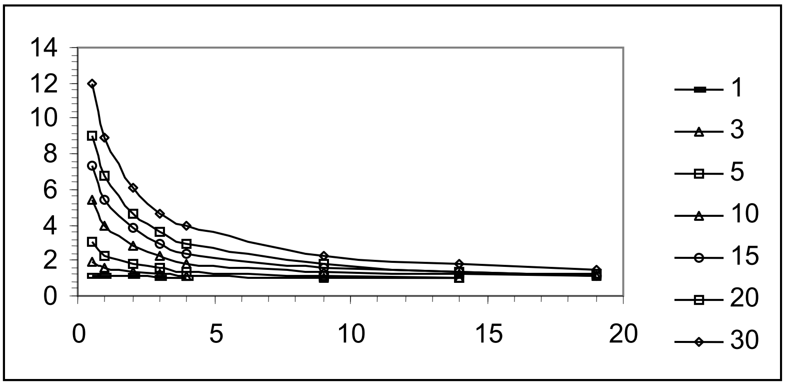

Figure 13. The proportion $\Delta X_{1/2}^{-}$ / $\Delta X_{1/2}^{+}$ as function of the depth h_1 towards the slab structure for various slab thicknesses Δh and angle of the edge α = 30°

CONCLUSIONS

On the base of analytical calculations of the gravitational field horizontal gradient U_{xz} for multiple models of semi-infinite edged horizontal slab are performed statistical studies that make possible the proposal of a method for estimating the slab structure parameters. This method includes three successive stages:

- For estimating the depth h_1 towards the slab structure is used a multiple regression with independent variables the ratio $\frac{U_{xz,b}^{max}}{\Delta U_{xz}^{max}}$ of the maximum gradient value $U_{xz}^{max}{}_{,b}$ on the basic level towards the difference ΔU_{xz}^{max} between the maximum gradient values on the basic level ($U_{xz}^{max}{}_{,b}$) and on level H=1 ($U_{xz}^{max}{}_{,H=1}$), the anomaly width $\Delta X_{1/2}$ for gradient value $\frac{U_{xz}^{max}}{2}$ and the natural logarithm of the ratio $\frac{\Delta X_{1/2}^{-}}{\Delta X_{1/2}^{+}}$ between the widths of the two branches of the horizontal gradient distribution on the basic level:

$$h_1 = f\left(\frac{U_{xz,b}^{max}}{\Delta U_{xz}^{max}}, \Delta X_{1/2}, \ln\frac{\Delta X_{1/2}^{-}}{\Delta X_{1/2}^{+}}\right)$$

The R-squared value of the multiple regression is very high. After limiting the range of the independent variables $\frac{U_{xz,b}^{max}}{\Delta U_{xz}^{max}}$, $\Delta X_{1/2}$ and $\frac{\Delta X_{1/2}^{-}}{\Delta X_{1/2}^{+}}$, the R-squared value is above 0,99. The established close relationship provides a high level of confidence in the estimation of the depth h_1 towards the slab structure.

- Once the depth h_1 towards the slab structure is found, the thickness Δh of the slab can be estimated. The following multiple regression is used:

$$\Delta h = f\left(h_1, \frac{U_{xz,b}^{max}}{\Delta U_{xz}^{max}}, \Delta X_{1/2}, \ln\frac{\Delta X_{1/2}^{-}}{\Delta X_{1/2}^{+}}\right).$$

- When the values for h_1 and Δh are known the angle of the edge α can be estimated using the following multiple regression:

$$\alpha = f\left(h_1, \Delta h, \frac{U_{xz,b}^{max}}{\Delta U_{xz}^{max}}, \Delta X_{1/2}, \ln\frac{\Delta X_{1/2}^{-}}{\Delta X_{1/2}^{+}}\right).$$

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FRACTAL PROPERTIES OF THE MEDITERRANEAN SEISMOTECTONIC MODEL FOR SEISMIC HAZARD ASSESSMENT

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ABSTRACT
The seismic hazard assessment of the big regions (such as Mediterranean) needs a regional seismotectonic model, which reflects the main seismogenic properties of the different seismogenic zones. Several models have been created during the last several years. A common work combining all available information about the hazard's model covered the whole Europe and Mediterranean region produced the general map - Jimenez, M. et al., (2001). This map is the target of thas study. We studied the compiled map of the model. The seismic zones fragmentation in space is investigated. The fractal dimensions and the fractal coefficients are established. This work is important for the seismic hazard assessment and its properties in the different regions.

INTRODUCTION

The present study focuses on the estimation of the fractal properties and coefficients of the seismogenic zones in the Mediterranean region. The area is divided into several seismotectonic provinces in accordance with the corresponding fragmentation and the specific seismogenic properties of the earth crust for the separate zones. The Mediterranean seismotectonic model (MSM) is presented in M.Jimenez et al. (2001). The separate zones could be characterized by their specific seismogenic properties, which could lead to different seismic impact on buildings and constructions. In that way this analysis gives the possibility for zone identification and comparison between different provinces each of them being most probably characterized by specific seismic hazard.

The classical example of a fractal object is defined by Mandelbrot (1982). If the length of an object P is related to the measuring unit length by the formula

$$P \sim l^{1-D} \qquad (1)$$

then P is a fractal and D is defined as the fractal dimension. Beno Mandelbrot gave this definition in the early 60-s of the 20-th century. His ideas support the view, that simple geometric forms can not describe many objects in nature. He considered that they have different levels of geometric fragmentation. It is expressed in irregularities of different scale – from very small to the quite big ones. This makes the measuring unit is extremely important, because measuring of the length, the surface or the volume of the irregular geometric bodies is strongly dependent on the smallest measuring unit in a way that the parameter value changes may vary hundred to thousand orders. This fact was first determined when measuring the coastal line length of West England and the results gave Mandelbrot (1982) the idea to define the concept of a fractal.

In geology and geophysics it is accepted that definition of the different 'fractals' as real physical objects is most often connected to fragmentation. This reveals that each measurable object has a length, surface or volume, which depends on the measuring unit and the object form irregularity. The smaller the measuring unit is, the bigger the common sum for the linear dimension of the object is and vice versa. The same is valid for 2D and 3D objects.

Another definition of a fractal can be made by the relation between the serial number of measuring to each of the measuring units and the object dimensions. If the number of the concrete measurement with a chosen linear unit is bigger than r, then it may be presented by:

$$N \sim r^{-D} \qquad (2)$$

and the fractal is completely determined by D as its characteristic fractal dimension. Applying this definition for the elements of faulting and faults fragmentation, some authors use this idea to depict formal models of the earth crust fragmentation established by Turcotte (1986), which indicate the level of fracturing of the upper earth layers.

From a physical point of view these models are acceptable in most cases considered for example by Ranguelov and Dimitrova (2002).

METHODOLOGY

Turcotte (1986) developed the theoretical approach for the linear case and for the 2D and 3D cases. He focuses his attention on the relations between the smallest measuring unit and object's size in analyzing linear, 2D and 3D objects (fig. 1).

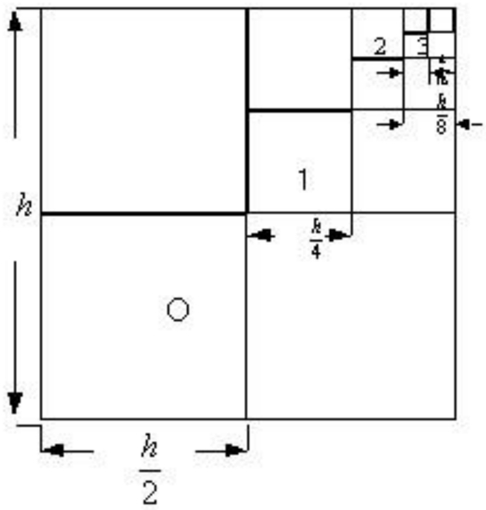


Figure 1. Simple fragmentation measuring of a quadrate with side length h (0), h/2 (1), etc.

If l is the measuring unit and with m we denote the obtained value for N at each measuring cycle, then the common sum of the lengths N at level m according to Turcotte is (1986)

$$N_m = (1-p_c)(1+\frac{n}{m}p_c + [\frac{n}{m}p_c]^2 ... [\frac{n}{m}p_c]^m) \qquad (3)$$

where Pc denotes the probability for measuring each length for the corresponding cycle of measurements.

Using formulae 1 and 2 by Turcotte we obtain the formula

$$\frac{N_{m+1}}{N_m} = 2^D \qquad (4)$$

which is valuable for the linear elements and

$$\frac{N_{m+1}}{N_m} = \left(2^2\right)^D \qquad (5)$$

which is valuable for the surface case.

Applying formulae 2 and 3 for the mapped earth crust destruction lines in Bulgaria by T. Tzankov et al. (1998), led to obtaining reasonable results by using the above model. This motivated us to verify this approach in analyzing the elements of the Mediterranean seismotectonic model. The existence of different geometrical objects of similar type like the different seismic hazard zones in various Mediterranean areas, makes it suitable to use such an approach when determining the fractal features of the considered seismotectonic model.

MEDITERRANEAN SEISMOTECTONIC MODEL (MSM) AND ITS FRACTAL PROPERTIES

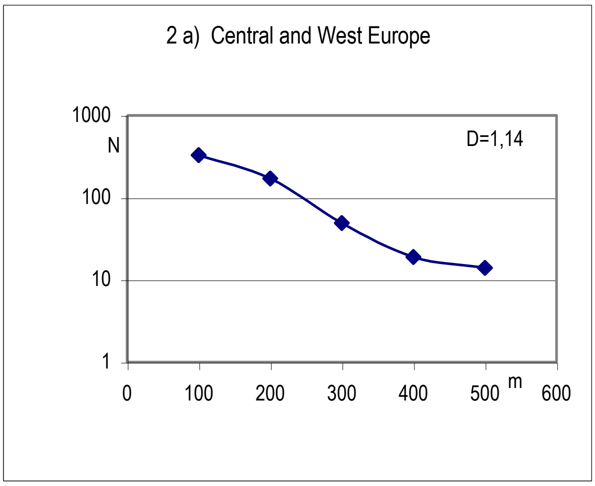
To study the fractal features of the Mediterranean seismotectonic model offered by M.Jimenez et al. (2001), we have used data from the map (Seismicity Source Regions for the Mediterranean Region). The map scale is 1:28 000 000. We have determined the number and the size of all lines delineating each of the surface elements of the model. The error in determining the size is less than 5%. The authors of the map have divided the region into several seismotectonic provinces (we follow their denoting):

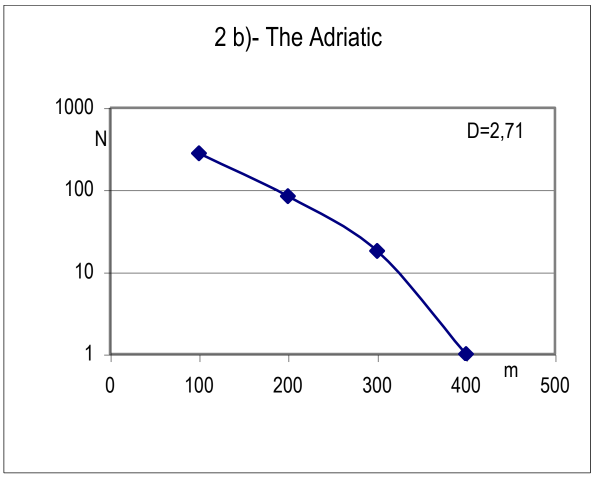
- The Adriatic (AD)
- Central and West Europe (CWE)
- The Pyrenees and West Africa (PWA)
- Greece (GR)
- Bulgaria and the Northern Balkans (BG NB)

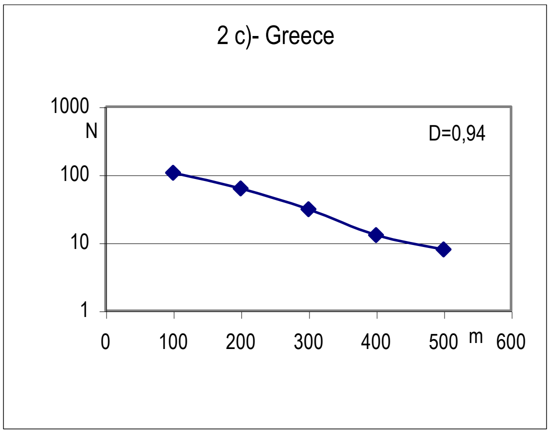
Each province was considered separately at first. Finally some general studies have been made for the whole Mediterranean region.

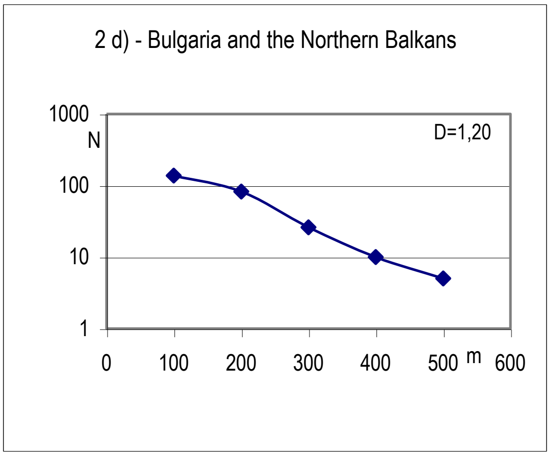
The lengths of the delineating lines for each seismotectonic zone vary between 100-500 km (they are very rarely bigger but the number of such cases is small enough). Cumulative plots have been developed in order to calculate the fractal dimension of each zone.

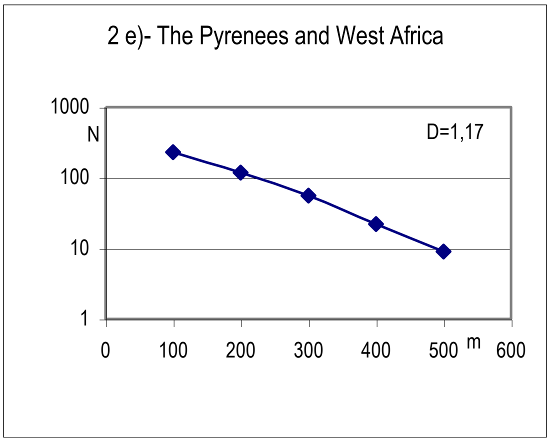
The results are presented on fig.2(a-f)











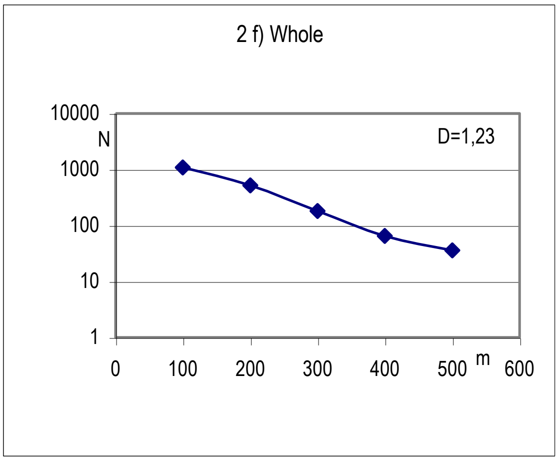


Figure 2 (a-f). Cumulative graphs for the MSM with the established fractal dimensions (linear elements) for the different zones (a-e) and in general (f).

We have also determined the surface fractal dimensions of the separate seismotectonic elements for the same region.
All surface areas have been determined and we have plotted the relations - number – area for each zone. For this purpose we have used the map M.Jimenez et al. (2001) , which is in a scale 1:30 000 000. The measured surface areas vary from 500 to 2500 km^2.

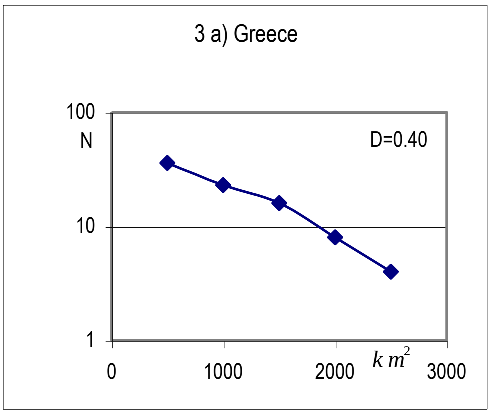
ANALYSIS AND SYNTHESIS

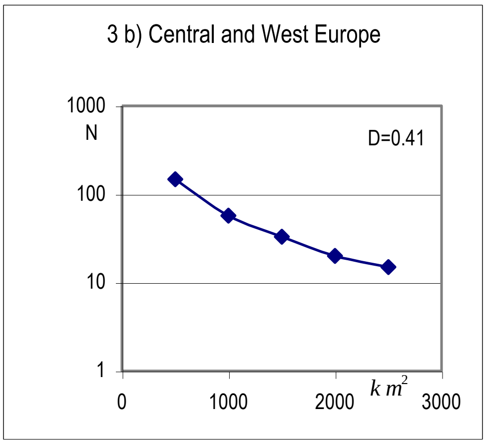
The obtained results for the different provinces reveal (table 1) :

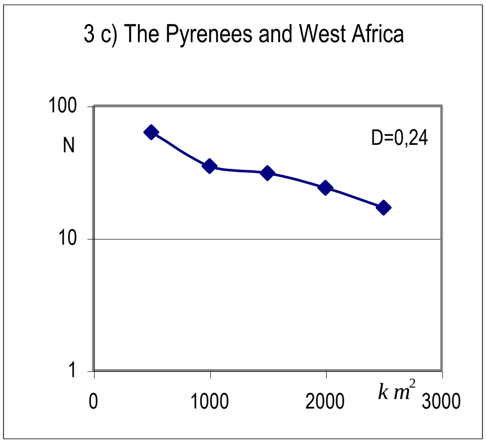
Table 1. Fractal dimensions for the linear (l) and surface (S) elements of the MSM

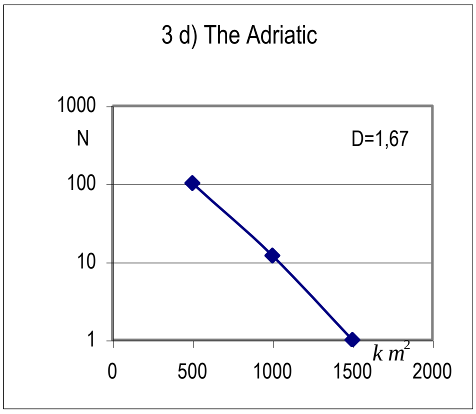
zone	$D_{(L)}$	$D_{(S)}$
AD	2,71	1.67
CWE	1,12	0.41
PWA	1,18	0.24
GR	0.94	0.40
BG NB	1.20	0.25
общо	1.23	0.38

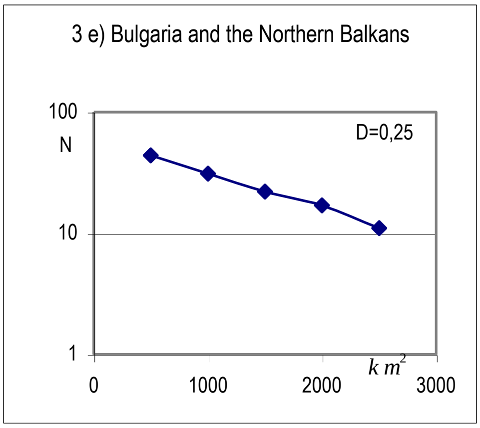
- The dimension values for the 'Adriatic' zone differ substantially from the other zones values. This concerns both the linear elements and the 2D elements, and it is reflected in both studied parameters at the level of non-linearity (the D-value respectively) being the biggest.
- All remaining zones are similar according to their non-linear behavior (considering the linear boundaries). The dimension values vary from 1.1 to 1.25 with Greece making an exception with a dimension under 1.0 (0.94)
- Regarding the 2D fractal features, the differences are smaller with the exception of the Adriatic zone again. Some grouping can be identified of different zones according to their fractal dimension values – 'Greece' and 'Central and West Europe' (0.41-0.40). These zones are quite different by their seismic activity and seismicity patterns, but they are similar concerning their seismically hazardous areas from "fractal" point of view.
- Other similar zones (by their linear fractal dimensions) are 'The Pyrenees and West Africa' and 'Bulgaria and the Northern Balkans' (025-0.24). These provinces have not similar geodynamic features but they are formally similar for sure according to the distribution of their seismically dangerous areas. In one way or another, the hazardous areas have similar sizes.











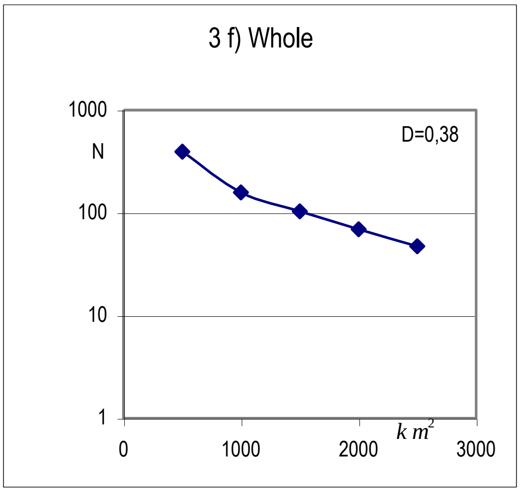


Figure 3 (a-f). Cumulative graphs for the MSM with the established fractal dimensions (surface elements) for the different zones (a-e) and in general (f).

CONCLUSIONS

The obtained results reveal that the applied approach can be useful in comparing the behavior of the seismogenic elements of the different seismotectonic provinces. The existence of clearly defined non-linear features of the seismic hazard areas' distribution shows similarity or non-similarity. Simple elementary relations can not describe this important sensitive part of human knowledge about the practical assessment of the seismic hazard. It becomes evident that more punctual and refined methods of the mathematical analysis are obligatory in order to avoid generalizations made only on analogs, which was done in many cases up to now.

The obtained results can serve as a base for developing of 'local' requirements and codes, regarding seismic safety in construction and on the general. The similar seismic hazard features in the different countries can be used for applying and/or adapting of already developed and used in practice regulation documents.

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EULER DECONVOLUTION OF MAGNETIC ANOMALIES OVER THE BASALTIC BODIES IN NORTHERN BULGARIA

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ABSTRACT
Euler deconvolution of magnetic anomalies over basaltic bodies along the Suhindol-Svishtov line in Northern Bulgaria was implemented. Original algorithms and programs for 3D Euler deconvolution using differential similarity transformations of the magnetic field was applied. This allowed simultaneous estimation of the singular point coordinates and the structural index, without requiring input data about the magnetization vector and the shape of the causative bodies. Thus, estimates of the depth range and the main features of the morphology of a number of basaltic bodies along the line of the paleovulcanic centers and their periphery were obtained. Most of the sources are vertical pipelike intrusions (volcanic necks) to the south and lenticular bodies to the north and along the periphery. The depth range of the massive bodies varies from several hundred meters to two kilometers.

INTRODUCTION

The basaltic bodies along the line Suhindol – Svishtov are the only manifestation of volcanic activity with outcrops at the surface in the typically platform setting of Central Northern Bulgaria. The interest towards these formations is supplied by the information they carry about the geologic structure and development of the Moesian platform in its southern part, as well as by the possibility to use them for the production from them of valuable construction material.

The presence of a number of natural outcrops of the basalts and quarries for their output had allowed comparatively detailed studies of their geologic characteristics and physical properties. Information about location, mineral composition, chemical constitution, magnetic properties and paleomagnetism of the basalts can be found in G. Bonchev 1904, Mavrudchiev *et al.* 1971, Jovchev *et al.* 1971, Nozarov *et al.* 1981, Bogdanov *et al.* 1983. Nevertheless, the information about the depth distribution of the basaltic bodies is scarce, and the published estimates of the source depths are of qualitative character (Nozarov *et al.* 1981).

In this article we present results from the application of one direct method for interpretation of magnetic anomalies with possibilities to give numerical estimates for both the depth and shape of the basaltic bodies. The method does not require a previously assumed geometrical and magnetic model and input data for the absolute value and direction of the magnetization vector.

GEOLOGICAL AND GEOPHYSICAL DATA

Fifteen separate basaltic bodies are exposed at the surface between the towns of Suhindol and Svishtov, along a line with azimuth 16° and length 35 km. Their size varies from 200 m to 1 km, forming in some places upland. The basalts are dark-colored and dense rocks, composed primarily of olivine and pyroxene, and belong to the sodium-alkaline type of the basalt-basanitic formation (Mavrudchiev *et al.* 1971, Bogdanov *et al.* 1983). The content of ferromagnetic components is comparatively high, from 6 up to 10%, represented mainly by titanomagnetite (Nozarov *et al.* 1981). The alignment of a number of outcrops along a single line is interpreted as a manifestation of a buried fault along which the magmatic material intruded (Mavrudchiev *et al.* 1971, Jovchev *et al.* 1971). The solidified formations are of subvolcanic type, volcanic necks, and rarely dikes.

The magnetic and paleomagnetic characteristics of the rocks were studied from a number of oriented specimens, collected from natural and man-made outcrops of basaltic bodies (Nozarov *et al.* 1981). The magnetic susceptibility varies from 0.016 SI to 0.046 SI, which determines comparatively high values of the induced magnetization. The natural remanent magnetization is high, with Königsberger ratio between 2 and 26. The normal magnetization is prevailing but for three of the outcrops in the southern part a reverse remanent magnetization was measured. The varying ratios of the vectors of induced and remanent magnetization create diversity in the effective magnetization directions. Paleomagnetic studies estimated the age of the basalt products as Pliocene-Pleistocene, and the depth of the magnetic chambers to be 50 km.

The contrast between the magnetic properties of the basalts and the embedding them nonmagnetic sediments (sandy and clay loam, marl and limestone) is a reason for an intense manifestation of the basalts in the magnetic field. The magnetic anomalies in the area are measured with a middle-scale survey of the vertical component Z. Here they are presented with the calculated modulus T_a of the anomalous magnetic vector (Fig. 1). In the figure, the intense anomalies with amplitude greater than 100 nT are located over and around the outcropping basalts. The contour pattern is isometric with maxima of the anomaly values over the outcrops at the Varcha area, Butovo-yug and Chervena. The anomalies from the same line at Ovcha Mogila, Varbovka, Tashladzhik and Cherna Mogila have an average intensiveness of the maxima between 100 nT and 250 nT.

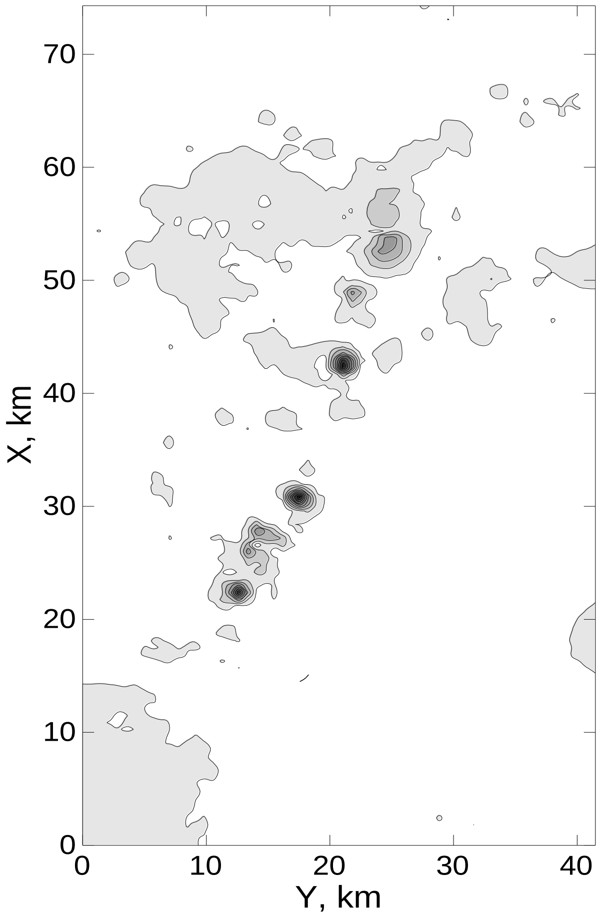

Figure 1. Map of modulus T_a, nT, of the anomalous magnetic vector, calculated from the measured component field Z.

Around these outcrops, at a distance of up to 15-20 km, several low intense magnetic anomalies with extrema below 100 nT can be observed. Their sources are probably buried relics from the area of outflow of the low viscous basaltic lavas. The magnetic anomalies reflect the joint effect of the magnetic bodies. Compared with the outcrops of these bodies, the magnetic anomalies T_a with their maximum and pattern give more information about the location and the shape of the massive intrusive body in plan view and depth. Inverse magnetic problems are posed and solved (see Dimitrov and Stavrev 1986) for obtaining such type of information. Their solutions determine the geometric and magnetic parameters of the source of the magnetic anomaly.

STUDY METHOD

The available information about the anomalous field and its sources in the area of interest advocates the use of direct method of solving of inverse problems. One of the effective direct methods, widely applied, is that of 2D or 3D Euler deconvolution. The latter name was suggested by Reid et al. (1990) but the approach was first proposed by Solovev (1960) and later independently developed in 2D by Thompson (1982). For sources of magnetic field A with one singular point $M(x_0,y_0,z_0)$ in the presence of a constant background B, Euler's homogeneity equation can be written as

$$\left(x-x_0\right)\frac{\partial A}{\partial x}+\left(y-y_0\right)\frac{\partial A}{\partial y}+\left(z-z_0\right)\frac{\partial A}{\partial z}=N\left(B-A\right), \qquad (1)$$

where (x,y,z) are the coordinates of the observation point, N=-n, where n is degree of homogeneity, and N is a coefficient, called structural index (Thompson 1982). The structural index depends on the geometry of the source. For a homogeneous point source N = 3, for a linear source (line of dipoles or poles, and for a homogeneous cylinder, rod, etc.) N = 2, for extrusive bodies (thin layer, dike, etc.) N = 1, for a contact, vertex of a block and a pyramid with a big height N = 0.

The unknown coordinates (x_0, y_0, z_0) are estimated by solving a determined system of linear equations (1) using a prescribed value for N with the least squares method. A solution with a minimum standard deviation is found through using different tentative values for N. The standard deviation should be below a given value, for example less than 15% to 25%, (Reid *et al.* 1990), the estimated source depth z_0. The window size and the respective number of the observation points, for which the system of linear equations is formed taking the data of a grid or a profile, are also parameters in the solving the inverse magnetic problem.

Here we apply one improvement of the Euler deconvolution method, which allows linearisation of the system of equations with N as an unknown, and in the presence of a constant, as well as of a linear background (Stavrev 1997). The problem is solved using a differential similarity transformations (DST) of the component $A(x,y,z)$ of the anomalous magnetic intensity. DSTs are functions of the following type (Stavrev, 1981)

$$S[A]=(u-3)A+(a-x)\frac{\partial A}{\partial x}+(b-x)\frac{\partial A}{\partial y}+(c-z)\frac{\partial A}{\partial z}, \qquad (2)$$

where u is a parameter with values ranging from 0 to 3, so that $(u-3)$ = - N in eq.(1), (a,b,c) are the coordinates of a point C, chosen for a center of the geometric similarity. When the similarity center $C(a,b,c)$ coincides with the singular point $M(x_0,y_0,z_0)$, then $S[A]$ = 0 at all observation points. In the presence of a linear background Φ, a linear function $S[A+\Phi]$ = $S[A]$ + $S[\Phi]$ is obtained, since Φ has constant derivatives in eq.(2). On the bases of these properties, the problem is reduced to obtaining a linear distribution of the DST of the observed field $F = A + \Phi$. For the purpose, the residual dispersion of the linear regression for the F data is minimized. The operations are implemented within the limits of a given window along the data grid of a map or a profile. The quality of the result for the unknowns x_0, y_0, z_0 and N is estimated according to two criteria: (a) the relative standard deviation (as mentioned above), and (b) the value of N, which should be between 0 and 3, and with a standard deviation less than a given value, related to the desired degree of approximation (Stavrev 1997).

This described approach we implemented with the developed by Gerovska and Araúzo-Bravo (2003) computer program for Euler deconvolution with unprescribed structural index. Along a data grid, windows of a given size are formed around each grid point. The window center is moved consecutively from point to point along rows and columns. Thus, the scheme of sliding and overriding windows is implemented. The obtained acceptable solutions for x_0, y_0, z_0 and N for sets of neighboring windows are statistically processed. Groups of results related to each separate source are formed with calculation of the mean value and a confidence interval for each estimated parameter.

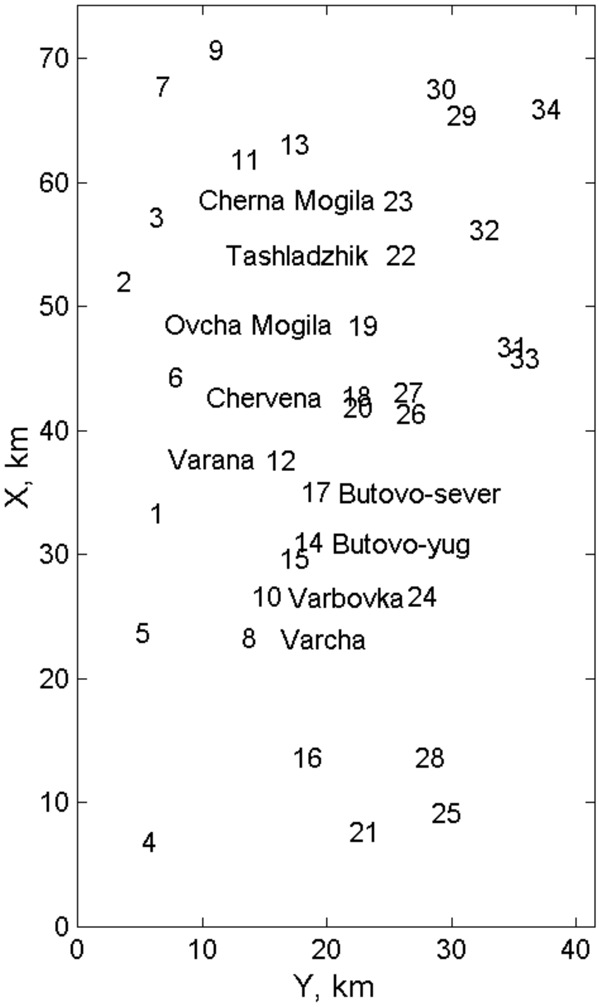

Figure 2. Indices of the formed Euler deconvolution solution clusters, corresponding to the basaltic bodies along the Suhindol-Svishtov line. The indices are used to find the corresponding statistical results for the clusters in Table 1.

RESULTS

Three-dimensional Euler deconvolution of the anomalous magnetic field over an area of 3000 km^2 (Fig. 1) over outcropping and possibly covered basaltic bodies along the Suhindol-Svishtov line was carried out.

According to the width of the anomalous magnetic field manifestations and the initial estimates for the depths of internal points of the bodies, the half width of the window is determined to be 3.2 km. Thus, one window includes 121 data grid points, from which solution for the 4 unknowns x_0, y_0, z_0 and N is obtained.

In Fig. 2, in a plan view of the map of the magnetic field, the numbers of the detected 34 clusters of solutions for the location of sources of magnetic anomalies of different intensiveness are presented. Their horizontal location and the depth with the ovals showing the confidence intervals of the obtained values are given as a graph in Fig. 3, and numerically in Table 1. The analysis of the obtained results gives us the opportunity to interpret the pattern of the anomalous magnetic field, outlining the following line characteristic points.

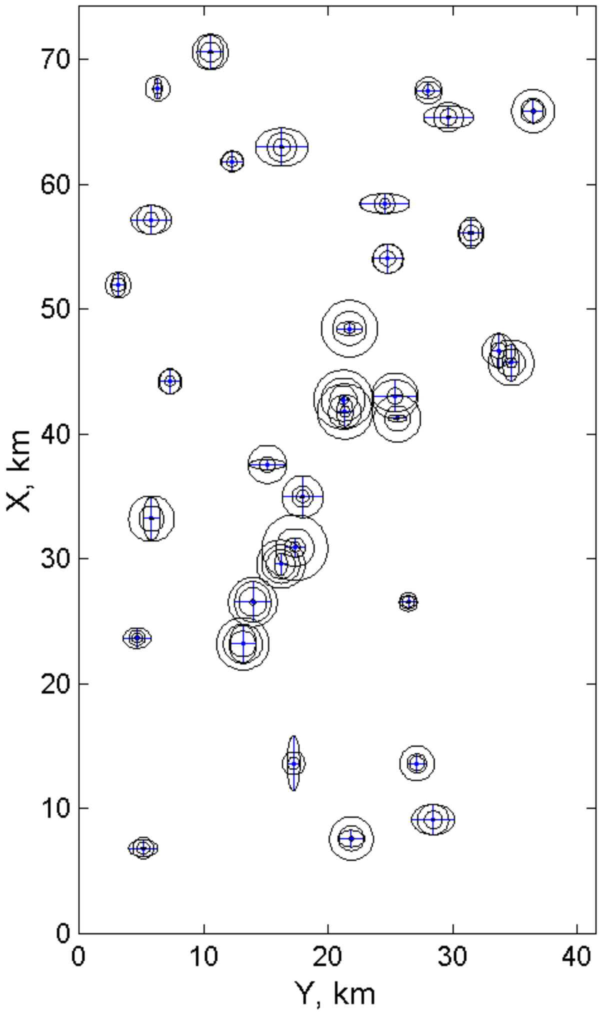

Figure 3. Plan view of the estimated location of the center of gravity of the Euler deconvolution solution clusters with confidence intervals, depicted as concentric circles for the depth and ellipses of confidence for the horizontal position.

The highly intense magnetic anomalies at Varcha, with number 8 in Fig. 2, at Butovo-yug with numbers 14-15, and at Chervena with numbers 18 and 20, have similar values for the depth z_0 and the structural index N. The depth to the internal similarity point of the bodies is within the interval 650 m and 860 m, mean value 760 m, and the structural index N is between 1.56 and 2.51, mean value 2.22. The latter speaks of a widened column-like shape of the basaltic bodies, most probably volcanic necks. According to the pattern and the intensiveness of the anomalies, these are vertical and sub-vertical massive bodies with depth to the bottom at least twice z_0, i.e. at least 1.5 km.

The anomalies with middle range intensiveness can be subdivided into two groups according to the results of the Euler deconvolution. The first group includes the anomalies at Varbovka, number 10, and at Ovcha Mogila, number 19. The depth z_0 is respectively 570 m and 670 m, and the structural index 1.87 and 1.99. From the values of *N*, we can conclude that the shape of the bodies is column-like. The body parameters are close to those of the previously described ones for the intense anomalies, but the body mass is either smaller or their shape is less elongated in depth. The second group of results is related to the bodies at Tashladzhik (number 22) and at Cherna Mogila (number 23). There, the depths z_0 are considerably shallower, 310 m and 200 m, and the values of the structural index are smaller 0.66 and 0.30, respectively. Such indices are typical of thin layers and dikes (*N* = 1), or of thicker layer shaped bodies and contacts with upper vertices close to the surface (*N* = 0). For intermediate values of *N* the body shape can be estimated as lenticular or parallelepiped with various thickness. In the studied case, it is probable that there exists preserved material in the craters of the two close paleovulcanos in the northern part of the Suhindol-Svishtov line.

Table 1. Estimated coordinates singular points and structural indices with their confidence intervals of the basaltic sources of the anomalous magnetic field along the Suhindol-Svishtov line. The estimation is for a window of 11×11grid points at ground level. Column $No_{sol.}$ shows the obtained number of solutions for one source. The confidence intervals are calculated for 95% confidence.

Index	$No_{sol.}$	x_0, km	y_0, km	z_0, km	*N*
1	42	33.24±1.67	5.81±0.68	0.50±0.41	0.56±0.68
2	11	51.95±0.88	3.13±0.57	0.27±0.23	0.60±0.63
3	59	57.17±1.13	5.78±1.60	0.29±0.30	0.61±0.70
4	6	6.84±0.66	5.15±1.16	0.26±0.16	0.22±0.37
5	11	23.66±0.80	4.65±1.09	0.21±0.09	0.19±0.27
6	48	44.21±1.02	7.29±0.85	0.20±0.27	0.38±0.75
7	5	67.68±0.78	6.30±0.29	0.21±0.27	0.41±0.52
8	76	23.21±1.46	13.14±1.09	0.78±0.26	2.40±1.11
9	8	70.60±1.34	10.53±1.08	0.40±0.30	0.84±0.86
10	44	26.56±1.61	13.94±1.45	0.56±0.42	1.87±1.34
11	8	61.84±0.75	12.30±0.92	0.20±0.22	0.56±0.78
12	17	37.58±0.41	15.11±1.42	0.31±0.45	0.85±1.17
13	77	62.99±1.51	16.27±2.08	0.33±0.24	0.83±0.83
14	68	30.91±0.78	17.32±0.82	0.76±0.55	2.21±1.76
15	20	29.60±0.87	16.19±0.50	0.77±0.19	2.50±0.39
16	11	13.65±2.17	17.21±0.51	0.23±0.22	0.44±0.86
17	16	35.00±1.67	17.94±1.63	0.25±0.17	0.56±0.71
18	14	42.77±0.41	21.20±0.36	0.86±0.32	2.42±1.03
19	39	48.45±0.55	21.70±1.03	0.67±0.45	1.99±1.52
20	15	41.82±1.17	21.33±0.64	0.65±0.44	1.56±2.31
21	10	7.61±0.66	21.85±1.04	0.49±0.38	0.93±0.96
22	89	54.05±1.14	24.78±1.24	0.31±0.27	0.66±0.71
23	7	58.47±0.78	24.53±1.96	0.19±0.21	0.30±0.66
24	6	26.55±0.52	26.42±0.64	0.23±0.13	0.34±0.44
25	62	9.13±1.18	28.43±1.70	0.34±0.27	0.74±0.83
26	5	41.27±0.26	25.54±0.74	0.50±0.44	0.39±1.05
27	8	43.07±1.26	25.35±1.75	0.32±0.59	0.61±0.78
28	6	13.64±0.73	27.12±0.79	0.28±0.40	0.57±0.87
29	31	65.39±0.88	29.65±1.99	0.33±0.26	0.84±0.61
30	8	67.52±0.68	28.05±0.94	0.22±0.31	0.73±0.83
31	33	46.68±1.39	33.68±0.61	0.33±0.33	0.69±0.83
32	30	56.11±1.23	31.46±0.90	0.30±0.21	0.63±0.62
33	54	45.73±1.43	34.68±0.67	0.55±0.35	1.12±0.65
34	37	65.87±0.91	36.45±0.81	0.49±0.37	1.37±1.03

At the periphery of the outcropping basalt bodies, where magnetic anomalies of low intensiveness are observed, the results indicate, without exceptions, comparatively shallow depths z_0 and small structural index values *N*. From the marked 20 anomalies (Figures 2, 3 and Table 1), depths within the interval 200 - 500 m, mean value 320 m, and structural indices ranging from 0.19 to 1.12, mean 0.64, were obtained. These results could be interpreted as reflecting the presence of thin to thicker buried remains of lava flows, filling the deeper forms of the paleorelief.

CONCLUSION

The results from the interpretation of the anomalous magnetic field in the region along the Suhindol-Svishtov line using the Euler deconvolution method with unprescribed structural index show in practice the possibilities for estimation of the depth and the shape of the causative bodies with a minimum of required information about the geometry and the magnetization of the bodies. The obtained results are in correspondence to the geologic idea for neck shaped basaltic bodies in the paleovulcanic craters. Besides, the magnetic data interpretation marks bodies from the outflow of basaltic lava.

The source depth and shape estimates can effectively serve as approximations for the construction of magnetic models of the basaltic bodies in the studied area. For the purpose, more detailed and precise magnetic surveys over and around the source outcrops should be done.

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MODELING THE TEMPERATURE FIELD AROUND HOT MAGMA BODY

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ABSTRACT
Modeling the temperature field around hot magma body implanted in the earth's crust is carried out in this article. The following model is treated: let in a layer of H thickness a magma body is implanted. The temperature T had to be found, it should satisfy this equation $a^2 \Delta T = \frac{\partial T}{\partial t}$, with initial condition $T(x, y, z, t = 0) = T_0(x, y, z)$ and boundary conditions $T(x, y, z = 0, t) = 0$, $K \frac{\partial T(x, y, z = H, t)}{\partial z} = Q_H$. Solving this problem we find out after how much time and how the heat flow on earth's surface changes. In order to investigate the basic characteristics of the temperature field calculations for cubic and prismatic bodies were carried out. . We have investigated the behavior of temperature inside and around the body as a function of time. The behavior of cooling body on earth's crust is found. Numerical results of heat flows of the earth's surface are depending on time according to profiles passing through the center of the bodies.

INTRODUCTION

The question about the duration of cooling of magma body is important to geological science. It is easy to answer these questions if we know the heat characteristics of the investigated body and the rocks nearby.

But often these data are difficult to get because heat conductivity of rocks gets lower when temperature rises and heat capacity increases when the temperature reaches 400° C. Ignoring changes connected with the temperature we can obtain more or less valid average values.

FORMULATION AND SOLVING THE PROBLEM

Let's treat the following case: The anomalous change of temperature provoked by the influence of thermal body has to be found. (fig. 1).

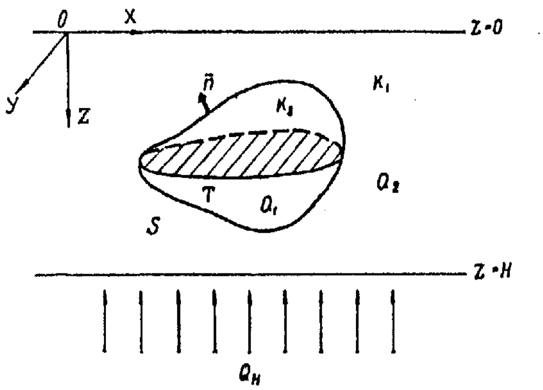

Figure 1.

Let in the layer with thickness H a body is implanted. We define the temperature satisfying the equation:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{a^2}\frac{\partial T}{\partial t} \quad (1)$$

where
$a^2 = a_1^2$ - the coefficient of heat conductivity of the body,
$a^2 = a_2^2$ -the coefficient of heat conductivity of the medium.

Initial and boundary conditions are:

$$T(M,t)\big|_{t=0} = T_0(M) = \begin{cases} \frac{Q_H}{K_1} z, & M \notin V, \\ T_1, & M \in V, \end{cases} \quad (2)$$

$$T(M,t)\big|_{z=0} = 0; \qquad K_1 \frac{\partial T}{\partial z}\bigg|_{z=H} = Q_H = const \tag{3}$$

On the body surface we get the following boundary conditions:

$$[T]_s = 0; \qquad \left[K\frac{\partial T}{\partial n}\right]_s = 0 \tag{4}$$

Solving the boundary problem (1) - (4) we can know after how much time and how the heat flow will change on the earth's surface:

$$K_1 \frac{\partial T}{\partial z}\bigg|_{z=0} = P(x,y,t) \tag{5}$$

where

$$P(x,y,t)\big|_{t=0} = Q_H$$

In order to investigate the basic characteristics of the heat body - calculations of cooling the body are made (cube, prism).The cube is at 300m depth and has sides equal 300m, i.e. -150<x<150; -150<y<150; 300<z<600, And the prism is at the same depth but has dimensions 4 times bigger on the Ox, i.e. -600<x<600 The dimensions on the Oy and on the Oz are the same.

At the beginning we will study how the temperature changes near the body and how the cooling the prism differs from that of the cube. In fig.2 we can see the changes of temperature in depth for different periods and point near the body.

It is easy to notice that in the direction of Ox passing through the center of the body the cooling of the prism is slower than that of the cube. The maximum temperature is concentrated around the body and for the first 100 years the temperature of the body goes down with 5%. After 1000 years the body temperature goes down with 25%. After 3000 years it remains 25% from the initial temperature, and after 10000 years 10% of the initial temperature is kept.

This can be seen in fig.3 and fig.4, where the changes of temperature in at around the body are given.

On fig.3 there is a change of temperature in the body:

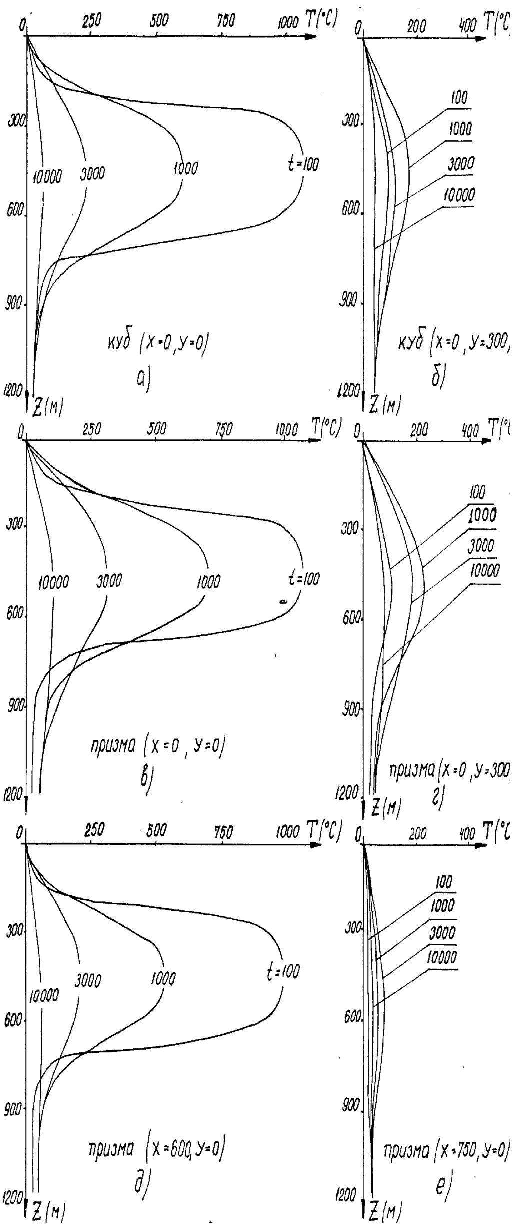

Figure 2.

——— center of the cube (x=0, y=0, z=450);

- - - - - - - center of the prism (x=0, y=0, z=450);

—·—·—·- prism (x=600, y=0, z=450);

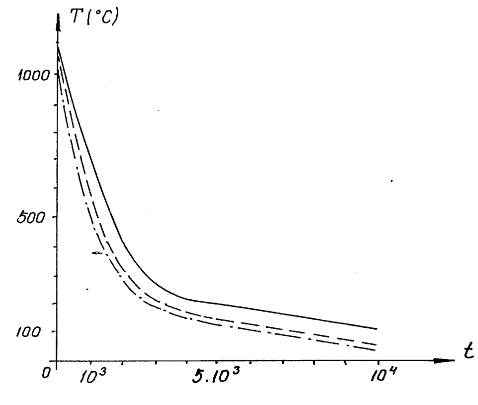

Figure 3.

In Fig.4 there is a change of temperature around the body:

——— around the cube (x=0, y=300, z=300);

- - - - - - - around the prism (x=0, y=300, z=450);

_._._._.. around the prism (x=750, y=0, z=450).

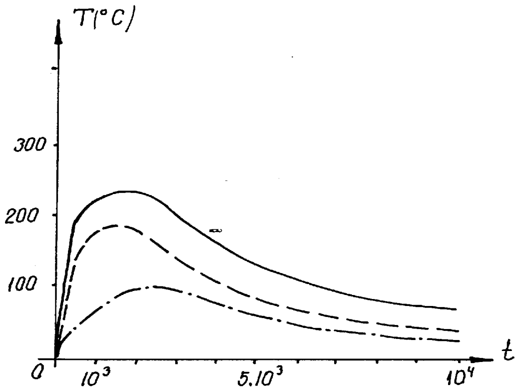

Figure 4.

We can see that in the body the first 2000 years the temperature goes down at the speed of 0,35 ÷ 0,4°C / y. With long periods the speed of cooling goes down quickly and at 4000 years the average speed is equal to 0,02 °C / y.

In the beginning near the body the temperature does up and then it begins to go down. The time for reaching the maximum depends on the distance to the body and the location of the point to the boundary of the cube maximal temperature 190 °C is reached for 1500 years from the initial moment of cooling the body. . We get different results for the prism depending on which side we investigate the temperature and how near it is. If we near the big side at a distance of 150 m. then the maximum temperature is bigger then that of the cube and it is 240°C. It is also reached for 1500 years.

If we are at the end of the prism then the maximum temperature is much lower 100° C, and it is reached much later – up to 2500 years from the beginning of the body cooling. After reaching the maximum near the body the temperature goes down very slowly – approximately 0.01 °C/y.

In tables 1, 2, 3 the calculations of non-stationary heat flow on the earth's surface are given. These results are presented in fig.5 for the cube and in fig.6 for the prism.

Table 1. Cube $q = \lambda u_z(t,\ x = 0,\ y,\ z = 0)$

y/t	0	150	300	450	600	750	900	1050	1200
100	0.796	0.431	0.086	0.062	0.06	0.06	0.06	0.06	0.06
1000	2.10	1.652	0.954	0.328	0.138	0.084	0.067	0.062	0.061
3000	1.182	1.008	0.672	0.356	0.192	0.118	0.086	0.072	0.069
10000	0.31	0.286	0.234	0.176	0.134	0.106	0.09	0.081	0.078

Table. 2. Prism $q(t,\ x = 0,\ y,\ z = 0)$

y/t	0	150	300	450	600	750	900	1050	1200
100	1.168	0.840	0.456	0.094	0.062	0.062	0.06	0.06	0.06
1000	2.636	2.114	1.264	0.282	0.198	0.104	0.074	0.064	0.062
3000	1.774	1.540	1.068	0.596	0.322	0.182	0.116	0.096	0.082
10000	0.542	0.504	0.414	0.310	0.226	0.168	0.132	0.114	0.108

Table 3. Prism $q(t,\ x,\ y = 0,\ z = 0)$

y/t	0	150	300	450	600	750	900	1050	1200
100	1.168	1.168	1.166	1.142	0.798	0.430	0.086	0.062	0.06
1000	2.636	2.624	2.570	2.376	1.743	0.978	0.338	0.148	0.108
3000	1.774	1.754	1.680	1.504	1.154	0.740	0.394	0.232	0.186
10000	0.542	0.534	0.506	0.456	0.382	0.298	0.226	0.184	0.170

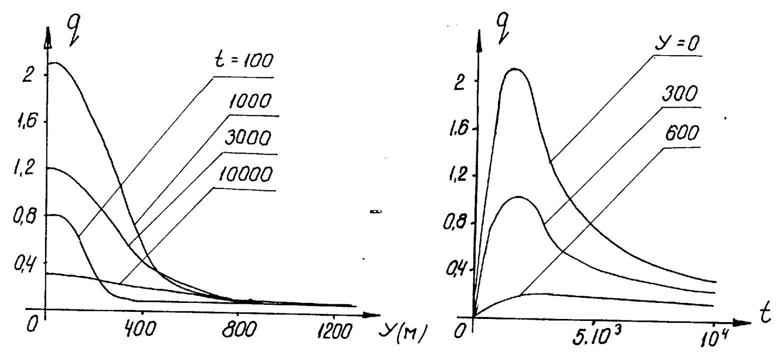

Figure 5.

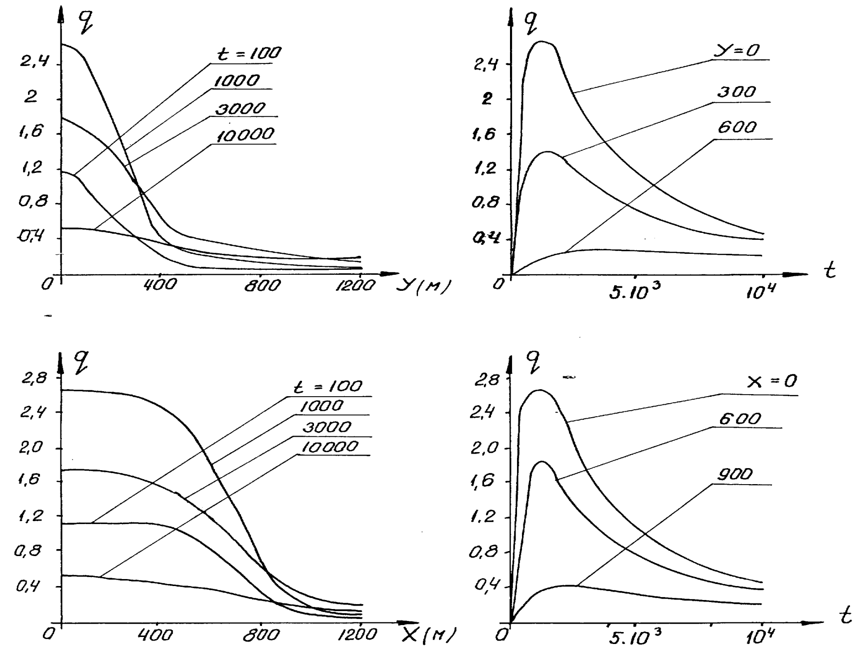

Figure 6.

CONCLUSION

The investigations carried out refer to a body that is not deep in the earth. If the body is at a great depth H, then all space characteristics increase (H/300) times, and those depending on time - $(H/300)^2$ times .
So for a body, which is at depth of 3000m. time characteristic increase 100 times. Then the maximum of heat flow on earth's surface for this body will be reached in 100-200 thousand years. The location of the heat flow will get worse 10 times. If the body is at depth (H=3000 m.) the flow be localized in an area with radius 4000-5000 m.

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STRUCTURAL FEATURES OF THE BOROVITZA DEPRESSION AND ITS PERIPHERY, ACCORDING TO GEOPHYSICAL DATA

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ABSTRACT
Integrated interpretation of the available regional gravity, airborne magnetic, gamma-ray spectrometry and earthquake distribution data is performed to study the metamorphic basement morphology of the Borovitza depression and its periphery and the peculiarities of the tectonic and magmatic setting.
The Borovitza depression is characterised by an intensive gravity low and specific magnetic field that reflect the basement morphology and the volcanic cover features. Vertical displacements of the metamorphic basement, as well as the presence of concealed acidic volcanic centres, subvolcanic and intrusive bodies, are revealed. The Besvodno-Novakovo NW striking regional fault zone outlined from the geophysical data divids the Borovitza depression into two parts. The presence of large annular gravity and magnetic anomalies interpreted as peripheral ring faults, filled up with ignimbrites, where considerable sinking of the basements occurs, provide additional support for the assumption that it is a calderas-type volcano-tectonic depression. At the northern periphery of the Borovitza depression the Topolovo structure is outlined connected with uplifting of high-density ophiolitic rocks.
Several centres of acid volcanism are distinguished within the depression. Specific gravity, airborne magnetic and gamma ray spectrometry anomalies define a large volcanic structure at the intersection of east-west and north-northwest faults in the area of Tri mogili village. The constructed gravity and magnetic models show that the above mentioned anomalies are caused by steeply dipping to the south sheet like acid volcanic bodies.

INTRODUCTION

The Borovitza volcano-tectonic depression is located at the northwestern part of the East Rhodopes Paleogene depression. According to Ivanov, R. (1972) it is a calderas-type elliptical structure, formed as a result of a vast eruptions of mainly rhyolitic tuffs, agglomerates, ignimbrites, and lavas, which overprints an inhomogeneous Pre-Paleogene metamorphic basement. The volcanic rocks are divided into a latite-andesite-rhyolite sequence of acid and intermediate volcanics and a felsitic rhyolite sequence. Concentric and radial faults and dyke-swarms related to calderas collapse are mapped at the eastern and western periphery of the structure. Linear faults and dyke-like structures, which are related to basement dislocation, are observed as well.

The great thickness of the volcano-sedimentary cover and the lack of deep boreholes in the depression area, determine the importance of the geophysical data to study its inner structural and magmatic peculiarities. Up to now, the geophysical information in the Borovitza depression area has been used either in quite regional aspect (Dachev, Ch., 1988; Josifov, D. et al., 1990; Josifov, D., 1990; Katskov, N. et al., 1988) or in terms of studying some structural and metallogenic aspects of its marginal parts (Josifov, D. et al., 1985; Maneva, B. et al., 1990, Nikova, L. et al, 1996).

The present work includes the Borovitza depression and part of its periphery. The morphology of the metamorphic basement, some features of magmatic and fault structures are studied on the basis of gravity, magnetic and airborne gamma-ray spectrometry data and earthquake centers location.

METHODOLOGY

Analysis and integrated interpretation of the available gravity and airborne magnetic and gamma ray spectrometry data at 1:50 000 and 1:25 000 scales is carried out. 2-D density and magnetic models are constructed, using SIGRAV-23 and SIMAG-21 programs (Stavrev, P. et al., 1988; 1991), which uses polygonal models of uniform averaged density and effective magnetization values. Optimization of the models is performed using interactive parameter selection method. In accordance with the seismological data (Shanov, S. and Kostadinov, V. 1992; Dachev, Ch. 1988), it is assumed that the Moho discontinuity rises from west to east to about 4 km and to about 2 km from south to north in the area studied.

The depth to the basement is determined by the method of consecutive approach (Nikolski, U., et all, 1975) using geologic-geophysical cross sections, constructed along several modeling lines. Attention is paid to locate the modeling lines near basement outcrops and drill holes that crosscut basement rocks, which reduces the interpretation ambiguity.

PETROPHYSICAL STUDY

To study the petrophysical parameters of the main litologic unit in the area about 1300 samples from earth`s surface and boreholes were analyzed. A summary of the results from the statistical analysis is shown at table 1. The acid volcanic rocks-rhyolites, ignimbrites, dacites are characterized by relatively low density ranging from 2,34 to 2,36 g/cm^3, low magnetic susceptibility (about $400.4\pi.10^{-6}$SI), and high natural remnant magnetization (NRM).The measurements on oriented samples collected from rhyolites and ignimbrites shows that the NRM vector is directed opposite to the inductive magnetization vector – the inclination ranges from –30° to -60°. The intermediate volcanic rocks– coarse and porphyry latites, andesites, etc. have higher densities ($\sigma_{cp.}$ = 2,52-2,64 g/cm³). Some of them have also high magnetic properties, while others are nonmagnetic. Density heterogeneities within the outcropping at the periphery of the depression metamorphic rocks are determined.

Table N 1 Physical properties of the rocks from the Borovitza depression area and its periphery

N	Lithological unit	Density			Magnetic susceptibility			Remanent magnetization		
		Number	Average g/cm³	Confid. interval	Number	Average $10^6/4\pi$,SI	Confid. interval	Number	Average 10^3 A/m	Confid. interval
1.	Ignimbrites	27	2,34	2,30-2,35	20	446	220-800			
2.	Rhyodacites	30	2,43	2,41-2,47	18	440	290-800	18	34000	(20-58)10^3
3.	Rhyolites	99	2,36	2,29-2,47	65	407	350-600	42	1730	(1,2-1,9).10^3
4.	Rhyolitic tuffs	79	2,17	2,12-2,20	41	148	90-200	32	5200	(3,2-6,5).10^3
5.	Monzonites	100	2,63		100	862				
6.	Coarse-porphyric latites	69	2,52	2,52-2,54	68	1754	1300-1900	62	1600	(1,1-2,0).10^3
7.	Middle- porphyric latites	68	2,53		120	256	190-320	120	188	85-205
8.	Fine- porphyric latites	92	2,63	2,60-2,66	92	2368	2000-2750	92	1287	(0,9-2,1).10^3
9.	Andezites	49	2,64	2,62-2,66	29	1863				
10.	Granites	16	2,58	2,52-2,64	21	135		21	57	40-80
11.	Granodiorites	58	2,53		15	1182		15	52	39-74
12.	Serpenitized ultramafics	127	2,52	2,49-2,54	127	3535	3210-3860	9	3720	(2,0-7,1).10^3
13.	Unaltered ultramafics	37	2,80	2,72-2,89	36	50	20-80	6	41	25-96
14.	Marbles	20	2,70		20	18				
15.	Biotite gneisses	272	2,63		271	39		165	28	
16.	Amphibolites	209	2,83		209	198		145	184	
17.	Amphibol-biotite gneisses	34	2,78		19	110		54	38	
18.	Schists with garnet	10	2,83		10	30		4	108	
19.	Gneiss-granites	24	2,61		23	59		4	0	

The biotite gneisses have an average density of 2,62-2,65 g/cm³, the underlying gneiss-granites – 2,61 g/cm³, while rock samples from orthoamphibolites and metagabbro, collected at the surface and from a deep borehole near villages Lenovo and Mouldava, shows densities varying around 2.80 g/cm³. The later rocks are considered to be oceanic crust remnants- metaophiolites (Kozhoukharova, E, 1984) that constitute the upper part of the large Rhodope nape system (Burg et all, 1990). The geophysical signature of the ophiolites is studied earlier on Bulgarian and Greek territory (Nikova, L. et al., 1995,1996; Tzvetkov, A., Tzvetkova,D., 1995; Maltezou, F. and Loucoyannakis, M., 1993).

REGIONAL POSITION OF THE BOROVITZA DEPRESSION

Distinct N-S, W-E, NW and NE striking regional geophysical anomalies are interpreted as regional deep penetrating fault zones, part of them causing displacements of the metamorphic basement (fig.1). The Dolnoslav fault zone is recognized as elongated to the north-south intensive gravity gradient, positive north-south trending magnetic anomalies, caused by serpentinite bodies, and concentration of earthquake centers at a depth of 5-10 km. Such a combination of geophysical anomalies is interpreted as reflecting the presence of a regional structure which southward extension may be characterized by the prominent Central Rhodope gravity gradient. According to the deep seismic data and the constructed models the gradient is associated with a regional gently dipping to the east reflection and density boundary (A. Велев, 1996, L. Nikova et al., 1996). Its geological nature is still discussed. To the north of Assenovgrad similar gravity anomaly has a NW strike and might be related to the Northern Rhodope fault zone (Bonchev, E., 1961).

As a result of previous interpretations of the gravity and magnetic data the Laki, Novakovo-Pilashevo and Zenda-Spahievo lineations are outlined at the northern and eastern periphery of the depression (Josifov, D. et al., 1990; Katskov, N. et al., 1988). They are interpreted as vertical displacements of the metamorphic basement as well as pathways for different types of magmatic activity – centers of acid volcanism, intrusive and subvolcanic bodies and dikes. Earthquake centers at a depth of 8-12 km are observed in the area of Konoush and Popovitza NW striking faults, outlined by the gravity and magnetic data. In addition to the linear features of the geophysical fields, a number of circular or elliptical anomalies are outlined, that are interpreted as sinking or uplifting blocks of the metamorphic basement.

Intensive, gravity high at the northern periphery of the depression is interpreted as an uplifted block of the metamorphic basement, called the Topolovo structure (fig. 1). It coincides partly with the so-called Topolovo wedge (I. Boyanov et al. 1983).

According to the constructed 2-D density models, the gravity high is explained in terms of an uplift of high-density metamorphics near the earth's surface. The mentioned structure is heterogeneous in respect to the basement topography and composition. The western and northern parts of the Topolovo structure are more elevated, while it is sinking gradually toward the southeast. Local gravity highs within the large anomaly are observed to the north. They are attributed to the presence of thick, shallow masses of high density ultramafic rocks (ophilites) outcropping near the village Mouldava. Intensive gravity low observed in the Topolovo village area is associated with a concealed granitic intrusion, partly outcropping to the south and cross cut by several drill holes to the north of the village.

Several large gravity minima are interpreted as concentric structures, related to downward dislocation of the metamorphic basement. These are the Borovitza, Dragoinovo, Briastovo and Tatarevo depressions (fig. 1). Intensive magnetic anomalies - common signature of the volcanic centers are observed in the area of the mentioned gravity lows.

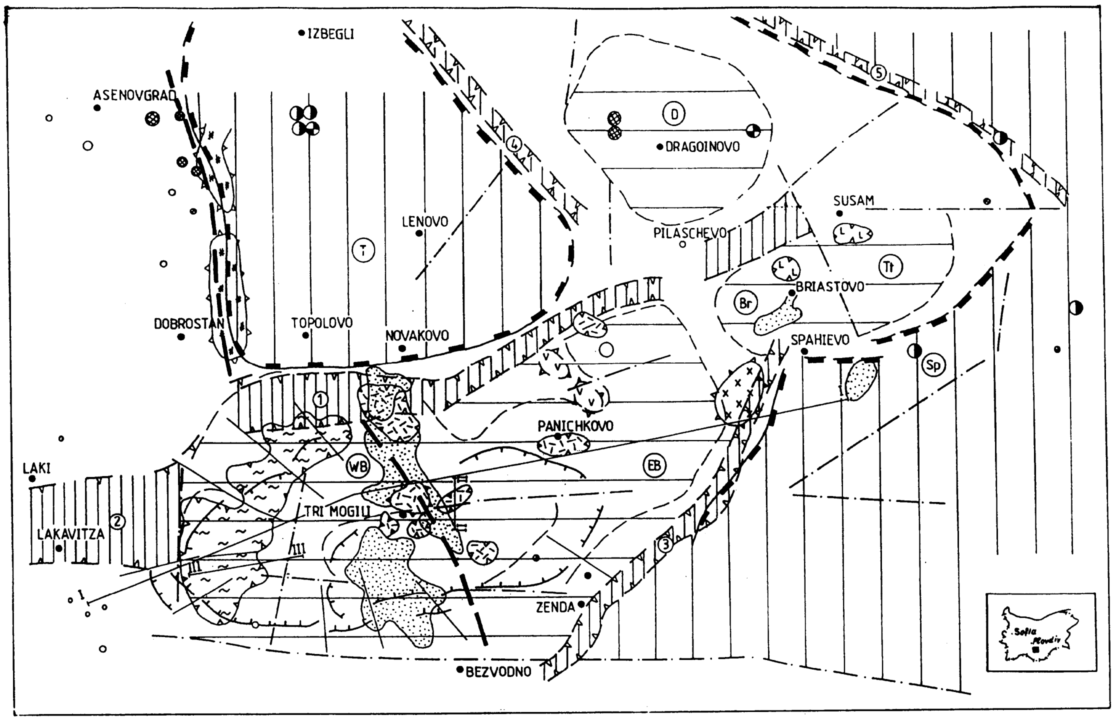

fig.1 Structural scheme of the Borovitza depression area according to the geophysical data

Fault zones: 1-Novakovo-Pilashevo; 2-Laki; 3-Zenda-Spahievo; 4-Konoush; 5-Popovitza.

Faults, according to gravity and magnetic data.

Boundary of the Western and Eastern Rhodopes marked by the Dolnoslav and Bezvodno-Novakovo fault zones

Boundary of ring structure, according to geophysical data

Boundary of high density metamorphyc blok build up of orthoamphibolites, metagabbro, eclogites.

Local gravity maximum related to subvolcanic bodies

Radial faults according to magnetic data.

Axis of magnetic and gravity anomalies, related to ring faults

a b *Local magnetic maximum related to: a) quartz-montzonitoid intrusion, b) serpentinites*

I______I *Line for gravity and magnetic modeling*

High potassium aerborn gamma-ray spectrometry anomalies related to the hydrothermal alterations of the acid and intermediate volcanics

a b *Structures of the metamorphic basement: a) Uplifted blocks: T-Topolovo; Sp-Spahievo; b) Depression: WB-West Borovitza; EB-East Borovitza; Br-Briastovo; D-Dragoinovo; Tt-Tatarevo.*

a b c *Local magnetic minimum related to acid volcanics charachterized by reverse magnetization: a) rhyolites; b) rhyodacites; c) ignimbrites*

a b c d *Epicentres of the earthquakes with magnitude: a) 0÷1; b) 1÷3; c) 3÷5; d) 5÷7*

a b c d e *Depth of the earthquake centres: a) 0÷3 km; b) 3÷5 km; c) 5÷10 km; d) 10÷30 km; e) 30÷50 km*

STRUCTURAL AND MAGMATIC FEATURES OF THE BOROVITZA DEPRESSION

The Borovitza depression is characterized by a large gravity minimum and concentration of positive and negative magnetic anomalies which are due to the considerable sinking of the metamorphic basement and the emplacement of a thick pile of relatively low - density and high magnetic volcanic rocks. The constructed contour map of the metamorphic basement top (fig.2) clearly outlines the depression as a NE striking elliptical low. The western, northern and southeastern periphery are characterized by a sharp sinking of the basement top along concentric and linear faults. The Bezvodno-Novakovo fault zone, which is considered to be a part of the mentioned above regional Dolnoslav structure, divides the Borovitza depression into two different parts - the west (WB) and the east (EB) ones – fig.1. Intensive negative magnetic and gravity anomalies predominate to the WB. 2-D gravity and magnetic models along ines I-I and II-II (fig.3, 4a) present the model of the causative bodies as shallow, dipping to the south slabs, related to the outcropping low density, high NRM ignimbrites.

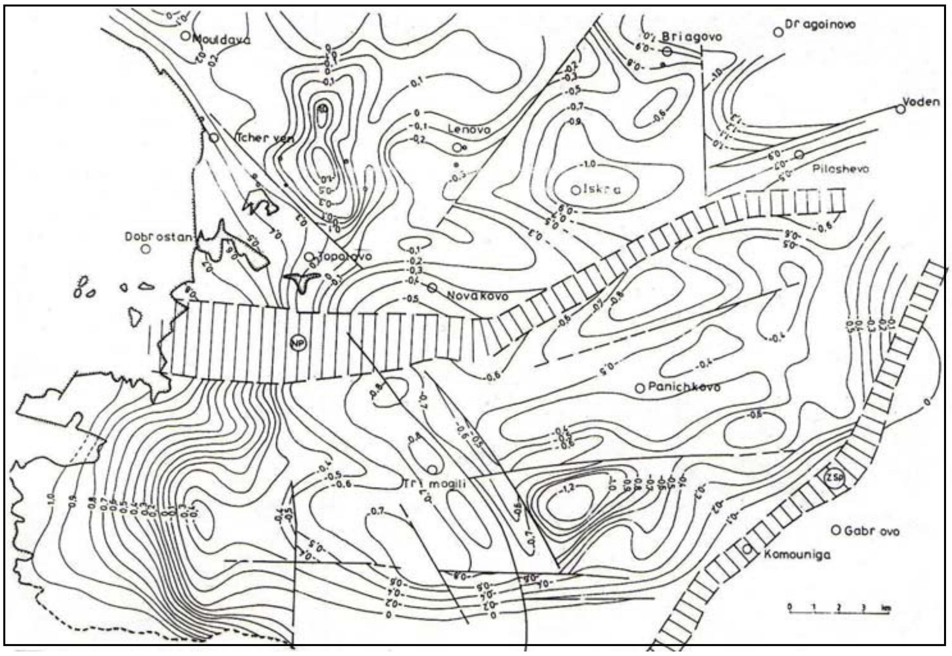

Figure 2 Map of the Pre-Paleogene basement elevation *in the Borovitza depression*

Fault zones in the metamorphic basement: NP-Novakovo-Pilashevo, ZSp-Zenda-Spahievo

Faults in the metamorphic basement.

-0,5 *Contour lines in the metamorphic basement elevation*

Outcrops of metamorphites

o *Location of the boreholes, cross cutting the metamorphic basement*

The shape and type of the anomalies suggest that they might reflect the presence of typical calderas-type peripheral ring faults filled with ignimbrites (G. Macdonald, 1972). Radial faults are also outlined at the west Borovitza structure, which are characterized by breaks of the contour lines of the magnetic and partly of the gravity maps. The observed in this block magnetic, gravity and gamma-ray spectrometry potassium anomalies are typical for the concentric volcanic structures environment.

The Eastern part of the depression (EB) is characterized by low intensity magnetic field and low abundance of the radioactive elements. According to the density models the increase of the gravity field to the east is explained with a gradual uplift of the metamorphic basement, the upper most part of which is build up of high - density ophiolitic-type rocks (fig. 3).

An internal concentric structure (the Mourga structure) is observed at the central part of the Borovitza depression. It is bounded by concentric negative and positive magnetic anomalies to the south and to the north respectively (fig. 1). The Bezvodno-Novakovo fault zone cross cuts the Mourga structure.

Local magnetic high flanked to the north and to the south by concentric magnetic lows and above the background potassium anomalies is observed at the Tri mogili area. These anomalies are located at the intersection of an E-W fault with the Bezvodno-Novakovo fault zone (fig. 1), along which several intermediate volcanic dikes have been mapped (Boyanov, I. et al., 1991). A 2-D magnetic model along line II-II (fig.4b) shows a south dip of the causative rhyolitic dike, characterized by a reverse polarity of the NRM. The top of the dike-like body is at 0,8 km and the bottom – at about 2-2,4 km. It is assumed that the concentric magnetic anomalies are probably related to centers of acid volcanics. Thus, the geophysical data suggest the presence of a large volcanic center in the Tri mogili area. To the south it consists of several volcanoes located within a concentric fault. Hydrothermal alteration of the rocks is observed at the northern periphery of the volcanic structure. The modeling line II-II runs trough the northern part of the structure. A similar volcanic center confined to the Bezvodno-Novakovo fault zone is established at the Syruar dere area to the north of the Tri mogili center. It is characterized by several negative magnetic anomalies from the 1:10 000 scale magnetic map. High values of the NRM (in average 1900.10^{-3} A/m) are established by laboratory measurements on samples from the earth's surface. The geophysical anomalies and the geological evidence show the presence of hydrothermal alteration, related to the volcanic edifice.

Intensive local negative magnetic and gravity anomalies, observed near Iskra and Doushka villages are studied. It has been established that the anomalies are related to a rhyolitic body intruded along a fault zone.

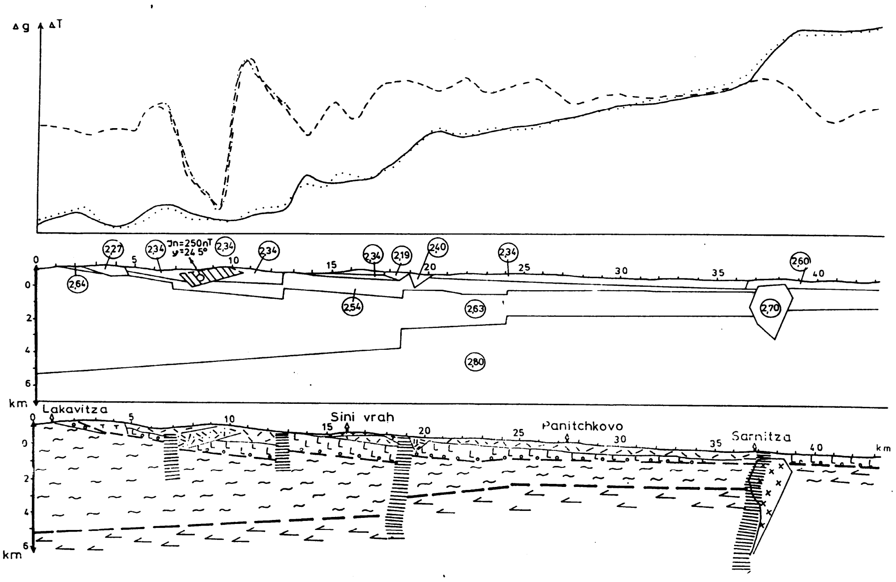

Figure 3. Density and magnetic model and the corresponding geological cross-section along line I-I.

Paleogene sediments	*Quartz-monzonitoid intrusion*
Ignimbrites	*Acid and intermediate acid tuffs*
Rhyolites	*Latites*
Biotite gneisses and gneiss-granites	*High density ophiolite rocks – ampibolites, metagabbro, eclogites*
Fault zones, according to the geophysical data	*2-D density model and the corresponding density value*
a b *Gravity anomalies: a) observed; b) computed*	a b *Aeromagnetic anomalies ΔT: a) observed, b) computed*

2-D magnetic model and the corresponding value J_n and inclination φ of the remnant magnetization

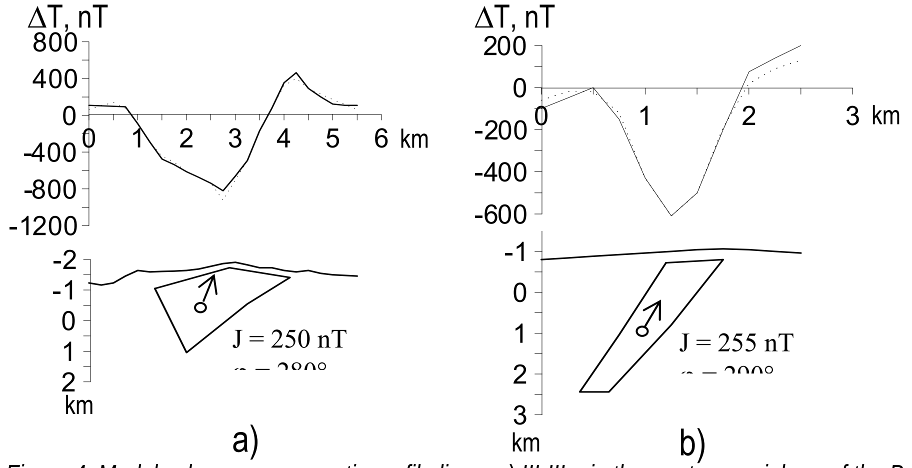

Figure 4. Models along aeromagnetic profile lines: a) III-III – in the western periphery of the Borovitza depression,

a b *Aeromagnetic anomalies ΔT: a) observed, b) computed* — *2-D magnetic model*

J=250 nT φ=245° — *Value J and inclination φ of the remnant magnetization vector*

CONCLUSION

- According to the geophysical data, the Borovitza depression is determined as a northeast trending complex structure of elliptical shape. The established sinking of the metamorphic basement along steeply dipping concentric faults and the presence of radial faults suggests that it might be considered as a calderas-type structure. The Bezvodno-Novakovo NW fault zone is outlined and it is interpreted as a south extension of the Dolnoslav regional fault zone within the Borovotza depression. The two fault zones are considered to be fragments of a common more regional structure which is expressed to the south by the Central Rhodope gravity gradient. The Bezvodno-Novakovo fault zone divides the Borovitza depression into two parts - the Western and the Eastern that have different geophysical characteristics, associated with differences in the composition and the thickness of the Tertiary volcanic cover.

- The geophysical data reveals the presence of large volcanic centers and associated hydrothermal alteration in the vicinity of the Bezvodno-Novakovo fault zone near the village Tri mogili and Saraiar dere. They may be considered as possible indices of concealed ore mineralizations at depth. More interesting is the southern part of the Tri mogili structure because of the inferred uplifting of the boundary between the acid and intermediate volcanics.
- At the northern periphery of the Borovitza depression a large gravity high is associated with an uplifted block of high - density metamorphics named the Topolovo structure. The 2-D density models, constrained by density laboratory information suggest that the Topolovo structure is built up in the upper part of high – density (in average 2,80 g/cm^3) ophiolitic rocks - amphibolites, ultramafics, and schists. Such types of rocks have been established recently at a number of sites in Bulgarian and Greek Rhodopes.

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BULGARIAN BLACK SEA OIL AND GAS - COMMON MYTHS AND UNCOMMON FACTS

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ABSTRACT
First quantitative model estimations of the oil and gas potential of the deep-water western part of the Black Sea basin, based on historico-genetic approach, show a level of hydrocarbon generation as high as in richest regions as the Caspian Sea and Niger Gulfs. But the data available are still insufficient for substantial evaluation - there are no drilling data. Therefore, to make better estimation is equivalent to apply better models, new and last reinterpreted data
The new theories, applied for temperature field reconstruction, are:

- 2D model for basin analysis with sedimentation and fluid flow history reconstruction;
- 2D inverse geothermal problem.

The new data is compilation from published and presented on scientific meetings information from the last ten years. Essentially new are suggestions for temperature field evolution, hydrocarbons migration and deep-sediments geochemistry in the light of last theoretical results and expedition measurements at areas with gas hydrates and mud volcanoes
The reinterpreted data is from in-situ geothermal measurements. These results are corrected accounting for gas hydrates existence
In conclusions, geological objects are classified on the base of their oil and gas potential.

INTRODUCTION

Black Sea – "the world's largest anoxic basin" and "the largest surface water reservoir of dissolved methane" – 96 Tg (Teragrammes; 1 Tg=10^{12} g) (Reeburgh et al., 1991). Moreover, this mass 2.4-6 times greater than the total annual geological methane contribution to the atmosphere (16-40 Tg - Judd et al., 2002).

State of O&G production in BG

Today on Bulgarian shelf are known 2 small fields with some economical value – oil field Tiulenovo (offshore part of found at 1951 coastal field) and Galata - gas field discovered in 1996 (Beckman, 2000).

History of offshore potential evaluation

The hydrocarbon potential is evaluated on the basis of traditional estimates (Bokov, 1979; Monahov et al., 1990) and the historic-genetic approach (HGA - Троцюк, 1982). Published are results from HGA models: for the Bulgarian shelf with 29 estimation points or sites (Геодекян и др., 1984); for the deep Black Sea basin (Гольмшток, Троцюк, Хахалев, 1989); for the Bulgarian continental slope - 9 sites (Троцюк и др., 1990); and more detail estimation for results of the whole Bulgarian offshore - 82 sites (Vassilev, 1995). These studies consider as most highly ranked the early Cretaceous, late Eocene - Oligocene- sediments or Paleocene-Eocene.

DEEP SEA HGA ESTIMATIONS COMPARISON

The historico-genetic approach (HGA) is used for estimation of the masses of generated oil and gas in the western Black Sea area between 27°30'-30°00'E and 42°00'-43°40'N. This area is shortly named Bulgarian in this work although the offshore economical zone of Bulgaria is approximately 33,200 km^2 or 88% from the studied area of 37,800 km^2

The input of the different complexes in the total amount of hydrocarbons (HC) generated by the Cenozoic sediments of the Bulgarian Black Sea sector is:

- Paleocene-Eocene - 76.3%
- Oligocene - 21.9%
- Miocene - 1.7%
- Pliocene - 0.1%

All evaluated sites took part in the process of generation during the last 20 to 65 million years (My) when 98% of proto gases were formed. Approximately 2/3 from the oil mass and 3/4 from the gases are produced in the Paleocene-Eocene sub complex. The quotas of the main morphological elements of the Black Sea basin in the generated gas masses are: shelf – 620 Petagrammes (Pg; 1 Pg = 10^{15} g); slope – 1,356 Pg; rise – 494 Pg; abyss – 1,872 Pg

A clear reflection of a simultaneous acting of all favorable for gas creation factors is the maximum at the sites from the Dolna-Kamchia trough. Their sections are characterized by the greatest thickness of the Eocene sub complex and a great amount of TOC.

The Oligocene sediments play an important role for HC generation in the North part of the slope. The quantity of HC-generation of the Oligocene at these sites is 70-100%. Therefore, the major generators of HC in the Cenozoic section of the examined areas are the Oligocene sediments and the upper sub complex of the Eocene.

In the Cenozoic sections of the Bulgarian continental slope high quantities of generated HC are established within the boundaries of the Dolna-Kamchia trough. Their values tend to increase with the water depths. The best conditions for HC migration and accumulation are supposed to exist in the northernmost flank of the slope.

Table 1. Site numbers, area (zone), latitudes and longitudes

Site #	Area	Lat, deg	Lon, deg	Site #	Area	Lat, deg	Lon, deg
4A	KF	28.70	42.87	7928	WB(r)	29.42	42.98
5A	KF	28.70	42.53	12	WB(r)	29.12	42.88
6A	KF	28.60	42.82	13	WB(r)	29.20	42.80
7A	KF	28.48	42.83	41	WB(r)	29.43	43.23
8A	KF	28.42	42.70	42	WB(r)	29.53	43.15
617	KF	28.93	42.79	44	WB(r)	29.68	43.02
53	KF	29.03	42.35	45	WB(r)	29.90	42.90
54	KF	28.85	42.48	67	WB(r)	29.08	42.10
55	KF	28.65	42.62	78	WB(r)	29.82	43.17
56	KF	28.58	42.68	79	WB(r)	29.98	43.05
68	KF	28.92	42.08	89	WB(r)	29.17	43.05
69	KF	28.80	42.02	90	WB(r)	29.33	42.95
70	KF	28.65	42.03	91	WB(r)	29.48	42.83
71	KF	28.78	42.78	101	WB(r)	29.07	42.58
111	KF	28.48	42.58	1G	WB(r)	29.67	43.28
113	KF	28.90	42.35	2G	WB(r)	29.68	43.18
114	KF	29.02	42.22	3G	WB(r)	29.45	43.05
7G	KF	29.02	42.83	4G	WB(r)	29.78	43.37
9G	KF	28.77	42.28	5G	WB(r)	29.83	43.23
5S	KF	28.27	43.91	6G	WB(r)	30.08	43.27
6S	KF	28.12	42.90	8G	WB(r)	29.28	42.83
7S	KF	28.17	42.84	14	WB(a)	29.37	42.68
8S	KF	28.29	42.72	15	WB(a)	29.48	42.58
3L	KF	27.85	43.02	16	WB(a)	29.63	42.47
1A	NS	29.63	43.42	18	WB(a)	29.85	42.33
2A	NS	28.86	43.04	19	WB(a)	29.95	42.27
3A	NS	28.70	42.97	22	WB(a)	29.63	42.10
5	NS	28.75	43.12	52	WB(a)	29.27	42.20
6	NS	28.80	43.08	92	WB(a)	29.78	42.62
10	NS	28.92	43.02	93	WB(a)	29.98	42.48
32	NS	29.23	43.35	102	WB(a)	29.25	42.42
34	NS	29.12	43.25	103	WB(a)	29.47	42.25
35	NS	29.18	43.15	104	WB(a)	29.62	42.20
36	NS	28.97	43.10	1S	MP	29.07	43.65
40	NS	29.33	43.28	2S	MP	28.58	43.33
61	NS	28.93	43.13	3S	MP	28.44	43.23
65	NS	28.93	42.97	4S	MP	28.18	43.05
74	NS	29.38	43.40	1L	MP	28.47	43.40
76	NS	29.50	43.40	2L	MP	27.80	43.20
7904	WB(r)	29.97	43.30	4L	BK	27.62	42.58

Shown tables discuss differences in data between authors.

The total organic carbon (TOC) is calculated from 11 polynomials of 3 degree, with respect to the age of rocks. For each site and age interval corrections for the sedimentation rate are made. In the Paleocene-Eocene sediments the average TOC varies in wide range from 0.01% to 0.74% (average - 0.34%). This changeability is determined by the increase of the sedimentation rate from very low value (1 m/My – site 2L near Varna) to moderate one (>300 m/My in site 101 at the abyssal plain). It is important to note the good correlation of the estimated TOC (0.7% at site 67) with the results of measurements in the closest Turkish offshore wells Igniada and Karadeniz. This fact, as well as the coincidence between the results of calculations and sample analysis in Samotino area shows the high precision of this prognosis.

Low level of TOC (especially the average value of 0.17% for sites 6A and 7A) is characteristic for the Oligocene sequences. This is the main difference from the previous results based on lithological types extrapolation – average 0.98% for the same sites. New TOC concentrations are with bigger variations caused by the sedimentation rates - from 1.

Table 2. Correlation of predicted in this paper different age sediment thickness and quoted or measured from Tugolesov et al. (1985), Monahov et al. (1990) and Trotsjuk et al. (1990)

			Qu				***Pl***		***Mi***		***Ol***		***Eo+Pa***	
Site #	**ID**	**Name**	**Predicted V*t, km**	Quoted Trotsju	Measured Tugolesov	Measured Monahov	**Pred V*t, km**	Quot	**Pred V*t, km**	Quot	**Pred V*t, km**	Quot	**Pred V*t, km**	Quot
1A	NS	1	**1.096**	1.400	1.800	2.329	**0.781**	1.050	**0.635**	0.800	**1.040**	0.350	**0.380**	1.550
2A	NS	2	**0.374**	0.500	0.727	0.800	**0.314**	0.600	**0.220**	0.700	**0.960**	0.300	**0.400**	0.600
3A	NS	3	**0.356**	0.400	0.633	0.667	**0.463**	0.600	**0.231**	0.500	**0.992**	0.600	**1.000**	1.400
4A	KF	4	**0.484**	0.400	0.704	0.758	**0.441**	0.500	**0.708**	0.400	**1.035**	0.700	**2.295**	2.800
5A	KF	5	**0.406**	0.650	0.700	0.708	**0.267**	0.200	**0.589**	0.600	**1.332**	1.900	**6.557**	4.700
6A	KF	6	**0.485**	0.750	0.655	1.000	**0.466**	0.500	**0.680**	0.500	**0.877**	0.550	**2.756**	3.350
7A	KF	7	**0.485**	0.900	0.554	1.000	**0.731**	0.500	**0.376**	0.300	**0.598**	0.400	**2.229**	1.800
8A	KF	8	**0.323**	0.600	0.547	0.980	**0.707**	0.450	**0.376**	0.200	**0.477**	0.300	**3.786**	3.600
		Sum, km	**4.010**	***5.600***	***6.320***	***8.241***	**4.170**	***4.400***	**3.816**	***4.000***	**7.312**	***5.100***	**19.403**	***19.800***
		Pr/Qu, %		**72**	**63**	**49**		**95**		**95**		**143**		**98**
1S	MP	1I	**0.387**		0.000	0.395	**0.419**		**0.268**		**0.260**			
2S	MP	Nanevo	**0.165**	0.000	0.000	0.000	**0.341**		**0.208**	0.155	**0.071**	0.073		0.120
3S	MP	Elizavetino	**0.186**	0.110	0.000	0.000			**0.183**	0.119	**0.279**	0.059		0.073
4S	MP	1III	**0.152**		0.000	0.000	**0.341**		**0.287**		**0.480**		**0.188**	
5S	KF	BG1	**0.242**		0.214	0.331	**0.620**		**0.242**		**0.526**		**1.906**	
6S	KF	Samotino E	**0.155**	0.030	0.030	0.000	**0.213**		**0.241**	0.220	**0.526**	0.508	**2.849**	2.650
7S	KF	Samotino S	**0.157**	0.045	0.148	0.222	**0.246**		**0.218**	0.210	**0.476**	0.473	**2.939**	2.880
8S	KF	BG2	**0.232**		0.385	0.510	**0.407**		**0.298**		**0.111**		**3.008**	
22	WB(a)	380	**0.574**	0.627	0.894	1.042	**0.509**	0.237	**1.305**	>.213	**3.280**		**4.500**	
		Sum, km	***2.250***		***1.671***	***2.500***	***3.098***		***3.250***		***6.010***		***15.390***	

Table 3. A comparison between the predicted in this paper values for Corg content and these from Trotsyuk et al. (1990)

			Qu		***Pl***		***Mi***		***Ol***		***Eo+Pa***	
			Pred	Quot	**Pred**	Quot	**Pred**	Quot	**Pred**	Quot	**Pred**	Quot
Site #	**ID**	**Name**	**Corg, %**		**Corg, %**		**Corg, %**		**Corg, %**		**Corg, %**	
1A	NS	1	**0.73**	0.4	**1.19**	0.8	**0.46**	0.7	**0.19**	0.8	**0.03**	0.4
2A	NS	2	**1.62**	1.2	**0.62**	1.6	**0.16**	0.5	**0.17**	0.8	**0.03**	0.2
3A	NS	3	**1.63**	1.2	**0.91**	1.6	**0.17**	0.5	**0.18**	1.0	**0.08**	0.3
4A	KF	4	**1.49**	1.2	**0.87**	1.6	**0.51**	0.5	**0.18**	1.1	**0.18**	0.4
5A	KF	5	**1.58**	1.5	**0.53**	1	**0.42**	0.6	**0.24**	1.4	**0.71**	0.5
6A	KF	6	**1.49**	1.2	**0.92**	1.6	**0.49**	0.5	**0.16**	1.0	**0.22**	0.5
7A	KF	7	**1.48**	1	**1.22**	1.6	**0.27**	0.2	**0.11**	1.0	**0.18**	0.4
8A	KF	8	**1.47**	1.2	**1.23**	1.6	**0.27**	0.9	**0.09**	0.8	**0.30**	0.5
Min			**0.73**	0.40	**0.53**	0.80	**0.16**	0.20	**0.09**	0.80	**0.03**	0.20
Max			**1.63**	1.50	**1.23**	1.60	**0.51**	0.90	**0.24**	1.40	**0.71**	0.50
Average			**1.44**	1.11	**0.94**	1.43	**0.34**	0.55	**0.16**	0.99	**0.22**	0.40
AvP/AvQ			**1.29**		**0.66**		**0.62**		**0.17**		**0.54**	

Table 4. A comparison between the predicted in this paper density and these from Trotsyuk et al. (1990) and measured in samples from 3 sea boreholes

			Qu		***Pl***		***Mi***		***Ol***		***Eo+Pa***	
			Pred	Quot	**Pred**	Quot	**Pred**	Quot	**Pred**	Quot	**Pred**	Quot
Site #	**ID**	**Name**	**Density, g/cm3**		**Density, g/cm3**		**Density, g/cm3**		**Density, g/cm3**		**Density, g/cm3**	
1A	NS	1	**1.91**	1.90	**2.17**	2.40	**2.31**	2.50	**2.43**	2.60	**2.50**	2.65
2A	NS	2	**1.77**	1.60	**1.90**	1.80	**1.99**	2.30	**2.15**	2.40	**2.29**	2.50
3A	NS	3	**1.77**	1.60	**1.92**	1.80	**2.03**	2.00	**2.19**	2.20	**2.36**	2.50
4A	KF	4	**1.79**	1.60	**1.96**	1.80	**2.12**	2.00	**2.30**	2.20	**2.50**	2.50
5A	KF	5	**1.78**	1.60	**1.90**	1.70	**2.04**	2.20	**2.26**	2.50	**2.61**	2.67
6A	KF	6	**1.79**	1.70	**1.96**	2.10	**2.13**	2.20	**2.29**	2.30	**2.51**	2.58
7A	KF	7	**1.79**	1.70	**2.00**	2.20	**2.15**	2.30	**2.26**	2.40	**2.46**	2.58
8A	KF	8	**1.76**	1.60	**1.95**	1.90	**2.11**	2.20	**2.21**	2.30	**2.50**	2.50
		Average	1.79	1.66	1.97	1.96	2.11	2.21	2.26	2.36	2.47	2.56
		Dp/Dq	**1.08**		**1.00**		**0.95**		**0.96**		**0.96**	
2S	MP	Nanevo	**1.73**		**1.83**	300/1.5	**1.93**		**1.97**	310/1.7		
6S	KF	R-1 Samotino Et	**1.72**		**1.80**		**1.89**		**2.01**	1.70	**2.37**	2.20
7S	KF	R-1 Samotino S	**1.72**		**1.81**		**1.89**		**2.01**	1.65	**2.37**	2.20

Table 5. A comparison between the predicted in this paper values for thermal conductivity and these from Trotsyuk et al. (1990)

			Qu		***Pl***		***Mi***		***Ol***		***Eo+Pa***	
Site #	**ID**	**Original Name**	**Predicted L, W/m.deg**	Quoted	**Predicted L, W/m.deg**	Quoted	**Predicted L, W/m.deg**	Quoted	**Predicted L, W/m.deg**	Quoted	**Predicted L, W/m.deg**	Quoted
1A	NS	1	**1.27**	1.20	**1.50**	1.60	**1.61**	1.60	**1.71**	1.70	**1.77**	1.75
2A	NS	2	**1.16**	0.90	**1.27**	1.20	**1.34**	1.40	**1.48**	1.60	**1.59**	1.60
3A	NS	3	**1.16**	0.90	**1.29**	1.20	**1.38**	1.30	**1.51**	1.40	**1.66**	1.63
4A	KF	4	**1.18**	0.90	**1.32**	1.20	**1.46**	1.30	**1.61**	1.40	**1.77**	1.66
5A	KF	5	**1.16**	0.90	**1.27**	1.00	**1.39**	1.40	**1.57**	1.60	**1.86**	1.76
6A	KF	6	**1.18**	1.00	**1.32**	1.30	**1.46**	1.40	**1.59**	1.50	**1.78**	1.68
7A	KF	7	**1.18**	1.00	**1.36**	1.40	**1.48**	1.50	**1.57**	1.60	**1.73**	1.65
8A	KF	8	**1.15**	0.90	**1.31**	1.20	**1.44**	1.40	**1.53**	1.60	**1.77**	1.66
		Average	1.18	0.96	1.33	1.26	1.44	1.41	1.57	1.55	1.74	1.67
		Dp/Dq	**1.23**		**1.05**		**1.02**		**1.01**		**1.04**	

Table 6. A comparison between the predicted in this paper temperatures and these from Trotsyuk et al. (1990) and Erickson & Von Herzen (1978)

			Qu		***Pl***		***Mi***		***Ol***		***Eo+Pa***		
			Predicted	Quoted	**Predicted**	Quoted	**Predicted**	Quoted	**Predicted**	Quoted	**Predicted**	Quoted	
Site #	**ID**	**Name**	**T, °C**		**T, °C**		**T, °C**		**T, °C**		**T, °C**		
1A	NS	1	**39**	49	**57**	75	**81**	111	**119**	126	**132**	190	
2A	NS	2	**26**	39	**41**	69	**51**	105	**90**	119	**105**	146	
3A	NS	3	**26**	32	**47**	59	**57**	86	**96**	117	**132**	178	
4A	KF	4	**31**	32	**53**	57	**85**	79	**128**	115	**213**	236	
5A	KF	5	**24**	40	**35**	54	**57**	115	**99**	175	**277**	364	
6A	KF	6	**27**	42	**46**	63	**71**	88	**101**	114	**184**	259	
7A	KF	7	**27**	53	**56**	73	**70**	86	**90**	102	**159**	209	
8A	KF	8	**24**	42	**55**	64	**70**	73	**88**	86	**212**	224	
		Average	28	41	49	64	68	93	101	119	177	226	***Average***
		Dp/Dq-1, %	**-0.32**		**-0.24**		**-0.27**		**-0.15**		**-0.22**		**-0.24**
			T, °C										
22	WB(a)	380	**30**	29	**51**	46	**99**	93	**202**	172	**336**	330	***Average***
		Tpr/Tqu-1, %	***0.05***		***0.10***		***0.07***		***0.17***		***0.02***		***0.08***
			H(pr), km										
			0.574		**1.083**	0.912	**2.398**		**4.678**	0.020	**9.178**		**4.500**
			Qu		***Pl***		***Mi***		***Ol***		***Eo+Pa***		

			Predicted	Quoted	**Pred**	Quot	**Pred**	Quot	**Pred**	Quot	**Pred**	Quot									
			T, °C																		
22	WB(a)	380	**11.6**	10.5	**12.9**	12.8	**14.3**	16.8	**15.4**	14.8	**17.1**	16.6	**20.0**	19.4	**22.8**	22.4	**26.3**	25.1	**9.05**	8.59	***Average***
		Tpr/Tqu-1, %	***0.10***		***0.01***		***-0.15***		***0.04***		***0.03***		***0.03***		***0.02***		***0.05***		***0.05***		***0.02***
			H(meas), m																		
				67.5		104.5		142.5		171.0		218.5		294.5		370.5		465.5		0.0	

DATA

New (last 10 y)

Last 10 years are without brand new specialized measurements data. Absent deep structure results from OBS, this could clear the geological history, or satellite's images in different ranges for direct gas or oil slicks detection. But new data appears in closest north and east areas – heat flow, geological sampling, gas contents, etc. These data is from expeditions looking for gas hydrates, mud volcanoes, gas vents and other phenomena, connected with global climate change.

Reinterpreted – GH existence corrections

Most interesting are possible corrections in heat flow data, because measurements, used methods and probes are from time when wide spread of gas hydrates was unthinkable. But all primary measurements records are destroyed (private information) and now possible are only theoretical approximations.

Such revisions are needed in all research areas, accounting last 10 years information explosion and huge new DB appearing.

NEW MODELS

2D basin

Sophisticated basin analysis programs with load temperature, TOC, sedimentation and mass transport determination procedures, with implementation of HGA and Lopatin's method, using small space and time step could create series of realistic scenarios and potential estimation.

2D inverse T

Inverse problem theory in marine geothermy will become a power tool firstly for gas hydrate research and then for the purposes of oil & gas industry.

CONCLUSIONS

New models must apply all known reliable or reprocessed data or useful methods. For example:

- The vitrinite reflectivity in the Paleozoic and Mesozoic sediments on shelf (Николов, 1993) and territory of Bulgaria (Велев и др., 1997; Велев, 2002; Велев, Ранкова, 2002), which are of critical importance also for the prospectivity of the pre-Paleogene regional formations (remain out of the vision for most of the petroleum geologists). These results suggest that probably on wide Bulgarian shelf areas, the enriched with organic matter pre-Paleogene formations from the south part of Moesian platform and Balkanides, had realized early the bigger part of their potential and then stay as a chemically passive witness of the basin sinking.
- To create detail reconstruction with Lopatin's method of maturity process using recommendation of Waples (1980).
- There are known unsuccessful attempts are for lower concentration oil phase's emigration modeling (Welte, Yalcin, 1988) and therefore we consider as potential oil source only the rocks with organic matter content over 1% (clays, argillites and clayey alevrolites, and rarely - marls).

Still looking their answers next conclusions:

1. Formations older than Paleogene are not important in hydrocarbons generation.
2. Main source are the rocks of “Maikop formation” (Mainly Oligocene).
3. They are relatively enriched with organic matter.
4. Higher than 1% contents of TOC demonstrate mainly pelites’ rocks of series.
5. From geothermal research Oligocene sediments are on different points of lithogenetic transformation.
6. In most general plan the movement of generated in series hydrocarbons is directed from locations of depocentres of Oligocene and Quaternary sedimentation.
7. Known 3 regional estimation of generated HC in the deep water Bulgarian part of the Black Sea give max and average values:

- Троцюк, 1990 – $11.9.10^6$ t/km^2 & $2.5.10^6$ t/km^2;
- Vassilev, 1995 –$16.0.10^6$ t/km^2 & $3.5.10^6$ t/km^2;
- Velev et al. 2003 - $1.3.10^6$ t/km^2

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BULGARIAN NATIONAL PROGRAM FOR GAS HYDRATES RESEARCH

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ABSTRACT
Results present model estimations of the Black Sea MHs and Draft of Bulgarian National Program for GHs on the base of the US National MH Multi-Year R&D Program Plan from 1999.
MHs represent an enormous gas resource. The estimate of 20.10^6 km^3 worldwide is many times the estimated oil and gas. For the Bulgaria, resources are estimated in the range $1\text{-}10.10^3$ km^3. In the same time we are dependent on imports for 70% of energy supplies. In 2000, total oil and gas production and consumption in equivalent natural gas are 0.06 and 12.14 km^3. If the production of methane is economically viable, a long-term energy security for centuries would be ensured, and environmental quality would be improved.
The Program must coordinate research to: (1) estimate GH resources; (2) obtain/develop technology for production of methane from hydrates; (3) understand the roles of hydrates in the global carbon cycle and global climate change; and (4) respond to industry for safety and sea floor stability, currently associated with the exploration, production, and transportation of conventional hydrocarbons. The Program is framed as four technology areas which will share data, concepts, and results.

INTRODUCTION

In the 1950s, Arthur C. Clarke wrote a novel in which energy was harvested deep in the Gulf of Mexico by submarines. Today fantastic became reality. One strange methane source – gas hydratess (GHs) - is most interesting object in the field of geo-sciences. And most money are spent for their research. Because clathrates – other name for these geological phenomena – are not only interesting, but in close dependence to humanity fate: its economical prospect and environmental conditions. But even between geo-scientists could found specialists, which haven't heard of them. What to say about wide public, state and private companies' managers, teachers, students and professors, inventors, ministries? After 20 years, all they and we will use, know, work and take in account GHs. The place between developed and developing countries; the prosperity of a nation and quality of life will be determined from our knowledges, skill and technologies to research and develop them. Or not?

Only a NPGH Research and Development (RD) will allow a country to follow right direction – the direction of prosperity. US, Great Britain, Germany, France, Japan (from 1995 5-years program for over $50 millions; now – second 5-years plan) and India started their programs. Some of them include as one of most perspective regions the Black Sea. More than dozen European scientific projects are carried out or plan expeditions for GHs research here.

As a result of this analysis the author develop proposal for creation draft NPGHRD in the frame of EC funded project "Centre for Sustainable Development and Management of the Black Sea Region" (CESUM-BS - ICA1-1999-70075).

GHs History

GHs have been discovered experimentally in 1811 by Sir Humphry Davy (chlorine bubbling in cold fresh water). Later (1832) Michael Faraday has established first chemical formula of GHs. In 1934 the phenomenon of pipeline blockage by hydrates was described in the USA by Hammerschmidt. In 1948 Strizhov has published assumption about GHs spreading in permafrost areas. In 1959 van der Waals and Platteeuw have published first fundamental thermodynamic description of GH phase. In 1970 a group of Soviet researchers initiated by Yuriy Makogon has registered the discovery of the possibility of GHs existence in the Earth crust. In 1972 natural GHs for the first time have been recovered in the Black Sea (Yefremova, Dgidgenko, 1974).

What is MH?

Methane hydrates (MHs) are type of natural formation that contains water and large amounts of methane, in the form of ice. From a scientist's point of view, MHs are crystalline solids that form under moderate pressure (for the Black Sea pure MHs exist at water depths greater than 500 meters) and at temperatures above the freezing point of water.

Why is it important to study MHs?

Hydrates are potential future energy resource; factor for climate change (a source and a sink for atmospheric CH_4); seafloor areas with hydrates are less stable; hydrates cause blocking in underwater gas pipelines; could be used to increase the volumes of gas in storage; they are markers for oil deposits; may be an alternative to pipeline as a way to move gas; could be used to patch leaks in underwater pipelines; might be used as a vehicular fuel, especially for ships or to drive machinery without affecting the energy content of the gas…

How much hydrate is there?

There is no definitive answer to this question at this time. However, the worldwide amount of carbon bound in GHs is estimated to total twice the amount of carbon to be found in all known fossil fuels on Earth and measured in petatons (10^{15} tons). Theoretically, one volume of pure MH should yield about 164 volumes of methane and 0.8 volumes of water. In nature, it is more typical to get 158 or so volumes.

'Gasbergs': How do we study them?

Drilling and submarines are best, but expensive. Seismic is most popular. The contrasts in velocity created by the hydrate-cemented zone produces a strong reflection called BSR "bottom simulating reflection". “Blanking” is the reduction of the amplitude of seismic reflections that is caused by cementation by hydrate of the strata. The blanking can be quantified to estimate the amount of GH.

Questions

To understand the role of the Black Sea GHs must be found answer of many questions: When do MHs appear in the Black Sea? What is their evolution? Where to look for relict MHs? Is it possible to reconstruct a "frozen" geological history of the basin by analyzing their structure? What is their role in the carbon budget, hydrocarbon migration, sea bottom relief origin and contribution to the atmospheric greenhouse gases?

SUMMARY OF PROPOSAL FOR NPGHRD CREATION

Problem Description

Absence of information even in academic environment and eco-journalists about the nature of the gas GH and their importance. Absence of an evaluation for the GH deposits and their distribution area in the Bulgarian Black Sea part. And as a result - absence of a NPGHRD - foundation for significant social, structural, technological and economical progress.

Target Groups and Beneficiaries

- The Bg population (20%) and the civilian organisations (20%) and mainly from the beach districts (aims: eco-education and culture (EEC); civilian activity (CA));
- Representatives of the municipality, district and state administration (30 - 100) (aims: effectively utilization of nature resources (EUNR); improvement of the environment (EE); EEC; CA; structural and social changes planing (SSCP));
- Business Leaders (EEC; CA; SSCP);
- Academic environments and eco-journalists - (professional qualification; alternative energy and raw material sources research).

Project Goals and Objectives

- Foundation of a NP, which to be proposed to the Ministry of Environment and Water. Its approval and realization would secure a durable ecological, social, economical and re-structural effect for gradually increased parts of population and varied organizations.
- The program is a base for introducing an ecological alternative energy and raw material resource) and stable growth of new and restructuring organizations and revealing of new positions for various high skilled specialists;
- Execution of the Frame Convention of OON about global climate change (1995) and the Convention for public participation in the process of decision making (1998);

Project Activities

- Identification / Inventory / Archives creation / Inquiry
- Model quantitative predictions / Results acquaint / Public discussion
- Draft program / Social discussion / Standartization
- Working out project report

1. Identification / Inventory / Archives creation / Inquiry

- Creation of project library - sources inventory: bibliographical, data bases, video tapes, Internet resources (on the whole 3 months (m); will grow and after the project);
- Creation of data base with the addresses of interested persons and organizations (parliament commissions, ministries, state and private organizations, media - press, TV) - "participants" (on the whole 1.5 m);
- Carry out an inquiry to find out concepts of participants about the content of such NP. Analysis publication of results in Internet for discussion enrich (on the whole 1.5 m)

2. Model quantitative predictions / Results acquaint / Public discussion

- Developing mathematical model for GH reserves prediction and data base with the necessary input information (6 m);
- Programming, tests, numerical experiments and graphical visualization of the results. Model accuracy estimation through re-interpretation of seismic records (on the whole 12 m);
- Building up academic report:"Model Estimation of GH reserves and distribution in the Bulgarian Black Sea Part", 20 copies preparing and sending to participants (2.5 m); report publication in Internet (0.5 m);
- Design, printing (500 - 1,000 copies) and distribution of a booklet (A4, 2 sided, color) with general results, Internet links and addresses for opinions and discussions (3 m).

3. Draft program / Social discussion / Standartization

- Study of the existing programs and creation draft NP GH (1st edition) through compilation and render an account of collected information. Copies preparation, sending; Internet page; discussion, analysis (2 m);
- Creation draft NP GH (2nd edition); copies; sending; Internet; discussion, analysis (2 m);
- Organize and carry out a work meeting for creation NP GH (3rd edition) with presence of representatives of applicants and media. Copies; sending; Internet publication (2 m)

Expected Results

Social Heighten civil knowledge for local and global factors determined the environmental quality; heighten the ability to affect; cultivate tolerance between social groups and organizations; heighten civil responsibility of the municipality and ministry administration; stimulate the dialog citizenship - NGO - academic sphere - media - authority; overcome apathy and desire for anonymous of participants and heighten their citizen activity.

Intellectual Product Project library; published materials; GH model and results; Draft Bg NPGH in the Black Sea.

ESTIMATION OF BULGARIAN BLACK SEA GHs

4D model of the MHSZ in the Black Sea during the Quaternary realized a simplified paleo-climate, focusing on the abrupt temperature and sea level changes. Major model advantages are the long period (allowed correct initial thermal conditions setting), detail 1' calculation and bottom depths grid (for better relief effect accounting), reinterpreted data from heat flow measurements (for possible hydrate existence), non-stationary processes equation accounting the heat of hydrates creation and dissociation.

The data are processed by applying different parameters depending of the geology and tectonic evolution of the area; sedimentation rates; submarine fans and canyons; and evidences of gas seepages, pockmarks and mud volcanoes. The equations governing the MH stability curve are also conformable to Hydrogen Sulphide content and salinity of the bottom and pore waters.

The estimations are based on the two main theories of GH formation - in situ bacterial production and pore fluid expulsion models. The implications of these models on atmospheric methane release or massive slumping and liquefaction, are briefly examined.

Models (Vassilev, Dimitrov, 2000;2002; 2003; Dimitrov, Vassilev, 2002; Poort, Vassilev, Dimitrov, 2002) predict the volume of MH stability zone (MHSZ) in the Black Sea of about 100,000 km^3, or 77-350 km^3 pure MHs with $10\text{-}50.10^3$ km^3 of gas Methane. This amount seems to be too high, even the total Black Sea resources of conventional hydrocarbons are in magnitude lower - about $3.5.10^3$ km^3.

The equilibrium model for the Last Glacial Maximum (LGM) suggests a drastic reduction of the reservoir volume (15-62%) since the LGM. Taking into account the process of climatic heat wave propagation in the sediments, the model predicts a present MHSZ enlarging in the frame of method accuracy. However, the temperatures at depth of 200 and 500 m under the bottom will reach 90 % of the temperature equilibrium 200 to 1,000 Ky after LGM and we must run models for longer time periods.

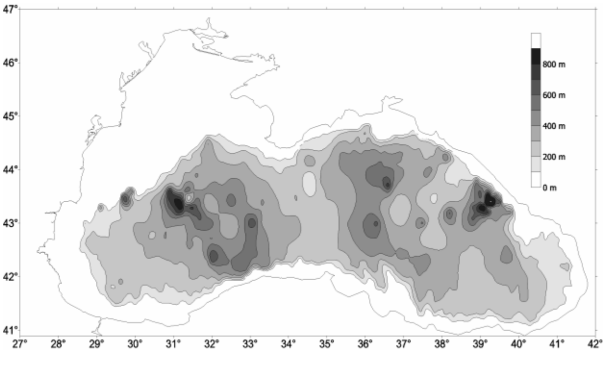

Figure. 1. The Black Sea hydrate stability zone thickness (m) calculated with in situ *measured temperature gradients*

Bulgarian natural gas consumption

In May 2001, Bulgaria signed a 25-year concession agreement with Patreco of the United Kingdom for exploration and extraction of natural gas. The area covered by the agreement is Bulgaria's sector of the Black Sea, including the Galata deposit which has estimated reserves of 53 Bcf. Beginning with 2002, Patreco plans to extract 14 Bcf of gas per year.

But Bulgaria is dependent on imports for 70% of its energy supplies. With virtually no supplies of oil and small reserves of gas, Bulgaria has had to pay for energy in hard currency at world market prices, resulting in less reliable supplies.
In 2000, oil production was 1,000 barrels per day (b/d) (159 m3 – 58,000 m3/y – 0.057 km3/y gas) and 0 gas, Petroleum consumption in Bulgaria in 2000, was 117,000 b/d (or equivalent gas – 6.64 km3/y) and gas 0.193 Tcf (5.5 km3/y).

So, in 2000, total oil and gas production and consumption in equivalent natural gas are 0.06 and 12.14 km^3. If the production of methane is economically viable, a long-term energy security for centuries would be ensured, and environmental quality would be improved.

DRAFT NPGHRD – 1ST EDITION

The author offer as first Bulgarian NPGHRD to be used the US National MHs Multi-Year R&D Program Plan from 1999 as most detail and logically linked. It would be edited taking in account Bulgarian peculiarities.

The US Plan illustrates how technology is expected to proceed to achieve Program goals. The Federal role provides for the coordination, integration, and synthesis of research efforts to:
(1) estimate gas resources from MHs;
(2) develop the technology for commercial production of methane;
(3) understand the dual roles of MHs in the global carbon cycle and their relationship to global climate change; and
(4) respond to industry concerns the safety, seafloor stability and pipeline plugging which are currently associated with the exploration, production, and transportation of conventional hydrocarbons.

The R&D Program is framed as four technology areas which will share data, theoretical concepts, and results.

The position of the President's Committee of Advisors on Science and Technology (PCAST) in its 1997 *Report on Energy Research and Development for the Challenges of the Twenty-First Century* was that MHs were not being addressed adequately in Office of Fossil Energy (FE), or in other Department of Energy (DOE) R&D programs, and that more emphasis through applicable R&D was needed.

The PCAST suggested first-year funding of $5 million, rising to $12 million in the fifth year. The current consensus of DOE is that a MH R&D program of $150 to $200 million over a ten-year period will be needed to accomplish mission goals.

The relative level of effort in the four technology areas and their changes are depicted in Fig. 2.

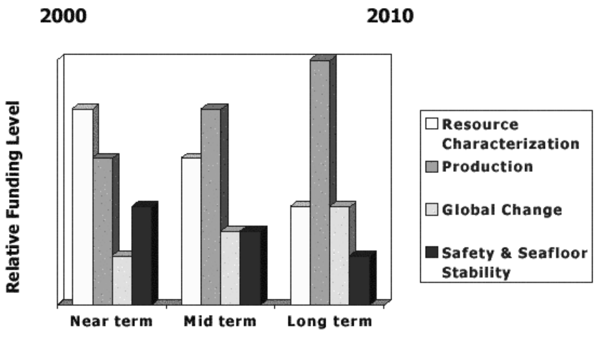

Figure 1 – R & D Funding Evolution

Figure. 2. R & D Funding by technology areas

Near-Term Benefits/Products (Within 5 Years)

- Assessment of the location and volume of MH resources for use in energy policy decision making;
- Techniques to mitigate methane hydrate formation in pipelines and production facilities offshore;
- Improved seismic and other geophysical tools for hydrates identification and characterization for use by the petroleum industry, military, etc.;
- Engineering concepts for production of gas from natural GH deposits;
- Databases containing ocean and atmospheric changes and coupling, for use in global climate modeling, including thermodynamic data applicable to CO_2 sequestration; and
- P-T-controlled sampling devices (which could be a prototype for NASA samplers).

Mid-Term Benefits/Products (5 to 10 Years)

- Improved estimates of recovery potential from the natural GH useful in guiding energy policy and planning;
- Advanced techniques to detect and analyze formation and reservoir systems;
- New or advanced production technologies, including tests of engineering concepts, for production of natural gas.

Long-Term Benefits/Products (10 to 15 Years)

Long-term, the Program will lead to an increased supply of cleaner fuel through development of technologies for commercial production of methane from marine hydrates, based on field testing and verification of improved geophysical technologies, production concepts, and reservoir model development for natural GH recovery.

PLAN-PROGRAM ELEMENTS

Resource Characterization

This key activity will involve the data compilation, field and laboratory studies, and model development necessary to understand and measure natural GH deposits and to assess the methane resource. This work will provide information to all program areas: resource characterization, production, sea floor stability, and environmental issues.

Table 1. Resource Characterization

RESOURCE CHARACTERIZATION

Activities & Sub-elements	Y00	Y01	Y02	Y03	Y04	Y05	Y06	Y07	Y08	Y09
Resource Assessm. (Near-Term)										
Historic / Bibliographic / Contractor Information	■	■								
Geologic Information	■	■	■	■	■					
Physical Property Information	■	■	■	■	■					
Location Map	■	■	■							
Laboratory Studies										
Hydrate Analysis	■	■	■	■	■					
Crystallography Studies	■	■	■	■	■					
Pore Water Chemistry	■	■	■	■	■					
Biochemistry and Natural Gas Hydrates	■	■	■	■	■					
Temporal History Studies	■	■	■	■	■					
Geo-Strata Water Movement and Behavior	■	■	■	■	■					
Thermodynamic Studies in Porous Media	■	■	■	■	■					
Kinetic Studies	■	■	■	■	■					
CO2 Hydrate Study Results Integration	■	■	■	■	■	■	■	■	■	■
Field Geophysical, Geochem., & Microbial Studies										
Seismic Interpretation		■	■	■	■	■	■	■	■	■
Well Logging	■	■	■	■	■	■	■	■	■	■
Geophysical	■	■	■	■	■	■	■	■	■	■
Geochemical	■	■	■	■	■	■	■	■	■	■
Microbial Processes	■	■	■	■	■	■	■	■	■	■
Novel Well-logging Techniques	■	■	■	■	■	■	■	■	■	■
Model Hydrate Properties										
Physical / Chemical Properties	■	■	■	■	■	■	■	■	■	■
Geological Modeling	■	■	■	■	■	■	■	■	■	■
Geophysical Modeling	■	■	■	■	■	■	■	■	■	■
Resource / Reserve Assessm. (Mid-Term)										
Reservoir Natural Gas Quality				■	■	■	■	■	■	■
Reservoir Natural Gas Quantity				■	■	■	■	■	■	■
Associated Free Gas				■	■	■	■	■	■	■
Multi-disciplinary Interaction				■	■	■	■	■	■	■
Economic Validation (Long-Term)										
Production Cost Estimates			■	■	■	■	■	■	■	■
Impact of Resource Development Economics				■	■	■	■	■	■	■
Field Validation		■	■	■	■	■	■	■	■	■
Technology Development										
Development of Seismic, Sonar, & Well-Logging Technologies	■	■	■	■	■	■	■	■	■	■
Develop P-T Controlled Coring	■	■	■	■	■	■	■	■	■	■
Dev. of Monitoring Sensors and Samplers for Subsea Hydrates	■	■	■	■	■	■	■	■	■	■

Production

The goal is to develop the knowledge and technology necessary for commercial production of methane from oceanic hydrate systems.

Specifically, the Program will:

- Develop a basic information necessary for production;
- Conduct reservoir and process engineering and economic analysis;
- Develop and test conventional recovery technologies and evaluate alternative recovery technologies.

Table 2. Production

PRODUCTION

Activities and Sub-elements	**Y00**	**Y01**	**Y02**	**Y03**	**Y04**	**Y05**	**Y06**	**Y07**	**Y08**	**Y09**
Primary Production Research (Near-Term)										
On-Line Production Database										
Sample Characterization & Ident. of Technology Gaps	■	■	■	■	■	■	■			
Obtain Input and Update with Drilling/Program Results	■	■	■	■	■	■	■	■		
Physical Process Modeling										
Sample Review and Lab Measurements	■	■	■							
Develop Production Models	■	■	■	■	■	■	■			
Preliminary Reservoir Engineering										
Onshore Site Selection & Test Design	■									
Offshore Site Selection & Drilling Criteria Specification			■							
Preliminary Production Modeling and Demo. Design										
Analyze Prior/Collaborative Production Test Results	■									
Prelim. Pilot Facility Development		■	■							
Preliminary Commercial & Alternative Methods Evaluation										
State-of-the-Art and Innov. Prod. Methods Evaluation	■	■	■							
Drill Exploratory Onshore Well			■							
Reservoir Simulation and Process Design (Mid-Term)										
Reservoir Engineering										
Select Offshore Sites			■	■	■	■	■			
Develop Field Test Reservoir Model			■	■						
Pilot Reservoir Studies for Model Verification			■	■	■	■	■			
Commercial/Alternative Process Design										
Develop Downhole Instrumentation for Logging Deposits			■	■						
Establish Alternative Production Technology			■	■						
Preliminary Economic Analysis			■	■						
Prod. Testing: Demo. Well & Alt. Prod. Evaluation (Long-Term)										
Process Model Validation										
Calibrate Model with Field Results								■		
Predict Demonstration Well Results									■	
Evaluation of Commercial Potential of Demo. Well Sites										
Drill Sampling Wells to Evaluate Potential Demo. Sites								■	■	
Tech. and Economic Analyses of Potential Demo. Wells								■	■	
Demonstration Well Site Selection Assistance								■	■	
Support for Industry Demonstration Well								■	■	■
Demonstration Production Analysis										■
Evaluate Program Accomplishments										
Select Novel Technology Facility Fabricator								■		
Tech. and Economic Analysis of Industry Demo. Well									■	■
Final Calibration of Production Model									■	■

Global Carbon Cycle

Releases of methane from hydrates add to the atmospheric carbon budget, either as methane, or indirectly as carbon dioxide through chemical/biological oxidation.

Utilization of this resource would provide additional low-carbon fuels - part of a strategy for reducing atmospheric anthropogenic greenhouse gases. This activity seeks to understand and quantify the dual roles of hydrates in the global carbon cycle and their relationship to global climate change.

Table 3. Global carbon cycle

GLOBAL CARBON CYCLE

Activities and Sub-elements	**Y00**	**Y01**	**Y02**	**Y03**	**Y04**	**Y05**	**Y06**	**Y07**	**Y08**	**Y09**
Mechanisms and Processes of Hydrate Flux (Near- to Mid-term)										
Evaluation of Dispersed Hydrates	■	■	■	■	■	■				
Site Monitoring	■	■	■	■	■	■	■	■	■	■
Measurement and Protocol Development	■	■	■							
Impact of Climate Change on Hydrate Stability	■	■	■	■						
Seafloor Stability and Release of Trapped Free Gas		■	■	■	■	■				
Consequences of Methane Release from Hydrates (Mid- to Long-Term)										
Ocean/Atmospheric Studies		■	■	■	■	■	■	■		
Biological Studies			■	■	■	■	■	■	■	
Application to Ocean and Climate Models							■	■	■	■
Methane Release in the Geologic Record (Near- to Mid-Term)										
Compilation of Existing Data	■	■	■							
Development of New Proxies	■	■	■	■						
Application to Ocean and Climate Models			■	■	■	■	■	■		
Integrated Model Development (Long-Term)										
Use Modern and Geologic Data in Ocean and Climate Models							■	■	■	■
Greenhouse Gas Mitigation (Near- and Long-Term)										
Environmental Benefits and Impacts	■	■					■	■	■	■
CO_2 Storage Options	■	■	■	■				■	■	■

Safety and Sea Floor Stability

This activity will be co-developed and integrated with the Resource Characterization effort.

Early emphasis will be focused on near-term solutions of both safety and sea floor stability, due to natural GH occurrence associated with the exploration, production, and transportation of conventional hydrocarbons.

These preliminary models will be upgraded in the mid-term to incorporate subsurface hydrate data obtained from early stage hydrate production modeling efforts.

Findings will be documented in a report on Advanced Mitigation Recommendations, which would conclude the Government's principal research effort to define safety and sea floor stability problems and offer practical solutions (if possible, offering low-cost problem recognition/avoidance solutions.)

Field demonstration and testing of both safety and sea floor stability mitigation technology is envisioned as a cooperative/co-funded effort with the oil and gas industry.

Possible and unpredictable future trends in global warming effects, that could exacerbate safety and/or sea floor stability due to hydrate dissociation, will be monitored and activities adjusted accordingly.

Table 4. Safety and sea floor stability

SAFETY AND SEA FLOOR STABILITY

Activities and Sub-elements	Y00	Y01	Y02	Y03	Y04	Y05	Y06	Y07	Y08	Y09
Basic Research in Safety and Seafloor Stability (Near-Term)	Изследване Високо ниво			Изследване Ниско ниво						
Safety/Risk Factor Research										
Devel. Database of Safety Issues/Incidents										
Devel. Preliminary Models and Predictive Tools										
Devel. Preliminary Mitigation Recommendations										
Seafloor Stability Research	Изследване Високо ниво			Изследване Ниско ниво						
Geological/Geophysical Studies										
Integrate Studies (w/Resource Characterization in 1)										
Develop Prelim. Seafloor Stability Models										
Advanced Safety & Seafloor Stability Model. Devel. (Mid-Term)										
Gas Hydrates Safety/Risk Factor Research Model Devel.										
Develop Advanced Seafloor Stability Models										
Develop Advanced Mitigation Recommendations										
Development & Field Demon./Testing of Safety and Seafloor Stabilty Mitigation Techniques (Long-Term)										
Development of Seafloor Safety Technology										
Field Testing of Safety Technology										
Development of Seafloor Stability Mitigation Tech.										

END OR START?

Look for additional information at http://www.io-bas.bg/gh/

Please, send ANY files to A. Vassilev at gasberg@io-bas.bg:

- Opinions, advices, web links
- Your new or edited parts of the National Program
- CVs of persons or organizations, etc.

Please, send post materials to:
Dr. Atanas Vassilev, IO-BAS, PO Box 152, Varna 9000

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SPECIFICITY OF GEOTHERMAL DRILLING BASED ON OIL AND GAS EXPLORATION COMPANY JASŁO ACTIVITIES

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ABSTRACT
Geothermal Energy is very often an area of interest to local communities and beyond (Poland, EU). The reason for it is the cleanness of such energy and its good accessibility. Therefore, it is possible to receive the energy source in certain area and make the area partly independent from conventional energy providers. The limiting factor is the high cost of making the underground heat available. Drilling of geothermal wells is most often the most expensive part of geothermal projects.
The paper presents technical and technological aspects of drilling geothermal wells, based on Polish and Slovak experience.
The construction of chosen vertical and directional geothermal wells in various geological and reservoir conditions is presented in the paper. Applied bits, drilling mud and drilling technique with a downhole motor, are discussed. Special attention was paid to the difference between geothermal drilling and oil and gas drilling.
The drilling progress results, which are an important factor influencing the geothermal installation cost reduction, close the paper.

INTRODUCTION

Geothermal energy belongs to the renewables, a subject of interest to World's political and economic elites. This is caused by the perspectives of finding new energy sources as well, as ecological and social advantages of geothermal energy. The efficiency of the whole undertaking depends on such factors as geological, hydrogeological and reservoir conditions, development techniques for exploitation and use of thermal waters as well as financing. The management of geothermal energy in the first phase of realization is related with high investment costs, which in the long run are compensated by low costs of exploitation. Among all investment costs, drilling costs are the highest.

DRILLING OF GEOTHERMAL WELLS IN POLAND

The first experimental geothermal well in Poland, Bańska IG-1, was drilled in the Podhale Basin in 1981 in the area where thermal waters reside in fractured carbonaceous Eocene and Miocene rocks at a depth of 2000 to 3200 m. Its productivity is 60 m^3/h at wellhead pressure 2.6 MPa and temperature on outlet ca.72 ^oC. The reservoir temperature ranges between 84 and 90 ^oC. Estimates are made that $4513.5 \cdot 10^{15}$ J thermal energy is gathered in a geothermal reservoir covering an area of 450 km^2. What is advantageous about thermal waters in the Podhale Basin is their very low mineralization, below 3 g/dm^3, and arthesian character.

In 1992 a geothermal doublet made of wells Bańska IG-1 and Biały Dunajec PAN-1, started to operate. It is run by the Experimental Geothermal Station, Polish Academy of Sciences. Geothermal heat is delivered to about 200 customers. Another geothermal doublet (well Bańska PGP-1 and well Biały Dunajec PGP-2) was made by the Oil and Gas Exploration Company Jasło. Apart from drilling works, the whole heat transport infrastructure between Nowy Targ and Zakopane has been provided as well. After setting up the third planned doublet (well PGP-4 and well PGP-5), the heat sale in the Podhale Geothermal should, according to P. Długosz (2001), amount to 1.2 mln GJ at the end of the year 2005. An alternative is taken into consideration to supplement the missing geothermal power by absorption heat pumps and lowering of temperature of water injected to the wells.

To increase the output and absorption properties of geothermal wells, in some cases stimulation procedures are recommended. This, however, mainly depends on the geological-reservoir conditions. According to E. Garbarz and S. Gazda (2001), the acidification procedures carried out in wells PGP-1 and PGP-2 caused penetration of the fluid in the reservoir followed by chemical reactions, which in turn, resulted in the increased productivity from about 88 m^3/h to about 250 m^3/h.

Favourable geothermal conditions can be found on a predominant part of Poland. The activity of Geotermal Station in Pyrzyce is the best evidence of it. In the years 1992 to 1993 NAFTGAZ Wołomin, now part of Oil and Gas Exploration Company Jasło, performed four geothermal wells. These are production wells GT-1 and GT-3, as well as injection wells GT-2 and GT-4. They are sited on the Liassic sandstones in the Lower Jurassic at a depth of 1500 to 1680 m where the thermal water at 62 to 64 ^oC is mineralized to about 110 g/dm^3.

The water table in the wells stabilized at a depth of about 34 m from the surface. Therefore, in order to install deep pumps 9 ½", the casing 9 5/8" in the production wells GT-1 and GT-3 had to overlap with the casing 13 3/8". The pumps were tripped on pipes 8 5/8 to a depth of about 150 m. The injection wells GT-2 and GT-4 were cased with 9 5/8" to the top. The casing shoes in all four geothermal wells were located right under the top of the production layer. Further drilling was carried out with bits 216 mm in diameter and diamond tools 8 ½" of diameter and clay-free polymer mud of a density reaching about 1060 kg/m^3. To improve the conditions of geothermal water flux to exploitation wells and its re-injection to the reservoir, all wells were broadened to a diameter of 420 to 430 mm with a hydraulic reamer. Then, the casing 13 3/8" and 9 5/8" was cleaned with scrubs and the near well zone by a few operations of reservoir water exchange. Johnson filters 6 5/8" made of stainless steel 304L, fractures 0.5 mm and active surface 11 to 14 %, were tripped to these wells. Individual filter sections were so selected as to locate their active parts in sandstone; to properly dispose filters in the well, they were additionally equipped with dielectric centralizers 6 5/8" × 15". Filter sets were equipped with a hanger and device for gravel pack disposal around the filter. They were tripped on mud pipes 3 ½" to the planned depth to be later suspended on a hanger (Fig. 1).

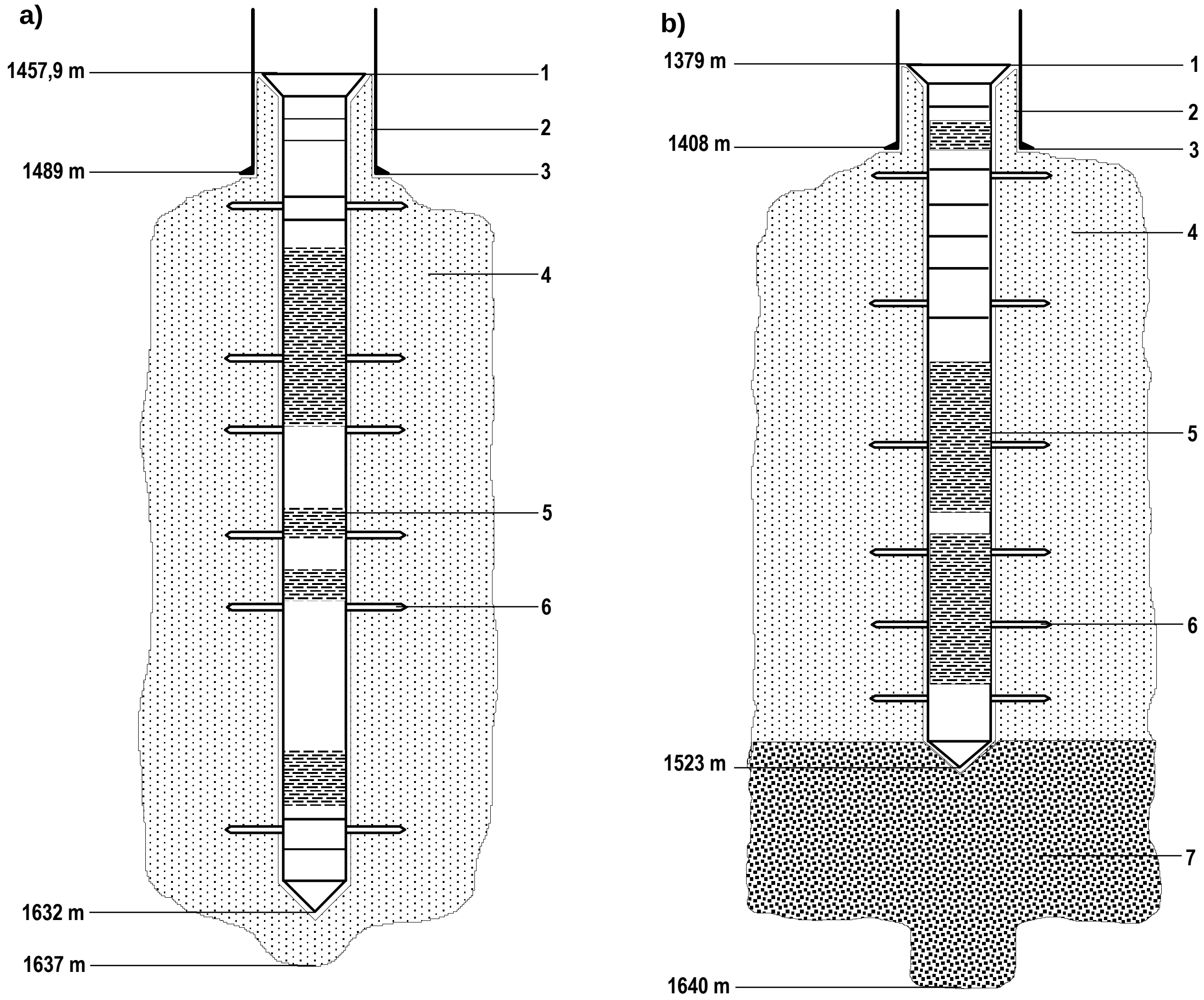

Figure 1. Scheme of: a) thermal water intake by well Pyrzyce GT-1, b) gravel pack filter in the injection well Pyrzyce GT-2 [4]: 1 - hanger + dielectric connection, 2 - protecting sieve, 3 - casing (9 5/8"), 4 - gravel pack (quartz sand 0.8 to 1.4 mm from Biała Góra, near Tomaszów Mazowiecki, Poland), 5 - Johnson filter 6 5/8" 130 Bar slot 0.5 mm, 6 - dielectric centralizers 6 5/8" x 15", 7 - gravel pack 1 to 3 mm.

The gravel pack was selected as to match the grain size of the drilled sandstones and quartz gravel 0.8 to 1.44 mm and 1 to 3 mm, respectively. The pack was very clean and of specific grain size.

The quality of the performed geothermal wells in the initial stage of production can be evaluated on the basis of the results of cleaning pumping operations with the use of air lift. The pumping was realized for three increasing rates from 60, through 90 to 170 m^3/h. The absorption wells received injected water at a maximum rate of 170 m^3/h at wellhead pressure 0.6 to 0.8 MPa. In the years 1990 to 1991 and 1996 to 1997 NAFTGAZ Wołomin performed analogous works in Skierniewice, where at a depth of 2875 to 2945 m and 2997 to 2886 m thermal waters at 68 ^{o}C were found in the Lower

Jurassic sandstones. More detailed information presented J. Kilar et al, 2001.

DRILLING OF GEOTHERMAL WELLS IN SLOVAKIA

In 1997, The Oil and Gas Exploration Company Jasło started drilling operations for Geoterm Kosice, described by A. Gonet et al., 1999. Their objective was to make thermal waters accessible in the area of Durkov, about 15 km from Kosice. First a vertical well GTD-1 was drilled, then two directional wells GTD-2K and GTD-3K were completed with a rig IRI 1200.

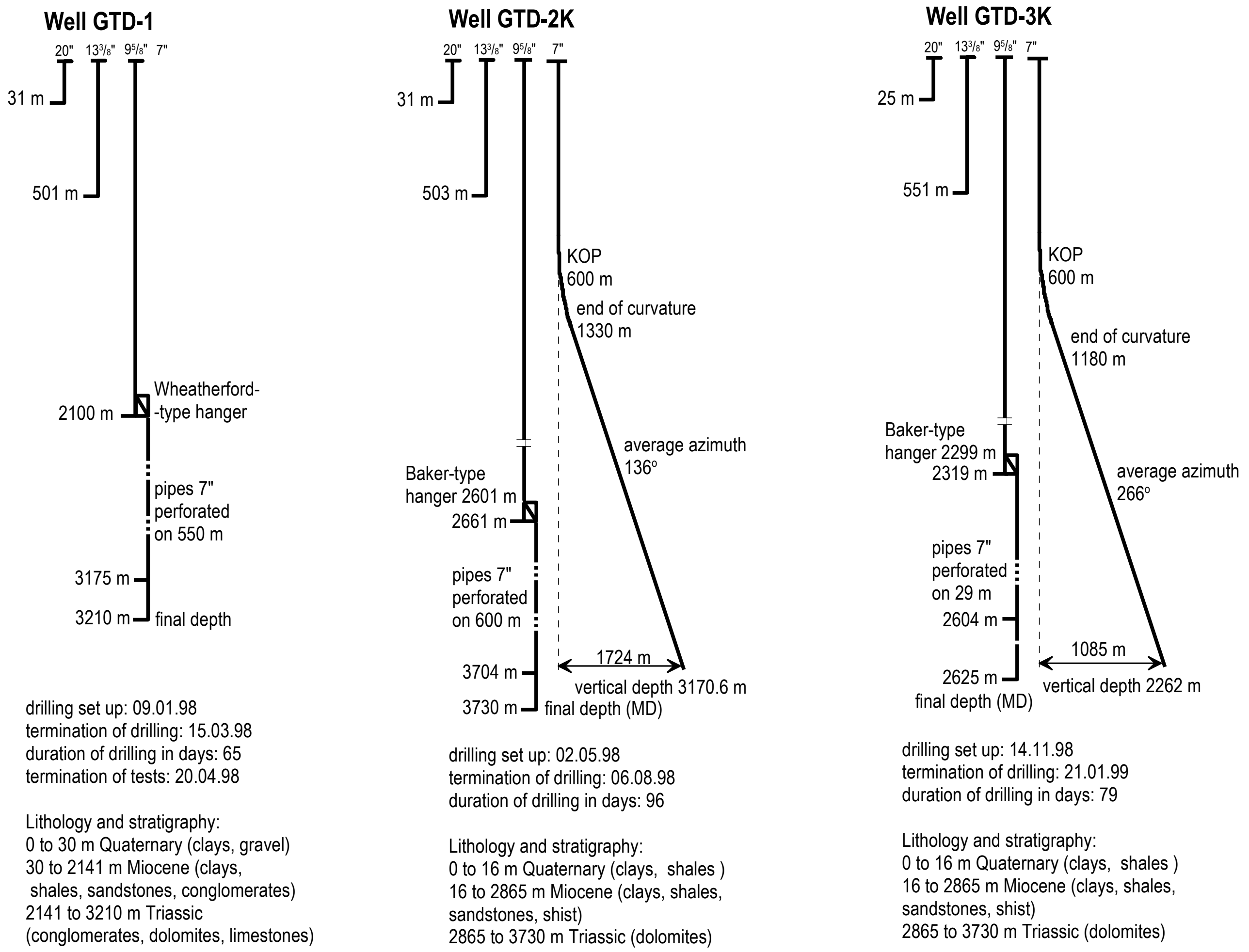

Figure 2. Profiles of geothermal well axes in the region of Durkov [2].

As a result the area of the aquifer intaking has to be increased and surface installment related with thermal waters management shortened.

Among the problems related with drilling of these wells, most prominent is the problem of drilling mud selection, casing, sealing of casing and drilling through the reservoir interval.

Practical experience has confirmed that the use of potassium-polymer mud was the right choice. A good technical state of the well and favourable technical-economic parameters of drilling were obtained. The latter was strongly influenced by the rig with a very efficient mud cleaning system, applied bits and parameters of drilling technology. Additionally, drilling wells were checked for proper lubrication and rheological parameters. When casing, attention was paid to the influence of temperature on elongation of steel pipes and on technology and efficiency of cementing. This manifested in disposal of a casing hanger compensating pipes elongation, and cementation collar to create a pumping chamber at a specific depth in the well. When getting to the aquifer zone, clay-free mud based on biodegradable polymers was used. To avoid colmatation of the aquifer, in the case of lost circulations no blockers or filling materials were applied. In the case of extreme lost circulations chemically treated water was used. The continuity of drilling works required constant water supplies to the rig and correct prevention of the outlet, to avoid eruptions of mineralized hot water to the surface.

Another unfavourable phenomenon in the drilling area was the influence of CO_2 contained in thermal waters, resulting in increasing corrosion and premature fatigue cracking of the string. To limit this unfavourable process, attempts were made to maintain mud pH in the range from 8.5 to 11. Another solution lies in using inhibitors of adsorption-type corrosion or internal lining of the string.

CONCLUSIONS

1. Geothermal energy is more frequently used because of ecological, social reasons. Another important factor is the considerable reserves of thermal energy.

2. When drilling geothermal wells it is recommended to use mud with very low solid content. Not to deteriorate the permeability of the reservoir zone, no blockers or filling materials should be used when drilling through the aquifer. Additionally, it is advisable to use a very good cleaning system for removing cuttings from the drilling mud.

3. Selecting the string, it is necessary to have the recipes for drilling mud, cement slurry and piping to account for the influence of temperature and mineralization of thermal waters.

4. To improve production and absorption parameters of geothermal wells, the following procedures are recommended:
- reaming, if sandstone makes up the reservoir layer;
- acidification, if limestones and dolomites make up the reservoir layer.

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TECHNICAL EQUIPMENT FOR CEMENTING PROFSPECTING DRILL WELLS

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ABSTRACT
Constructions and action of a set of technical equipments for cementing prospecting drill wells with small diameter (59 and 76 mm), consisted of cone and cylindrical packer, packer for horizontal drill holes, hydraulic mixer for grouting slurries and hydraulic dispersing device for grouts improving have been examined.

During prospecting wells drilling in an area, where underground mine workings exist, very often problems met are water loss in the upper part of the wells and water inflow in their lower part, especially for holes, drilled underground. The main reason for that is rock fissuration, caused by blasting in underground mines. Drill wells cementing by using common procedure of "face flooding" is not very efficient because the procedure goes at low pressure (1- 2 MPa) and grout can't penetrate into the rock fissures. Well known equipment in literature for preparation and forcing the grout into the drill holes are complex, expensive, with big dimensions and are not good enough for underground usage. For these reasons, in the period 1984 - 1988 for GORUBSO - Madan mine enterprise a scientific team from the University of Mining and Geology "St. Ivan Rilsky", Department of Drilling and Petroleum Engineering (V. Arisanov, N. Tchervenakov et al., 1985, 1986, 1988) elaborated a set of contrivances and corresponding technology for preparation of grouts and cementing drill holes with small diameter (59 and 76 mm).

During the process of elaboration, the main requirements of GORUBSO - Madan and the character of drilling conditions underground had been taken into account:

- small drill well diameters (59 and 76 mm);
- diamond core drilling in medium hardness rock (IX- X category);
- need of simple and highly reliable in their usage constructions, easy for transportation in underground mine conditions.

The set of contrivances consisted of:

- turbine flow meter;
- drillable cone and cylindrical packers;
- device for final high pressure grouting;
- hydro jet mixer for grout slurries preparation;
- hydraulic dispersing device for grouts amelioration.

Turbine flow meter is used for water inflow or water loss measuring. It is of classic type in which a sensing element a propeller with agate bearings is used. Turbine rotation frequency is proportional to flow speed i. e. to the quantity of liquid flow in corresponding part of the well. At every turbine turn the sensor of flow meter sends trough the cable an impulse to the counter at the mouth of drill well. Data received is used for designing well run - out record and from it parts of the drill hole are defined where there is water inflow or water loss.

Basic element of created equipment set are packers. They assure the possibility to produce pressure on cement slurry grout and this improve its penetration into the rock fissures during cementation process run. Two packer constructions were elaborated - cone packer (V. Arisanov, N. Tchervenakov, 1985) and cylindrical packer (N. Tchervenakov, V. Arisanov, 1986).

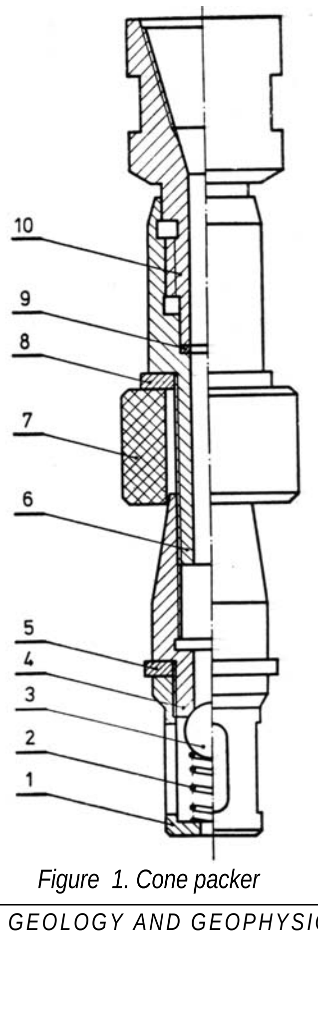

Figure 1. Cone packer

Cone packer is presented on fig 1. It is designated to insulate zone of grouting from upper drill well zones and by this way grout slurry can be forced at higher pressure. Packer consists of reverse valve pos. 1, 2, 3, cone body 4, stopping washer 5, screw- shaped spindle 6, elastic washer 7, pressing washer 8, washer 9 and combined safety adapter 10. Elastic washer 7 diameter is some bigger than hole diameter (60 mm for 59 mm hole diameter). Excluding washers 5 and 8 and upper adaptor 10, all other elements of the packer have smaller diameter than the well hole one and this permits to be taken out as a core from the well and by this way many times used.

Cone packer is turned on the lower part of the drill string and is lowered in the well without any rotation to the depth required. Because of the friction with hole walls, elastic washer 7 is in upper position. To put the packer into action, drill string must be slightly elevated and in the same time turned right. As a result of friction with well wall, washer 7 stays in rest and cone part of the body 4 penetrates into the hole of elastic washer 7, deforms it and press it with greater force to the well wall. Friction force between cone body 4 and elastic washer 7 tries to lift elastic washer 7, but friction force between elastic washer 7 and hole wall counteracts it and self wedging effect occurs. When cone angle is small enough, friction force between elastic washer and hole wall is always greater than the friction force between cone and elastic washer and washer rests immobilized to hole wall. When turning right screw spindle into the body 4 and by pressing washer 8 elastic washer 7 is deformed and tightened to hole wall. Stopping washer 5 prevents elastic washer 7 from dropping off. After putting the packer into action we force the slurry into the hole by a grout pump. When injection works are over, we take out drilling string out of the well and for the purpose we slowly turn it left and in the same time slightly lift it up. As a result of this manipulations safety adapter 10 is unscrewed from the screw spindle 6. We take out drilling string from the well together with adapter 10 of the packer and all other parts of the packer rest in the well until cement sets and hardens. All this prevents cement wash out and ensure high quality of grouting works. After cement setting and hardening we bring down drill string and drill again the grouted part of the hole with single core barrel. Because outer diameter of return valve pos. 1, 2, 3, body 4 and screw spindle 6 are smaller than diamond core bit inner diameter, we take them off from the well as a core and after cleaning them up we can use them again. Stopping washer 5, elastic washer 7 and washer 8, being made by easy to drill material are drilled by the diamond core bit.

In well known packer constructions the contact with hole wall and its wedging up is assured by using cone jaws. In as above described construction, this function is obtained by elastic element of the packer. For the purpose its outer diameter is greater than drill hole diameter and the effect of self wedging occur when cone stem gets into the elastic element. This makes packer construction very simple and in the same time avoiding cone jaws assures the possibility greater part of packer details to be worked out with enough small diameter just to use them as a drillable packer, i. e. to leave them into the well during cement of the grout slurry setting and hardening and after it to take them out of the hole as a core and use them again. Leaving the packer in the hole during the time of cement setting and hardening is very effective especially during grouting hole parts with great water inflows because this prevents grout wash out and its forcing out from the rock fissures. In the same time this construction possess some disadvantages and some of them are avoided in the next constructions. Its main disadvantage is: once placed, packer can't be moved up, turned or removed. Because of the small difference between hole diameter and the elastic sleeve, it can't be used in heavily broken rock and cavernous zones, where hole dimensions could be with great difference of hole diameter. In the same time we must say that isuch conditions during prospecting drilling in medium to hard rocks aren't too often.

The knowledge gained during experiments and application of cone packer was very useful with the start of cylindrical packer elaboration (fig. 2).

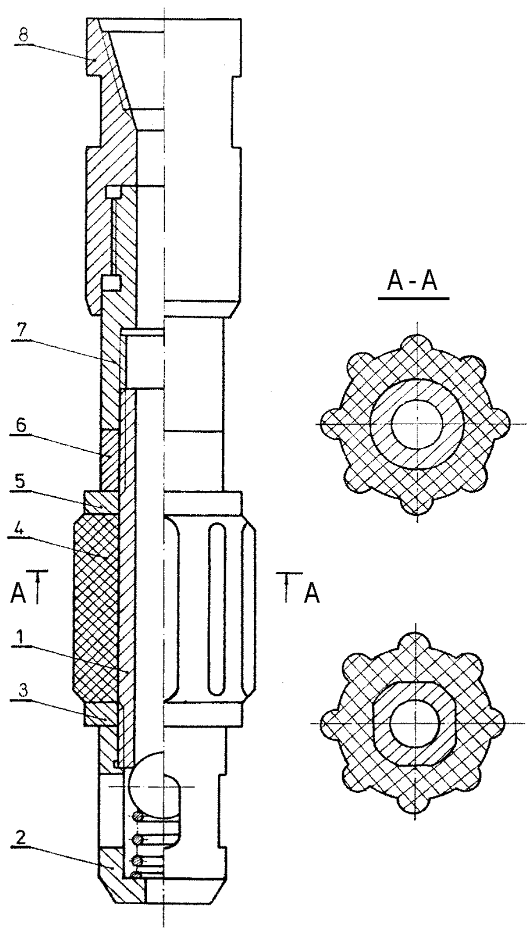

Figure 2. Cylindrical packer

Cylindrical packer consists of stem 1, reverse valve 2, lower washer 3, rubber pad 4, upper washer 5, sleeve 6, body 7 and upper adaptor 8. Rubber pad 4 has longitudinal ribs and their outer diameter is bigger than the hole well diameter, but rubber pad main diameter is smaller. The stem 1 and corresponding to it surface of rubber pad 4 could be with cylindrical or prismatic surfaces. Upper adapter 8 and body 7 are connected by easy dismountable flat double start thread.

Upper adaptor 8 is screwed to the lower part of drilling string and packer Is descended down to well hole without any rotation of drilling string. When it reaches bottom of the well, pump for drilling fluid is turned on, all the slime gathered there is washed out, then the packer is lifted and positioned upper of the well zone, where the water inflow is registered. Packer positioning follows this order: drill string must be turned right. As a result of friction between rock and rubber pad 4, the last one rests immobile and retains immobile the stem 1. The body 7 is screwed on the stem 1 and by washer 5 presses rubber pad 4, it deforms and closes the well. During the screwing the friction force in the thread between body 7 and stem 1 tries to turn right stem 1 and rubber pad 4, but the friction force between rubber pad 4 and well wall is bigger and the pad rests immobile. In this position we start grout forcing. After injection finishing, drill string is removed following the order: we slightly lift and turn left drilling string. Unscrewing occurs in the thread between adaptor 8 and body 7 because it is easy to unscrew (flat double start thread). We take out of the well hole drilling string together with upper adaptor 8. Packer rests in the hole during cement setting and hardening and after that we drill the cement bridge with single core barrel and diamond core bit. Excluding rubber pad 4 and aluminum washers 3 and 5, outer diameter of all other parts of the packer are smaller than the inner diameter of diamond core bit and we take them out of the well as a core. After cleaning we can use them again.

In comparison with cone packer, construction of cylindrical one is more simple. It has many advantages and one of them is the special shape of rubber pad. As designed longitudinal ribs are more elastic in comparison with cylindrical pad and this make possible packer to be used in well holes with bigger dimensions than standard ones. The presence of gap between main diameter of pad and drill hole diameter permits washing up the drill well before grouting and to be used in heavy water inflows. Big advantage of this packer is that its putting into action is only by turning right without any lift of drill string, so this assures the possibility to be taken out from the hole when necessary.

Technology applied for bringing in and out of drilling string from horizontal holes includes its turning. Just to use this cylindrical packer construction in horizontal holes for Sofia Geological enterprise, a special adapter was elaborated (fig. 3). It is screwed between drilling string and packer and permits bringing the packer into the hole with rotation of the string. Adaptor consists of upper adaptor 1, stem 2, upper connector 3, body 4, lower connector 5 and lower adaptor 6. At the upper part of the upper adaptor 1 a standard female cone thread is cut and connection with drilling string is made trough it. At the lower part of lower adaptor 6 a standard male cone thread is cut to connect the cylindrical packer. On the upper connector 3 and lower connector 5 a left hand cone thread is cut. Adaptor is screwed between cylindrical packer and drilling string and in initial position upper connector 3 and lower connector 5 are in unscrewed position. During bringing into the hole of drilling string and the packer, elastic element of packer rubs to hole wall and make some resistance to drilling string bringing into the hole. Because of this friction force the stem 2 and lower adaptor 5 are in low position. When drilling string rotate the face of lower connector 5 rubs to lower adaptor 6, but the force between them is not enough to put the packer into action. When required depth is reached, drilling string is slightly elevated and slowly turned right. As a result upper adaptor 1, stem 2 and lower connector 5 are elevated and lower connector 5 is screwing into the upper connector 3. Drilling string rotation passes trough upper adaptor 1, stem 2, lower connector 5, upper connector 4, body 4 and lower adaptor 6 to packer and puts it into action. After finishing grouting works we release drilling string from the packer by turning left and slight elevation of drilling string. Unscrewing happens at the thread between the upper adaptor and the body of cylindrical packer, because there the connection is of a flat double start thread and friction force there is very small. All other elements of the packer are brought out of the hole as a core after cement setting and hardening.

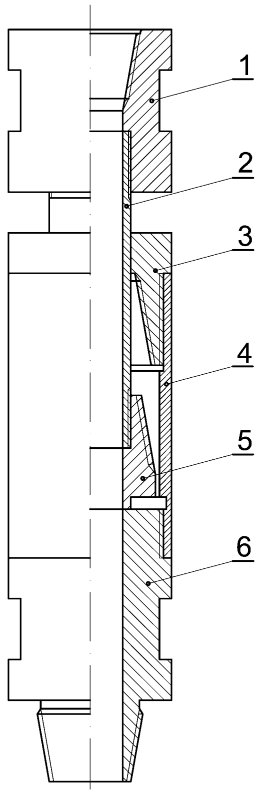

Figure 3. Adaptor for horizontal drill holes

Additional increase of pressure during grout forcing could be obtained by using the device, shown on fig. 4 (V. Arisanov, N. Tchervenakov, 1985). It is a piston pump, screwed on before the packer and consists of lower adaptor 1, plunger case 2, reverse valve 3, 4 and 5, piston 6 and 7, piston stem 8, end piece 9 and upper adaptor 10. For rotation transmission from drilling string to packer, the surfaces of upper adaptor 10, end piece 9 and body of the piston 6 are prepared as face connectors. The set of packer and device for additional grouting pressure is lowered to the predetermined level and packer is fixed as explained above. We are forcing the grout slurry by means of the mud pump and at the same time trough the spindle of drilling device we produce reciprocating motion of drilling string about 40- 50 cm to and fro. Movement up of drilling string in the working chamber of cylinder 2 creates vacuum, which closes the packer valve, opens the valve 3, 4, 5 of additional grouting pressure device and cement slurry trough longitudinal hole of piston stem 8 enters into the working chamber of cylinder 2. Drilling string motion down creates pressure in the working chamber 2, which closes valve pos. 3, 4, 5 of the device for additional grouting pressure, opens the packer valve and piston 7 under high pressure forces grouting slurry into the drill hole. Advantages of the construction is its simplicity, high pressure and possibility for smooth regulation of pressure and flow by axial pressure and speed of drilling string movement.

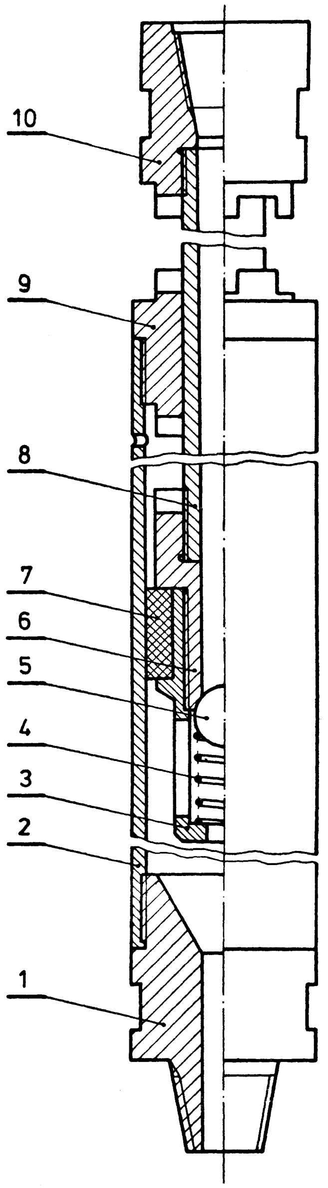

Figure 4. Device for additional grouting pressure

For cement grouting slurry preparation in field conditions propeller type clay mixing machines are used. Their big dimensions make them not worthy for underground conditions. That why for the purpose a hydro jet type mixer was created, presented on fig. 5. (V. Arisanov, N. Tchervenakov and all, 1989). Trough the hose 1 mixer is connected to washing pump, which pumps 80- 120 dm^3/min water into the mixer. Water gets out from the nozzle 4 with a very high speed and as a result makes vacuum 0.8 - 0.9 MPa in the working chamber of the body 6. Under the vacuum action in the working chamber trough the entering pipe connection hose and suction moth, connected to it (they can't be seen on the drawing) cement is sucked from the cement bag. In the working chamber it mixes with getting into water. So obtained cement slurry trough diffuser 8 enters into slurry reservoir. Device functions using energy from forced by slurry pump liquid. By this way outer dimensions of the device are much smaller than common clay mixers ones. High speed of the current in working chamber assures very good dispersing and mixing of cement slurry.

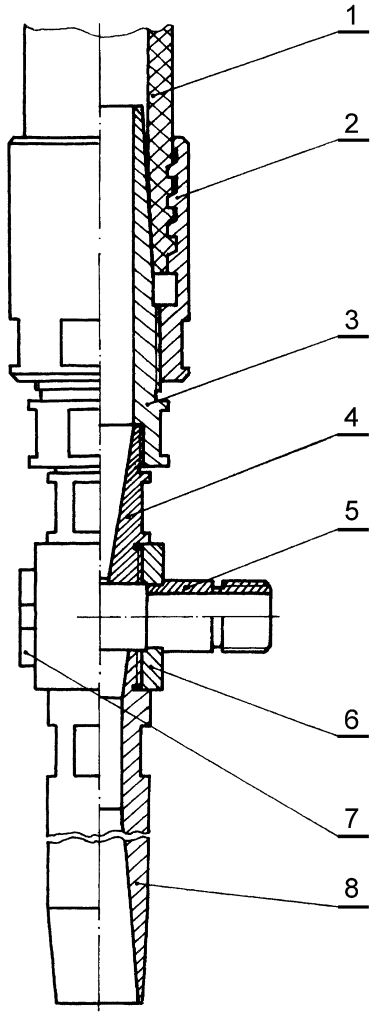

Figure 5. Hydro jet mixer

For improving of cement slurry parameters a hydraulic disperser, presented on fig 6 is used (N. Tchervenakov, V. Arisanov 1989). In the cone stem 4 mutually crossing each other helical channels are cut. Their cross section in the outset is bigger and diminishes to their end. The smallest cross section is at the point of crossing. Stem 4 is in the body 5 and to it is connected entering pipe connector. To pipe connector 3 by the nut 2 is connected hose 1. Cement slurry, forced by mud pump trough hose 1 enters with high speed into the entering pipe connector 3, where it parts to two currents and enters helical channels of cone stem 4. At crossing points the two currents collide each other at high speed and this finely disperse cement particles and improves its rheologic properties. Because of the stem cone shape at its end cross section of channels diminishes, current speed grows up and this leads to fine dispersion.

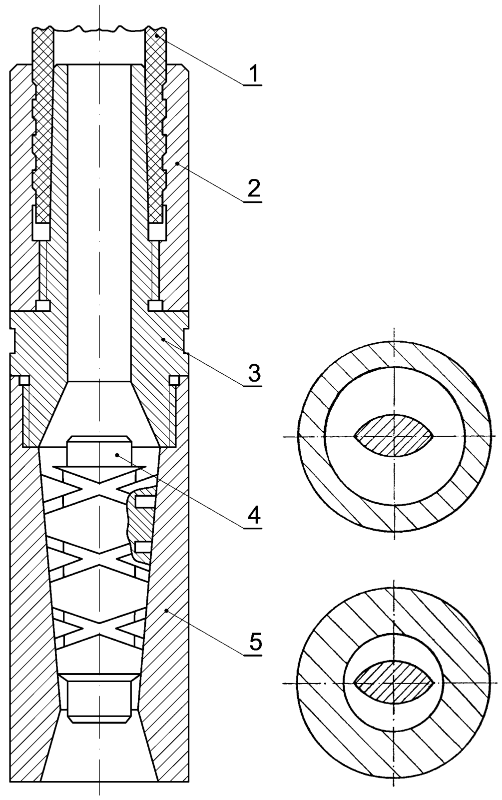

Figure 6. Hydraulic disperser

So described device for additional grouting pressure, hydro jet type mixer and hydraulic disperser replace a very expensive and with much bigger outer dimensions set of devices of Heny enterprise for preparation and forcing under high pressure cement grouting slurry. Together with packers and flow meter they cover all technological cycle of operations for liquidation of high water inflows or losses. Its simple construction, reliable work and small outer dimensions make them very suitable for underground operations.

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