ANNUAL

OF THE

UNIVERSITY OF MINING AND GEOLOGY

"ST. IVAN RILSKI" - SOFIA

PART I: GEOLOGY

Vol. 45 **2002**

"St. Ivan Rilski" Publishing House

SOFIA, 2002

ISSN 0387 5467

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Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 1-5

CRETACEOUS/TERTIARY BOUNDARY IN THE CARPATHIAN TYPE UPPER CRETACEOUS NEAR THE VILLAGE OF KLADORUB, VIDIN DISTRICT

Dimitar Sinnyovsky, Boris Valchev, Dimka Christova-Sinnyovska

University of Mining and Geology “St. Ivan Rilski”, Sofia 1700, Bulgaria

ABSTRACT
The present study of the Kladorub Formation, which is a part of the “Carpathian type Upper Cretaceous”, revealed a new K/T boundary interval section in Bulgaria. The studied interval comprises the boundary nannofossil zones of the Cretaceous and Paleocene - Micula prinsii and Biantholithus sparsus. Between these boundary zones, a 4 cm dark layer was established, marking the great change in the calcareous nannoplankton. The lithological analyses of the boundary interval between – 2.75 m to +4.00 m showed that this part of the section is represented mainly by siltstones and minor limestones and marls.

INTRODUCTION

The Cretaceous/Tertiary boundary is marked by a giant impact event 65 million years ago. It is expressed by a few centimetres thin layer, recognized worldwide by an iridium and associated trace metal spike, shocked quartz, microtektites and rare minerals. This layer was first established by Alvarez et al. (1980). It marks the great change in the Earth floras and faunas – major plankton extinction (more than 90 % of the calcareous nannoplankton and planctonic foraminifers that are in the beginning of the nutrient chain), about 60 % of angiosperm species, many groups of echinoids, corals, warm water molluscs and primitive mammals. This level also marks the final extinction of ammonites, belemnites, rudistid and inoceramid bivalves, nerineid and actaeonellid gastropods, marine reptiles, dinosaurs etc. (Barnes et al., 1996).

During the last decade a gradual transition between Cretaceous and Paleogene deposits has been established in many Bulgarian sections from the Fore-Balkan and Stara Planina structural zone.

The present investigation is devoted to a new outcrop of the Cretaceous/Tertiary boundary interval on the territory of the West Fore-Balkan, established in the rocks of the so called “Carpathian type Cretaceous” in Vidin district.

PREVIOUS RESEARCH

The Cretaceous/Tertiary boundary interval was established in different facial types in Bulgaria: limestone-marl periodites near Byala, Varna district (Stoykova, Ivanov, 1992) and Ljuti dol, Vratsa district (Sinnyovsky, 2001; Стойкова и др., 2000); turbidites near Emona, Bourgas district (Sinnyovsky, Stoykova, 1995), Kozichino and Aytos Pass (Sinnyovsky, Vangelov, 1997) and Marash river south of Kotel (Стойкова и др., 2000); a cyclic limestone succession near Moravitsa (Синьовски, 1998) and Mezdra (Стойкова и др., 2000), Kozya river, Razkrachenitsa and Chudnite skali (Вангелов, Синьовски, 2000; Sinnyovsky, 2001). Nevertheless, the boundary is geochemically proved only in three of these outcrops – the first one near Bjala (Preisinger et al., 1993a,b), the outcrop near Moravitsa, west of Mezdra town (Синьовски, 1998) and the outcrop along Kozya river, east of Chudnite skali (Вангелов, Синьовски, 2000; Sinnyovsky, 2001).

The sedimentary rocks in the surroundings of the village of Kladorub were first described as “Lutetian” by Берегов (1937) who accepted the overturned beds as normal and considered younger age for the “shales” as compared to the “sandy complex”. Later they have been included into the so-called “Sinaya Cretaceous”, “Banat Cretaceous” or “Carpathian type Cretaceous”.

The term “Sinaya Cretaceous” was introduced by Ст. Бончев (1923) for Senonian flysch deposits along Timok River. В. Цанков (in Цанков et al., 1960) cited the opinion of prof. Filipescu that these rocks were very similar to the “Banat type Cretaceous” and differ significantly from the “Sinaya Cretaceous” in Romania. In this paper, the rocks SE of Kladorub are described as ‘bluish marls with interbeds of sandy marls’ of Maastrichtian age. This is the first age determination of the rocks and is proved by ammonites, inoceramids and globotruncanides.

The term “Carpathian type Cretaceous” was introduced in the Bulgarian geological literature by Ц. Цанков (1961,1963) to substitute the term “Sinaya Cretaceous” and to distinguish the Cretaceous rocks exposed north of the line Vrushka Chuka – Kiryaevo – Rakovitsa - Rabisha – Kladorub from the Cretaceous sediments in the West Balkan. This type Upper Cretaceous was mentioned by В. Цанков (1968).

Ц. Цанков (1961) described the relationships between the South Carpathian and Balkan structures in the area using

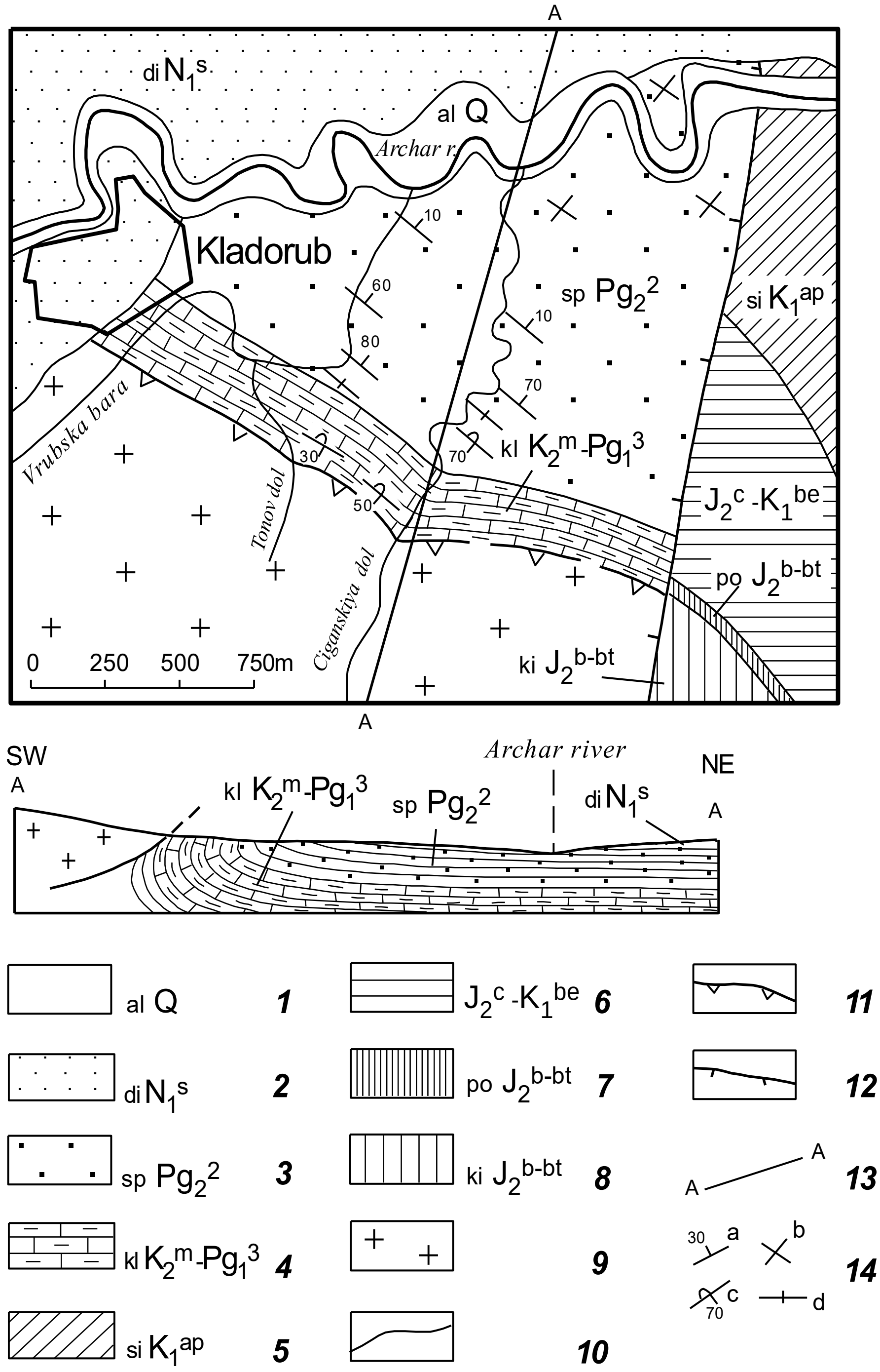

Figure 1. Geological map and geological section A-A of the studied area near Kladorub village, Vidin district (after Sinnyovsky & Petrov, 2000 with additional data): 1 – fluvial deposits; 2 – Dimovo Formation (Sarmatian): sandstones and limestones; 3 – Staropatica Formation (Eocene): conglomerates, sandstones and shales; 4 – Kladorub Formation (Upper Campanian – Upper Paleocene): siltstones, silty limestones and marls; 5 – Simeonovo Formation (Aptian): Urgonian limestones; 6 – West Balkan Carbonate Group: Javorets, Ginci and Glogene Formations (Callovian – Berriasian): micrite nodular limestones; 7 – Polaten Formation (Bajocian-Bathonian): carbonate sandstones and sandy limestones; 8 – Kiper Formation (Bajocian-Bathonian): sandstones and conglomerates; 9 – Belogradchik Pluton (Paleozoic): granites; 10 – lithostratigraphic boundary; 11 – reverse fault; 12 – normal fault; 13 – line of geological section; 14 – dip and strike: a) inclined, b) horizontal, c) overturned, d) vertical

stratigraphic data from the report on the geological mapping of Връблянски et al., carried out in 1959.

Further paleontological determinations of the ammonite fauna and biostratigraphic subdivision of the Maastrichtian near Kladorub were made by Tz. Tzankov (1963,1964). He described an about 90 m long outcrop of overturned 35-45° to the north beds of 'ash-gray or gray-greenish silty marls' along Vrubska bara, south of the village of Kladorub. Rich macrofossil and microfossil assemblages proved Maastrichtian age of these rocks. The macrofossils are represented by inoceramids with prevailing *Inoceramus regularis* d'Orbigny, *Inoceramus balticus* Böhm and *Inoceramus impressus* d'Orbigny, and ammonites *Baculites anceps leopoliensis* Nowak, *Diplomoceras cylindraceum* (Defrance), *Hauericeras sulcatum* (Kner), *Pseudokossmaticeras brandti* (Redtenbacher), *Pseudokossmaticeras galicianum* (Favre), *Pseudokossmaticeras galicianum tercense* (Seunes), *Pachydiscus gollevillensis* (d'Orbigny), *Pachydiscus neubergicus* (Hauer), determining the Maastrichtian Constrictus Zone. The other ammonites determined in this association are of longer stratigraphic range. The author reported also a rich Maastrichtian microfossil assemblage composed mainly of representatives of the genera *Anomalina* and *Globotruncana*.

Later Tzankov (1972) named these rocks "Kladorub Complex". According to Тенчов, Йолкичев (1993) this is a nude name. The rank of the Kladorub Formation was pointed by Филипов et al. (1995), but the name "Kladorub Formation" was used for small outcrops near Rakovitsa village on the geological map of Bulgaria, Sheet Zaechar and Bor (Дечева et al., 1990), and near Kladorub village – on Sheet Vidin (Филипов et al., 1992). This name was qualified by Тенчов (1993) as a nude name. All of these authors did not argue the Maastrichtian age and lithological characteristics of the unit.

During the field season 1998, the mapping team of Geology and Geophysics Enterprise, Sofia, provided 4 samples for nannofossil analyses. It was found that three of the samples are of Maastrichtian age but the fourth one contained Upper Paleocene nannoflora. Thus, the stratigraphic range was amended to Maastrichtian – Upper Paleocene (Sinnyovsky, Petrov, 2000).

GEOLOGICAL SETTING

The Kladorub Formation crops out SE of Kladorub Village as a narrow, 2 km long and 300 m wide strip trending NW-SE. The outcrops are restricted along Vrubska bara, Tonov dol and Ciganskiya dol SE of the village (Fig. 1). The outcrop along Vrubska bara, described by Ц. Цанков (1964) and pointed as "type section" of the unit (Tzankov, 1972), is almost totally covered. Nevertheless, the unit is well exposed along Ciganskiya dol, 1,3 km E-SE of this outcrop. The beds are overturned with strike and dip 200-220°/30-60°.

According to previous investigations, the Kladorub Formation comprises sandy and silty marls of Maastrichtian-Paleocene age.

The lower boundary of the unit is a reverse fault along the boundary with the Paleozoic granite of Belogradchik pluton (Fig. 1). The upper boundary with the Eocene conglomerates of Staropatica Formation is unconformable. The eastern boundary is a normal fault with Jurassic rocks – Polaten Formation and the West Balkan Carbonate Group. Neogene terrigenous sediments of the Dimovo Formation cover the unit to the west.

RESULTS

This paper presents preliminary results on the K/T boundary interval, obtained during the 2001 field season in the frame of the research program of the University of Mining and Geology "St. Ivan Rilski". Subject of the study is the fine-grained carbonate-siltstone sequence of the Kladorub Formation which crops out SE of the village of Kladorub, Vidin District.

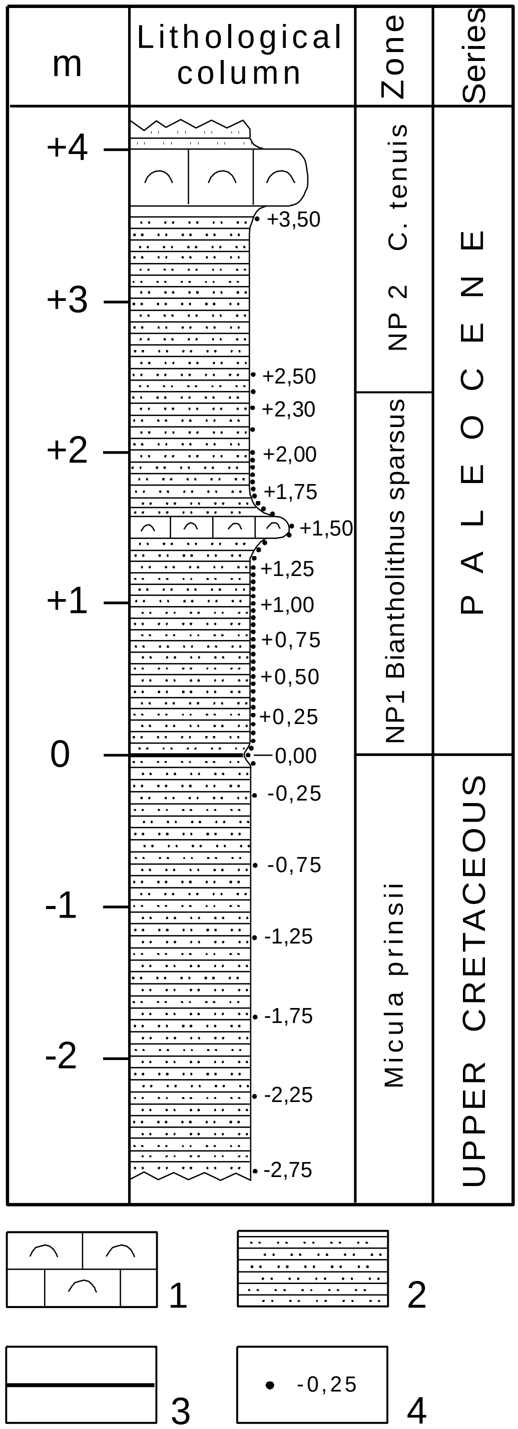

Figure 2.. Section of the K/T boundary interval in Kladorub Formation, situated in the valley of Ciganskiya dol, 1.3 km SE of Kladorub village, Vidin district: 1 – compact bioclastic limestone beds; 2 – siltstones, silty limestones, hypolimestones and marls; 3 – dark-colored K/T boundary layer; 4 – sample

The corrected stratigraphic range of the unit provides a good opportunity to establish a new gradual transition across the K/T boundary in Bulgaria.

The first sampling in Ciganskiya dol, carried out in the beginning of the summer of 2001, revealed three important facts: 1) wider stratigraphic range of the sequence (Upper Campanian – Uppermost Paleocene); 2) discrepancy between the former lithological description of the unit and the present results; 3) uninterrupted section – relatively well exposed and without significant faults and folds. All these facts allowed to: 1) establish the K/T boundary layer; 2) revise the lithological composition of the Kladorub Formation; 3) refine the biostratigraphical subdivision of the Campanian – Paleocene interval on the basis of calcareous nannoplankton and planktic foraminifera.

The present study presents new data about the position of the K/T boundary layer and the lithology of the investigated boundary interval.

K/T boundary. Detailed lithological and paleontological studies were focused on the K/T boundary interval, restricted within 7 m (Fig. 2). It is located about 50 m North of the reservoir catchment in Ciganskiya dol. 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.

The presence of the two boundary zones allowed locating a dark, 4 cm thick layer, marking sharp change in the calcareous nannoplankton assemblages.

The samples below this layer contain rich nannofossil association represented by more than 50 Cretaceous species. The most abundant forms are: *Micula decussata* (Vekshina), *Micula wastika* Stradner & Steinmetz, *Watznaueria barnesae* (Black), *Cribrosphaerella ehrenbergi* (Arkhangelsky), *Gartnerago obliquum* (Stradner), *Broinsonia enormis* (Shumenko), *Arkhangelskiella cymbiformis* (Vekshina), *Microrhabdulus decoratus* (Deflandre), *Eiffellithus turriseiffeli* (Deflandre), *Kamptnerius magnificus* Deflandre, *Chiasmozygus litterarius* (Gorka), *Prediscosphaera cretacea* (Arkhangelsky), *Prediscosphaera columnata* Perch-Nielsen, *Prediscosphaera microrhabdulina* Perch-Nielsen, *Prediscosphaera grandis* Perch-Nielsen, *Ceratolithoides aculeus* (Stradner), *Zygodiscus spiralis* Bramlette &Martini etc. All Upper Maastrichtian markers are also present *Lithraphidites quadratus* Bramlette & Martini, *Nephrolithus phrequens* Gorka, *Micula murus* (Martini), *Micula prinsii* (Perch-Nielsen).

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. There are single reworked forms represented by the most abundant Cretaceous species *Micula decussata* (Vekshina), *Watznaueria barnesae* (Black), *Arkhangelskiella cymbiformis* (Vekshina) and some other species. Nearly 95% of the nannofossil association is represented by the survivors *Braarudosphaera bigelowi* Gran & Braarud and *Thoracosphaera operculata* Bramlette & Sullivan. *Cyclagelosphaera reinhadrtii Markalius inversus* (Deflandre) and *Neocrepidolithus dirimosus* Perch-Nielsen are also relatively frequently encountered survivors.

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 the disappearance of the Cretaceous species and the appearance of the zonal marker. *Cyclagelosphaera alta* Perch_Nielsen is another Paleocene species appearing in this interval. The first specimen was found in sample KLA+0.75 m. The thickness of the NP 1 Biantholithus sparsus is 2.40 m (Fig. 2). The first appearance of *Cruciplacolithus intermedius* (van Heck & Prins) marks the lower boundary of the NP 2 Cruciplacolithus tenuis. 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.

Lithology of the Kladorub Formation. So far the rocks of the Kladorub Formation, based on field determinations, have been described as different types of marls – sandy, silty and calcareous with rare limestone interbeds (see "Previous research"). The present granulometrical study of several samples from the K/T boundary interval shows high terrigenous content.

Only two of the investigated samples may be classified as marls: sample KLA –0.75 – very silty marl with 28.49% $CaCO_3$, 26.92% clay and 43.51% silt, and sample KLA +2.10 – silty marl with 33.40% $CaCO_3$, 26.40% clay and 39.40% silt.

Three of the samples are classified as siltstones: the boundary layer, sample KLA +0.05 – clayey-carbonate siltstone with 51% silt, 27.85% $CaCO_3$, 13.65% clay and 7.50% sand; sample KLA –0.05 – sandy-carbonate-clayey siltstone with 50% silt, 17.90% $CaCO_3$, 20.05% clay and 12.05% sand; sample KLA +3.50 – clayey-carbonate siltstone with 52.30 % silt, 31.55% $CaCO_3$, 14.60% clay and 1.55% sand.

The interval immediately above the K/T boundary layer is more carbonate. Sample KLA +0.20 is classified as clayey-silty limestone with 63.60% $CaCO_3$, 17.80% silt, 18.10% clay and 0.50% sand. Sample KLA –2.75 is a mixed type, classified as clayey-silty hypolimestone: 49.20% $CaCO_3$, 25.16% silt, 24.65% clay and 0.77% sand.

These samples show that carbonate and silt components are predominant in most of the samples, but the variation of the clay component is critical for determining the rock as marl or siltstone. On the basis of these results it may be concluded that the main rock type in the boundary interval of the Kladorub Formation is not marl but siltstone.

CONCLUSION

The present results confirm the unique opportunity for complex investigation of the K/T boundary interval in Bulgaria. After the recent publications on the boundary layer from several facial types in the Fore-Balkan and Stara Planina structural zone, this outcrop provides opportunities for detailed study of this boundary in fine-grained terrigenous rocks. The section of Kladorub Formation is the most complete boundary section in Bulgaria, covering a well-exposed, complete stratigraphic interval from the Upper Campanian to the uppermost Paleocene. The nannofossil evidence for the K/T boundary interval allows further biostratigraphic, geochemical, sedimentological and mineralogical investigations. This section is a good basis for future correlation of the boundary in different facial environments.

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Recommended for publication by Department of Geology and Paleontology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 7-11

CYCLICITIES IN THE SVIDOL FORMATION NEAR CEROVO VILLAGE, NW BULGARIA

George Ajdanlijsky

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, E-mail: ajdansky@staff.mgu.bg

ABSTRACT
Based on detailed lithofacial studies of a section of Svidol Formation (Lower Triassic) located near Cerovo Village, Svoge District, a one-sequence stratigraphic unit was recognized and subdivided into transgressive and highstand system tracts. Parasequence sets, parasequences and higher-order cycles are recognised and characterized within each system tract. The unit is 27 m thick and corresponds to the sequence stratigraphic unit in the same formation that was earlier described near Sfrazen Hamlet, northerly along the Iskar Gorge. The detailed study of the inner architecture of the higher-order cycles allows high-resolution stratigraphic correlations between the two sections. Comparative analysis of the data from the two sections indicates variations in the thickness and structure of the higher-order cyclic units of the sequence. The absence of reliably determinable fossil fauna in the section do not allow a correct definition of its chronostratigraphic span. The character of the described mesoscale cyclicities enables their comparison with those, established in other parts of the Lower Triassic section in the area and is a step toward elaboration of a general cyclostratigraphic model for the whole Lower Triassic Series in the studied area. The collected new data about the structure of the formation suggest a possible tide-dominated delta character in some portions of the depositional environment.

INTRODUCTION

The rocks of the Svidol Formation represent the transition between the red continental successions of the Petrohan Terrigenous Group (Lower Triassic) and the typical marine carbonate rocks of the Iskar Carbonate Group (Lower-Upper Triassic). Even in the nomination of the formation (Čatalov, 1974), "… the cyclic structure of its facieses …" has been pointed out among its main characteristics. According to the same author (Čatalov, 1975), the typical for this formation types of stratification and its lithologic composition indicate, that the unit was formed in the conditions of a low-relief terrigenous-carbonate tidal flat.

Despite of its wide distribution in NW Bulgaria and the Moesian platform, Svidol Formation is poorly exposed because of the specific lithological features of the rocks that build it up. For this reason, detailed lithofacial and stratigraphic descriptions of concrete sections of the unit are practically lacking in the literature. The Iskar Gorge is one of the few areas in Bulgaria, where relatively complete and frequent outcrops of the Svidol Formation occur. The southernmost outcrop of the unit, that is located in the gorge near Cerovo Village, Svoge District (Fig. 1), provides excellent opportunities for a detailed lithofacial and stratigraphic study.

This paper presents the first, more detailed lithologic and stratigraphic description of the Svidol Formation in the area of the Iskar Gorge. Object of study is the section at the "Red wall" locality in the eastern end of Cerovo Village. On the basis of detailed field and laboratory lithofacial studies, different in rank sedimentary cyclicities are characterized and a sequence stratigraphic subdiivision is proposed. After a comparison with results from earlier analogous investigations on Svidol Formation (Tronkov and Ajdanlijsky, 1998 b) near Sfrazen Hamlet, located to the north along the gorge, conclusions about the formation structure and traceability of the characterized stratigraphic units and levels in the area are drawn.

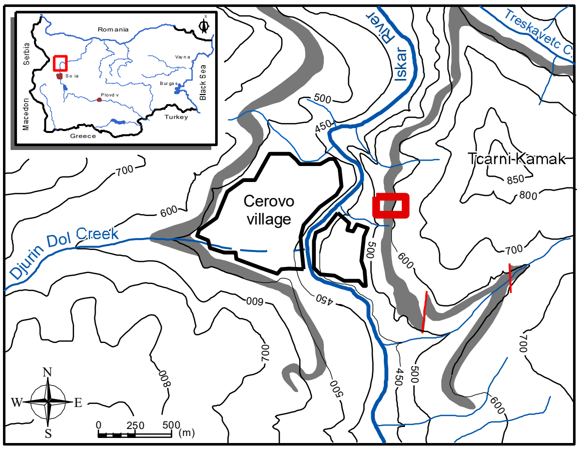
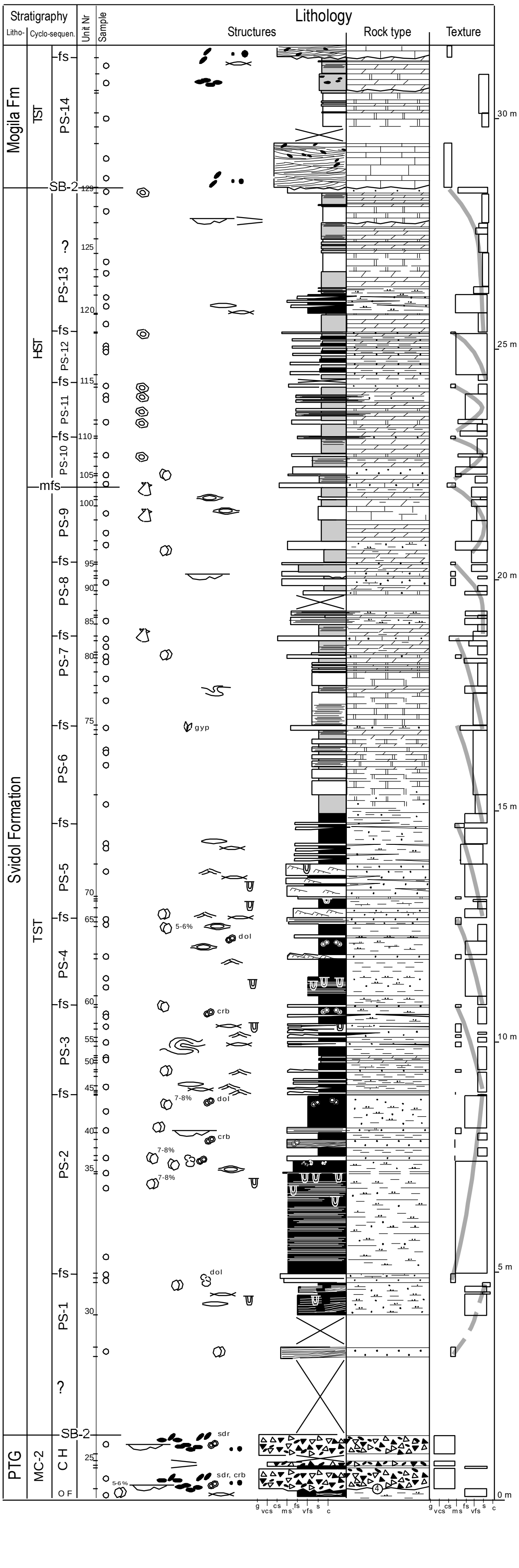


Figure1. Schematic map of Svidol Formation outcrops (gray) in the area with location of the studied section.

The description of the fluvial deposits is based on the Miall (1996) lithofacial scheme. The lithologic determinations in the Svodol Formation are according to the proposed by Sultanov (1980) classification of clay-carbonate rocks. The field color description of the rocks in the section is based on the Rock-Color Chart (1991).

SECTION DESCRIPTION

The description of the studied section includes the bordering parts of the underlying Petrohan Terrigenous Group (PTG) and the overlying Mogila Formation. The aim is to provide a more correct determination of the scale, character and genesis of the sedimentological cyclicity in the Svidol Formation and a correct comparison with those in the other part of the Lower Triassic Series in the area.



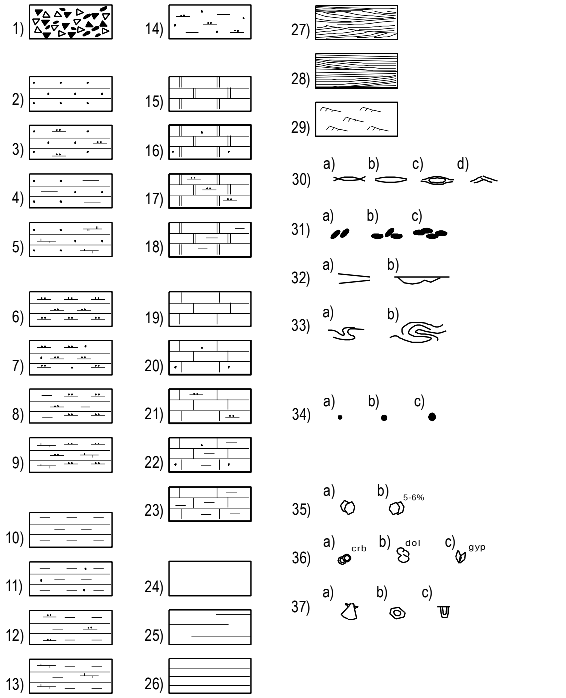


Figure 2. Lithologic-stratigraphic column of the studied section. Legend: Lithotypes (1-22): Clastic rocks (1-14): 1 - clay-carbobate breccia-conglomerate; Sandsones (2-5): 2 –pure; 3 –silty; 4 – mudy; 5 – limy (dolomitic); Siltstones (6-9): 6 –pure; 7 – sandy; 8 –mudy; 9 – limy (dolomitic); Mudstones (10-13): 10 – pure; 11 – sandy; 12 –silty; 13 – limy (dolomitic); 14 – hyporocks; Carbonate rocks (15-22): Dolomites (15-17): 15 – pure; 16 – sandy; 17 –silty; 18 - mudy; Limestones (19-23): 19 – pure; 20 – sandy; 21 –silty; 22 – mudy-sandy; 23 – mudy; Sedimetary structure and texture (24-34): 24 – massive; 25 – discontinuous; 26 – even, parallel; 27 – large scale trough cross-bedding; 28 – low angel cross-bedding; 29 – small scale cross-bedding; 30 – a) flaser, b) lenticular, c) nodular and d) bi-directional ripples; 31 – gravel structure: a) imbrication, b) lag structure and c) lenses; 32 – bed shape: a) wedge and b) scour-and-fill; 33 – synsedimentary deformational structure: a) slides and b) slumps; 34 – gravel grain size : a) <2 cm ; b) 2-5 cm and c) 5-10 cm; 35 – clastic mica: a) chaotic and b) paralel to lamination. Index – content (%) in the unit; 36 – paleopedo-genic and evaporite products: a) spots, b) single and cluster-like calcretes, and c) gypsum crystal. Index – mineralogy: crb – carbonate, dol – dolomite; 37 – fossils and trace fossils: a) brachiopoda, b) crinoids and c) bioturbations. The abbrevia-tions are explained in the text.

The Petrohan Terrigenous Group

The uppermost part of the Petrohan Terrigenous Group comprises a cyclic fluvial succession with significant development of paleopedogenic products both in allo- and autochtonous position. The thickness of the individual fluvial cycles ranges from 3,5 m to 4,5 m, rarely to 9 m. The base of the cycle is an erosional surface, covered by channel clay-carbonate breccia-conglomerates (lithofacies Bbr). Upward in the cycle dominate cross-laminated sandstones of lothofacieses Sl and Str, which alternate with hyporocks (lithofacies Fm и Fl) and less commonly with siltstones and mudstones (lithofacies Fsc). Synsedimentary deformations and escape structure are frequently observed in the sandstones.

The boundary between PTG and Svidol Formation is a rapid lithologic transition and can be traced on the basis of: (1) the disappearance of the features of channel erosion, disappearance of the wide development of paleopedogenic products and inundates; and (2) the appearance of thin layers of dolo-marls, appearance of features of intensive bioturbation of the deposits and the domination of bi-directional over one-directional ripple marks (Tronkov and Ajdanlijsky, 1998a; Ajdanlisjky, 2000, 2001a).

According to the stratigraphic subdivision of the PTG proposed by Tronkov and Ajdanlijsky (1998a), the described interval belongs to the uppermost part of mesocycle MC-2.

The Svidol Formation

The studied section of the Svidol Formation is a type 2 sequence unit with thickness about 27 m, which is build up of transgressive and highstand system tracts (Fig. 2). The lithologic composition of the formation shows a large variety of terrigenous, terrigenous-carbonate and carbonate rocks (Fig. 3).

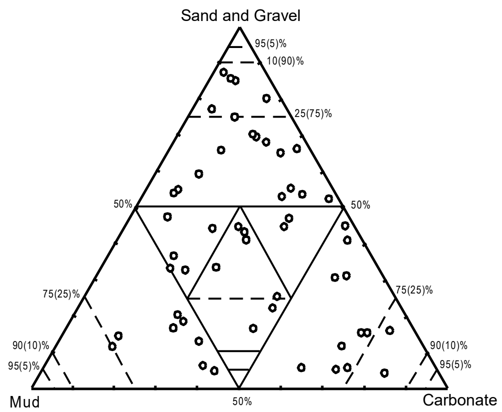


Figure 3. Lithologic characteristics of all representative rocks for the studied outcrop of Svidol Formation (according to the classification diagram of Sultanov, 1980).

The transgressive system tract (TST) is 20,7 m thick. Its lowermost part (7,4 m) is build up of two parasequences, represented by upward-fining lithofacial successions (Fig. 2, Itihofacial units 27-42). The parasequence thickness is 3,5 and 3,9 m. Fine-grained lithofacies, hyporocks with massive structure dominate in the interval. As a rule, paleopedogenic spots, calcretes and cluster-like aggregates with calcite or dolomite composition appear in the upper part of both units. There again, the most abundant bioturbations are observed. As a whole, the interval shows the maximum mica content in the formation.

If we exclude the appearance of yellowish-gray to pale-olive (5Y7/2-10Y6/2) nuances and the few thin layers of limy grayish- orange (10YR7/4) sandstone, the colors of this interval are identical to those that dominate in the uppermost part of the PTG.

The middle part of the TST is build up of three parasequences with total thickness 6 m. The thickness of a single unit varies from 1,9 m to 2,15 m. Terrigenous rocks still dominate in this interval, but in contrast to the previous one, every parasequence forms a upward-coarsing lithofacial succession. Generally, the sandy lithofacieses are of wide occurrence and the carbonate content in the rocks is increasing upward. Characteristic for the interval is the wide development of bi-directional small-scale cross-lamination (ripple marks), the graduate disappearance of the aleopedogenic features (here presented only by spots), the shift of the bioturbated intervals to the middle part of the parasequences as well as the preserved mica occurrence in the sediments (mainly in its uppermost parts). Flaser and nodular lamination are significant. One small-scale slump-like synsedimentary deformational structure is observed in the lowermost of the three parasequences (Fig. 2, PS-3) in the package (Fig. 2, lithofacial unit 54).

The red colors, represented mainly by moderate red (5R4/4-6), are gradually replaced upward in the interval by ochre and whitish-beige (5YR7/2-10YR7/4) ones.

The pattern of the uppermost 7,3 m of the TST is entirely different from that of the two already described intervals. Despite the preservation of the tendency from the middle part of the tract the parasequences to form upward-coarsening facial succession, here they are built up predominantly of marls, dolo-marls and muddy dolomites. The stages of maximum deepening are marked by silty marls. The sandstones are untypical for the interval. Most often, the role of the coarsest sediments is played by hyporocks or sandy limestones, developed as single 10-15 cm thick layers. Terrigenous mica is practically absent. Fine-bedding dominates among the structures in this interval.

In the lower two of the four parasequences that build up the interval, upward-thinning sets of dolomite-marl couplets occur. There again, in one of the courser dolomite layer, single small gypsum crystals were observed that are orientated perpendicular to the bedding. At the same level, small-scale synsedimentary slide-like structure occur. Upward in the package, the thickness of the parasequences decreases - from 2,15 m in its lower part, to 1,6 m in the upper one. There, mainly within the layers of massive micrite limestones, single and poorly defined brachiopod and bivalve fragments were found.

Medium-dark to medium-gray colors (N4-5) dominate over the ochre and whitish-beige tones (10YR7/3-6/6) in this interval.

As a whole, the TST is build up of retrogradational parasequence sets, and only in its uppermost part shows the features of aggradational pattern on stacking. The maximum flooding surface (mfs) is marked by a thin fine-laminated dark-gray silty marl layer (Fig. 2, lithofacial unit 103).

The highstand system tract (HST) is 6,4 m thick and is build up of a progradational parasequence set, in which the thickness of the single parasequences gradually increases upward from 1 m to above 3,1 m (?). The parasequence set can be subdivided into two groups: (a) the lower two parasequences, which show bipartite trend of lithofacial coarsening (a feature, which is slightly hinted also in the uppermost parasequence (Fig. 2, PS-9) of the TST; and (b) the parasequences from the upper part of the tract that are represented by upward-coarsening facies successions. Despite of the domination of marls and dolomites in this part of the section, the role of the coarsest sediments in the parasequences is plaid by limy sandsones. Parasequence PS-11 (Fig.2, lithofacial units 111-115) is build up by dolomite-marl couplets successions, similar to those in parasequences PS-6 and PS-7, but in contrast to them, detrital fragments of crinoids are observed in the coarser part of every couplet. More complex is the structure of the parasequence PS-12, which represents a succession of five uniform marl-mudstone-sandstone triplets (Fig. 2, lithofacial unit 116). In the uppermost parasequence of the TST, features of small-scale intraformational erosion are observed.

In the confines of HST, a relatively rapid change from grayish colors again to ochre, green and even red (10R6/5) is noted.

The upper boundary of Svidol Formation (Fig. 2, SB-2) is erosional and transgresive.

The Mogila Formation

The described in detail by Tronkov (1983) cylicity in the shallow-marine carbonate successions from the lower part of Mogila Formation is observed very well in this section. Here, in the lowermost part of the formation, fining-upward cycles with thickness from 2,8 m to 3,1 m occur. Generally, the single cycle is formed of cross-bedded to massive calcarenites, parallel bedded and massive micrite, clayey to muddy limestone and dolomicrites, which vertically replace each other. The base of the cycles is a low-relief erosional surface, often covered by single, mainly dolomicrite pebble- to cobble-sized intraformational clasts.

DISCUSSION AND CONCLUSSIONS

According to their structure, the established two system tracts (TST and HST) and the divided in them four intervals (parasequence set) in the studied section of Svidol Formation almost completely correspond to those, established by Tronkov and Ajdanlijsky (1998b) in the section of the same formation situated to the north along the gorge, near Sfrazen Hamlet. The subdivision of the TST into three intervals as well as the general features of the interval structure are almost identical. The same concerns the number of similar interval parasequences from the two sections – three for the middle interval of TST and four for HST (intervals B and D in the scheme proposed by Tronkov and Ajdanlijsky, 1998b). The absence of suitable exposures in the middle part of the Sfrazen section and in the lower part of Cerovo section hampers the exact comparison of the structure of the other two intervals.

The comparative analysis of the thickness of these units reveals a tendency to a relatively stable increase (from 27% to 47%) of the thickness of almost all four parasequence sets in the northern (near Sfrazen) section. An exception from this tendency is only the lower interval of the TST, the thickness of which remains almost constant in both sections (7,4 m and 8 m, respectively). The obtained data from the preliminary studies in other sections of the Svidol Formation in the area of Iskar gorge completely confirmed this tendency.

The identity in the parasequence set structure, as well as the almost complete identity (as a scale and as a structure) of the dolomite-marl couplets succession in both sections allows a high-resolutional stratigraphical correlation between them. The different as order cyclicities in the TST from the two sections can be very well correlated.

Except for a refinement of the existing stratigraphic model of Svidol Formation, the present study reveals also some differences in its structure between the sections in the area of Iskar Gorge and those from Teteven district and Vratchanska Stara planina Mountain, published by Čatalov (1974). For example, the described by Čatalov second (upper) cycle in the formation (represented only with its transgressive part) was not established in the sections from the Iskar Gorge. Another significant difference is connected with the structure of the interval of the formation that represents the stage of the maximum deepening of the sedimentary environment. While in Teteven area, this interval is almost completely composed of micritic and biodetrital limestones, that from the sections in the gorge is build up mainly of mixed terrigenous-carbonate lithofacieses.

According to Čatalov (1975), the Svidol Formation was formed under the conditions of an epicontinental tidal flat, for witch the cyclic development of the sedimentary processes was characteristic. On the basis of new data (Hori et al., 2001) it could be supposed, that the described above sedimentary architecture and cyclicity could be a product of tide-dominated delta complex development as well.

The data obtained about the scale and character of the mesoscale cyclicity in Svidol Formation in the area of the Iskar Gorge are comparable with the characteristics of the mesocyclicity established in the PTG (Tronkov and Ajdanlijsky, 1998a; Ajdanlijsky, 2000; 2001b) and in the Mogila Formation (Tronkov, 1983) in the same region. The fluvial mesocycles (MC-0, MC-1 and MC-2) within the PTG as well as the sequence stratigraphy unit described in Svidol Fromation are of the same order (probably 3-rd order, according to the scheme proposed by Miall, 1997, Table 3.1). The subdivision of these fluvial mesocycles into submesocycles and fluvial cycles, respectively the subdivision of the sequence into system tracts, parasequence sets and parasequences, reflects the transition to the next (higher-order) level of cyclicity in them. The structure of the individual parasequences in the Svidol Formation and especially the subdivision of distinct sedimentary couplets and triplets series in some of them on one hand, and the described by Tronkov (1983) and Nikov (1999f) cyclicity in the Opletnja (lower) Member of the Mogila Formation on the other, approximately correspond to the 5-th order cyclicity described by Goldhammer et al., (1987, 1990) in the Latemar's Alpine Triassic platform carbonates.

The absence of reliably determined fossil fauna in the studied section does not allow us to define more precisely the chronostratigraphic range of the above described cyclicities.

The meso- and upper-rank cyclicities recognised in Svidol Formation section near Cerovo Village, are identical with those, described by Tronkov and Ajdanlijsky (1998b) in the same formation at Sfrazen hamlet, located to the north along the Iskar Gorge. Despite some lateral variations in the form and the scale of their occurrence, they could be a good base for more detailed stratigraphic subdivision and correlation of the discussed formation in the area.

The described mesoscale cyclicity is comparable to that, established in other parts of the Lower Triassic section in the area and provides a sound base toward elaboration of a general cyclostratigraphic model for the whole Lower Triassic Series in the studied area. The collected new data about the structure of the formation suggest a possible tide-dominated delta character of the sedimentary environment that controlled the deposition of the formation.

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Recommended for publication by Department of Geology and Paleontology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 13-20

DUCTILE SHEAR ZONE AND BRITTLE FAULTS IN THE SOUTHWESTERN SLOPE OF ZLATITSA-TETEVEN MOUNTAIN (CENTRAL BULGARIA)

Manol Antonov, Venelin Jelev

University of Mining and Geology “St. Ivan Rilski”, Sofia 1700, Bulgaria, E-mail: msantonov@staff.mgu.bg; vjelev@staff.mgu.bg

ABSTRACT
The newly established Anton ductile shear zone is characterized by distinct SL fabric, constant orientation of mylonitic foliation and stretching lineation, and uniform top-to-north shear sense. It follows the southern contact of Vezhen pluton and is superimposed mainly on its granodiorite phase and the rocks of Dalgidel Group. The mylonitic foliation within the zone is cut by undeformed aplite veins of the pluton and most probably was formed towards the end of the Hercynian tectonic cycle. Late Alpine reverse faults and thrusts intersect the zone obliquely. These brittle faults are concentrated in two strips. The southern one includes the Anton reverse fault and the northern – the Vezhen thrust, Dzhemina reverse fault-thrust, Mechesh reverse fault, Kashana reverse fault-thrust and Svishtiplaz allochthone. The faults of the northern strip may be used to divide tectonic units of different age (Early and Late Alpine).

INTRODUCTION

The southwestern slope of Zlatitsa-Teteven Mountain between Zlatitsa pass and Anton village was not subject of detailed geological investigations until now, except its ridge part. That is why the descriptions of the established separate fragments of fold and fault structures (Poushkarov, 1927; Kamenov, 1936; Mandev, 1942; Trashliev, 1961; Tsankov, 1961; Kouykin and Milanov, 1970; Kouykin et al., 1971; Antonov, 1976) as well as some regional overviews (Bonchev, 1961; Bonchev and Karagyuleva, 1961; Yordanov et al., 1965; Vrablyanski, 1971; Cheshitev, 1971; Tsankov, 1995; Cheshitev, 1995 and others) suggest contradictory ideas about the structure of the region studied.

The region was mapped in scale 1:25 000 in view to reveal its prospective for endogenic gold-sulphide ore mineralizations. This work presents some results of this mapping concerning the location, geometry, trend, kinematics and temporal relationships of a newly established ductile shear zone and of some Alpine reverse faults and thrusts known from previous studies. The boundary between the high-grade and low-grade metamorphic rocks, cropping out in Zlatitsa pass and west of Anton Village and assumed to be a post-, syn- or pre-metamorphic thrust (Mandev, 1942; Tsankov, 1961; Kouykin and Milanov, 1970; Ivanov et al., 1987 and others), will be characterised in another paper.

Regional setting

Most of the previous investigators of the western part of Zlatitsa-Teteven Mountain assumed that it comprises parts of two large tectonic units, designated by different names. The northern unit was at first described as Etropole anticline (Kamenov, 1936), and later – as Central Balkan anticlinorium (Kouykin and Milanov, 1970), Shipka anticlinorium (Bonchev, 1971), Shipka Stara Planina (Cheshitev, 1971) or Etropole unit (Tzankov, 1995). The southern unit was characterised as eastern part of the Svoge anticline (Kamenov, 1936) or Svoge anticlinorium (Kouykin and Milanov, 1970), northern part of Sredna Gora anticlinorium (Bonchev, 1961) or Chelopech unit (Tsankov, 1995). All authors assume that the boundary between these two units is tectonic. It has been described as Sub-Balkan deep-seated fault (Bonchev, 1961), Kashana thrust (Kouykin and Milanov, 1970) or Dzhemina reverse fault (Vrablyanski, 1971; Cheshitev, 1971).

Along the ridge of Zlatitsa-Etropole Mountain, the northern unit is represented by a large anticlinal fold, known as Etropole or Central Balkan anticline. Most of the authors (Kouykin and Milanov, 1970; Kouykin et al., 1971; Antonov, 1976 and others) consider it to be the westernmost second-order fold in the confines of the Central Balkan or Shipka anticlinorium. The data from adjacent territories (Nachev, 1963; Antonov, 1971; 1976 and others) demonstrate that it was formed at the end of the Early and before the Late Cretaceous. Its core is built up of Early Proterozoic low-grade metamorphic rocks, referred to the Berkovitsa and/or Dalgidel Groups and Grohoten Formation, as well as of granodiorites from the Late Hercynian Vezhen pluton. Several small and isolated outcrops of its Mesozoic mantle and southern limb are preserved. They comprise sandstones and limestones of Lower and Middle Triassic age (Petrohan Terrigenous and Iskar Carbonate Group).

The southern unit is a fold-and-thrust structure. It comprises small fragments of fold limbs, built up of Upper Cretaceous sedimentary rocks. Precambrian gneisses as well as Paleozoic low-grade metamorphic rocks and granitoids, intersected by Late Cretaceous subvolcanic dykes and bodies, are thrusted over them along longitudinal faults.

Ductile shear zone

During the present investigation, a subequatorial ductile shear zone along the southern contact of Vezhen granodiorite pluton was recognised (Fig. 1). It will be designated further as

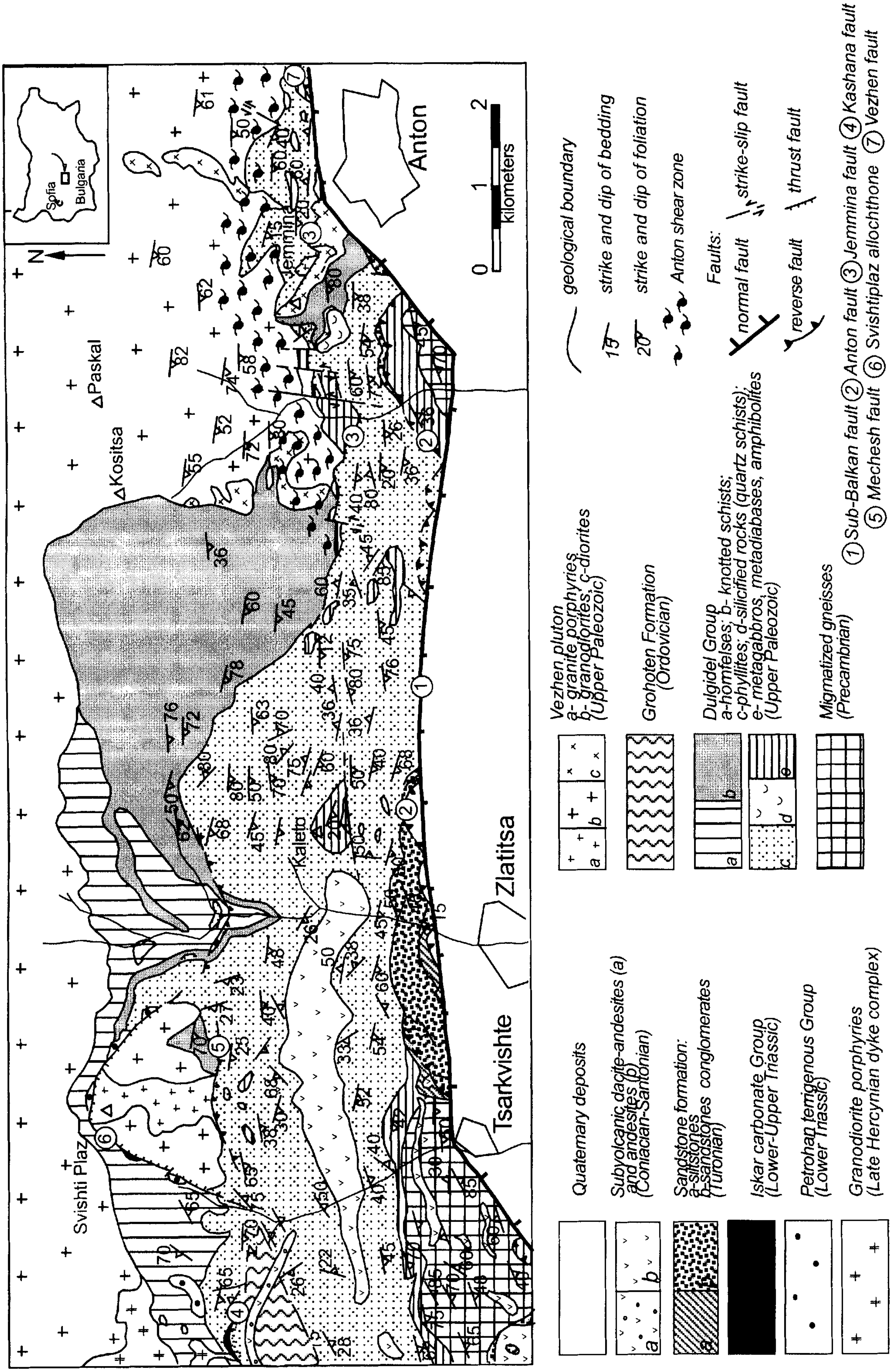


Figure 1. Geological map of the southwestern slope of Zlatitsa-Teteven mountain (Central Bulgaria)

Anton shear zone. It comprises mainly mylonites and blastomylonites and less commonly cataclasite-mylonites and protomylonites. This zone is more than 3 km long, 500-700 m thick, dipping 50-60º to the south.

Most of the previous investigators have described the rocks in this zone but failed to recognise it as an independent and important element of the regional structure. Poushkarov (1903) first mentioned "granitogneisses" north and northeast of Anton village and described them as "amphibole granitogneisses" and "chlorite granitogneisses". Bonchev (1908) confirmed their presence, but emphasised that there was no sharp boundary between them and "the typical granites". Later Mandev (1942) also mentioned that the granodiorite close to the contact with the Paleozoic rocks was "gneiissified and in places mylonitized". On the maps of Kouykin and Milanov (1970) and Kouykin et al. (1971) a "zone of cataclasis and mylonitization" is shown immediately north and northwest of Dzheminski Kamak Peak. These authors assume that the zone is related to the movements along Kashana thrust. According to them "the granodiorites lying at the front of the thrust are strongly schistose at a distance of 300-800 m". This opinion is shared by Velchev et al. (1973f), who describe "cataclised and mylonitized diorites and granodiorites" as well as "striped mylonite" north of Dzheminski Kamak Peak.

The ductile shear zone is superimposed mainly on the granodiorite phase of the Vezhen pluton and partly on the green-schist rocks (metapelites and metaaleuropelites) of Dalgidel Group and the diorites of the first phase of the pluton. The northern boundary is a very gradual transition to less and less schistose granodiorites and diorites, in an interval of visible thickness 200 to 600-700 m. The southern boundary is also a gradual transition towards the low-grade metamorphic rocks of Dalgidel Group.

To the north of the shear zone, the granodiorite protolith is represented by mesocratic rocks, medium- to coarse-grained, of massive texture. Principal minerals are plagioclase, potassium feldspar, quartz, amphibole and biotite. Due to the fact that these minerals participate in different quantities, amphibole-biotite, biotite and amphibole granodiorites can be recognised. The diorite protolith is melanocratic, fine-grained, built up mainly of plagioclase, amphibole, biotite and a little quartz.

To the south of the shear zone, the rocks of Dalgidel Group crop out. They are represented mainly by metapelites and meta-aleuropelites, comprising chlorite, sericite, muscovite, quartz and albite as well as rare grains of epidot, rutile, zircon and ore minerals. Their structure is microlepidoblastic to microlepidogranoblastic. According to the quantities of the principal rock-forming minerals, phyllites (quartz-sericite schists) and quartz-chlorite-sericite schists are recognised. Meta-aleurolites are rarely observed as thin interbeds while metapsammites form single layers amongst the metapelites. In the valley of Elenska river and northwest of Dzheminski Kamak Peak, they form a packet of rhythmic flysch alternation.

The changes in the composition and the structural features along the shear zone allow the recognition of three domains: central – formed of mylonites and blastomylonites, northern – of granodiorite and partly diorite protomylonites and southern – of mylonitized greenschist rocks. Due to the gradual changes of the deformation gradient, the boundaries between the domains are transitional zones 10-50 m thick. Only in the western part of the zone, situated between the rivers of Elenska and Madzharin, anastomically ramificated narrow shear zones are observed in the diorite protolith. Pods of slightly schistose or equigranular diorites occur amongst them.

The central domain of most intensive deformation is from 30 to 120 m thick. It is situated at a distance of several to 10-15 m north of the southern contact of Vezhen pluton. The mylonites and blastomylonites of the central domain are augen-striped rocks featured by relic magmatic mineral association comprising plagioclase (oligoclase-andesine), biotite, amphibole, single grains of K-feldspar (microcline) and rare alanite. The metamorphic association includes entirely re-crystallized quartz, sericite, epidot and chlorite. The relic plagioclase is represented by crystaloclasts and porphyroclasts. Biotite is red-brown, affected by muscovitization with separation of epidot and dusty iron-titanium products. The relic amphibole as well as the alanite form porphyroclasts as well. The metamorphogenic quartz is entirely re-crystallized and forms strips of lenticular and mosaic structure. These strips alternate with pods domains built up of fine-crystalline (due to dimension reduction) sericite, plagioclase and epidote. The boundaries of the porphyroclasts are usually resorbed but sometimes are sharp. Oval and rare angular porphyroclasts elongated parallel to the foliation prevail.

The protomylonites and cataclastic mylonites of the northern domain are distinguished by larger size and prevailing angular shape of the porphyroclasts. Plagioclase porphyroclasts possess frequently deformed crystal lattice and cataclasis developed along their periphery.

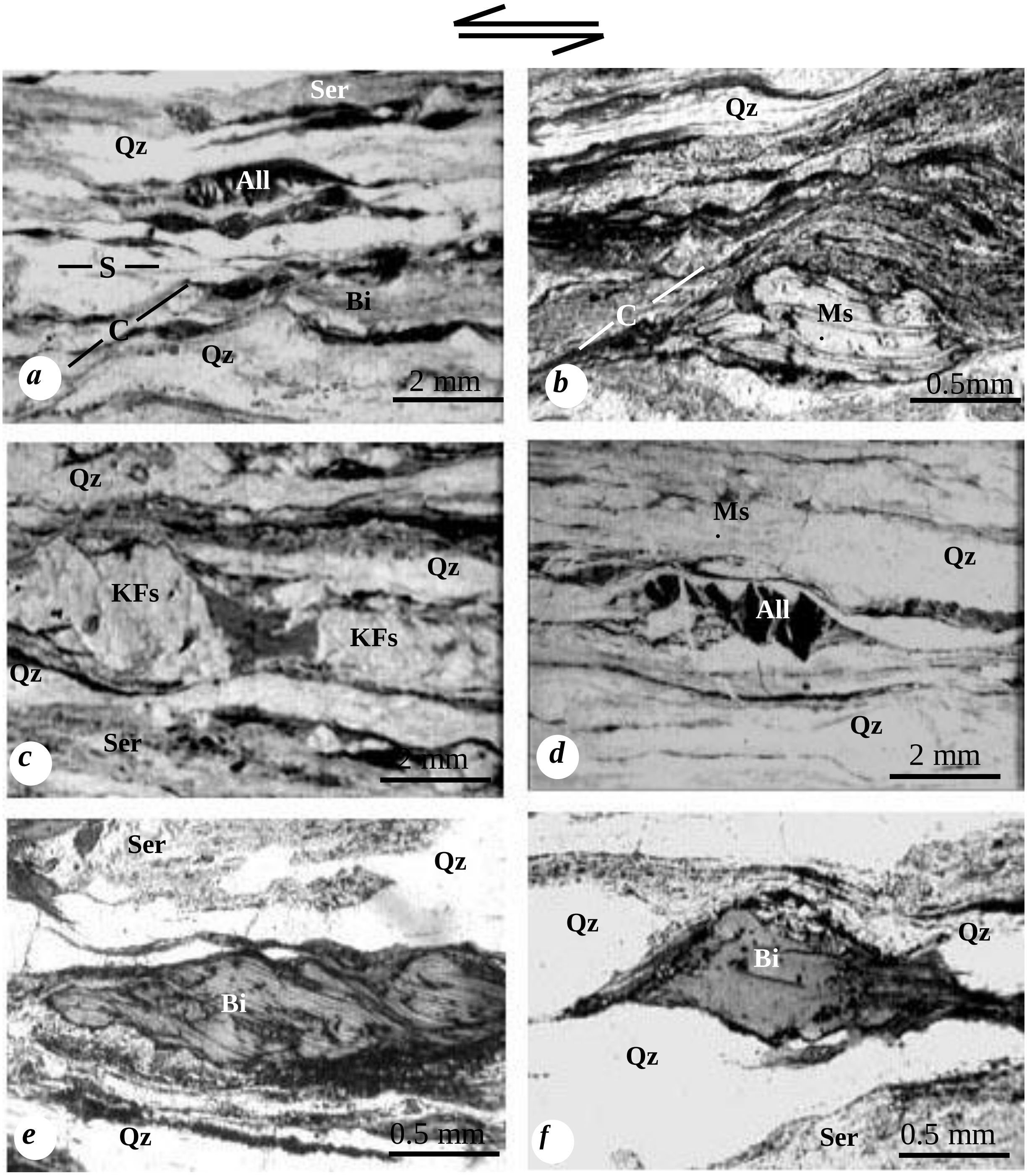
The mylonitized pelites and aleuropelites of the southern domain comprise apophyses of the granodiorite protolith, altered to protomylonites.

The ductile shear zone exibits a distinct SL-fabric of dominating mylonitic foliation and mineral stretching lineation. They are determined by planar-parallel and linear preferred orientation of the mica minerals and mineral aggregates, the long axes of porphyroclasts and domains enriched in quartz and mica.

The orientation of the mylonitic foliation is 80-100º/50-70º to south. It almost entirely coincides with the trend of the axial cleavage of the rocks of Dalgidel Group. To the west of the valley of Elenska River and to the north of Anton Village, this foliation is folded in cm and dm kink-folds (Table 2, b). The stretching lineation lies in the planes of the mylonitic foliation. Usually it is subparallel to the dip line of the mylonitic foliation.

The shear sense was determined by means of microstructural synkinematic criteria (Passchier and Trouw, 1996), recognised in five oriented rock samples which were collected from different domains of the ductile zone. The microscopic observations of S-C' fabrics, σ - porphyroclasts, mica fish etc. in thin sections parallel to the stretching lineation and perpendicular to the mylonitic foliation demonstrate (Table 1) that a thrust shearing top-to-north took place. Additional

Table 1



Micro-photographs of thin sections at right angles to foliation and parallel to lineation (X-Z sections) looking up towards the east for the samples of granodiorite mylonites of the Anton shear zone (Qz – quartz; Bi- biotite; Ms- muscovite; KFs- K-feldspar; All- allanite; Ser- sericite; N II): a and b – S-C'- fabric relationships and mica fish; c – tiling structure in K-feldspar porphyroclast with antithetic micro-faults; d – fragmented allinite porphyroclast, intersected by synthetic and antithetic micro-faults; e – mica fish intersected by antithetic micro-shears; f – mica (biotite) fish

detailed investigations are required to clarify the kinematics of the ductile deformation.

The ductile shear zone between Dzheminski Kamak Peak and the ridge separating the rivers of Madzharin and Bouchoum is obliquely cut and covered by the allochthone of Dzhemina thrust. This zone was probably formed at the end of the Hercynian tectonic cycle, because it is intersected by undeformed aplitic veins of the Vezhen pluton (Table 2, c).

Brittle faults

Several small and isolated outcrops of rocks from the Turonian sandstone formation are exposed amongst the schists and phyllites of Dalgidel Group in the southern foot of Zlatitsa Mountain. They mark the traces of Late Alpine faults. These outcrops are relics of Late Alpine fold limbs, which are cut by longitudinal faults. From south to north, three relatively larger faults are traced – Anton reverse fault, Dzhemina reverse fault-thrust and Kashana reverse fault–thrust, as well as two smaller faults – Mechesh reverse fault and Svishtiplaz allochthone.

The Anton reverse fault was recognised and nominated by Kouykin and Milanov (1970) as "Anton thrust". During the present study, the fault was traced more accurately in the field. It continues to the west across Sanardere valley and ends into Balamdere valley. The fault trends 80-85º and dips 60-70ºS. Its hanging wall, built up of migmatized gneisses and rocks of Dalgidel Group (metabasites, metagranites, felsites, quartz-chlorite-sericite schists and phyllites) is cut by the longitudinal Sub-Balkan normal fault. The footwall comprises mainly phyllites of Dalgidel Group and only locally, immediately beneath the reverse fault plane, the rocks of the sandstone formation (Turonian) are preserved.

The Dzhemina reverse fault-thrust was established and nominated by Milanov et al. (1964f) as "Dzhemina reverse fault" and described by Vrablyanski (1971). Later it was considered by Kouykin and Milanov (1970) and Kouykin et al. (1971) as the easternmost part of "Kashana thrust". Velchev et al. (1973) named it "Kashana reverse fault". The fault is traced reliably from the western end of Anton village to the valley of Bochoum River to west. That is why it is assumed here as an independent rupture. The fault trace, mapped during the present study only in separate areas, coincides with the fault lines given by the previous investigators. From Anton village, where the fault is cut by the Sub-Balkan normal fault, to the valley of Kalimandere (southwest of Dzheminski Kamak Peak), the fault zone dips 30º/S (Table 2, d). To the west it becomes steeper – up to 45-50º/S. The zone includes banded tectonic breccia and tectonic clay (Table 2, e, f). Its thickness varies from 0,5 to 8-12 m. Maximum thickness was measured in Mandzharindere and Kalimandere River. There, the diameters of the breccia polygenic clasts are 1-5 cm. They are well polished and well rounded. (Table 2, f).

The hanging wall, i. e. the allochthone is built up mainly of phyllites and knotty schists of Dalgidel Group. Quartzdiorites and very small outcrops of granodiorites are exposed in the massif of Dzheminski Kamak Peak and to the east forming a lower imbrication plate along the left (north-northeastern) riverside of Zhitnitsa river (Table 2, e). The foot wall, i. e. the autochthone, comprises phyllites, quartz-chlorite-sericite schists and a flysch alternation of Dalgidel Group. Northwest of Dzheminski Kamak Peak it includes mylonites of the ductile shear zone.

West of Dzheminski Kamak Peak, the reverse fault–thrust is replaced by five small transversal faults of probable strike-slip character. The strike-slip with largest visible horizontal amplitude of about 500 m is traced immediately to the east of Elenska River. Its trend is subequatorial (10º) and the length is more than 1 km.

The Vezhen thrust was recognized by Mandev (1942) and later was considered as a western continuation of the Stara Planina granite nappe (Bonchev, 1961; Bonchev and Karagyuleva, 1961) or Central Balkan thrust (Yordanov et al., 1965). It was described by Kouykin et al. (1971) as "Vezhen part of the thrust" or "Vezhen allochthone". A small segment (about 300 m long) of the western termination of the thrust is exposed in the western part of the region studied. Along this segment east of Gusheva River, migmatized gneisses are thrust over the rocks of Dalgidel Group.

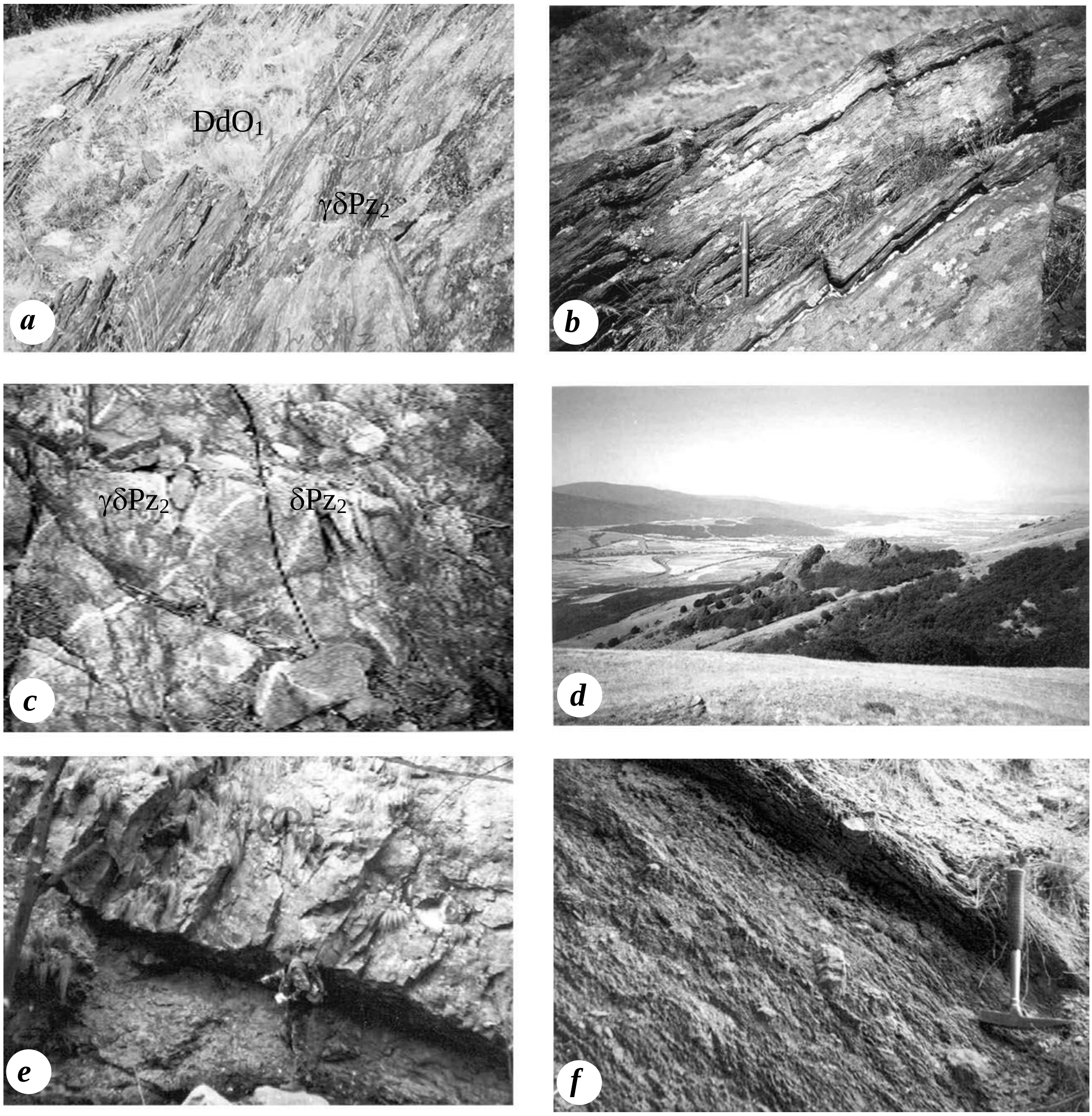
The Kashana reverse fault-thrust was recognised by Trashliev and Trashlieva (1956f) and Trashliev (1961) and described as a "deep dislocation line", but it was named by Milanov et al. (1964) as "Kashana dislocation" and "Kashana thrust" (Kouykin and Milanov, 1970; Kouykin et al., 1971). According to Milanov et al. (1964), the "Kashana dislocation may be traced to the east along the northwestern, northern and eastern slopes of Svishtiplaz Peak and across the valley of Kouroudere River to the southwest of Balkan Chalet. Kouykin and Milanov (1970) and Kouykin et al. (1971) continue the fault trace to the west of Anton Village, assuming the Dzhemina reverse fault–thrust to be its easternmost part.

Despite the detailed observations around Kashana mine and along the ridge of Svishtiplaz Peak during the present investigation, reliable field criteria to trace the Kashana reverse fault–thrust to the east of Kashana Chalet and in the valley of Klissekyoi River could not be found. That is why its identification with the thrust along the ridge of Svishtiplaz Peak, assumed to be part of the Etropole thrust (Antonov, 1976) or with the thrust traced north of Mechesh Peak, is still problematic. In the area around Kashana mine, the reverse fault–thrust trends east – west, dipping 40-50º to south. There, it was proven by a number of boreholes along several profile lines (Trashliev, 1961).

The Mechesh reverse fault was established by Kouykin and Milanov (1970) and Kouykin et al., 1971), who showed it on their maps and sections as a small satellite fault, intersecting "the allochthone of Kashana thrust". During the present study the fault was traced reliably only to the north of Mechesh Peak at a distance of about 700 m along the contact between the rocks of Dalgidel Group and a granite-porphyry body. Its trend is subequatorial (80-90º) and its average dip is about 60º to south. The tracing of its continuations to the west and east is obstructed both by the lack of exposures and the uniform character of the rocks of Dalgidel Group.

The Svishtiplaz allochthone was recognised by Kouykin and Milanov (1970) and Kouykin et al. (1971), who argued that this fault was the eastern continuation of Kashana thrust. Later it was assumed to be part of the Etropole thrust (Antonov, 1976). The thrust plane is traced along the northwestern and northeastern slopes of Svishtiplaz Peak. It is distinctly marked by the boundary between contact-metamorphic rocks of Dalgidel Group (knotty schists and hornfelses) and allochthonous granitoids and granite-porphyries, where thin lenses of Triassic sandstones (Petrohan terrigenous Group) and very small outcrops of limestones (Iskar carbonate Group) are preserved (Fig. 10). The thrust plane dips gently 15-25º to SSE. As mentioned above, there are no reliable field data in the valleys of Klissekyoi and Kouroudere River in order to relate Svishtiplaz allochthone with Kashana thrust. In the valley of Kouroudere river, southeast of Svishtiplaz Peak, a subequatorial fault zone determined as reverse fault–thrust was observed. It could be reliably traced only at a distance of 250 – 300 m. This zone dips 45-55º to south and could be the eastern continuation both of Svishtiplaz allochthone or of Mechesh reverse fault.

Table 2



a – contact between milonite aleuropelites of Dalgidel Group (DdO1) and granodiorite mylonites ($\gamma\delta Pz_2$) NE of Jemminski Kamak peak (look to west); b – crenulated mylonite foliation in the central domain of the ductile shear zone NNW of Anton village (look to west); c – diorite (δPz_2) and granodiorite ($\gamma\delta Pz_2$) protomylonites, intersected by undeformed vein of aplite NW of Elenska river (look to northwest); d – general view of Jemmina reverse fault-thrust and Jemmina peak (look to west); e – tectonic breccia in the base of a granodiorite allochthonous flake of Jemmina reverse fault-thrust in the valley of Zhitnitsa river; f – banded tectonic breccia of Jemmina reverse fault-thrust in the valley of Madzharin river (look to east)

East of Govedarnika locality to the river of Bochoum, phyllites and knotty schists crop out. In the valleys of Sanardere and Slavtsi rivers, their scarce exposures are affected by landslides and rock-falls, which make the tracing of fault zones practically impossible.

DISCUSSION AND CONCLUSION

The Anton shear zones is characterised by: 1) distinct SL-fabric and constant trend of mylonitic foliation and stretching lineation; 2) identical shear sense in the three domains; 3) the central domain is most intensively deformed and is related mainly to the southern contact of Vezhen pluton; 4) within the diorite protolith and the green-schistic rocks of Dalgidel Group, this domain transitionally passes into narrow, anastomosing shear zones with preserved, slightly deformed or undeformed pods of the protolith among them; 5) undeformed aplitic veins of the pluton intersect the mylonitic foliation; 6) the ductile shear zone is obliquely or transversally cut by Late Alpine brittle faults.

On the basis of the features mentioned above, it could be assumed that the inhomogeneous ductile deformation of the Anton mylonitic zone took place at significant crustal depth, during a single, probably Late Hercynian deformation event, immediately after the intrusion and cooling of the Vezhen pluton. The primary cataclastic deformation of the granodiorites and diorites lead to reduction of the grain size in microscopic shear zones and subsequent ductile deformation.

The Late Alpine reverse faults and thrusts are concentrated in two strips. The southern one comprises the Anton reverse fault and the small reverse fault north of Tsarkvishte Village. The northern strip includes Vezhen thrust, Dzhemina reverse fault-thrust, Mechesh reverse fault, Kashana reverse fault–thrust and Svishtiplaz allochthone. It is problematic to treat them as an uninterrupted fault zone due to lack of reliable field criteria. They probably represent independent en-echelon reverse faults and thrusts with imbricated frontal parts. The use of faults from the northern strip to distinguish Early Alpine and Late Alpine tectonic units is well argumented by the field data.

ACKNOWLEDGMENTS

We are much obliged to the management of Navan Chelopech Plc, both for the sponsorship of this study and permission to publish part of the results. We are also grateful to St. Pristavova for the petrologic characteristics of rocks from the ductile shear zone and to K. Shipkova for the preliminary discussions concerning the shear sense criteria.

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Recommended for publication by Department of Geology and Paleontology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 21-26

COMPOSITION OF PALEOGENE VOLCANICS IN THE REGION OF ARDA MOUNTAIN, SOUTH RHODOPES

Milorad Vatsev

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia, Bulgaria

ABSTRACT
The Upper Arda graben basin is located in the area of Arda Mountain in the Southern Rhodopes, both on the territory of Bulgaria and Greece. The volcanic and volcano-sedimentary rocks overlie and associate with Upper Eocene and Oligocene terrigenous sediments. Dacites, rhyiolites and tuffs are dominating rock types. Ignimbrites are also quite common. The volcanics are quartz-feldspar rocks containing plagioclase and K-Na feldspar nearly in equal quantities, or with prevalence of plagioclase. Femic minerals are biotite, rarely amphibole and augite. The rocks are high-K and the relation K_2O/Na_2O does not depend on the SiO_2 content. The modal and petrochemical composition indicate calc-alkaline to subalkaline trachydacite-trachyrhyolite or high-K calcalkaline dacite-rhyolite series. The volcanic rocks are part of the Paleogene collision-related volcanics from central part of the Rhodopes region.

INTRODUCTION

The Upper-Arda Graben (trough) or basin (UAG) (Vatsev, 1985, 1989a) is one of the southernmost Paleogene basins in the Rhodope region on the territory of Bulgaria. It is located in the southernmost, high part of the Upper Arda region in the Central Rhodopes (CR) and occupies the area of Arda Mountain. Its southern part extends on the territory of Greece and is known as Dipotama basin (Baker and Liati, 1991). The Bulgarian part of the basin is denoted as Vitina depression (Bahneva, Stefanov, 1973).

Brief information and data on the petrographic composition and stratigraphic position of the volcanics in UAG are given in the publications of Bahneva, Stefanov (1973) and Vatsev (1985, 1989a). They report data on the Oligocene age of the volcanics and occurrence of ignimbrites. More detailed petrologic characteristics of the rocks under consideration have not been reported so far. The petrologic and geochemical data about the same rocks on the territory of Greece are much more complete (Eleftheriadis and Lippolt, 1984; Eleftheriadis, 1995).

The present work, which is a continuation of earlier studies of the author, aims at giving a more detailed information about the volcanics of UAG and improving the understanding of the volcanism in the CR. The volcanic rocks are characterized on the basis of field, micropetrographic and petrochemical studies. For this purpose, 33 silicate analyses were used. 26 of them were made in Bulgaria, of which 21 based on author's investigations and analysed at the "Geochemistry" Central Research Laboratory of the University of Mining and Geology by classical water silicate analysis. The other 6 analyses are from literature sources and 7 are from Greece (Innocenti et al., 1984; Ellefteriadis, 1995).

GEOLOGICAL SETTING

The Palaeogene Upper Arda volcano-sedimentary basin (Vatsev, 1985,1989a), as well as the other depressions in the CR, overlie the Pre-Cambrian basement of the Rhodopes region (RR) as well as Upper Cretaceous and Paleogene granites (Soldatos, Christofides, 1986: Kamenov et al., 1999). It is bordered on the north by several WNW-ESE subparallel faults with subsided southern blocks. The graben is 25-30 km long and 5-8 km wide on the territory of Bulgaria. The southern, wider part of the basin (10-15 km) is located in Greece. The relatively uplifted blocks of the basement, exposed along the Bulgarian-Greek border at the village of Arda, at Gramada summit, south-east of Mochure, at the villages of Vitina and Plovdivtsi, mark the complex block-graben structure of UAG.

The Upper-Eocene sedimentary fill of UAG in its northern, Bulgarian part consists from bottom to top of the following units: 1) Hulevina breccia-conglomerate Formation (200-250m) (Vatsev, 1985); 2) Palova sandstone Formation (70-90 m) (Vatsev, 1985); 3) Radichevo conglomerate Formation (150-200 m) (Vatsev, 1985) and 4) Gudevo argillite-sandstone Formation (450-500 m) (Vatsev, 1985), containing seams of coal and tuff layers. The Late Eocene age is dated on the basis of fossil flora (Vatsev, 1985).

The overlying Oligocene sedimentary and volcanic rocks are represented by: 5) Gozdevitsa sandstone-conglomerate Formation (150-200m) (Vatsev, 1989), containing tuff layers and 6) Gramada volcano-sedimentary Formation (900-1300m) (Vatsev, 1989).

The Gramada Formation is composed of three volcanic units (sequences), divided by two wedge-shaped, fluvial and caldera-lacustrine sedimentary and pyroclastic units: Milenovo tuff-argillite-sandstone Member (15-90 m) (Vatsev, 1989a and Mochure tuff-argillite-sandstone Member (10-25 m) (Vatsev, 1989a). The volcanic rocks of the first (150-200 m), third (500-600m) and fifth (250-300 m) unit show similar composition and structure. They comprise ignimbrites, with and without fiamme, lapilli and ash-tuffs, dacites and rhyolites (rhyodacites). The ignimbrites, dacites and rhyolites with porphyry texture are better developed in the upper parts of the volcanic units. A late element of the volcanic sequences are dacite-rhyolite extrusive rocks, containing phenocrysts (to 10-15 cm) of Na-K-feldspar and less quartz and biotite, as well as amphibole and diopside-augite. In the upper part of the bodies, the rocks are grey-black and poorest in phenocrysts (10-20%).

The Oligocene age of the rocks was proved on the basis of fossil flora, identified in the sedimentary rocks of Malenovo tuff-argillite-sandstone Member and in the late Late Eocene sediments of the underlying units (Vatsev, 1989a,b). The age of the volcanic rocks in Greece is about 27-30.6 Ma – Oligocene (Elefteriadis and Lippolt, 1984).

One of the most important features of UAG is the close interrelation between volcanism and tectonics, development of volcanic-tectonic depressions of block-caldera type and significant volume of ignimbrites.

PETROGRAPHIC CHARACTERISTICS

The volcanic rocks in UAG, regardless of differences in genesis and stratigraphic position, are not essentially altered and have practically identical crystal phases. The phenocrysts (20 to 63 % of the rock volume) are plagioclase, Na-K feldspar, quartz, biotite, amphibole and augite, which are relatively evenly distributed.

Plagioclase crystals (3-6 mm) show a zonal structure. Their composition varies from the centre to the periphery from andesine (An 50-45) to oligoclase (An 30-20). The number of zones varies from 3-5 to 6-7. Normal and locally reverse zonality is observed. The composition of the zones varies by 4-6 numbers of the plagioclase, but spotted zonality may occur as well. Some crystals have more basic cores.

Na-K feldspar is represented by automorphic and broken individuals of sanidine, found in tuffs, ignimbrites and rhyodacites.

Quartz crystals (2-4 mm) are transparent and slightly smoked grains, with irregular outlines, sometimes partially hexagonal or corroded by volcanic glass. Polymineral xenogenous quartz crystals have been found as well, containing powder inclusions, zircon and apatite.

Biotite (2-5%) is represented by varieties rich in iron and is often affected by opacitization and chloritization. There are biotite grains with thin, darker coloured outer zone.

Amphibole is a relatively rare mineral (below 1%) of unsteady development. It is represented by ordinary green, often altered amphibole. Pyroxene is a rare mineral, appearing as single grains of augite, often replaced by amphibole.

Accessory minerals include zircon, apatite, magnetite, rutile and orthite. Magnetite was formed earlier and is more typical. The minerals filling cavities are trydimite, cristobalite, rarely Na-K feldspar.

The ground mass of the volcanic rocks is composed of volcanic glass, devitirified to a different extent. There are rocks with vitrophyric, hyalopelitic, felsitic and spherulitic texture. The latter is related to devitrification of volcanic glass. Some varieties show relatively homogeneous structure of the ground mass, and others – a vague fluidal-striped texture, controlled by liquation processes and magma flow.

The fiamme of the ignimbrites show striped structure and are 1 to 3 cm long and up to 1.5 cm thick. The pumice clastics are lenticular and vary from 2-3 to 5-7 cm in length. The shape, boundaries and structure of the fiamme are indicators of their plastic deformations within the ignimbrite flows.

The volcanic rocks under consideration contain xenoliths and polymineral grains of gneisses and granodiorites.

The observed characteristic associations of phenocrysts, inherent to normal calc-alkaline to subalkaline acid rocks, and the refraction coefficient of the ground mass (1,495-1,510) allow to differentiate amphibole containing biotite and mainly biotite dacites and rhyodacites or rhyolites, ignimbrites and tuffs of analogous composition. They originated most probably from one melt.

PETROCHEMICAL CHARACTERISTICS

The volcanic rocks from UAG are acid (SiO_2 from 64 to 72 wt%) normal calc-alkaline and subalkaline varieties. On the basis of the classification and nomenclature of igneous rocks (CNI) - (Na_2O + K_2O)/SiO_2 diagram (Bogatikov et al., 1985) (Fig. 1a) they are calc-alkaline and subalkaline dacites and rhyodacites. Based on the same data, according to the classification of volcanic rocks (TAS Diagram) (Le Bas et al., 1992), they belong to the trachydacite-trachyrhyolite series (Fig. 1b). According to the K_2O-SiO_2 diagram (Peccerillo and Taylor, 1976, supplemented by Ewart, 1982) they may be classified as dacites and rhyolites with high K content (Fig. 1c). The ratio K_2O/Na_2O for most of the analyses is below 1 (Fig. 1d). Recalculations of the normative mineral composition were carried out by the methods of the American geologists C.I.P.W. Parallel to that a number of important typochemical coefficients and normative characteristics were calculated.

On the basis of the normative mineral composition, according to the AQP diagram (Le Bas, Streckeisen, 1991), the rocks may be referred to the calc-alkaline rhyolite (Fig. 2a) to subalkaline dacite-rhyolite series.

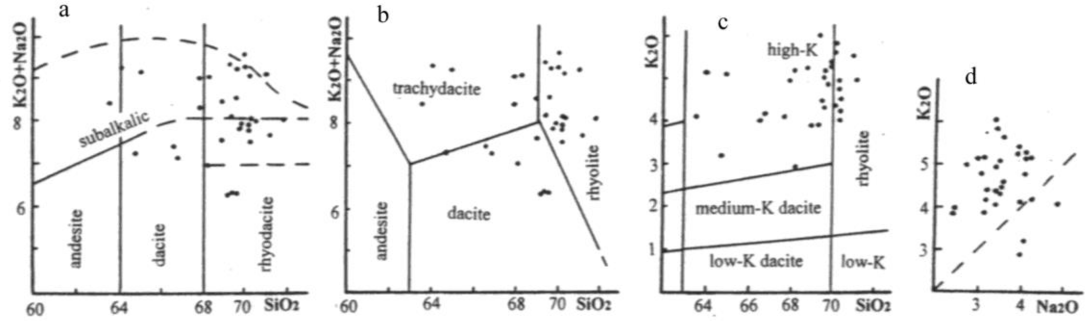

Figure 1. Petrologic diagrams of the Paleogene volcanic rocks from Upper-Arda graben: a) Diagram $Na_2O + K_2O/SiO_2$ wt%; b) Diagram $Na_2O + K_2O/SiO_2$ wt% (TAS); c) Diagram K_2O/SiO_2 wt%; d) Diagram K_2O/Na_2O wt%; data of diagrams see in paper

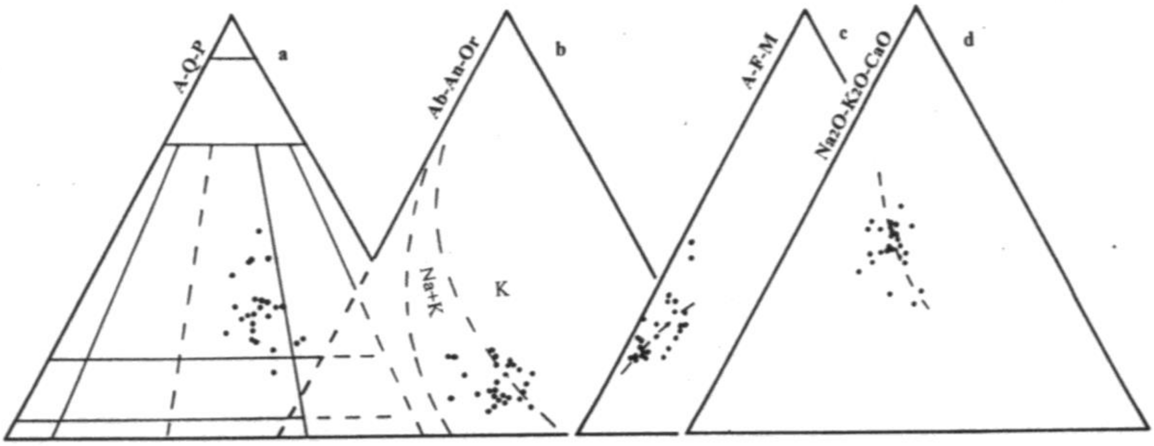

Figure 2. Mineralogical and petrologic diagrams of the Paleogene volcanic rocks from Upper-Arda graben: a) Diagram AQP, A – alkcaly feldspar, Q – quartz, P – plagioclase; b) Diagram Ab-An-Or normative minerals; c) Diagram AFM, A = $Na_2O + K_2O$, F = FeO + $0{,}9Fe2O_3$, M = MgO; d) Diagram Na_2O-K_2O-CaO wt%; data of diagrams see in paper

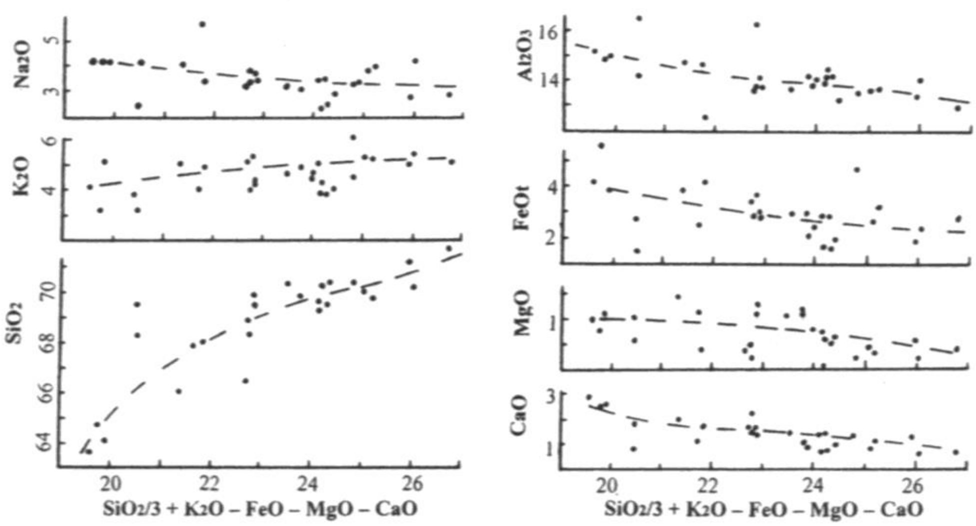

Figure 3. Variation diagrams of the parameter of Larsen of the Paleogene volcanic rocks from Upper-Arda graben

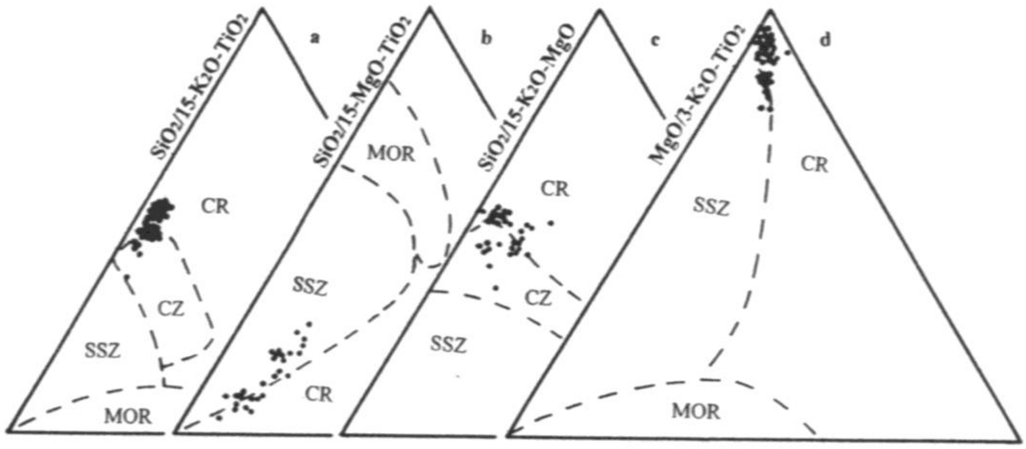

Figure 4. The Paleogene volcanic rocks from Upper-Arda Graben on the diagrams of correlations of Si, Mg, Ti and K. Environments: MOR – middle oceanic ridge, CR – continental rift, SSZ – subduction zone, CZ - continental collision; data of diagrams see in paper

Ignimbrites, dacites and rhyolites with different stratigraphic position do not differ substantially by the content of SiO_2 and alkalies, the content of Na_2O varying from 2.4 to 4.9, on the average 3.55 wt%, and that of K_2O varying from 2.95 to 6.05, on the average 4.48 wt%. On the basis of the total content of alkalies (from 6.3 to 9.6 wt%), the rocks are normal and subalkaline, or high-K calc-alkaline. The data on the Al-An-Or diagram (Fig. 2b) mark the presence of K- and Na-K rocks, according to the distinguishing lines suggested by Irvine and Baragar (1971).

These data, as well as the K_2O/SiO_2 diagram and the characteristic presence of K-containing minerals, emphasise the K specificity of the volcanic rocks. The K-content in them is moderate (K_2O < 7 wt%), and the presence of normative quartz more than 20% characterises these rocks as trachydacites and rhyolites. The normative plagioclase coefficient *np* = 100An/(Ab + An) varies from 7.5 to 33.3 and its average value is 15.2; the normative quartz coefficient *q*` = 100Q/(Q + Ab + An) ranges from 16.5 to 56.3, on the average 32.2. It must be pointed out, however, that the rocks do not differ substantially by the content of normative Q, Or, Ab and An; the content of An is low (5-13 %).

The rocks are poor in CaO (from 1.26 to 3.84, with average value 2.38 wt%) and MgO (from 0.24 to 2.58, with average value 2.32 wt%). The content of normative wollastonite and enstatite is in the range of the first several percents. The content of these oxides is in a reverse relation to that of SiO_2 and that of the normative An with respect to Q and Or, respectively.

The content of Al_2O_3 varies from 12.6 to 16.9, the average value being 14.2 wt%, and the rocks are moderate low- and moderate high-aluminous (Bogatikov et al., 1985). Normative corundum practically has not been found.

The UAG volcanics are characterised by low content of TiO_2 - from 0.2 to 0.58, on the average 0.35 wt%, with a tendency to decrease in the more acid rock varieties.

The fiamme ignimbrites and dacites, poor of phenocrysts, are characterized by a decrease of the SiO_2 content by 3-6 wt% and increase of Al_2O_3 by 1-3 wt%, of CaO by 0.5-1 wt%, of MgO by 0.7-1 wt% and a negligible increase of TiO_2 and MnO.

When considering the bulk composition of the volcanics, it is found out that parallel to the increase of the values of Larsen's parameter, the contents of SiO_2 and K_2O also increase, the content of Na_2O slightly decreases and the contents of Al_2O_3, CaO, MgO, TiO_2 and $FeO+Fe_2O_3$ decrease. The variation diagrams (Fig. 3) as well as the AFM and Na_2O-K_2O-CaO diagrams (Fig. 2c, d) mark the calc-alkaline trend of the volcanics.

Variation diagrams constructed according to Larsen's parameter (Fig. 3), mark the high-K tendency with increasing SiO_2 content. The poorly expressed negative correlation between Na_2O and SiO_2 can be explained by the characteristic property of acid magmas to include Na together with Ca in the fraction of more difficult to melt early crystal phases (plagioclase, biotite, amphibole, zircon) and the early cooled ground mass. In this connection, it should be taken into consideration that, in the relatively more alkaline dacites with grey-black vitrophyritic matrix, the Na_2O content is higher than that of K_2O.

On the basis of the modal and normative composition, as well as of the petrochemical characteristics of the volcanic rocks from UAG, they can be referred to the normal to subalkaline trachydacite-trachyrhyolite series (CNI, TAS) or to the high-K dacite-rhyolite series (K-Si diagram) (Fig. 1). The rocks of this series, represented mainly by ignimbrites and rhyodacites, are characteristic with the great similarity of their petrographic and normative composition. The magma evolution is marked by the subsequent development of ignimbrites, banded rhyodacites and volcanics containing more phenocrysts. These peculiarities of the rocks are related most probably to unstable conditions of crystallisation, transport and magma cooling. The dacite-rhyodacites with phenocrysts of Na-K -feldspar mark the K-character of the volcanics and are element of an opposite trend. This melt was probably derived from the lower parts of the magma chamber.

The volcanics from UAG are analogous to the volcanic rocks in other depressions in CR and WR – Smolian graben (Vatsev, 1989), Bratsigovo-Dospat depression (Vatsev, Katskov, 1988) and Mesta graben (Vatsev, Nedyalkova, 1984).

DISCUSSION AND CONCLUSIONS

Typical for the studied volcanic rocks is that the K_2O/Na_2O ratio does not depend strictly on the SiO_2 content. This feature and the petrologic composition of the rocks are indicators of a crustal tectonic activity (Marakushev, Yakovleva, 1975).

A comprehensive consideration of the problems related to the origin of the volcanics in UAG is impossible without considering the basic questions of magmatic activity as a whole, at least in the Central and Western Rhodopes. This is beyond the scope of the present study and only some basic problems will be outlined:

- Cretaceous-Paleogene zonal metamorphism and granitization were established and dated in the region of Rila Mountain and Central Rhodopes (Arnaudov et al., 1980; Arnaudov, Amov, 1998; etc.); the composition of the granodiorite-granitic metatect is close to that of the gneisses of the basement.
- Uniform in composition Late-Cretaceous and Paleogene granodiorite-granitic plutons (formerly known as South Bulgarian granites) are of wide occurrence (Kamenov et al., 1999; Soldatos,Christofides, 1986; etc.) in the Central Rhodopes, Western Rhodopes and Pirin Mountain (Gagorcev et al., 1987); there are also metamorphosed granitoids in the Rhodopes region.
- The basic tectonic and morphotectonic unit in the Central and West Rhodopes is the West-Rhodopean dome and the neighbouring Madan and other domes, related to the processes and stages of metamorphism during Cretaceous and Paleogene time, sequence granite intrusions and Oligocene dacite-rhyolitic volcanism.
- Development of Paleogene grabens on the background of the metamorphic-magmatic domes, filled with considerable volumes of sedimentary and acid volcanic rocks - UAG, Smolian graben (Vatsev, 1989), Bratsigovo-Dospat depression (Vatsev, Katskov, 1988), Mesta graben (Vatsev, Nedyalkova, 1984), etc.
- Spatial relation and uniform composition of the consecutively intruded Late Cretaceous and Paleogene granite plutons and Paleogene volcanics, indicating uniform conditions of magma generation and emplacement in the same heated conduits.
- The tectonic, metamorphic and magmatic Cretaceous-Paleogene activities mark thickening and activation of the crust and activation of the upper mantle in the RR. Cretaceous-Paleogene basic-ultrabasic rocks are not established in the region, but the activated state of the upper mantle can be deduced from petrological data about the volcanics (Fig. 4) and from isotopic-geochemical data about the Late-Cretaceous, coarse-porphyric K-feldspar granites (Unit 1) of the West-Rhodope batholith; the Paleogene granites (Units 2 and 3) are considered to be late- and post-collisional (Kamenov et al., 1999).

The above considerations lead to the conclusion that the Oligocene dacite-rhyolitie volcanics originated most probably from palingenetic anatectic magmas, connected with tectono-magmatic activisation of RR. Analogous ideas, concerning the genesis of the Oligocene volcanics from the Central Rhodope and West Rhodope depressions, have been reported by the author in the above mentioned publications.

The intensive Cretaceous-Paleogene metamorphism, accompanied by consecutive intrusions of large granite plutons and formation of large magma-metamorphic domes, are indicators of tectonic activation and thickening of the Earth's crust in the RR. They are related during the time with the collision in the Alpo-Himalayan belt (Dercourt et al., 1993; Koronovski et al., 1997; etc.). The development of Eocene-Oligocene grabens and the volcanic activity are related to a following stage of uplift and extension in the West-Rhodope dome and the RR. The Paleogene magmatic products from RR have been related to collisional processes in the papers of Dabovski et al. (1991), Yanev et al. (1998) or to orogenic episode such as a rapid tectonic uplift under an exstensional geotectonic regime (Eleftheriadis, 1995).

The petrologic data about the volcanics from UAG plotted on the diagrams $SiO_2/15$-K_2O-TiO_2, $SiO_2/15$-MgO-TiO_2x2, $SiO_2/15$-K_2O-MgO and MgO/3-K_2O-TiO_2 (Fig. 4) show as well identical grouping; the dividing lines are proposed by Demina, Simonov (1999). The presented petrologic and tectonic data suggests that the volcanics from UAG are most probably collision-related. The distribution of the plots in the next-door neighbour part of the field of continental-rift-related volcanics, indicates tectono-magmatic activation of a stable (40-50 km) continental crust and are probably an indicator of the transition to a following rift stage of development. The data about subduction-related volcanics suggest the idea of the complex character of the collision and of elements of residual sbduction in the lower part of the lithosphere.

The cessation of volcanism around the boundary Paleogene-Neogene is accompanied by an inversion, spread all over the Palaeogene depressions (Vatsev, 1984, 1999). During this stage, minor plutons were intruded in the East Rhodopes (Mavroudchiev, 1992). This is a late-collisional stage of compression, complex faulting and shearing.

The late Late-Oligocene-Neogene post-collisional stage is a stage of arch uplifting, extension and faulting, and having elements of residual collision. It is characterised similarly of development of considerable ore mineralizations (Amov et al., 1993), rare basalt dikes in ER (Marchev et al., 1998) and a new generation of depressions and sedimentary basins in and around Rhodope region (Vatsev, 1984, 1999).

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Recommended for publication by Department of Geology and Paleontology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 27-32

PALEOGENE ACCRETIONARY LAPILLI TUFFS IN MESTA GRABEN (SOUTH-WESTERN BULGARIA)

Milorad Vatsev

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia, Bulgaria

ABSTRACT
Accretionary lapilli tuffs have been identified in four locations in Paleogene rhyodacite tuffs from Mesta graben. The lapilli are spheroids 3-12 mm in diameter, consisting of volcaniclastic material, mainly volcanic glass. The lapilli consist of core and rim. Depending on the core composition, three types are distinguished: lapilli with ash core; lapilli with primarily centred complex core; lapilli with stone (primary hard) core. The core diameter is usually greater than one half of the total diameter. The rim is composed of fine ash and is zonal. The accretionary lapilli tuffs and associated tuffs were formed in subaerial conditions during volcanic eruptions. They associate whit deposits of pyroclastic flows, pyroclastic surge and ash falls.

INTRODUCTION

Paleogene volcanics are characteristic rock types of Mesta graben (trough) and build up the predominant part of the Mesta volcano-sedimentary Group (Vatsev, 1978). They are most widely spread and have maximum thickness in the upper part of Breznitsa and Kupen Formations (Vatsev, 1978). According to petrological composition, they are referred to the dacite-rhyodacite series (Vatsev, 1979; Vatsev, Nedyalkova, 1984). Tuffs are of wide occurrence and contain accretionary lapilli tuffs (Vatsev, 1979).

The aim of the present study is to characterise the accretionary lapilli tuffs. Accretionary or pisolitic tuffs, these interesting rocks, have been described in very few works in the Bulgarian literature (Yanev, 1965).

As a result of our investigations (Vatsev, 1979), four deposits of accretionary lapilli tuffs have been identified in Mesta graben: 1) in Gostunska river valley, southwest of the village of Gostun, 2) at Mogila locality, northeast of the village of Bukovo, 3) in the valley of Tufcha river, west of the village of Banichan, 4) near the village of Ossikovo.

The spheroid formations in the ash accumulations and tuffs, similar to pea-size grains, are given different names: mud balls, mud pellets, tuff pellets, volcanic hail, accretionary lapilli, volcanic pisolites, ash lapilli, ash hail, etc. Quite popular is the name accretionary lapilli (AL). The lithified grains of such lapilli or ash hail and the accompanying volcanic ashes, which form the matrix, are called accretionary lapilli tuffs (ALT).

MEGASCOPIC DESCRIPTION OF THE ACCRETIONARY LAPILLI

In the four deposits in Mesta river valley, the ALT occur in association with ash and lapilli tuffs and effusives of rhyolite (rhyodacite) and dacite composition (Vatsev, 1979; Vatsev, 1984; Vatsev, Nedyalkova, 1984). The packets of tuffs, containing layers of ALT, range from 0.6 to 2-8 m in thickness. AL occur in several layers (2-20 cm) with restricted or unclear spatial extent. The individual layers of such tuffs differ by the quantity and saturation with AL, and the latter are relatively limited in size. It is assumed that the change of the original spheres to flattened spheroids and ellipsoids by compaction results in diminishing of the short axes, but does not affect the long axes. For this reasons the long axes are the measure of the primary size of the spheres, accepted by all researchers. Fig. 1 shows the cumulative curves of the greatest diameter of AL, as seen in cross-section. The diameter of most lapilli is from 3 to 8 mm. The median of the greatest diameter in the deposits is: Banichan - 3,9 mm., Bukovo - 4,2 mm, Gostun - 4,3 mm and Osikovo - 4,1mm. The largest AL in the investigated deposits have a diameter of 12 mm, and in single cases - to 20 mm. The majority of the published data about AL sizes from different deposits of tuffs with various age (from Vendian to Pleistocene), show approximately similar sizes: Lacroix (1904) of Pelee eruption - from 2-3 to 5-7 mm; Richards and Bryan (1927) in tuffs from Australia - 6-9 mm; Moore and Peck (1962) in thirteen occurrences in USA - from 2 to 10 mm, maximum to 20 mm; Maleev (1962) in Zakarpatie - from 3 to 15 mm; Kotova (1965) in eight localities in East Kazakhstan - from 2 to 14 mm; Korotaeva and Melnikov (1968) and Govorova (1975) from deposits in Ural - from 2-3 to 12 mm; Shcherbakova (1972) in Pribalkhash - from 5 to 11 mm, maximum 13-20 mm; Lyahovich (1956) in Siberia -from 2-4 to 8-10 mm; Yanev (1965) in the gorge of Iskar river - from 2 to 9 mm; est.

AL from localities in the valley of Mesta river have the shape of flattened spheroids, flattened in the bedding plane (S_1). The ratio between the long and short axis in sections perpendicular to the bedding has been measured in 10 grains for each deposit. The average values of these ratios are as follows: Gostun - 1,41; Bukovo - 1,43; Banichan - 1,38 and Osikovo - 1,39.

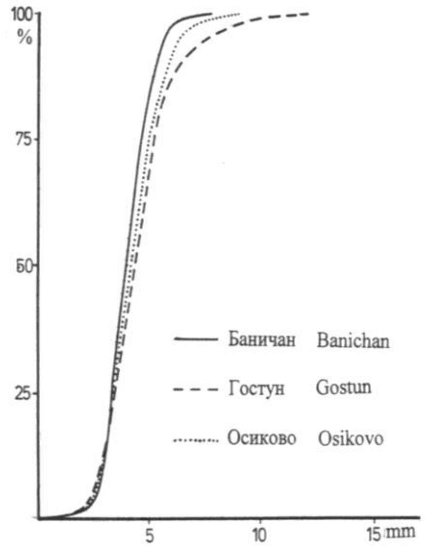

Figure 1. Cumulative curves of the greatest diameter of accretionary lapilli as seen in section across bedding.

AL usually contain a core and a rim (shell). Depending on the core composition, three types of lapilli have been distinguished: a) lapilli with ash core; b) lapilli with primarily centred complex core; c) lapilli with stone (primary hard) core - Table 1- 1-13.

The AL with ash core are prevalent. Such cores are built of volcanic ashes, which is more coarse-grained than the peripheral parts. The disposition of ash particles in these cores is in disorder. The core centre is usually built of coarser grains, which diminish from the inside outwards. The majority of accretionary lapilli cores have spherical shape, some of them are slightly elongated or slightly flattened and have spheroid shape. In rare cases, the cores are of more complicated shape, caused by sticking together of two cores, coated subsequently by several thin layers. The core diameter is usually greater than one half of the total diameter of the lapilli.

Peculiar varieties of lapilli cores are those ones with primary formed centre and complicated structure. Primary centres, around which such lapilli are generated, in some cases are represented by small accretionary lapilli or fragments of them, and in other cases - by sand-size volcaniclastic grains.

In the first case, the centre of the lapilli cores contains small AL - 1-3 mm in diameter. Volcanic ashes, mainly with silt grain size, surround this inner small AL. That outer envelope, actually is a outer part of core of the large lapillus and its thickness is greater or equal to the diameter of the inner lapillus. Such complex cores are surrounded by an outer rim, which is identical to the rims of all other AL.

In the second case, the centre of accretionary lapilli core contains volcaniclastic grains or fragments of AL. The first ones have diameter of 0,25-0,5 mm, and are considerably more coarse-grained than the grains, building the core. When the rock fragment is small and flattened-elongated or irregular, it is partially surrounded by volcanic ashes with silt size, and they form together a spheroid core. In such case the ash in the core is in small quantities and is unevenly distributed. The greatest thickness is observed over the flat and slightly convex walls and the smallest one - over the sharp, convex outwards edges of the fragments. The shape, size and petrographic composition of the small fragments, serving as cores of some AL, are similar to those of the matrix and of the tuffs, associating with them.

The cores of few AL consist of fragments of other broken AL. Fragments of this type are elongated. Their outlines contain parts of outer spherical surface of lapilli and uneven, ribbed sections with marks of breaking. Elements of the concentric structure of the envelope are observed in them as well. These data indicate in a convincing way the dynamic character of the AL generation. They were broken not only by falling on the earth, but also simultaneously with their formation, most probably in a turbulent pyroclastic cloud. Broken lapilli are mixed with unbroken ones in specimens from every locality – Table I – 14 -16.

The quantity of AL with primary hard-stone cores is relatively smaller. Such cores are built of fragments of volcanic rocks (rhyodacite, dacite), volcanic glass or of quartz and/or feldspar crystals with or without stickers of volcanic glass. The fragments are flat, elongated or irregular, slightly rounded, 2-8 mm in size, but there are also individuals up to 20 mm. In some cases the core is entirely built of stone and is covered by a rim of fine ash or has a negligible sticker of ash at the flat and concave walls.

One or several fine-grained concentric layers, composed by relatively finer - pelitic volcanic ash, surround the accretionary lapilli core. The boundary between the core and the rim is transitional and clear, but not an abrupt one. Depending on the different ratios between grain diameter and rim thickness and structure, two types of AL have been distinguished: a) AL with complex concentric rim; b) AL with surface rim - Table 1.

A characteristic feature of the AL with complex concentric rim is that it is composed by several fine-grained layers, and the core size is not as large as compared to the whole lapilli. The layers of the rim are mainly thin, delicate and fragile, and envelope tightly the core. They differ in colour and in the size of the building them grains. Individual layers of the rim in some lapilli are much thinner at one point compared to another; other layer or layers are discontinued, covered by another layers and form odd “angular unconformity”. It is characteristic that some layers or the rim become thinner over convex outwards edges. The thickness of the layers and the rim of strongly flattened AL is greater in their borders.

According to Moore and Peck (1962) this is due probably to the flattening of the grains and is not a primary feature. This opinion is maintained also by the bending and tearing of a part of the rim – Table 1.

TABLE I

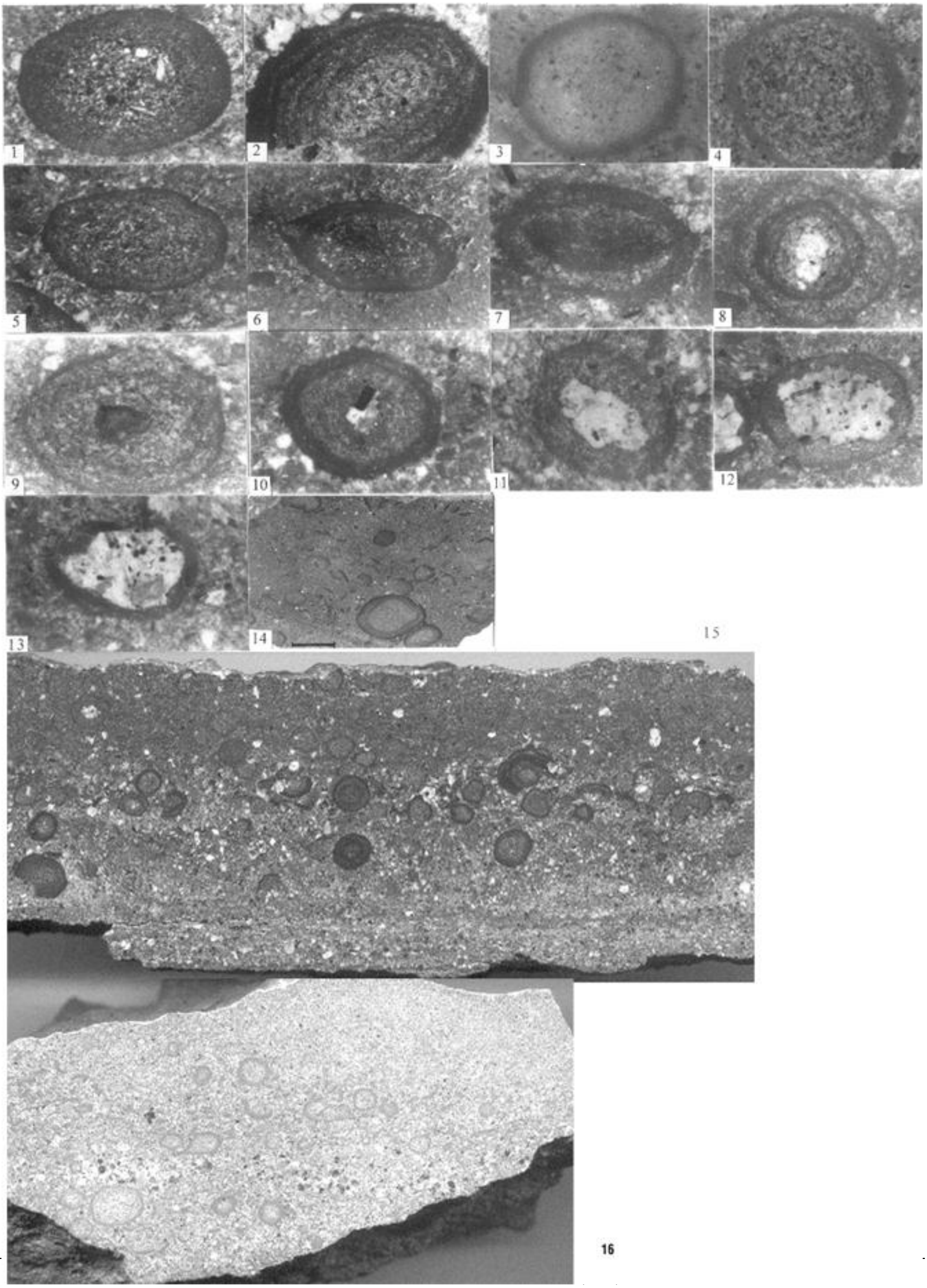

Table I

1 – Accretionary lapilli with thick outer layer (rim) and ash core (diameter of the accretionary lapill of photo 1-16 is 7-12 mm).
2 - Accretionary lapilli with thick zonal outer layer and ash core; darker layers are finer grained.
3 - Accretionary lapilli with fine outer layer and ash core.
4 - Accretionary lapilli with fine outer layer and ash core with faint preferred orientation of the grains in some layers.
5 and 6 – Deformed, flattened accretionary iapilli with folded outer layer.
7-11 - Accretionary lapilli with ash core, centered by clasts of: (7) volcanic glass, (8,9) volcanic rock, (10) piece of accretionary lapilli, (11) little accretionary lapilli.
12 and 13 - Accretionary lapilli with volcaniclastic stone core.
14 - Accretionary lapilli tuff with broken lapilli and in lover part of photo deformed accretionary lapilli, deposit Gostun (skale 1 cm).
15 - Accretionary lapilli tuff and part of stratified tuff in base, deposit Gostun.
16 - Accretionary lapilli tuff, deposit Banichan.

It is characteristic for the lapilli with surface rim, that the thickness of the rim is considerably greater than the thickness of the crust. One and rarely two-three concentric layers commonly build the crust. The thickness of the rim is not large – from 0,2 to 2 mm and is uneven at different points of the lapilli.

The outer surface of AL is ideal. In some cases it is complicated by depressions and convex ribs, resulting from breaking of a part of the rim. In other cases the crust is deformed at the contact with coarser crystal or clastic fragments of the matrix, or with other lapilli. Some AL are not well rounded and have apparently crinkled outer surface. Most often in the occurrences, these are minor lapilli with thin surface rim, at places flat, slightly concave or bent. The folds develop along the sides of the flattened AL, which initially were perpendicular or nearly perpendicular to the bedding. Bending of the rim is observed also in some broken lapilli.

It is assumed that such folds were formed when these less competent grains with thin rim collided with the earth or with other lapilli of the pyroclastic cloud.

The broken AL occur together with unaffected ones and have uneven distribution. The ratio of the broken grains to the intact ones is different in one or another specimen. The greatest quantity of broken lapilli is observed in the layers with prevailing development of grains with thin surface rim and relatively more coarse-grained tuff matrix. On the basis of this it can be supposed that these materials were deposited by higher transporting agent. The breaking of lapilli is manifested in different ways. Some of them have lost one side or rim, others are fragments of lapilli with preserved parts of the core and rim, and a third group represent fragments of the crust or the core. The fragments of the crust are flat, flat-elongated or irregular and are disposed with the flat side parallel or slightly inclined to the plane of bedding. The core fragments are difficult to distinguish from the matrix.

MICROSCOPIC DESCRIPTION OF THE ACCRETIONARY LAPILLI

All the layers of ALT in the occurrences under consideration are connected by appearance, structure and composition with the associating with them ash- and lapilli-ash tuffs. As seen under the microscope, AL in all occurrences are quite similar in composition, structure and pattern. They, as well as the matrix are built of volcanic ash, i.e. clastic fragments of volcanic glass, plagioclase (oligoclase, andesine), sodic-potassic feldspar, quartz, biotite and rock fragments. ALT and the associating with them ash and lapilli tuffs and lavas are acid by composition - dacite and rhyodacite (Vatsev, Nedyalkova, 1984).

The dark hexagonal plates and small grains of hematite with size around 0.001 mm in diameter are abundant in the outermost layers of the grains of ash hail, but they are present also in the silt-pelitic matrix. The last one, in some layers of the deposit by the village of Gostun, is considerably enriched in ore powder, which imparts pink to violet-red colour to the ALT. The outer layers of AL, as well as the fine matrix have deep violet-red colour. Hematite and probably gypsum are an early cement of AL and tuffs. Gypsum is presented in contemporaneous AL and tuffs (Tomita et al., 1985).

Authigenic minerals are opal, clayey minerals - montmorillonite, hydromica and zeolites.

Volcanic ash of AL in the studied specimens vary in size from very fine to the size of coarse ashes (from 0.001 to 1 mm). The sizes of ash grains diminish clearly from the centre to the rim of lapilli and impart a characteristic graded zonal structure to them. Commonly each lapillus consists of a core, relatively homogenous, without clear texture, covered by fine concentric layers. The cores are built of coarser fragments and grains, similar in composition and structure to the matrix, which envelops the AL. In fact, at places where the matrix and the core of a broken lapillus are in contact, they hardly can be distinguished, although some slight differences in size and colour of grains mark the boundary. The measurements shows that the clastic material is less in the cores, but in some cases single coarse grains form the main part of them. A considerable part of the ashes is fine-grained and the silt grains are widely spread. The grain-size distribution of the layers, including the core, varies from 0.01 to 0.005 mm.

The cores of all AL are rimed, by one to five and more fine layers, the thickness of which varies from 0.02 to 0.8 mm. The ash grains of the rim vary in size from 0.05 to 0.6 mm. Their size diminishes towards the outer layers, which are the most fine-grained. The outermost layers contain also finer material, which cannot be identified under the microscope. The individual thin layers commonly look like graded layers in a sedimentary sequence. The boundaries between layers are distinct. The layers begin commonly with more coarse-grained material, which gradually passes into finer grained material, usually dark coloured. The upper boundary of the layers is marked by a sudden interruption with the basal coarser-grained part of the next layer. Thus, the common decrease of the grain-size distribution from the inside outwards is interrupted by slight changes. A characteristic feature of AL is that the grain-size distribution of the layer material varies along with the content of mafic minerals and first of all with the content of ore powder (hematite), which causes formation of slight concentric coloured belts.

The flat and elongated grains in the AL rim, as well as the scaly minerals show a preferred orientation, being tangentially disposed. This orientation is most pronounced in the outer layers, and is not observed in the core. Only in the outermost part of the core, when it is built of finer grains – fine silt, a poorly expressed preferred orientation is observed, mainly of the scaly minerals - biotite.

AL, as identified in Paleogene tuffs of Mesta Graben are quite similar by appearance and structure to such formations in other parts of the Rhodope Mountains, which are not discussed in the present paper, as well as to some formations in other regions, quite different in age – Vendian - Holocene (Moore and Peck, 1962; Kotova, 1966; Govorova, 1975; Maleev, 1964; Hoblitt et al., 1981; Tomita et al., 1985; ets.).

SHORT DATA ABOUT THE ORIGIN

Accretionary lapilli have been described in ash of contemporary volcanic eruptions (Lacroix, 1904; Moore and Peck, 1962; Fedorchenko, Shilov, 1963; Hoblitt et al., 1981; Tomita et al., 1985; etc.). Studying the ALT, the researchers identify not only their size, shape, structure and composition, but also the primary genetic features of the rocks, containing AL, and of those in association with them. These are the natural types of rocks, characterised by typical combination of sedimentary (lithologic) features - composition, structure, texture, character of the boundaries, thickness, shape, area development and their sequences, formed during certain processes and conditions of volcanic activity and sedimentation. These features give ground to distinguish a number of lithologic types of rocks (tuffs) and genotypes or depositional systems among the volcanic and volcaniclastic rocks (Botvinkina, 1974; Maleev, 1975, 1980; Fisher, 1979; Fisher and Schmincke, 1984; etc.) in the studied region.

However, it is not possible in this paper to discuss in detail the origin of ALT in Mesta graben and this natural phenomenon, connected with volcanic explosive eruptions. That is why here are indicated only some data related to characteristic sequences of tuffs, containing AL:

-The ALT of Mesta graben are developed in tuffs from the basal parts of the first order volcanic cycles.

-The volcanic and volcaniclastic rocks in studied region are aerial, dacite-rhyodacite.

-AL and ALT of Mesta graben are analogous to these characterised in many publications.

-The individual genetically related sequences of characteristic types of subaerial tuffs consist of:

1) Basal unit – composed by massive coarse-grained and grain-supported lapilli tuffs (50-30 to 15-10 cm), deposits of a pyroclastic flow;

2) Unit of the massive and stratified tuffs – coarse- to fine massive and stratified tuffs, containing sand-wave or dune-like structure (3-10 cm), deposits of a turbulent pyroclastic surge;

3) Unit of ALT and fine tuffs with unclear horizontal stratification (1-10 cm), deposits of ash fall and ash fall with AL – Table 1- 14-16.

The poor development and absence of the basal unit in the sequences from different occurrences should be taken into consideration. The available sequences of the above mentioned types of tuffs give ground to conclude that AL of Mesta graben associate with deposits from the marginal parts of the pyroclstic flow and connected with them pyroclastic surge, ash fall with AL and ash fall.

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Recommended for publication by Department of Geology and Paleontology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 33-38

ALPINE GEOTECTONIC EVOLUTION AND METALLOGENY OF THE EASTERN PART OF THE BALKAN PENINSULA

Petko Popov

University of Mining and Geology “St. Ivan Rilski”, Sofia 1700, Bulgaria; kpopov@staff.mgu.bg

ABSTRACT
Several consecutive stages are recognized in the Alpine evolution of the eastern part of the Balkan Peninsula. They are marked by different geotectonic settings: intracontinental rifting, ocean spreading, subduction, early collision, intracollisional rifting, late collision, late to postcollisional orogeny. The Strandja metallogenic zone and Kremikovtsi ore field developed during the intracontinental rifting stage. The ophiolite complex and related ore deposits in the Vardar metallogenic zone as well as the sedimentary iron ore deposits in the continental shelf were formed during the spreading stage. The Pirin-Rhodopian metallogenic zone was related to the early collisional granitoide plutons. The Apuseni-Banat-Timok-Srednogorie metallogenic zone was formed as a result of intracollisional rifting. The West Balkan metallogenic zone developed along the northern border of the intracollisional rift. The Transbalkan and Circum Black See metallogenic zones are related to the postcollisional orogeny.

INTRODUCTION

The eastern part of the Balkan Peninsula, with the exception of the Moesian platform, belongs to the Alpine-Himalayan tectonic belt. The Balkanide tectonic system developed in this territory along the northeastern continental margin of the Vardar paleoocean. The system is connected with the Pontides to the east and the Carpathians to the northwest. At the same time, the Balkanide system is conjugated to the west with the Dinaride system, which is related to the evolution of the Dinaride ocean.

In this paper, the Rhodopean and adjoining part of the Serbo-Macedonean regions are discussed in the framework of the Balkanide system, together with the strictly Balkanide structures (Stara Planina, Srednogorie).

Numerous plate tectonics models have been proposed to explain the Alpine evolution of the investigated territory [Dewey et al., 1973; Grubic, 1974, 1980; Bocaletti et al., 1974; Karamata, 1974; Hsu et al., 1977; Bogdanov et al., 1977; Popov, 1981, 1996; Robertson and Dixon, 1984; Boyanov et al., 1989; Dabovski, 1991; Dabovski et al., 1991; Gochev, 1991; Popov et al., 1997; and many others]. The new data suggest a new, more perfect model for the Alpine evolution of the Balkanide tectonic system, which is based on the Wilson’s cycle. The successive development of numerous tectonic settings marks different stages of this evolution: intracontinental rifting; ocean spreading; subduction; early collision; intracollisional rifting; late collision; post-collisional orogeny.

The Alpine metallogeny of the eastern part of the Balkan Peninsula is characterized by a broad variety of genetic types of ore deposits. They were formed as a result of the consecutive development of different geotectonic settings and accompanying magmatic, sedimentary and metallogenic events. Several metallogenic zones can be distinguished: Strandja, Vardar, Pirin-Rhodopian, Apuseni-Banat-Timok-Serednogorie, West-Balkan, Trans-Balkan and Circum-Black Sea zones.

In the beginning of the Alpine evolution, the continental massifs of Europe (the Moesian platform) and Africa (Rhodopean, Serbo-Macedonian, Pelagonean etc. blocks) were acreted into a single continent as a result of Early Paleozoic subduction and Hercynian collision [Haydoutov, 1991]. This event is marked by the deposition of Upper Carboniferous-Permian epicontinental molasse deposits.

A quasi-platform setting was established in the investigated territory at the end of the Permian and beginning of the Triassic. It is indicated by low tectonic activity, flat relief as well as by the Lower Triassic continental and Middle-Upper Triassic carbonate deposits. The Alpine tectonic activization commenced in restricted regions and then gradually embraced larger territories.

INTRACONTINENTAL RIFTING SETTING AND RELATED MINERAL DEPOSITS

Intracontinental rifting is the first stage of the Alpine evolution. It developed mainly during the Triassic along the Pindos–Dinaride zone in the western part of the Balkan Peninsula. In this area it is marked by basalt-andesite-dacite, spilite-keratophyre and gabbro-diorite-granodiorite-granite complexes as well as by related Zn Pb, Cu, Ba, Fe, Mn etc. deposits of different type.

Greenschist facies Triassic basic volcanic rocks and associated terrigenous and carbonate deposits build up the Strandja allochthon. They reflect the intracontinental rifting processes in the southeastern part of the Balkan Peninsula. These rocks and related mineral deposits mark the development of the **Strandja Metallogenic Zone**. Only part of this zone is exposed at present. Several volcano-sedimentary copper-zinc-lead massive sulphide deposits of variable mineral composition (Kartsalevo, Raevo, Keremidoto, etc.) associate with the Triassic greenschists and metadiabases in this region. They are located in the confines of the ***Gramatikovo ore field***. There are also some occurrences of ilmenite-chlorite schists in this region.

Intracontinental rifting of subequatorial direction took place in the Eastern Balkan. This process is demonstrated by the formation of a flysch trough. Numerous faults of the same direction and local basalt eruptions developed in the West Balkan at the same time. Most likely, the initial iron mineralization in the ***Kremikovtsi ore field*** (north of Sofia) was deposited during the hydrothermal-sedimentary processes as a result of a high temperture anomaly related to these events.

The strata-bound copper-uranium deposits in Permian (Smolyanovtsi in Bulgaria) and Triassic (Doykintsi in Serbia) sandstones in the West-Balkan region are possibly related to this setting.

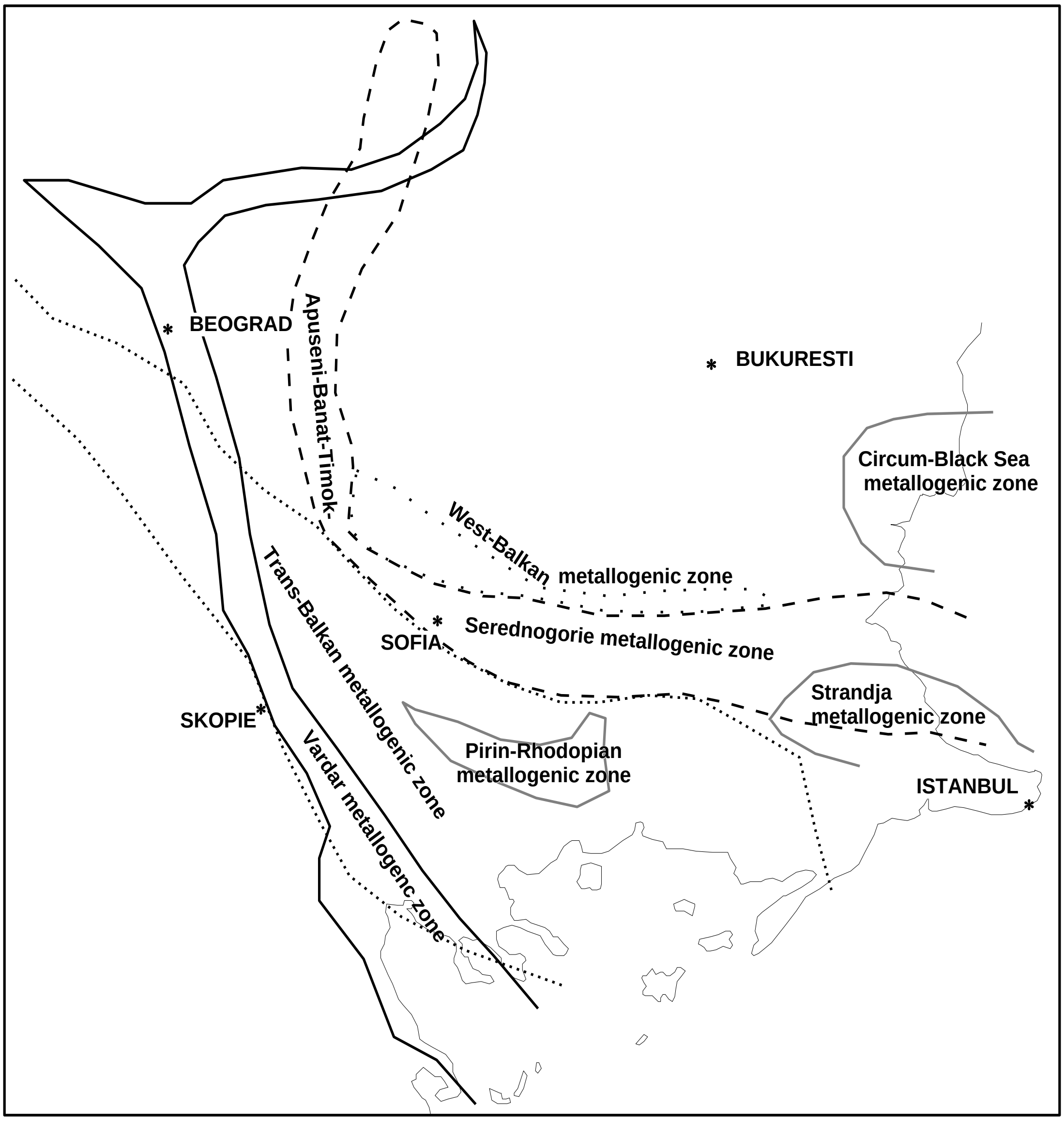

Figure 1. Main alpinian metallogenic units in the Eastern part of the Balkan Peninsula

OCEAN SPREADING SETTING AND RELATED MINERAL DEPOSITS

Ocean spreading is the second stage of the Alpine evolution. The spreading lead to a complete break up of the continental crust and initiation of the Mesozoic Tethys during the Jurassic. These events took place in the zone of Vardar River and propagated to the north along the line Kraguevats-Belgrade. As a result the Vardar ocean opened. A magmatic association of ophiolite type was generated [Karamata 1975]. Three major units of this Vardar ophiolite complex are well exposed: 1 – peridotite suite (with small dunite and lherzolite bodies) at the base; 2 – differentiated magmatic cummulates; 3 – Diabase-Chert Formation and associated terrigenous sedimentary rocks, gabbro and rare diorite to granodiorite intrusives. At the same time the territory to the northeast developed as a continental shelf.

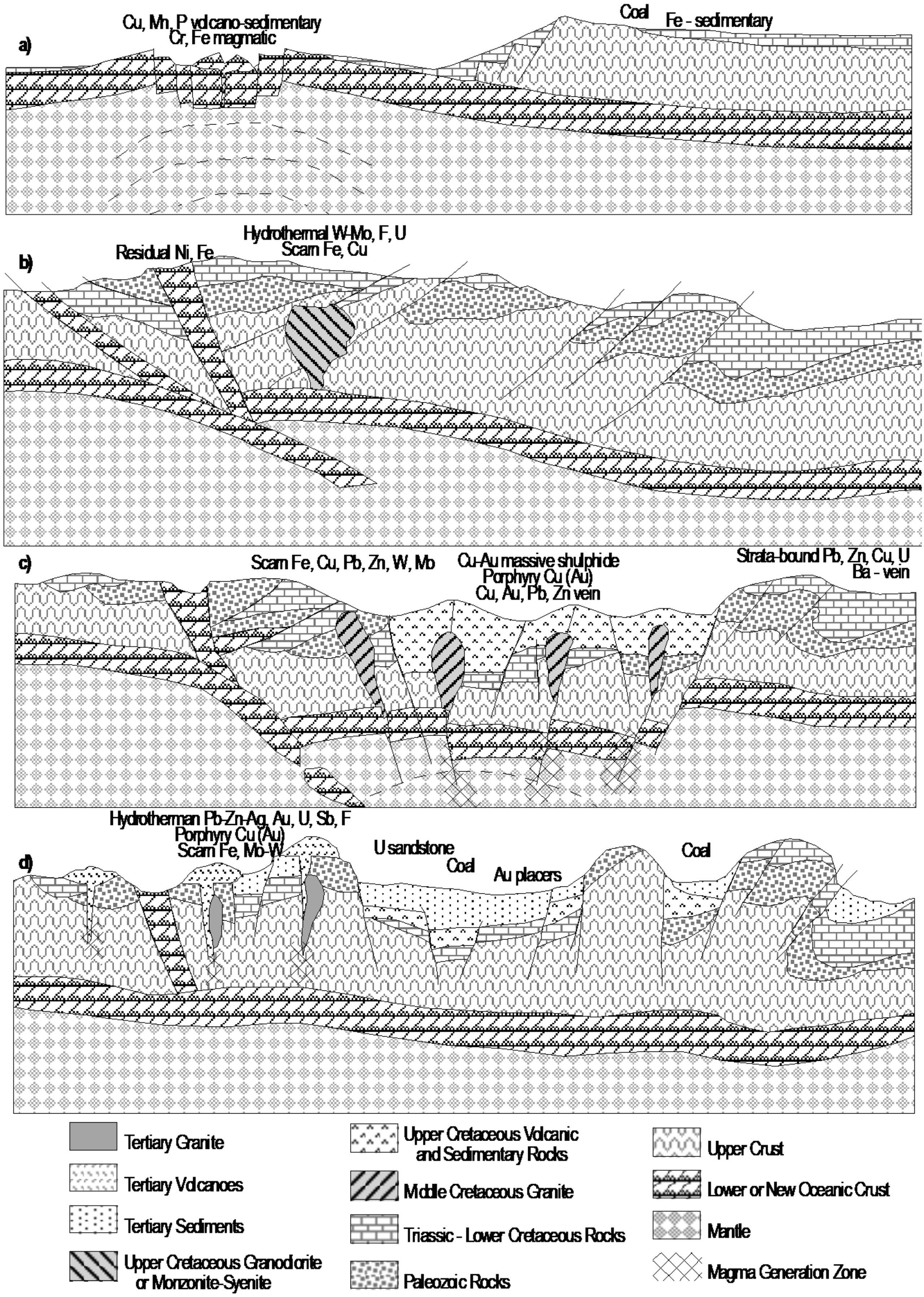

Figure 2. Models of the different tectonic settings and position of mineral deposits: a) spreading; b) early collision; c) intracollisional rifting; d) post-collisional orogen.

The development of the Vardar Ophiolite Complex and the related typical ore deposits defines the **Vardar Metallogenic Zone**. Podiform chromite deposits are most important. They are related to the Jurassic ultramafic complexes. The chromite deposits are related to dunite intrusions. Sheet-like, lense, nest, rarely pipe and schlieren type ore bodies are typical. The main ore deposits are located in Luboten (Raschka) region, near Skopje (Nada, Orashe, Kafe-Odzhak, Stankovats, etc.). The ore deposits in the Kopaonik Mauntain are located in the Yelitsa (Rudna Kosa, Peret), Turnava (Velika Chukara, Goluitsa), Troglav (Malinyak, Vidakov Prevoy) and Velouche regions. The main ore deposits in the Loyane-Preshevo region are Ostrovitsa, Furli Kamen, Fiorina, and Loki Kech. There are several ore occurrences in the Chalkidiki region, too.

Magmatic magnetite deposits are rare. They are represented by the Lipovats ore deposit (SE of Aranjelovats). It is related to the Shumadiya harzburgite.

Forsterite deposits occur in the Kopaonik (Polyane – NW of Rashka) and Golesh (Medvedtse – SW of Prishtina) ultramafic massifs.

Volcano-sedimentary copper, manganese and phosphorite deposits are related to the Diabase-Chert Formation. The copper massive sulphide deposits of Cyprus type are wide-spread to the North and South of the town of Chachak (Serbia).Typical representatives of this type are massive sulphide or disseminated ore mineralization in the Topolishnitsa, Stancha, Shevoulya, Laykovicha, Rechitsa, Novakovicha and Rebel deposits. Strata-bound manganese deposits (Drache – West of Kraguyevats) are rare. Several concretion-type phosphorite ore occurrences occur between Kraguyevats and Topola towns (Shoumadiya region).

During the ocean spreading stage, numerous sedimentary iron deposits were formed in different areas of the continental shelf. They are hosted in Lower-Middle Jurassic carbonate-terrigenous sediments in the ***Troyan ore region*** in the Central Balkan, as well as in the West Balkan, Strandja and Kraishte regions.

SUBDUCTION SETTING AND RELATED MINERAL DEPOSITS

The closure of the Vardar paleoocean towards the end of the Jurassic and the beginning of the Cretaceous marks the third stage of the Alpine evolution. The oceanic type crust subducted to the northeast under the European active margin and initiated a new magmatic front. A number of granitoid bodies were intruded along the line Chalkidiki-Shtip. At the same time a flysch-type back-arc basin developed in the Balkanides (Nish-Troyan trough after Nachev and Yanev [1980]).

Ore deposits, related to the subduction-type granitic intrusions along the eastern border of the Vardar Ocean, are not known. By Skenderov et al., [1986], the absolute age data suggest that the lead-zinc, barite and uranium ore deposits in the Ustrem region (SE Bulgaria) may be formed during that stage.

EARLY COLLISIONAL SETTING AND RELATED ORE DEPOSITS

The early collisional setting developed during the Early Cretaceous and marks the fourth stage of the Alpine evolution. Intensive folding and thrusting processes were concentrated mainly in two zones. The first one is marked by the thrust structures in the Serbo-Macedonian zone, Kraishte region, Southeastern Rhodope and Strandja Mountain. Some of these allochtons include obducted ophiolite sheets. The second zone extends around the Moesian platforme in the Fore-Balkan and Stara Planina Mountain. A typical hinterland fold and thrust belt was formed as a result. Most likely, the described as Late Cretaceous granite plutons in the area of the Rhodopes, Pirin and Rila Mountains are related to these collisional processes [Popov et al., 1996].

The **Pirin-Rhodopian metallogenic zone** is marked by the development of syncollisional granite plutons. Several small vein type tungsten-molybdenum deposits (Gruncharitsa) as well as metasomatic fluorite deposits (Mihalkovo area) have been explored. There are also numerous skarn or hydrothermal molybdenum, iron, copper, lead-zinc, antimonium, gold and uranium ore occurrences.

Numerous ore deposits are related to the weathering of ultramafic rocks. They were formed in uplifted area of the Vardar suture. A series of residual nickel and iron deposits originated as a result of lateritisation processes. Nickel-silicate deposits (Fe, Ni, Co, Cr) are wide-spread in Northern Greece (Edessa, Sfikia), Kopaonik (Rudjintsi, Velouche), Shumadiya (Ba) and Froushka Gora regions. Residual iron deposits, as for instance Mokra Gora in the Zlatibor region, are not very important. The magnesite deposits are of essential economic significance. They are represented by veinlet type deposits in the weathering crust, as well as by vein type deposits. The Brezak, Rajana, Tsvetni Vruh, Liska, Troglavchich, and Magura deposits are more important.

Several oolitic type sedimentary Fe ore deposits are located in the Shoumadiya region, between Beograd and the town of Kraguyevats. They are hosted mainly in Aptian and Albian sedimentary rocks. The origin of these deposits is related to the weathering of ultramafic rocks from the Vardar suture and migration of the Fe-bearing solution to the neighbouring basin.

INTRA-COLLISIONAL RIFT SETTING AND RELATED ORE DEPOSITS

The intra-collisional rifting during the Late Cretaceous marks the fifth stage of the Alpine evolution. It took place after the Early-Middle Cretaceous collisional deformations and before the Paleogene collisional processes. The Apuseni-Banat-Timok-Serednogorie rift-like tectonic and metallogenic zone was formed along the active continental margin, probably as a result of postcoliisional collapse and conjugated astenospheric diapirism [Popov, 1996; Popov et al. 2002]. A 2000-7000 m thick volcano-sedimentary complex and associated intrusions were formed. The magmatic rocks belong to 4 series: tholeiitic, Ca-alkaline, subalkaline and K-alkaline. This zone marks a new tectonic plan in the investigated territory. This is a transit-type structure, because it penetrated deeply into the

Carpathian tectonic system. The high temperature and intensive faulting controlled the metallogenic activation along the northern margin of the rift and the formation of the West-Balkan metallogenic zone.

During this stage, another flysch-type trough was formed upon parts of the Vardar suture, the Serbo-Macedonian and Pelagonian massifs

The Apuseni-Banat-Timok-Serednogorie metallogenic zone (ABTS zone) is unconformably superimposed upon older structures, including Early Cretaceous ones. Numerous ore deposits of about 14 different types associate with the volcanic and plutonic complexes. Porphyry copper (±Au, Mo) and massive sulphide (Cu, ±Au) deposits are most important. They are represented by the porphyry copper deposits Assarel, Medet, Elatsite (Panagyurishte region), Majdanpek, Veliki Krivel (Timok region), Moldova Noua (Banat region) and Prohorovo (Strandja region), as well as the massive sulphide deposits Bor (Timok region), Chelopech, Radka, Elshitsa, Krasen (Panagyurishte region).

A great diversity of skarn type ore deposits is widespread. The iron deposits Ocna de Fier (Banat region) and Krumovo (Strandja region), the copper deposits Malko Turnovo (Strandja region), Moldova Noua (Banat region), the lead-zinc deposit Dognecea (Banat region) as well as the tungsten-molybdenum deposit Baita Bihorului (Apuseni region) are the most representative ones.

Vein-type copper, gold-copper and gold-lead-zinc hydrothermal deposits are very typical of Bourgas region in the Eastern Srednogorie. There are also numerous small hydrothermal gold, silver-gold, gold-copper-lead-zinc, barite and uranium deposits.

Volcano-sedimentary manganese (Pozharevo – W Srednogorie) and iron deposits are also related to this stage.

The West-Balkan metallogenic zone is situated along a segment of the northern boundary of the ABTS zone. It comprises part of the hinterland miogeoclinal fold-and-thrust belt which was formed during the Early Cretaceos collision, and uplifted during the rifting. The Late Cretaceous metallogenic processes were controlled by the high-temperature front, related to the magmatic activity in the ABTS zone. Numerous strata-bound type hydrothermal lead-zinc-silver (Sedmochislenitsi, Izdremets), copper (Plakalnitsa, Venetsa) and uranium (Sliven) deposits were formed. They are hosted mainly in carbonate rocks. Shear-zone, vein or metasomatic stock type ore bodies are very rare. There are also numerous barite veins (Zverino).

LATE COLLISIONAL SETTING

The late collisional setting marks the sixth stage of the Alpine evolution. The collision processes continued after the Late Cretaceous. The intensive Laramide and Pyrenean tectonic deformations affected mainly the territory of the Srednogorie, Stara Planina and Fore-Balkan zones. Magmatic and metallogenic activity is not known during this stage. The final deformations occurred towards the end of the Oligocene, in the framework of the post-collisional stage.

POST-COLLISIONAL SETTING AND RELATED ORE DEPOSITS

The post-collisional setting marks the final stage of the Alpine evolution. The extensional regime commenced during the Priabonian and continued almost without breaks during the Oligocene and Neogene. The postcollisional orogenic belt was formed as a result of a general uplift. Intensive faulting, vertical block displacement and molasse type sedimentation in depressions are typical. The Trans-Balkan volcanic belt was formed as a result of the magmatic activity along the orogen axis. It is superimposed unconformably upon the collisional Alpine structures and intersects the Vardaride and Dinaride sutures. Most of the Tertiary magmatic rocks belong to the calk-alkaline, rarely – to the subalkaline series. Most likely, the magma-generation processes started during the final acts of the collision. At the same time, Early Paleogene-Miocene carbonate-terrigenous sequences of Crimea-Caucasian type were deposited in Dobrudja (NE Bulgaria). The Trans-Balkan and Circum-Black-Sea metallogenic zones were formed as a result.

The Trans-Balkan metallogenic zone is characterized by ore deposits that are developed predominantly in association with the Tertiary magmatic and depositional processes. Vein-type, rarely metasomatic lead-zinc (+Ag) ore deposits are wide spread. They are the most important and characteristic types for that metallogenic zone. Such are the ore deposits of Madan, Luki, Madzharovo, Davidkovo, Osogovo, Blagodat, Kratovo-Zletovo, Trepcha, Chalkidiki, Alexandroupoli etc. regions. Several gold deposits of vein (Chala, Madjarovo) or metasomatic type (Adatepe, Sedefche, Rozino) have been explored in the last years in the Eastern Rhodopean region, as well as in Northern Greece. Porphyry copper (Au-bearing) deposits occur in some places (Bouchim, Skouries). The porphyry-type molybdenum deposits (Machcatitsa, Axioupolix, Kimeria-Sterna) are not very significant. There is also a series of hydrothermal uranium (Smolyan), antimonic (±Au) (Alshar, Ribnovo) and fluorite (Slavyanka) deposits. Several skarn type iron (Damyan), copper (Pirinia) and lead-zinc (Osogovo region) deposits occur, too.

Several asbestos and rarely magnesite deposits were formed as a result of the Tertiary magmatic activity. The asbestos deposits are related to the area of intersection between the Tertiary Trans-Balkan Zone and the Vardar Suture. These mineral deposits were formed as a result of hydrothermal activity related to the Tertiary subvolcanic-hypabissal intrusions. They occur predominantly in the Kopaonik (Korlache, Bzenitsa, Shtava), Preshevo (Livi Do), Kozarevo (Ruyishte) and Shoumadiya regions.

Infiltration-type uranium deposits are related to the Tertiary molasse deposits in Upper Thrace (Momino, Orlov dol), Mesta (Eleshnitsa) and Struma grabens (Simitli, Melnik), as well as in Leskovac and Byasna Kobila areas. Shear-zone type infiltration uranium deposits occur in the areas of old granitic rocks.

The Circum-Black Sea metallogenic zone is located in NE Bulgaria and extends to Sauth Ukraine, South Russia and Georgia. Several sedimentary manganese deposits in the Oligocene deposits occur along the Bulgarian continental shelf (Shabla, Ignatievo) and in other parts of the zone (Nikopol, Chiaturi, etc.).

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 39-44

SILVER AND SILVER-BEARING PHASES FROM CHALA AND PCHELOIAD DEPOSITS (EASTERN RHODOPES) AND ENIOVCHE DEPOSIT (CENTRAL RHODOPES)

Sergey Dobrev[1], Strashimir Strashimirov[1], Margarita Vassileva[1], Haralampi Dragiev[2]

[1] University of Mining and Geology "St. Ivan Rilski" Sofia, 1700, Bulgaria, e-mail: sergey@staff.mgu.bg; sbs@staff.mgu.bg
[2] GORUBSO – Kardjali Plc, 83 Republikanska str., Kardjali, 6600, Bulgaria; e-mail: gorubso@kj.bia-bg.com

ABSTRACT
Samples from Pb-Zn mineralisations in the three deposits are studied to establish the form of silver and other trace elements in them. Ag and Ag-bearing minerals such as acanthite, Te-acanthite, freibergite, Zn-freibergite, Ag-Zn-tennantite, pearceite, Te-pearceite, cervelleite (?) and mineral phase with composition $(Cu_{1.75}Ag_{1.29}Zn_{0.26})_{3.30}(Sb_{0.44}Te_{0.33})_{0.77}S_{2.93}$ nominated as "mineral A" are found. Ag is established as well in isomorphic form in galena and also in secondary copper minerals (probably as fine admixture of acanthite). New for the deposits are pearceite $[(Ag_{11.41}Cu_{4.12}Fe_{1.01})_{16.54}As_{1.47}S_{11.00}]$ and Te-pearceite $[(Ag_{11.32}Cu_{4.09}Fe_{0.65})_{16.06}(As_{1.68}Sb_{0.13})_{1.81}(S_{10.95}Te_{0.18})_{11.13}]$. Final diagnostics of cervelleite(?) and "mineral A" needs additional studies.
Key words: Pb-Zn deposits, trace elements, Ag and Ag-bearing minerals,

INTRODUCTION

Object of this study is the form of occurrence of silver in economic parageneses in the three deposits. The problem of Ag distribution in lead-zinc ores in the Rhodope deposits is discussed in several papers published until now (Breskovska et al., 1984; Kolkovski and Manev, 1988; Bonev and Neykov, 1990; etc.), but not many data are available for the deposits included in the present study. This problem is important not only for clarifying the geochemical development of ore-bearing systems, but also from practical point of view, due to its impact on the optimisation of mineral dressing processes and extracting silver from ores as additional economic component.

MATERIALS AND METHODS

The study is based on 35 ore samples located as follows: Eniovche (20), Pcheloiad (10) and Chala (5). 40 polished sections were prepared from the samples and were studied by through NU-2 and Amplival pol-U microscope at magnifications x 64 and up to 900. Photos were taken by digital Panasonic CCD colour camera model GP KR22, and images were processed through software Matrox Rainbow Runner Studio, iPhoto Express, Photoshop 5.0. Electron microprobe analyses were done by means of JEOL JSM 35 CF (Tracor Northern TH 2000) with EDEX system using JEOL standards in the laboratory of EUROTEST Plc., Sofia.

GEOLOGICAL SETTING

Eniovche deposit is a typical representative of Pb-Zn deposits, related to the Central Rhodope Dome (Ivanov et al., 2000). Due to its setting far from other deposits, it has been described as a separate one, not related to any ore field. In some publications Eniovche deposit is considered as a part of Nedelino ore field (Bogdanov, 1959, etc.). The ore bodies are steep veins with orientation WNW, cross-cutting metamorphic rocks (Fig. 1). There are also metasomatic replacement ore bodies in distal skarns, formed in marble layers.

Pcheloiad and Chala deposits belong to Zvezdel-Pcheloiad and Spahievo ore fields, respectively. Both fields are situated in the Eastern Rhodope Paleogene depression (Fig. 1) and are related to Paleogene volcano-plutonic centres. The ore bodies represent veins with subequatorial direction and fill radial faults (Breskovska and Gergelchev, 1988; Maneva, 1988; etc.). The host rocks of the Pb-Zn mineralisation belong to the Paleogene volcano-sedimentary complex.

MINERALOGICAL CHARACTERISTICS OF SILVER AND SILVER-BEARING PHASES

Eniovche deposit

Samples from Eniovche deposit are from vein type mineralisation (level 200) and also from metasomatic replacement ore bodies (levels 550-600). Silver and silver-bearing phases are better developed in metasomatic replacement ores from the eastern flank of the deposit.

Acanthite. In the present study, compositions within the system Ag – S are nominated as acanthite. No measurements are available for the temperature conditions for the association in which these compositions are found and it is difficult to strictly confirm whether the phase observed was argentite or acanthite because both minerals are isochemical. The suggestion for primary formation of argentite is based on the presence of chalcopyrite, sphalerite and other sulphides usually formed above 200° C, as well on the minor distribution of alteration processes affecting these minerals. The stability of argentite is above 192° and phases observed in polished

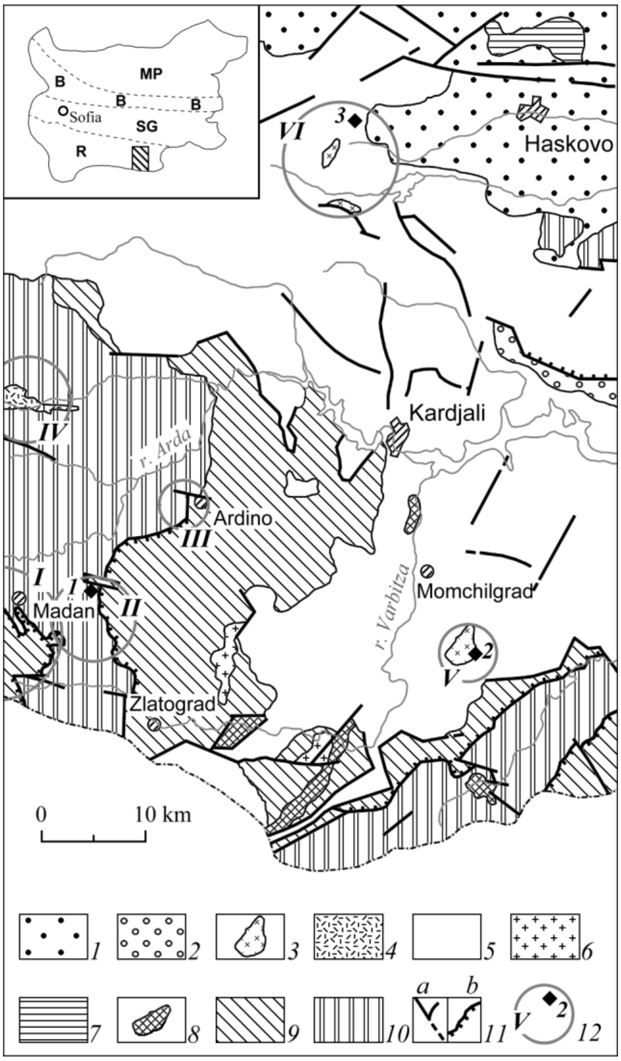


Figure 1. Schematic geological map, showing location of studied deposits (after GEOLOGICAL MAP OF P.R. BULGARIA, 1989; METALLOGENIC MAP OF BULGARIA, 1989).

Abbreviations on inset map: MP – Moesian Plate; B – Balkanides; SG – Srednogorie Zone; R – Rhodopes.

*1. Neogene terrigenous sediments; 2. Paleogene molasse; 3. hypabyssal intrusive rock; 4. subvolcanic rhyolite bodies; 5. Eocene-Oligocene sedimentary, volcano-sedimentary and volcanic rocks (Eastern Rhodope depression); 6. Upper Cretaceous granitoids; 7. Triassic sandstone, schist, marble; 8. serpentinite; 9. Rhodopian Supergroup (schist, gneiss, marble, amphibolite, etc.); 10. Prarhodopian Supergroup (gneiss, gneiss-schist, amphibolite, migmatite, etc.); 11. faults (a), thrust and nappe (b); 12. base-metal ore fields and deposits studied: **I** – Madan ore field, **II** – Nedelino ore field (**1- Eniovche deposit**), **III** – Ardino ore field, **IV** – Davidkovo ore field, **V** – Zvezdel-Pcheloiad ore field (**2- Pcheloiad deposit**), **VI** – Spahievo ore field (**3- Chala deposit**).*

sections should be acanthite. Acanthite grains are found among chalcopyrite as well expressed rims (20x100÷200 μm), build up of single grains and located along the contacts between chalcopyrite, ankerite and Mn-calcite (Plate A), or as larger grains (50-200 μm) in chalcopyrite near the contact with pyrite. Microprobe analyses established minor presence of Cuand Fe (Table 1, No 1, 2, 3), which is probably due to the influence of the chalcopyrite matrix.

A fine isometric aggregate containing Ag, Te, Cu, S ± Sb (10 x 15 μm) is observed in galena near the contact with pyrite. It is composed of three or four different phases with minor size and closely integrated which do not allow their precise determination. The high Ag content in the aggregate additionally complicates their determination, because of possible photocorrosional effects expected.

Freibergite is observed as fine isometric inclusions in galena, or as grains in association with tennatite, close to contact of galena with chalcopyrite (Plate B) The colour of both minerals is light grey and in reflected light they are hardly distinguished, but through SEM the difference is well visible (inset on Plate B). Microprobe analyses determine Ag content about 12 wt % and the phase could be nominated as Ag variety of tetrahedrite, known as freibergite (according to Mozgova and Tzepin, 1983, Chvileva et al. 1988). Zn content in some of the analysed grains is up to 6 wt. % and they could be nominated as *Zn freibergite*. (Table 1, No 4, and 5).

Ag-bearing Zn tennatite is found as fine oval grains up to 10 - 30 μm along the contacts between sphalerite and galena or in association with chalcocite. The absence of Sb determines it as end-member in tennantite-tetrahedrite row and increasing content of Zn (up to 10.61 wt. %) nominates it as Zn variety of tennantite. Silver content is not high (to 0.27 wt. %), but remains constant within the grains (Table 1, No 6, 7).

Cervelleite (?) is an extremely rare Ag mineral found for the first time in abandoned Bambolla Mine (previously known as Moctezuma tellurium deposit), Sonora, Mexico (Criddle et all. 1989) as thin rim around acanthite and hessite in association with native silver, benleonardite, pyrite and sphalerite. The mineral is tellurium analogue of aguilarite. Cervelleite-like mineral was described by Helmy (1999) in Precambrian Ag-rich volcanogenic Zn-Cu-Pb deposit Um Samiuki (Eastern Desert, Egypt). Two varieties of the described mineral are discussed in this deposit – a Cu-rich one (Cu up to 6 wt. %) and the other containing <0.25 wt. % copper.

Findings of similar minerals were described as "unnamed mineral" by Gadjeva (1983, 1985) in Shadiitza (Nedelino ore field, Central Rhodopes). Later Bonev and Neykov (1990) and Bonev (1991) described a mineral with very similar composition to that mentioned by Gadjeva (1985) in the Pb-Zn Ardino deposit. Ag_4TeS phase is found by Marinova and Kolkovski (1994) in Belevsko deposit (Davidkovo ore field, Central Rhodopes). In all these findings there is also a very broad range of copper content from 3.3 wt. % (Gadjeva, 1985) up to 18.17 wt. % (Marinova and Kolkovski, 1994). Analysis of the available data shows that variations of copper content in this phase is due to the possibility of replacement position of silver by copper. As a rule, the described grains are very fine and photocorrosional effects additionally cause difficulties for precise diagnostics of the phases found.

Cervelleite (?) in Eniovche deposit was first reported by Dobrev (2001). It is developed in the central part of a large

Table 1. Microprobe analyses of Ag and Ag-bearing phases

No	Sample No	mpr. an. No	Mineral phase	Element content [wt. %]									Formula
				Ag	Cu	Zn	Fe	As	Sb	Te	S	Σ	
Eniovche deposit													
1	9	4	acnt	82.89	-	-	-	-	-	-	16.72	99.61	$Ag_{1.79}S_{1.21}$
2	9	5	acnt	84.02	1.77	-	-	-	-	-	14.66	100.45	$(Ag_{1.85}Cu_{0.07})_{1.92}S_{1.08}$
3	9	7	acnt	84.76	1.29	-	0.24	-	-	-	12.78	99.07	$(Ag_{1.95}Cu_{0.05}Fe_{0.01})_{2.01}S_{0.99}$
4	13	14	Zn frbg	17.96	27.05	4.59	-	-	25.44	-	24.55	99.59	$(Cu_{7.55}Ag_{2.94}Zn_{1.24})_{11.73}Sb_{3.70}S_{13.57}$
5	18	25	Zn frbg	12.01	27.66	6.11	0.14	1.24	28.95	-	23.61	99.72	$(Cu_{7.73}Ag_{1.97}Zn_{1.65}Fe_{0.04})_{11.39}(Sb_{4.22}As_{0.29})_{4.51}S_{13.08}$
6	12	8	Ag-bear. Zn ten	0.27	40.91	9.54	1.31	16.94	1.38	-	29.12	99.47	$(Cu_{9.52}Ag_{0.04}Zn_{2.16}Fe_{0.35})_{12.07}(As_{3.34}Sb_{0.17})_{3.51}S_{13.43}$
7	6	24	Ag-bear. Zn ten	0.15	41.95	10.61	0.93	17.93	-	-	28.40	99.97	$(Cu_{9.74}Ag_{0.02}Zn_{2.39}Fe_{0.25})_{12.40}As_{3.53}S_{13.07}$
8	13	10	cerv(?)	58.15	12.51	1.55	-	-	-	17.85	9.71	99.77	$(Ag_{2.69}Cu_{0.98}Zn_{0.12})_{3.79}(Te_{0.70}S_{0.30})_{1.00}S_{1.21}$
9	13	11	cerv(?)	59.70	10.52	0.42	-	-	-	21.15	8.45	100.24	$(Ag_{2.87}Cu_{0.86}Zn_{0.03})_{3.76}(Te_{0.86}S_{0.14})_{1.00}S_{1.23}$
10	13	12	min. A	30.16	24.03	3.71	-	-	11.63	8.96	20.32	98.81	$(Cu_{1.75}Ag_{1.29}Zn_{0.26})_{3.30}(Sb_{0.44}Te_{0.33})_{0.77}S_{2.93}$
Pcheloiad deposit													
11	30	36	prc	60.94	12.96	-	2.80	5.45	-	-	17.46	99.61	$(Ag_{11.41}Cu_{4.12}Fe_{1.01})_{16.54}As_{1.47}S_{11.00}$
12	30	35	Te-bear. prc	59.75	12.72	-	1.77	6.16	0.74	1.16	17.18	99.48	$(Ag_{11.32}Cu_{4.09}Fe_{0.65})_{16.06}(As_{1.68}Sb_{0.13})_{1.81}(S_{10.95}Te_{0.18})_{11.13}$
13	25	19	(Ag,Te) Zn tetr	0.26	37.04	5.51	0.38	3.25	27.63	0.30	25.29	99.66	$(Cu_{9.73}Ag_{0.04}Zn_{1.41}Fe_{0.11})_{11.29}(Sb_{3.78}As_{0.72})_{4.50}(S_{13.16}Te_{0.04})_{13.20}$
14	25	21	(Ag) Zn ten-tetr	0.55	40.83	8.81	0.39	12.84	9.01	-	27.43	99.86	$(Cu_{9.86}Ag_{0.08}Zn_{2.07}Fe_{0.11})_{12.12}(As_{2.63}Sb_{1.14})_{3.77}S_{13.12}$
15	26	28	Ag Zn ten-tetr	7.13	35.55	9.73	0.40	5.48	15.99	-	25.83	100.11	$(Cu_{9.05}Ag_{1.07}Zn_{2.40}Fe_{0.11})_{12.63}(Sb_{2.13}As_{1.17})_{3.30}S_{13.04}$
16	26	29	Ag Zn tetr	7.79	37.03	6.48	0.44	4.32	18.90	-	24.37	99.33	$(Cu_{9.74}Ag_{1.21}Zn_{1.65}Fe_{0.13})_{12.73}(Sb_{2.60}As_{0.96})_{3.56}S_{12.71}$
Chala deposit													
17	32	32	(Te) acnt	88.69	-	-	-	-	-	1.55	9.41	99.65	$Ag_{2.19}(S_{0.78}Te_{0.03})_{0.81}$
18	31	22	(Ag) enrg	1.55	46.14	-	2.15	16.26	-	-	33.11	99.21	$(Cu_{2.86}Ag_{0.06}Fe_{0.15})_{3.07}As_{0.86}S_{4.07}$
19	31	23	(Ag) enrg	0.68	48.08	-	1.61	17.54	-	-	32.66	100.57	$(Cu_{2.96}Ag_{0.02}Fe_{0.11})_{3.09}As_{0.92}S_{3.99}$
20	32	31	(Ag) enrg	1.25	46.53	-	1.62	16.84	-	-	32.92	99.16	$(Cu_{2.89}Ag_{0.05}Fe_{0.11})_{3.05}As_{0.89}S_{4.06}$
21	34	34	(Ag) enrg	0.32	46.41	-	2.23	17.26	-	-	32.93	99.15	$(Cu_{2.88}Ag_{0.01}Fe_{0.16})_{3.05}As_{0.91}S_{4.05}$
22	32	30	Ag cov(?)	10.85	55.86	-	0.77	2.08	-	-	29.99	99.55	mixture
23	34	33	2500 μm²	9.86	48.57	0.20	5.60	5.24	-	-	31.27	100.74	mixture

Abbreviations: **Ag-bear.=(Ag)** – Ag-bearing; **Te-bear=(Te)** – Te-bearing; **ten** – tennantite; **acnt** – acanthite; **frbg** – freibergite; **cerv** – cervelleite; **min. A** – mineral A (formula calculated as skinnerite); **prc** – pearceite; **ten-tetr** – tennantite-tetrahedrite; **enrg** – enargite; **cov** – covellite, **mpr. an.** – microprobe analysis

galena aggregate (Plate C) as irregular grains. In reflected light it is grey with slight greenish shade. Its reflectivity is relatively high, but 3 – 5% lower, compared with galena. The mineral phase is isotropic. Two quantitative analyses (Table 1, No 8, 9) establish components that are very close to the discussed above. The stechiometric formula are as follows:

$(Ag_{2.69}Cu_{0.98}Zn_{0.12})_{3.79}(Te_{0.70}S_{0.30})_{1.00}S_{1.21}$

$(Ag_{2.87}Cu_{0.86}Zn_{0.03})_{3.76}(Te_{0.86}S_{0.14})_{1.00}S_{1.23}$

Mineral A is found as a thin rim several microns thick around cervelleite (?) (Plates C, D). In reflected light it is grey but darker, compared with cervelleite (?) and its reflectivity is lower compared with cervelleite and galena (probably about 30%). Minor size of the mineral does not allow distinct observation of anisotropic effects typical for it. Microprobe analysis (Table 1, No 10) established composition similar to goldfildite and freibergite but stechiometric estimations lead to formula much closer to skinnerite (Karup-Moller and Makovicky, 1974) with some deficit in the cation part and distinctly higher silver content: $(Cu_{1.75}Ag_{1.29}Zn_{0.26})_{3.30}(Sb_{0.44}Te_{0.33})_{0.77}S_{2.93}$. It is possible that the analysed phase has an intermediate composition between goldfildite, skinnerite and pyrargirite or a mixture between them, which could be hardly distinguished at the magnifications used. Outside of the contour marked by skinnerite, there is another mineral grain with elongated shape, the optical features of which are similar to those described for the last two minerals. Microprobe analyses established contents of Ag, Te, Cu and Sb, but its minor size does not allow precise determination of its stechiometry. It is possible this phase to be very fine intergrowth between mineral A and cervelleite (?).

The most common Ag-bearing phases are members of the tennantite-tetrahedrite row. They demonstrate a broad range of trace elements presence especially Ag, Zn and Te in them.

Pcheloiad deposit

Samples from Pcheloiad deposit are from ore zones 2 and 14 (level 490) and adit 56.

Pearceite is found in samples in association with chalcopyrite and pyrite. It is observed as fine irregular inclusions in chalcopyrite along the contact with pyrite (Plate E). The colour in reflected light is light grey but due to the minor size (20–30 μm) of it's grains the anysotropic effects typical for this mineral are not distinctly observed. Microprobe analyses established increased content of Te and Sb in some grains (Table 1, No 11, 12) which are common trace-elements in the pearceite-polybasite group. The crystallochemical formula of pearceite with content of Te is:

$(Ag_{11.32}Cu_{4.09}Fe_{0.65})_{16.06}(As_{1.68}Sb_{0.13})_{1.81}(S_{10.95}Te_{0.18})_{11.13}$

and the phase should be nominated as *Te-bearing pearceite.*

Ag-tennantite-tetrahedrite is relatively frequently found in galena-sphalerite association. They form thin veinlets in sphalerite or irregular isometric and slightly rounded grains along the contact between sphalerite and pyrite or chalcopyrite. Rarely phases associate with secondary covellite developed over chalcopyrite, or they form thin veinlets together with chalcopyrite cutting sphalerite. Some of the grains are often up to 200–300 μm or even to 2 – 3 mm and analyses established higher content of silver in them. The chemical composition of some analysed grains is characterised with increased content of Zn and presence of Te (Table 1, No 13 - 16). Silver content in some of them is up to 7–8 wt. %, but it is not enough to classify them as freibergite (according to the classification of Chvileva et al., 1988). In cases when Sb dominates over As, the phases are represented by intermediate members closer to tetrahedrite and they are nominated as *Ag-Zn tetrahedrite*. Crystallochemical formulas of the analysed grains from the tennantite-tetrahedrite mineral row are given in Table 1.

Chala deposit

Samples from Chala deposit are from level 474.

Te-acanthite is found as fine isometric grains along the contact between bornite and Ag-enargite. Their colour is lighter but in the reflected light microscope they could be hardly distinguished. Observation in the scanning electron microscope allows distinct observation of their differences, compared with the other neighbour minerals. Chemical composition obtained through quantitative microprobe analysis determines it as acanthite and presence of Te (1.55 wt. %) nominates it as *Te-bearing acanthite* (Table 1, No 17, Plate H).

Ag-bearing enargite. Inclusions of this mineral are observed among chalcopyrite aggregates (Plate F), often in association with idiomorphic pyrite. They are quadrangle, elongated or irregular in shape and their size is 40–100 μm. In some cases the mineral forms a rim or fine aggregates over corroded quartz along the contact with chalcopyrite. Elongated enargite-galena aggregates (about 130 μm) or single elongated enargite grains (70 μm long) in galena are developed as well. Enargite also forms fine intergrowths with other sulphides (Plate G). Enargite is isochemical with luzonite and here it is determined on the base of the differences of the optical properties of both minerals. The content of Ag in it is comparatively low, so the mineral phase could be nominated as *Ag-bearing enargite* (Table 1, No 18-21).

Ag-bearing covellite is developed over primary chalcopyrite and tennatite in association with bornite and chalcocite. It is characterised by inhomogeneous texture and contains numerous sectors with light grey colour. Such sectors are quite distinctly distinguished, when observed in COMPO regime of the scanning electron microscope (Plate H). They probably reflect very close intergrowths between covellite and Te-bearing acanthite (?) and this is the reason for higher Ag content (over 10 wt. %) registered in the analysis (Table 1, No 22).

The higher Ag content in the observed association of secondary copper minerals is confirmed by area quantitative microprobe analysis covering about 2 500 μm^2 in the central part of an aggregate and it registered about 10 wt. % of Ag (Table 1, No 23). Different mineral phases could not be distinguished because of the very close intregrowth relations between them, but the analysis draw the attention to copper mineralisation in this deposit as possible carrier of a part of silver in it.

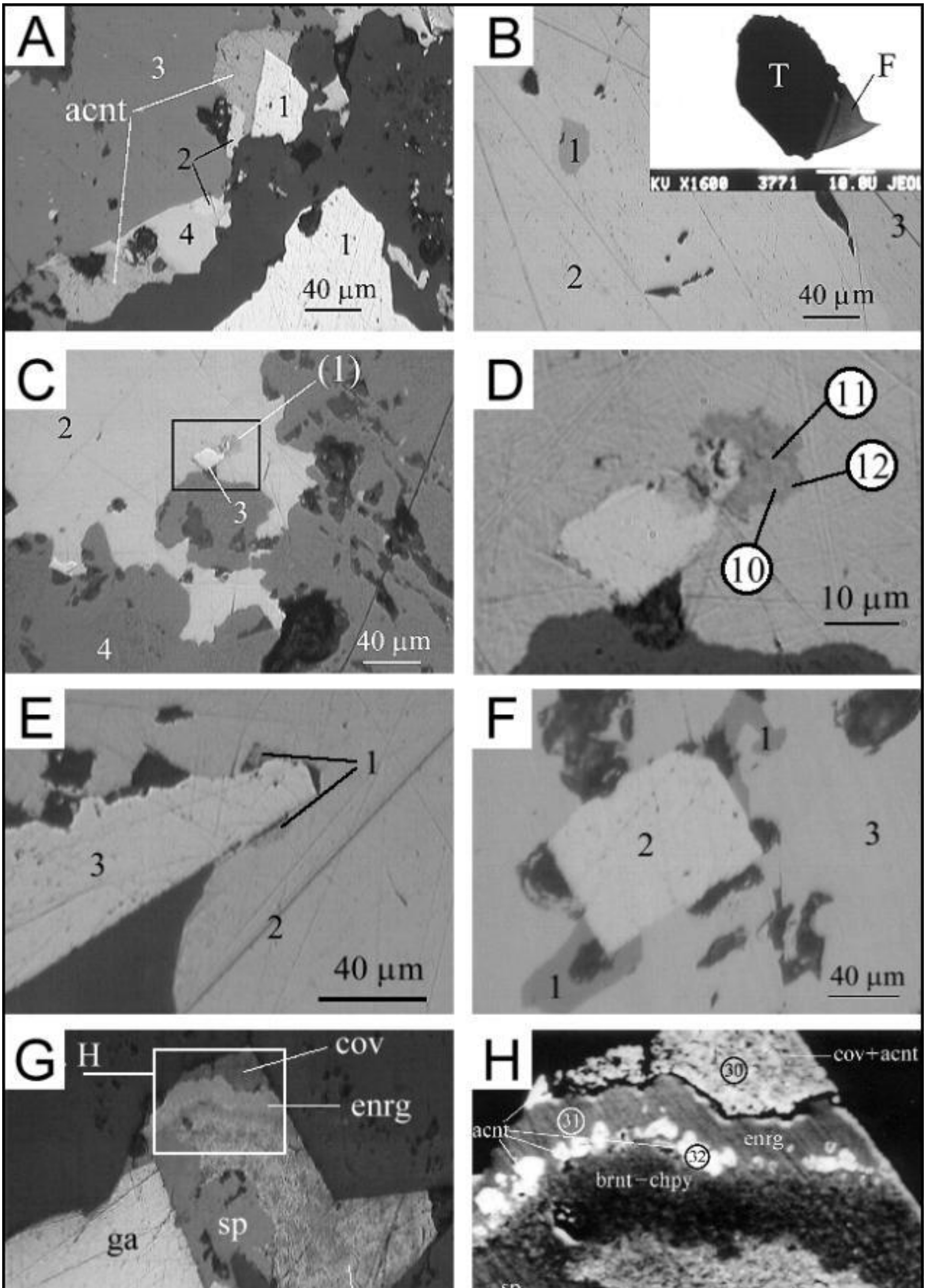
CONCLUSIONS

The results from the present study suggest that galena in the three deposits associates with mineral microinclusions of silver and silver-bearing minerals such as acanthite, freibergite, Ag-bearing Zn tennantite, cervelleite (?) (Eniovche deposit), pearceite, Te-bearing pearceite, Ag – tennantite-tetrahedrite (Pcheloiad deposit), Te-acanthite, Ag-bearing enargite, Ag-bearing covellite (Chala deposit). ICP analyses of galena monomineral probes registered silver in a broad range (from traces to 138 ppm) but in most cases the studied galena contains microinclusions of Ag-bearing minerals that could not be separated during the preparation of monomineral probes and it is not possible to distinguish the ratio between isomorphic presence of silver in galena and its presence as single silver-bearing mineral phases in it.

Samples from metasomatic ore bodies in Eniovche deposit contain various types of Ag and Ag-bearing minerals compared with those from the vein part of the deposit. This could be explained with development of re-mobilisation and re-distribution processes.

The most frequently found silver bearing phases in Pcheloiad deposits are phases from the tennantite-tetrahedrite mineral row developed along the contacts between galena and chalcopyrite. It should be mentioned that in most cases phases closer to the tetrahedrite end member contain more silver compared with the tennantite members of the mineral row.

Ag-tennantite-tetrahedrite commonly form visible grains among galena, chalcopyrite and sphalerite. Pearceite and Te-bearing pearceite are also found in this deposit. Silver content in galena as isomorphic element is relatively low.


A
3
acnt
1
2
4
1
40 μm
B
T
F
KU X1600 3771 10.0U JEO
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3
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(1)
2
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D
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12
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10 μm
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1
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G
H
cov
enrg
sp
ga
40 μm
chpy
H
30
cov+acnt
31
acnt
32
enrg
brnt−chpy
sp
KU X1000 3772 10.0U JEO

Plates

Plate A. deposit Eniovche. Acanthite (acnt) developed along the boundary of sulphide minerals. (pyrite – 1, galena – 2, sphalerite – 3, dark grey – gangue mineral) – *Refl. light N II.*
Plate B. deposit Eniovche. Inclusion of tennantite and freibergite (1) in galena (2) near the contact with chalcopyrite (3). Tennantite and freibergite could not be distinguished in reflected light. Right corner top – fragment from Plate 2 performed through SEM (Backscattered electron image, COMPO regime). Tennantite – (T), freibergite – (F).
Plate C. deposit Eniovche. Aggregate set up by cervelleite (?) and mineral "A" (in quadrangle) along on the contact between galena (2) and pyrite (3), (4) – sphalerite, dark grey – gangue. – *Refl. light N II.*
Plate D. Fragment from Plate C. Ciphers in the circles – No of microprobe analysis.
Plate E. deposit Pcheloiad. Pearceite (1) along the contact between chalcopyrite (2) and pyrite (3). – *Refl. light N II.*
Plate F. deposit Chala. Ag-bearing enargite (1) along euhedral pyrite crystal (2) among chalcopyrite (3). – *Refl. light N II.*
Plate G. deposit Chala. Sphalerite-chalcopyrite-enargite aggregate (sp, chpy, enrg) on a boundary of galena grain (ga) with quartz. Secondary copper minerals are well established (covellite – cov, chalcocite – chct, bornite – brnt). – *Refl. light N II.*
Plate H. A fragment from Plate G. Covellite-enargite-chalcopyrite-bornite-chalcocite-sphalerite aggregate with acanthite. Ciphers in circles show location and No of microprobe analysis. – *Backscattered electron image, COMPO regime.*

Typical for Chala deposit is a relation between Ag-bearing phases and secondary copper minerals such as covellite. A very fine mixture of secondary copper minerals and Ag-bearing minerals forms aggregates up to several mm. Te-bearing acanthite and Ag-bearing enargite are other minerals that carry silver in this deposit. During ore dressing, part of Ag-bearing minerals, closely associating with copper minerals, may be lost.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 45-50

ALPHA STABLE GEOSTATISTICAL MODEL IN MINERAL RESOURCES EVALUTION

Svetlozar Bakardjiev

University of Mining and Geology “St. Ivan Rilski”, Sofia 1700, Bulgaria; zarcobak@yahoo.com

ABSTRACT
The author offer Alfa-stable geostatistical model providing the answers to problems: what accuracy of an estimate of reserve of mineral raw material, with what can appear increase of extracted economically cost effective reserve and so on. The model is geostatistics imitative and is founded on the empirical characteristic of allocation of contents of extracted builders in deposits. From many possible probability models of the separate object most representative are the Alpha-stable probability distribution. These distributions have asymmetry and very wide right tail, i.e. they are successful replacement of lognormal distribution. It is known, that lognormal distribution, while, and is unique, on the basis of which the geostatistical theory designed. The offered model consists of some main sub models. The variogramm sub model is clone to correlation function of symmetric Stable random process. 3D kriging sub model designed on the basis of optimization of estimates on values alpha, which is obtained from input data set through a modified method of Press. If the outcomes satisfy the requirement, it is possible will be connected: to a sub model of efficiency of prospecting drilling, to a sub model of economy of prospecting operations, to a sub model of the market of the capitals and others, bound with the concrete tasks. On the basis of offered the theory designs a software environment and a mining deposits are treated given. The obtained outcomes are widely made comments in a context of accuracy and reliability of the obtained estimates. The preliminary outcomes allow assuming, that the offered Alfa-stable geostatistical model is promising improvement of a number of geostatistical models. In a major degree it is possible to consider this model empirically justified. The value of model is possibility combination of our model with expert estimates with the purposes of creation of more objective prognoses of expected increases of mineral resources in unexplored objects.

INTRODUCTION

Zolotarev in this monograph on stable laws developed [44] a method for stochastic modeling further referred as Model with Point Sources of Influence (MPSI). There also he discussed various possible applications of the MPSI in finance, astrophysics, hydrodynamics, etc. [44]. The method is very suitable for modeling chaos medium (cf. [17]).

In this paper we present a new approach in which, a stochastic medium characterized by a Point Sources of Influence with a Poissonian density. The assumption of Poissonian distribution is quite asset returns common in the field of finance, ore field geology [3], [10], [7], [9], hydrogeology [28]. In these areas, the study of various real phenomena involves sampling and measuring of their properties, e.g. asset return volatility. The most common characteristic of these data sets is the large values of sample variation as well as the unimodal-asymmetric shape of the probability distribution (i.e. a small part of the sample data values has very high values, while the large part is characterized with very low values). This phenomenon was extensively analysed by Mandelbrot [22] and Mittnik and Rachev [25], [26], [27], Bakardjiev [3]

It is generally accepted that the choice of the probability distribution functions (pdf's) should be based on the principles and the hypotheses through which the real data sets are described. The most popular hypothesis is the so-called Law of the Proportional Action, which leads to a lognormal distribution of the sample data [1]. This hypothesis is almost canonized. Indeed the log-transformation reduces significantly the variation and changes the shape of the sample distribution, so it looks like normal distribution. Unfortunately in most cases, especially in geological data, the standard χ^2-analysis for the first and second order errors rejects the lognormal assumption.

Mandelbrot [22] showed that an acceptable alternative is the **Stable** (Paretian) probability distributions. These distributions are asymmetric and possess heavy tail. Unfortunately, most of the stable probability distributions (with few exceptions) have no analytical representation. The increments of the process are also α-stable: $x_{t+\tau} - x_t \overset{d}{=} \gamma\left(f(.+\tau) - f(.)\right)\zeta 1$, and this contradicts with all existing parametric Kriging procedures. Moreover, it is not guaranteed that the mean exists, while the variation is always unbounded. Also, the difference between the stable and lognormal distributions is detectable only for significant number of sample observations (greater than 10000). These are the main reasons that the stable distributions are not very popular for processing of real data, see the discussion in [25] and [26].

The monographs of Zolotarev [44] and Samorodnitsky and Taqqu [35] increased the interest to stable laws for stochastic modeling of real-nature processes (for financial modeling see also [34]).

In this paper we present some promising numerical applications of the MPSI. The obtained numerical results seem to describe a very good approximation of the stochastic behavior mainly observed in real processes.

BRIEF REVIEW ON STABLE LAWS

The stable distributions were introduced by Paul Levi [21].

By definition, a univariate distribution function $F(x)$ is stable if and only if its characteristic function has the form

$$\varphi(t)=\int e^{itx}dF(x)$$
$$\varphi(t)=\exp\left(iat-\gamma|t|^{a}\left[1-i\beta sign(t)\omega(t,a)\right]\right)$$

where

$$\omega(t,a)=\begin{cases}\tan\frac{a\pi}{2} & if a\neq 1\\ \frac{2}{\pi}\ln|t| & if a=1\end{cases},$$

$$sign(t)=\begin{cases}1, & if t>0\\ 0, & if t=0\\ -1, & if t<0\end{cases},$$

And

$$0<\alpha\leq 2, -1\leq\beta\leq 1, \gamma>0, -\infty<\alpha<\infty$$

The stable distribution is completely determined by four parameters α, β, γ and α where:

α is called the characteristic exponent. It measures the "thickness" of the tails of α-stable distribution. The smaller the value of α, the higher the probability in the distribution tails.

β is a symmetry parameter. The distribution is symmetric about α if $\beta=0$ and is called symmetric α-stable ($S\alpha S$). The Gaussian (α =2 any β) and Cauchy (α =1; $\beta=0$) distributions are both $S\alpha S$.

γ is a scale parameter, also called the dispersion. It is similar to the variance of the Gaussian distribution. However for the Gaussian case (α =2 any β) where σ^2 is the variance.

α is a location parameter. For $S\alpha S$ distributions, it defines the mean if $\alpha\in(1,2]$ and the median if $\alpha\in(0,1]$.

It is simple to be shown that if a random variable X is $S\alpha S$, the characteristic function is of the form

$$\varphi(t)=\exp\left(iat-\gamma|t|^{\alpha}\right)$$

A α-stable distribution is called standard if $\alpha=0$ and γ=1. If X is a stable random variable with parameters α, β, γ and α, then $(X-\alpha)\gamma^{-\frac{1}{\alpha}}$ is a standardized variable with characteristic component α and symmetry parameter β. In this case, the characteristic function is further simplified to

$$\varphi(t)=\exp\left(-\gamma|t|^{\alpha}\right)$$

GENERALIZED CENTRAL LIMIT THEOREM

According to generalized central limit theorem, the random variable X is the limit in the distribution of normalized sums of the form

$$S_n=\left(X_1+...+X_n\right)/a_n-b_n$$

where $X_1, X_2,..., X_n$ are i.i.d. and if and only if $n\to\infty$ the distribution of X is stable. If the X_i's have finite variance, then the limit distribution is Gaussian. However, if X_i's are with or without finite variance, then the limit distribution is α-stable.

THE MODEL OF POINT SOURCES OF INFLUENCE (MPSI)

From a modeling point of view, the MPSI may be viewed as an analysis of the interactions in a Poissonian ensemble of random shocks, see [44]. The Poissonian ensemble (PE) of points is defined by a random countable system of points in the area $V\subset\Re^n$. Suppose V_1 and V_2 are disjoint sets in V with finite volumes denoted by $|V_1|$ and $|V_2|$ and satisfying the following conditions:

The number of the points in the areas V_1 and V_2 (N_1 and N_2, respectively), are independent random variables.

The probability $P(N_1=k)$ for k=0,1,2... depends on k and $|V_1|$, but not on the shape of V_1.

If the volume of V_1 decreases to zero, the probability for two or more points in V_1 is negligible in comparison with the probability for exactly 1 point in V_1 that is,

$$P(N_1=0)=1-\rho|V_1|+o(|V_1|);$$
$$P(N_1=1)=\rho|V_1|+o(|V_1|);$$
$$P(N_1\geq 2)=o(|V_1|);$$

where $\rho(\rho>0)$ is a constant defined as a mean density of the points in the area. It is indeed well known, see for example [44]) that the random function N_1 has Poissonian distribution:

$$P(N_1=k)=\frac{\lambda^k\exp(-\lambda)}{k!},$$

where the parameter (the intensity) $\lambda=\rho|V_1|$. For different set of points, ρ can be different. The intensity λ can be expressed by the mean number of points in the area and therefore λ is a measure; $\lambda(V_1+V_2)=\lambda(V_1)+\lambda(V_2)$. In this case, ρ is the density of λ with respect to the Lebesgues' measure on $\Re^n$. With an additional homogeneity assumption, ρ becomes constant.

We define MPSI by a countable array of random pairs $x_i,\ M_i,\quad i-1,2,...,N_1,$ possessing the following properties:

x_i re points from the PE;

The random variables M_i are independent, uniformly distributed and independent in the Poissonian ensemble;

The number of points N_1 in any area of finite volume $|V_1|$, the point locations x_i and the parameters characterizing the points M_i are independent random variables.

The ensemble $(x_1;M_1),\ (x_2;M_2),...,(x_{N_i};M_{N_i})$, is called a regular marked point process and the variables $M_1,\ M_2,...,M_{N_i}$ are called marks.

Assume that the PE of points is defined in the area $V\subset\Re^n$. It can be also assumed that there are local disturbances in any point of the PE. The points produce "field of influence" based on "law of influence". The influence is called "point source of influence" and the law is called "influence function". In the general case, the influence function is defined as $u(x, y, M)$, where x is the location of the point, y is the location influenced by the point, M and is the intensity of the influence. The quantities x,y and M are vectors.

The main task of the MPSI is the analysis of:

$$\xi=\sum u(x_i,\ y_i,\ M_i)$$

where $x_i\in PE$ for $i=1,2,\ldots,N_1$. So we are interested in characterizing the random field of influences caused by the entire Poissonian ensemble of disturbances. For simplicity, we can assume that the coordinate system's origin is in y, i.e.:

$$\xi=\sum_{x_i\in PE}u(x_i,M_i)$$

The sum field ξ determined by all the PE of random shocks in area V can be analyzed as a boundary of the combined field in the increasing series of subareas of V. Denote by S_R the sphere in $\Re^n$ with a center at the origin and radius R and let $V_R=V\bigcap S_R$. The number of PE points in V_R is N_R and these points generate the field

$$\xi_R=\sum_{i=1}^{N_i}u(x_i,M_i),x_i\in V_R$$

The combined field ξ produced by the whole PE is defined as the weak limit

$$\xi=\lim_{R\to\infty}\xi_R$$

To show the existence of the above limit, it is enough to check the limiting behavior as $R\to\infty$ of the characteristic function

$$\chi_R(t)E\exp(i(t,\xi_R)),t\in\Re^n$$

see [44], where general conditions for the existence of the limit are derived.

Recall now that the most important features of the MPSI are the following two facts:

The PE of disturbances; and the functions of influence $u(x,M)$ determine the disturbances.

We should emphasize that the PE leads to a Poissonian-summation scheme that guarantees the infinite partitioning of the random variable ξ. The functions of influence $u(x,M)$ are used only for definition of the measure $\mu(A)=\rho\int_{A^*}P(dM)dx$, where A is Borel subset of $\bar{V}\in\Re^n$ and $A^*=\{(x,M):\ u(x;M)\in A\}$. If we use point sources of influence that do not possess Poissonian distribution, the corresponding results will be quite different from ours.

STABLE RANDOM FIELDS

Consider the $2D$ plane with points defined by the coordinates t_1 and t_2. A characteristic x is a function of the space coordinates t. If $x(t)$ is a random function it can be considered as a $2D$-random field. The change of the considered random function along a straight line will form a random process that can be called a section of the random field. However, it will no longer be of the type of the model .

The random field is determined by the distribution of the random field values $x(t)$ in n any points of the considered area $x(t_1),x(t_2),...,x(t_t)$. If this distribution is multivariable stable, it is possible to refer the field as a stable field, see [35]. The model is applicable in this case with little modifications for the memory function.

In the most general case the stable fields are heterogeneous and highly anisotropic (the variance among sections of the random field is very high), i.e. the field section properties depend on not only of the location but also on the direction. But there are also isotropic fields (sections of the random field are independent on the direction). An isotropic homogeneous field with a section defined by α-stable motion can be defined as an

α-stable Levy field, determined by the index of stability α and the scale parameters w or γ.

For illustration coincide the Brownian motion of particles in $2D$-constant gradient field. Along a line perpendicular to the direction of the gradient we can count the number of particles passing through a series of line intervals with a constant length. If the Brownian motion was absent (only a gradient flow) the particle density distribution is uniform. As a result of the Brownian motion, the particle density distribution becomes Gaussian. When the process is defined the point sources of influence, depending on the parameters, the particle density will deviate from the Gaussian model and often becomes closer to an α-stable process; in some intervals the particle density can reach very large values - a typical picture of -stable density.

STUDY OF THE SCALAR FIELD OBTAINED BY THE MODEL OF THE POINT SOURCE OF INFLUENCE

The computer program, implementing the proposed algorithm, outputs data for the local potential field for each time step of the particle movement. Using this information we can create 3-D kriging models. Very important is the problem of creating three-dimensional maps. In most cases the maps are plotted on the base of regular grid of measurements; in our case the measurements are located randomly. So we have to define a regular grid within our area of study and to interpolate the values in the grid points using our randomly located measurements. The procedure is based on the inverse distance method using the Euclidean D_{ik} distances between the interpolation (k) and observation () points:

$$Y_k = \frac{\sum_{i=1}^{n}\left(Y_i / D_{ik}^{a}\right)}{\sum_{i=1}^{n}\left(1 / D_{ik}^{a}\right)},$$

where Y_k is the interpolated value at the k th grid point, Y_i is the measured value in the i-th observation point, α is equal to 1 or 2.

In the literature there are many versions and modifications of the weight function. For example, the so-called J. Matheron geostatistical method [23] [24] uses for this purpose the variogram function, which is similar to the structure function defined by Kolmogorov [20]. The common point among all methods is the determination of weighted average.

In some cases we can attempt to solve the direct problem, in other --- the reverse problem. It is obvious that for the reverse problem, the determining average value is a bad function. In our opinion, this approach has serious drawbacks, although there are opposite opinions (cf. [29], [11], [13] and [42]). On the other hand, in many cases the original data seems to follow the stable distribution and, as it was mention above, this is a plausible model for processes with point sources of influence.

METHOD OF EVALUATING THE VECTOR FIELD

Apparently, the already mentioned inverse problem involves the evaluation of the potential at a random point using discrete measurements of the field. With real data, the problem of dispersion is of great importance. Typically, the range of the geo-chemical data is within $10^{-7} \div 10^{0}$, which in fact implies almost infinite variation. Log transformation of the data significantly reduces the variation.

The analysis of the values shows that for most of the chemical elements the expected value and value of γ differ significantly. This difference can produce significant errors when we analyze anomaly areas characterized with higher or lower concentrations.

The proposed method for data processing is very simple and gives reliable results. In the general case, the method procedure includes the following steps:

Evaluation of the parameters α and γ for the characteristic function of symmetric α-stable ($S\alpha S$) distribution using sets with limited number of observations (< 100). The applied method is an optimized version of the method of Press [4].

Determination of the correlation function of $S\alpha S$ process using the data along a section of space.

Development of modified version of $3D$ kriging simulation based on a weight function $w(r)$ defined as $w(r) = 1/\|D(x,y)\|^{C_{yar}}$, $\sum w(r) = 1$, where r is the correlation function of $S\alpha S$ of process, $\|D\|$ is distance between a y_i, x_i pairs, and C is a scale dependent constant. Optimizing weight coefficients $w(r)$ stability to α.

Simulation of $3D$ $S\alpha S$ space data using the method of Point Source of Influence (MPSI) proposed by Zolatorev:

Poassonian of points x_i with λ density is generated in the simulation volume. The existing permeability observations are included in the assemble by means of Poassonian density screening [10];

1. For each point x_i $S\alpha S$ random values M_i with γ mean are generated;
2. For each point x_i an influence function is defined $u = 1/\|D(x,y)\|^{C_{yar}}$ where r is the correlation function of $S\alpha S$ process;
3. For each point y_i (located on structured or unstructured grid within the simulation volume) the estimated value z_i is defined as $z_i = \sum_{x_i} u(x_i, y_i, M_i)$.
4. Check stability of α in original and simulation data

The pilot outcomes three dimension Alpha Stable Kriging are shown accordingly on Fig. 1, 2, 3. On the first figure is shown model, which is founded on reference tools of three-dimensional simulation, in a case utilized of possibilities of the program Rock Works. is it's visible that the model is very chaotic. On next figures is shown model on a basis Alpha Stable Kriging. The model is very well compounded with the substantial geological data, which is compounded with outcomes shown on next Figure (3). Cross Validation shows, that Alpha Stable Kriging is a successful formalism for an estimate of a mining deposit.

CONCLUSION

The obtained results have methodological importance and give the basis for development of the method, so it can allow us to develop better model representations of complex natural processes.

The method application to difficult equations of a gradient will require further researches, to take into account processes, arising in *3D* models, in particular occurrences of forces of interaction.

The results obtained in this paper allow us to assume, that the inclusion parameterization of geological processes will not render of influence to adequacy of application base MPSI. However, a more detailed research on this problem within the framework of complete stochastic models is required.

Use of this engineering for construction of common model MPSI is represented perspective, though already in zero approach there are questions, on which at present there is no answer.

The proposed method can be considered as a new technique for modeling and evaluation of processes with heavy tailed distributions.

The computer experiments show that the method can be applied in many areas of modeling real phenomena --- physics, geology, environmental studies, hydrology, etc.

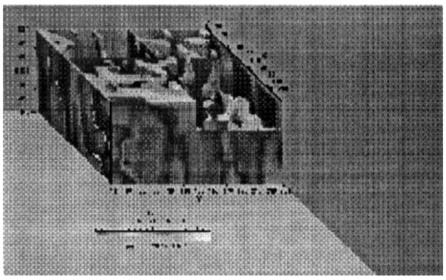

Figure 1. Here is shown 3D model on base Inverse distance method. It is visible, that the geological object (Mining deposit Kremikovtci) is rather random

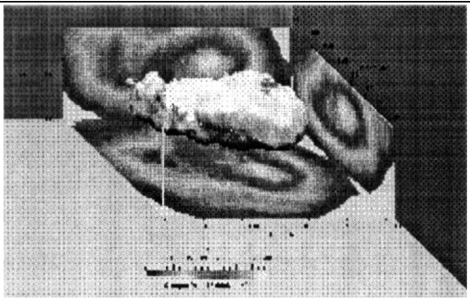

Figure 2. Here is shown 3D model on base alpha stable kriging method. It is visible, that the geological object (Mining deposit Kremikovtci) is rather compact and the zones such as " of Mining poles " are planned

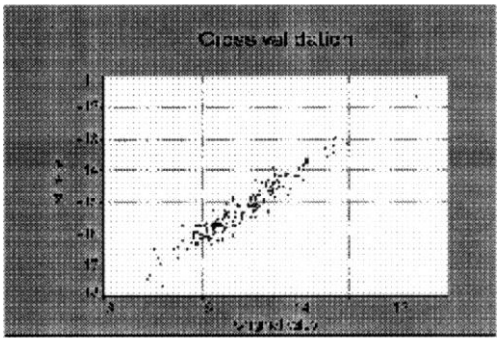

Figure 3. Here is shown cross validation matching between the original data (horizontal axes) and estimation in the same points on base alpha stable kriging method (vertical axes). It is visible, that the correlation very good, that is model has no a problem from calibration..

The proposed approach for solution of the inverse problem is at initial level of development, as there are no additional tests of its applicability. For now, it is tested and verified only for geostatistical data. The approach effectiveness is due to the new formalism for calculation of the correlation distance among the observations. In the classical geostatistics the solution is obtained using the classical variogram. Except for the Stable modification of the variogram for the Gaussian model, all other variogram models are useless. This conclusion is very important for the methods of image processing and map generation.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 51-56

METALLOGENY OF THE ZLATOUSTOVO VOLCANO-TECTONIC DEPRESSION (EASTERN RHODOPES)

V. Georgiev[1], B. Kolkovski[2], N. Metodiev[3], P. Milovanov[3]

[1]University of Mining and Geology "St Ivan Rilski",1700 Sofia, Bulgaria, E-mail:vlado69geo@yahoo.com
[2]Sofia University "St Kliment Ohridski", 1000 Sofia, Bulgaria
[3]Geology and Geophysics, 1505 Sofia, Bulgaria

ABSTRACT
The Zlatoustovo volcano-tectonic depression originated during the Paleocene in the area around Zlatoustovo fault zone. This fault zone trends E-W and separates Harmanli and Southeastern Rhodopes blocks in the Eastern Rhodopes. The following structures, from north to south, are divided within the Zlatoustovo depression: Lozen depression, Ibredjeck horst, Bryagovo depression and Madjarovo step. Coal occurrences are related to Paleocene and Eocene terrigenous sediments. The volcanic activity started towards the end of the Priabonian and continued during the Oligocene. The volcanics belong to the high-K Ca-alkaline and shoshonitic petrochemical series. Initially, several acid volcanoes developed along the Zlatoustovo fault zone. Zeolite deposits are related to pyroclastic varieties in these volcanoes. Polymetallic ore mineralizations associate with Sveta Marina volcano. The Lozen Au-polymetallic ore field is connected, both spatially and genetically, to Lozen volcano. The Madjarovo latite volcano, centred by a monzonitoide intrusion, developed in the area of Madjarovo step. Stratified Mn ore occurrences associate with the initial stages of the evolution of this volcano. The Madjarovo Au-polymetallic ore field is related to the final stages. The ore deposits are epithermal, of low-sulfidation type, and mainly vein-like. Sb mineralizations are located in the SE periphery of the Zlatoustovo depression. Placer gold is found in the Neogene-Quaternary sediments in the Ibredjeck horst.

INTRODUCTION

Zlatoustovo volcano-tectonic depression is situated in the Eastern Rhodopes, in the border area between two blocks – Harmanli and Southeastern Rhodopes. These blocks are built up of high-grade metamorphic rocks intruded by pre-Paleogene granitoid plutons.

The closure of the Tethys ocean in Late Cretaceous-Paleogene times (Dabovski, 1991) was followed by collision between Eurasia and African plate fragments resulting in accretion of separate "exotic" fragments of the African plate (as for example Rhodopes, Sakar, Strandja, etc.) to the southern margin of Eurasia.

The Harmanli block is considered to be a part of the Sakar fragment (Boyanov, 1992, etc.), and the Southeastern Rhodopes block - an element of the Rhodopes fragment. The boundary between these two blocks is marked by the Zlatoustovo fault zone (Fig.1) Its general trend is E-W, turning to WNW only in the westernmost parts of the structure. The Late Alpine Zlatoustovo volcano-tectonic depression developed upon and around this fault zone. This depression has not been described as a uniform structure until now. In our scheme it includes the following second-order structures: Madjarovo step, Bryagovo depression, Ibregjeck horst, Stambolovo and Lozen depression (Boyanov, 1992, 1995). The Zlatoustovo depression partly coincides with the Madjarovo depression of Boyanov (1971). Later Boyanov (1995, etc.) limited the Madjarovo depression to a high-rank structure that spatially corresponds to the Madjarovo step in our scheme. To the west (in the area of the town of Kardjali), the Zlatoustovo depression integrates with the Northeastern Rhodopes and Momchilgrad depressions. To the east it extends to the Maritsa fault zone. To the north and south the Zlatoustovo depression is bordered by the uplifted basement of the Harmanli and Southeastern Rhodopes blocks, respectively.

GEOLOGICAL EVOLUTION

The formation of ***Zlatoustovo depression*** commenced probably during the Paleocene. The earliest sediments in the confines of the depressions are Biser breccia and Leshnikovo sandstone-conglomerate formation. The transgression continued during the Priabonian with deposition of breccia-conglomerate, coal-sandstone and marl-limestone units (Goranov, et al., 1992).

The volcanic activity started in the end of the Priabonian. Beli Plast rhyodacite, Zimovina rhyolite-rhyodacite, Mezek and Lozen rhyolite complexes (I acid volcanism) were the earliest volcanic sequences formed in Priabonian-Rupelian times.

Tuffs and tuffaceous limestones, referred to Beli Plast complex, were deposited to the west, around Zlatoustovo fault zone.

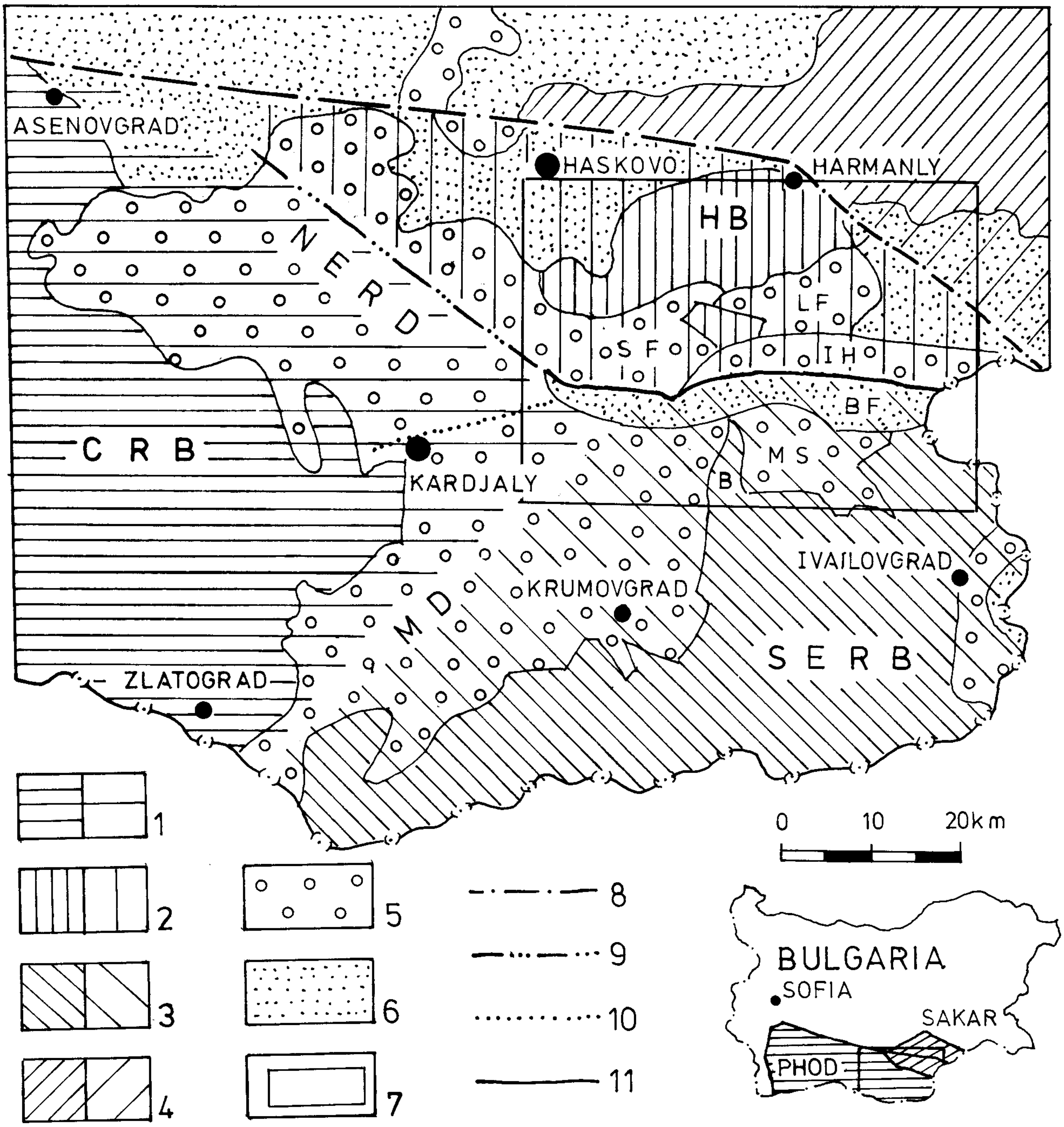

Figure 1. Generalised geological map of the Eastern Rhodopes (after Iovtchev et al., 1971, modified). 1 - Central Rhodopes block; 2 - Harmanli block; 3 - Southeastern Rhodopes block; 4 - Sakar block; 1a, 2a, 3a, 4a - surface exposures of the basement of the respective blocks; 5 - Paleogene sediments and volcanics; 6 - Neogene-Quaternary deposits; 7 - boundaries of the studied area1; 8 - Maritsa fault zone; 9 - Pchelarovo fault set; 10 - Ardino fault; 11 - Zlatoustovo fault zone.

Lyaskovets volcano, comprising the rocks of Zimovina complex, was formed in the westernmost parts of the Zlatoustovo depression.

Mezek complex is located in the easternmost parts of the Ibredjeck horst where together with acid tuffs some extrusive bodies were also formed.

The effusive rocks of Lozen complex build up Sveta Marina volcano in the Ibredjeck horst as well as Lozen volcano (Yanev, et al., 1975) situated within the Lozen depression.

Silen volcano, composed of the rhyolites of Perperek complex (II acid volcanism), is located in the western parts of Zlatoustovo depression. Some later phases of this volcano are established in the area of Lozen volcano. These are Cherna Mogila trachyrhyodacite and Planinets trachyrhyolite complexes (II and III acid volcanism) as well as some diorite-porphyrite bodies of Cherna Mogila complex that intrude the rocks of Lozen volcano.

Madjarovo volcano is located in the southern parts of the depression. It is formed of the rocks of Madjarovo latite complex (II intermediate volcanism). Intermediate tuffs, tuffites, and tuff-breccias interbedded with reef limestones were deposited during the earliest stages. Later followed eruptions of trachybasaltic andesites, various latites, trachydacites and quartz-trachytes. They form an elliptic volcanic edifice (17x11 km) elongated in WNW direction (Fig. 2). This large volcano associates with numerous smaller satellite and parasitic volcanic cones. In the vicinity of the town of Madjarovo, few relatively small intrusive bodies are also found (Mavrudchiev, 1959). They are probably parts of a larger intrusion, emplaced in the main magma conduit that fed the Madjarovo volcano. The volcanic cone is cut by numerous dykes of trachybasaltic-andesite, latiteandesite and latite compositions. Most of them are radial, but some are randomly oriented.

Valche Pole unit (of Oligocene-Miocene age) was deposited within the Bryagovo depression, and Ahmatovo Formation (Miocene-Pliocene) - in the Lozen depression.

METALLOGENY

Volcano-sedimentary zeolite deposits are related to the tuffs of the Beli Plast rhyodacite and, to a lesser extent, to the tuffs of the Mezek and Perperek rhyolite complexes. The zeolite-bearing bodies are stratum- or lens-like. These deposits, as well as the hosting tuffs, are located around the Zlatoustovo fault zone. In the western part of the depression, there are deposits of clinoptilolite (associated with chlorite, celadonite and montmorillonite) related to the pyroclastics of Beli Plast (Most and Rabovo deposits) and Perperek (Perperek deposit) complexes. In the area of Lyaskovets village, the tuffs of the Beli Plast complex are mordenitized and contain analcime and clinoptilolite (Djourova and Aleksiev, 1988). Mordenite-clinoptilolite zeolites, accompanied by erionite, analcime and stilbite, occur in acid tuffs of the Mezek complex in the eastern parts of the Ibredjeck horst (Ivanova, et al., 2001).

Sveta Marina lead-zinc deposit is closely associated with the volcano of the same name. The ore mineralizations form stratum- or lens-like bodies within the Priabonian sediments. The following stages of mineralization are recognised on the basis of the most important minerals (Breskovska and Gergelchev, 1988): 1) quartz-galena-sphalerite with minor pyrite and chalcopyrite; 2) quartz-barite-sulfosalts (with restricted distribution) – the sulfosalts are tetrahedrite and tennantite; 3) carbonate (also locally present) - calcite, dolomite. The authors, cited above, described also a stage of later sulfosalts, but they are represented by separate pyrite, galena and sphalerite crystals over carbonates and probably belong to the carbonate stage.

The Lozen lead-zinc ore field is related, spatially and genetically, to the Lozen rhyolite volcano. According to Breskovska and Gergelchev (1988), the ore bodies are of two types: shallowly dipping veinlet-disseminated ore mineralizations interbedded with sediments and volcanics; and fault-hosted steeply dipping vein-like bodies of veinlet-disseminated and vein type ore mineralizations. The ore-hosting rocks were affected by intensive hydrothermal alteration prior to the ore mineralization. The alteration in the upper parts of deposits is argillization (mainly montmorillonite), and in the lower levels it is of quartz-sericite type.

According to Breskovska and Gergelchev (1988), the ore mineralization was formed in three stages: 1) quartz-galena-sphalerite (or quartz-sulphide) – the productive stage, with pyrite and chalcopyrite as subordinate minerals; 2) quartz-barite with gold (of restricted distribution); and 3) carbonate (calcite, dolomite, ankerite) stage. According to Bogdanov (1983) the barite mineralization is later than the carbonate one. Concentric horizontal zonality in the spatial distribution of ore mineralization was described (Bogdanov, 1983): Cu-Pb-Zn mineralizations concentrate in the outermost parts, Pb-Zn – in the middle and Au-Ag mineralizations - in the outermost parts of the deposit.

Madjarovo *polymetallic and gold-polymetallic* ***ore field***. Veinlet-disseminated type copper-molybdenum mineralization of non-economic significance occurs within the monzonitoid bodies in Madjarovo volcano.

Polymetallic and gold-polymetallic ores are localized mainly in the inner (central) parts of the volcano (Gorno Pole, Arda, Momina Skala, Patronkaya, Gaberovo, Radonovsko, Harmankaya, Chatalkaya and Brusevtsi deposits). The ore bodies are of vein type, steeply dipping (70-90^{o}) and most of them are radial with respect to the Madjarovo volcano. They are located mainly within the volcanics and locally - in the sedimentary and metamorphic rocks from the basement of the volcano. Small metasomatic bodies are hosted in limestones.

The host rocks of the ore field rocks are affected by three temporal types of hydrothermal alterations: early pre-ore, pre-ore, and syn-ore. The first type is a regional propylitization of the volcanic rocks. Secondary quarzites (advanced argillizites) are also related to the first type. They form concentric zones around monzonitoid intrusions: the alterations in the inner parts are of argillizite type, propylites are established in the peripheries and the most intensively altered parts are converted to diaspor-bearing alunite-quartzites and zunyit-bearing diaspor-quartzites. Pre-ore metasomatics are restricted along faults and belong to the adularia-sericite type (Velinov and Nokov, 1991). The syn-ore alteration is represented by sporadic kaolinization and is poorly studied.

Various in number and composition stages of ore mineralization have been distinguished by different authors (Radonova, 1960; Atanasov, 1962; Kolkovski, 1971; Breskovska and Gergelchev, 1988). Our studies suggest five mineralization stages: 1) specularite-guartz with gold (productive for Au); 2) quartz-chalcopyrite (also productive for Au); 3) quartz-galena-sphalerite with pyrite and chalcopyrite as

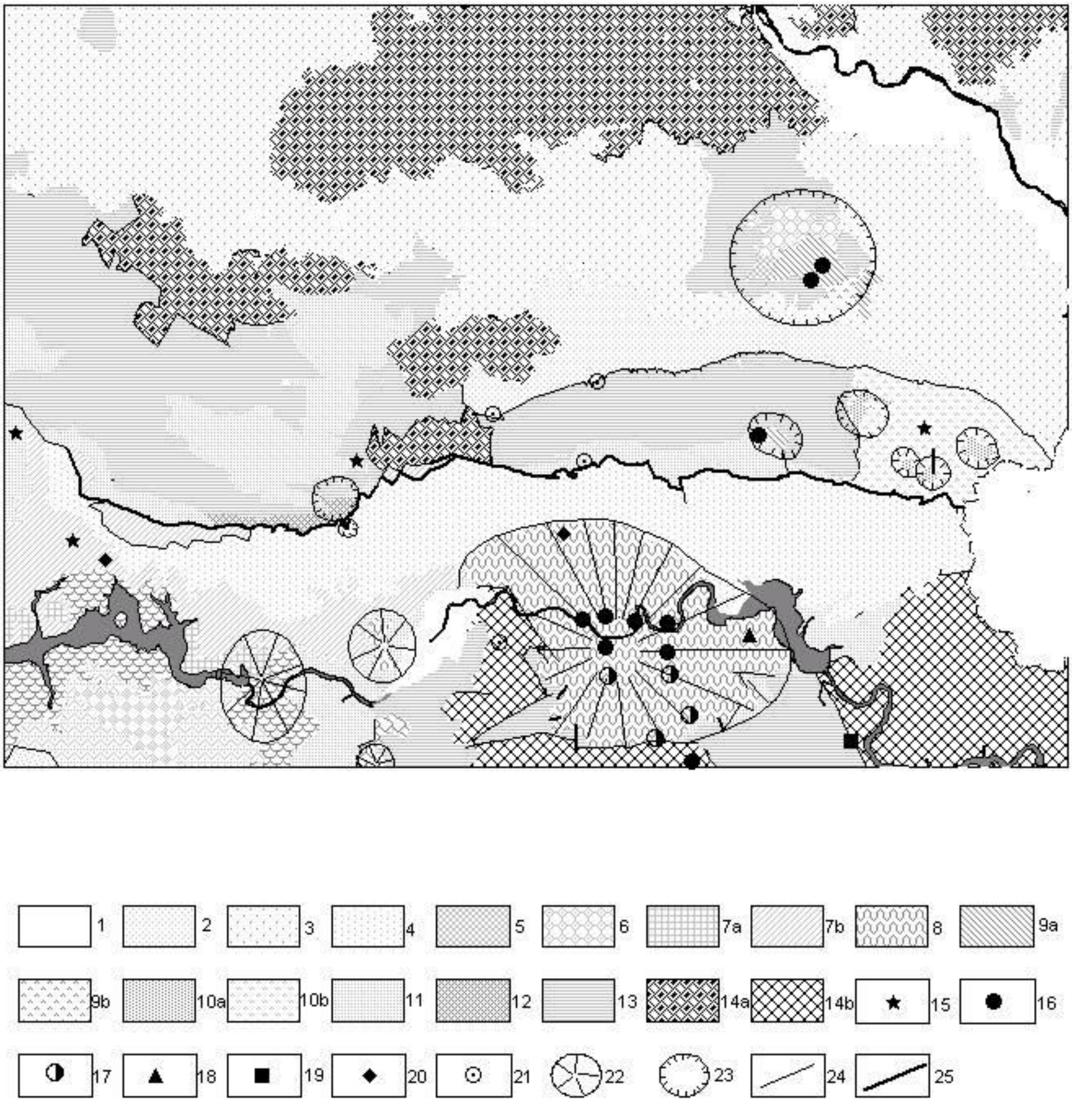

Figure 2.. Metallogenic map of the Zlatustovo volcano-tectonic depression. Quaternary: 1- alluvium; 2- proluvium; Miocene-Pliocene: 3-Ahmatovo Formation; Oligocene-Miocene: 4-Valche Pole Formation; Oligocene: 5- Planinets trachyrhyolite complex; 6-Cherna Mogila trachyrhyodacite complex; 7-Perperek rhyolite complex: 7a- rhyolite; 7b- tuffs; 8-Madjarovo latite complex; Eocene-Oligocene: 9-Lozen rhyolite complex: 9a- rhyolite; 9b- tuffs; 10-Mezek rhyolite complex: 10a- rhyolite; 10b- tuffs; 11-Beli Plast rhyodacite complex - tuffs; 12- Zimovina rhyolite complex; Paleocen- Eocene: 13-Paleogene sedimentary complexes; 14-pre-Paleogene basement; Ore deposits: 15- Zeolite; 16- Polymetallic (Pb-Zn); 17- Gold-polymetallic; 18- Manganese (pyrolusite); 19-Antimony; 20-Weathering deposits (halloysite-kaolinite, kaolinite, psilomelane-pyrolusite); 21-Placer gold; 22-Volcanic cone of the Madjarovo volcano; 23-extrusive bodies; 24- fault; 25- Zlatoustovo fault zone; MV -Madjarovo volcano; LV -Liaskovo volcano; SV - Silen volcano; SMV - Sveta Marina volcano; MZV - Mezek volcano; LZV - Lozen volcano ***Placer gold*** *is found both to the north and south of the Ibredjeck horst, in the areas of the villages of Tankovo, Zlatoustovo, Efrem, etc., and within the Lozen depression. They might have resulted from the destruction of the coarse-grained sediments that build up a large part of the horst. Au-bearing placers are identified along Bryagovska River and they could have formed at the expense of the gold dispersed in the metamorphic rocks exposed near by. Non of these occurrences is of economic significance.*

subordinate minerals (productive for Pb, Zn, and to some extent for Cu, Ag, and Au); 4) quartz-chalcedony-barite with Ag-sulfosalts and electrum (productive for Au); and 5) carbonate-quartz (locally present). In the surface parts of the ore field, the hydrothermal solutions produced minerals, typical of supergenic conditions (chalcophanite, wavellite and anglesite). This was probably caused by mixing of hydrothermal and rich in oxygen meteoric solutions.

A dome-like zonality in the distribution of ore mineralizations has been described around the main magmatic and ore-controlling structure - the vent of the Madjarovo volcano (Iliev, 1980). The predominating ore mineralizations in the inner and lower parts of the ore field are Pb-Zn, while Au-bearing dominate in the upper and peripheral parts of the deposit

Madjarovo ore field is related both spatially and genetically to the Madjarovo volcano. They have a common source in depth and both result from the evolution of one magma chamber.

Manganese (pyrolusite) ore occurrences (Borislavtsi and Kochash) form beds or networks of tiny veinlets in lava flows on the slopes of Madjarovo volcano. The gold-polymetallic Madjarovo ore field is also associated with this large volcano. The ore mineralizations are epithermal, of low-sulfidation type.

The Mareshnitsa antimony occurrence is situated to the southeast of the Madjarovo volcano. It is hosted in breccia-conglomerates of the Krumovgrad Group. The ore mineralization consists of quartz and stibnite as well as minor calcite, realgar, pyrite and pyrrhotite (Mladenova and LŸders, 2000). This mineralization, as usual in the Eastern Rhodopes, is located in the periphery of the depression. Its connection with the volcanism in not so clear and is, to a certain extent, hypothetical. As a more low-temperature mineralization, it seems to be formed at a greater distance from the volcanic edifices.

The halloysite-kaolinite deposit of Dolni-Glavanak, as well as some occurrences of this type (Topolovo, Topolovo-E and Borislavtsi) are related to weathering crusts formed upon the northern periphery of the Madjarovo volcano (Todorova, 1988). In the weathering zone of the tuffs of Perperek complex, kaolinite and psilomelane-pyrolusite mineralizations were formed. All of them are covered by sediments of the Valche Pole unit which contains coal occurrences.

CONCLUDING REMARKS

The cyclic evolution of the volcanism in the Eastern Rhodopes, that is believed to be a four-fold alternation of intermediate and acid phases (Ivanov, 1960, 1963; Harkovska, et al., 1989, etc.), is an idealised and abstract scheme. In fact, the magmatic activity usually evolved from intermediate to acid in the individual volcanic edifices. Several magmatic chambers with similar, but not contemporaneous development might have existed. Their activities overlapped in space and time and that is why their products at the surface overprint and interfinger laterally, creating the impression of a cyclic evolution. Thus, the idea of the existence of several alternating phases (I, II, etc.) of intermediate and acid volcanism is used here for the readers' convenience.

Only acid volcanism belonging to different phases occurred around the Zlatoustovo fault zone and in the northern parts of the Zlatoustovo depression where mainly zeolite deposits are localized. There, polymetallic ore mineralizations are of subordinate significance and their association with acid volcanics is a quite unusual case in nature. Mainly intermediate volcanism developed in the southern parts of the depression where Madjarovo Au-polymetallic ore field and some Mn mineralizations associate with the Madjarovo volcano. Sb mineralizations are also identified.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 57-63

GEOCHEMICAL ASSOCIATIONS IN RADKA ORE DISTRICT

Kamen Popov

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia, Bulgaria, kpopov@staff.mgu.bg

ABSTRACT
Results from statistical processing of primary geochemical halo samples from Tsar Asen, Radka and Chervena Mogila deposits are discussed. The concentrations of chemical elements are determined by emissiom-spectra analysis. The data are processed by factor analysis for determination of spatial groups of elements in the tree deposits. The following geochemical associations are recognized: a) in Tsar Asen deposit: ([Ag, Cu] As) Au, [Co, Ni] and [Pb, Zn], where Ba and Mo show independent behavior, b) in Radka deposit: [Ni, Co], (Ba, As, Ag), ([Pb, Zn] Ag) and [Mo, Au] where Cu is independent, c) in Chervena Mogila deposit: ([As, Ag] Pb, Au, Ba), ([Ni, Co] Mo) and [Cu, Zn]. The spatial distribution of the elements and the derived geochemical associations mark the difference in depth and temperature conditions of the ore-forming processes.

BRIEF GEOLOGICAL OVERVIEW

Panagyurishte Ore Region is located about 55-95 km ESE of Sofia (B. Bogdanov, 1981). A complex of Upper Cretaceous sedimentary, volcanic and intrusive rocks is exposed in this region. Three rock units are divided: a) Turonian Terrigenous Group, b) Lower Senonian Volcano-sedimentary Group and c) Upper Senonian Sedimentary Group. The Upper Cretaceous rocks transgressively overlie Pre-Cambrian, Paleozoic and Triassic rocks, and are locally covered by Paleogene, Neogene and Quaternary sediments. The Lower Senonian Volcano-sedimentary group is further subdivided into Krasen-Petelovo, Svoboda-Ovchihulm, Elshitsa and Pesovets volcano-intrusive complexes (K. Popov, 2001a). They include the homonymous effusive formations and related comagmatic subvolcanic and hypabyssal intrusives. The volcano-intrusive complexes are products of different magma chambers and differ in the time of their formation, composition of the rocks and structural evolution.

Radka Ore District is situated in the SE part of the Panagyurishte Ore Region. It is related to the evolution of the Upper Cretaceous Elshitsa volcano-intrusive complex (N. Obretenov *and* P. Popov, 1973; P. Popov *et al.*, 1994). This complex comprises the rocks of Elshitsa stratovolcano, the Elshitsa pluton as well as numerous subvolcanic and

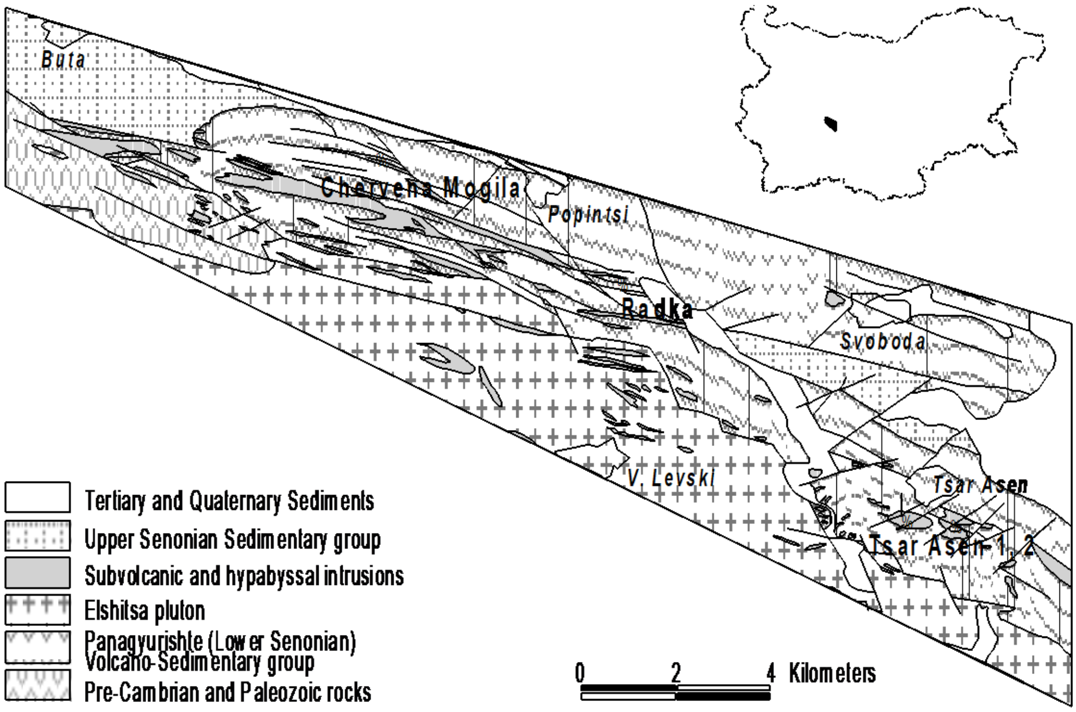

Figure 1. Geological scheme of Radka Ore District.

subvolcanic-hypabyssal minor intrusives and dikes. The ore district is a stripe-like area of E-SE direction, about 20 km long and 4 km wide in the northern slope of the Elshitsa stratovolcano. The Elshitsa pluton is exposed along the southern border as a result of fault uplift of the central block of the volcano. ESE (120-130^{o}) faults are typical. Two fault groups dominate: a) subvertical to northern dipping (80- 65^{o}) faults; b) southern dipping (45-60^{o}) faults. Their relations probably mark a conjugated faulting, which accompanies the uplift of the central part of Elshitsa volcano. Faults of 60-80^{o}, 150-170^{o} and 20-40^{o} direction are also common. They contribute to the higher permeability in some parts of the region.

A porphyry copper – massive sulphide ore system of linear type is developed in the ore district (K. Popov, 2001b). It was formed after the volcano-tectonic faulting and block segmentation of the Elshitsa stratovolcano. The fault swarm of ESE (120-130^{o}) direction as well as the accompanying stock and dike-like minor intrusions control its spatial position. The ore-forming process is characterized by asymmetrical development along the ore-controlling fault swarm. The Tsar Asen porphyry copper deposit is located in the SE flank of the ore district (Fig. 1). The massive sulphide deposits Radka and Chervena Mogila as well as numerous ore occurrences successively follow to the NW. The amount of sulphosalts, lead-zinc and gold mineralization increases in this direction while the temperature of ore emplacement decreases. K-silicate and propylitic hydrothermal alterations as well as sericitic and argillic alterations in the littocap associate with the Tsar Asen porphyry copper deposit. Predominantly propylitic, sericitic to advanced argillic alterations form successive zones around the massive sulphide deposits.

METHODS OF STUDY

The main aim of this study is to define the geochemical associations in the haloes of Radka, Tsar Asen and Chervena Mogila deposits in Radka Ore District. Groups of elements with similar spatial distribution are interpreted as geochemical associations but they are not identical to the existing mineral parageneses and associations. Modern statistical routines, organized in certain sequence, were used for their differentiation as shown in the following scheme:

Preliminary data preparation
↓
Univariate statistical analysis
↓
Cluster analysis
↓
Factor analysis

The individual stages of the applied method are described below. Factor analysis is mainly used for extraction of geochemical associations, while the objective of prior stages is a preliminary preparation and “familiarization” with data. Each of the applied analyses possesses a character of self-dependent investigation, which serves different geological tasks. Preliminary preparation aim collection, organization and archiving of data in computer form, which is accessible for subsequent analyses. The univariate statistical analysis examines the properties of distribution for element’s concentrations, as the anomalies and maps for individual elements could be prepared as the result. Cluster and factor analyses are used for grouping of elements based on the similarity of their spatial distribution. The main objective to combine these statistical procedures in a common sequence is to develop a uniform methodology for study of geochemical haloes and associations.

USED DATA AND PRELIMINARY PREPARATION

The primary geochemical halo data are used for investigation of geochemical haloes in Tsar Asen, Radka and Chervena Mogila deposits. The element contents are determined mainly by semi-quantitative emission-spectra analysis for a standard assemblage of 22 elements. The typical for the studied area assemblage of 10-15 elements is used during later sampling stages, since some of the elements were not detected or were detected only in a few samples in the beginning of the sampling period. The results of statistical processing only for the elements Ba, As, Ag, Pb, Zn, Cu, Ni, Co, Mo and Au, which are commonly studied in the three deposits, are presented in this paper with the aim to make a comparison between the derived geochemical associations. The Au concentrations are determined by emission-spectra analysis after chemical enrichment. Some quantitative determinations for Au and Ag contents by AAS and AES-ICP are used in Chervena Mogila deposit as well. The analytical results are verified by standard inner and outer laboratory accuracy control, whereupon significant deviations where not detected. All concentrations are presented in ppm units.

The Radka deposit halo was studied generally with 417 samples, where 214 are patch rock samples from the surface and 203 drill samples from several boreholes situated along profile line No 15. Tsar Asen deposit was studied with 1838 samples, where 257 were collected from the surface. The rest 1581 are drill samples from boreholes positioned along profiles A and VII from Tsar Asen 1 area and profiles E and XII from Tsar Asen 2. Chervena Mogila deposit was investigated with 783 samples, where 493 are surface samples and 290 are drill samples from five boreholes. Its surface is studied mainly by several trenches and patch samples around them. Generally, the sampling was not done on a regular survey grid and the data from the cross-sections are based on downward survey boreholes. Therefore the obtained results did not represent the entire distribution of chemical elements.

The presence of some elements is not determined in some samples, because of lower concentrations and insufficient sensitivity of emission-spectra analysis. Such data are replaced by a value equal to half of the lower limit of analysis sensibility. These data should not be excluded, because of the possibility to skew statistical distribution of the element and to increase its average content. In cases, when a sample was not analyzed for a particular element, then this sample was not used for calculation of the statistics for this element, as well as for determination of its correlation relationships with the other elements.

Table 1. Statistics calculated on the data from three deposits.

	Mean value	Median	Minimum	Maximum	Variance	Standatd deviation	Skewness	Kurtosis
Tsar Asen deposit								
Ba	758.4875	700	50	7000	188447.2	434.1051	3.381271	27.98798
As	62.84004	50	50	200	575.381	23.9871	1.81213	3.589405
Ag	0.347334	0.2	0.1	3	0.124987	0.353536	2.797355	12.722
Pb	13.8599	7	1	700	1436.767	37.90471	11.57918	164.277
Zn	63.00054	50	15	1000	3964.114	62.96121	6.811959	75.62133
Cu	1070.743	500	0.5	10100	3111321	1763.894	3.339556	12.51682
Ni	7.194233	5	0.5	70	37.25703	6.103853	2.94289	17.87328
Co	10.02584	7	0.5	300	136.8547	11.69849	11.5741	245.4383
Mo	6.86235	5	0.5	150	98.17837	9.9085	6.725931	69.56122
Au	0.024013	0.0015	0.0015	1	0.003875	0.062252	7.396453	86.13288
Radka deposit								
Ba	1341.127	1000	50	10000	906291.3	951.9933	3.897478	23.59711
As	101.9185	100	50	300	1414.58	37.6109	1.196747	3.723692
Ag	0.431175	0.5	0.1	3	0.097235	0.311825	2.874435	16.15526
Pb	33.70983	15	2.5	3000	27515.63	165.8784	14.70323	250.6651
Zn	124.0767	70	15	10000	258556.9	508.4849	17.87245	344.5467
Cu	419	100	3	10050	1060510	1029.811	5.786596	42.71888
Ni	7.94964	7	0.5	30	26.3989	5.137986	1.104547	0.619962
Co	8.31295	7	0.5	30	63.54305	7.97139	1.126899	0.517454
Mo	9.491607	5	0.5	700	1326.589	36.42238	16.85363	313.9194
Au	0.01838	0.0015	0.0015	0.5	0.002913	0.053974	5.728896	39.10217
Chervena Mogila deposit								
Ba	1269.83	1000	100	7250	1047866	1023.653	2.328667	7.489797
As	114.2016	100	50	1250	19604.74	140.0169	6.466718	44.90588
Ag	0.876539	0.5	0.15	49.47	5.977162	2.444823	12.0744	207.8978
Pb	104.1137	20	0.5	7000	191306.7	437.3862	10.15461	125.9087
Zn	117.2542	30	15	5000	112335.9	335.1654	9.739956	124.2805
Cu	129.8212	70	5	7000	117349.9	342.5637	12.70421	221.6551
Ni	5.500639	5	0.5	30	25.17935	5.017903	2.293026	6.609995
Co	4.333333	3	0.5	150	49.539	7.038395	12.24836	237.2022
Mo	3.509817	3	0.5	30	16.7309	4.090342	3.049325	12.41778
Au	0.130043	0.03	0.0015	5.9	0.163005	0.403739	7.786549	79.52349

UNIVARIATE STATISTICS

Descriptive statistics is used as the first stage of statistical data processing. The main aim is initial analysis of the distribution of particular chemical elements by statistics, such as average value, variance, standard deviation, skewness, kurtosis, etc. The majority of elements possess clearly positively skewned distributions as shown in table 1, i.e. the major part of the data have lower concentrations and higher element contents are measured in a small number of samples. Such shape of distribution is most commonly observed in geological studies of chemical element's behavior. Symmetrical distributions are usually typical for equilibrium systems, while the asymmetry prompts for import or export of a particular element. Positive skewness in distribution's shape could be interpreted as a matter influx caused by a superimposed ore forming process.

CLUSTER ANALYSIS

Cluster analysis (Tryon, 1939) combines different algorithms for classification. The main objective is data organization for obtaining reasonable structures. Furthermore, the objects are jointed in such a manner so that every group should consist of similar objects. The cluster analysis is very useful during the exploratory phase of large databases, especially when a prior hypothesis is lacking, nevertheless that this is not a typical statistical procedure and a test for significance of invoked groups is not available (StatSoft, 1999).

Hierarchical grouping method is used in the present paper, since the elements with most similar spatial distribution generate the kernels of groups in the beginning. Each of the other elements is attached to that group, objects of which are mostly similar to it during subsequent steps. The grouping procedure continues until jointing of all elements into a single group. The resulting arrangement of elements represents the structure of their relationships. The Pearson's correlation coefficient *r* is used as a criterion for spatial similarity between elements. Weighted pair-group averaging is used as an assessment for the similarity between an already formed group and other element, which leads to least loss of information during later grouping steps. The number of objects in each group is used as weights in averaging when jointing two groups. The cluster analysis results are shown on figs. 2-4. The elements with highest correlation relationships are enclosed in square brackets while lower correlations are marked by ordinary brackets. The elements which possess a slight tendency for jointing to a particular group are added with "±" symbol. The rest of elements, which are not included in any group, possess independent spatial behavior.

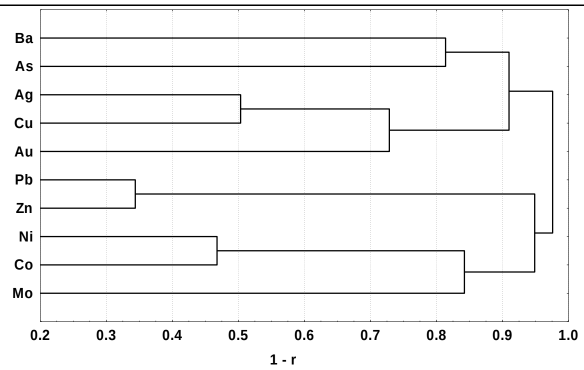

Figure 2. Cluster analysis on Tsar Asen deposit data. Extracted groups are [Pb, Zn], [Ni, Co], (Ag, Cu) ±Au.

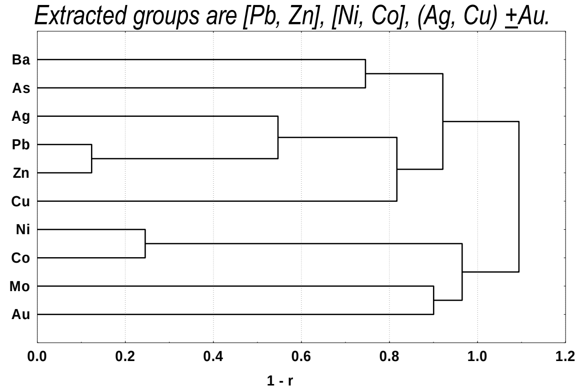

Figure 3. Cluster analysis on Radka deposit data. Extracted groups are [Pb, Zn] ±Ag, [Ni, Co].

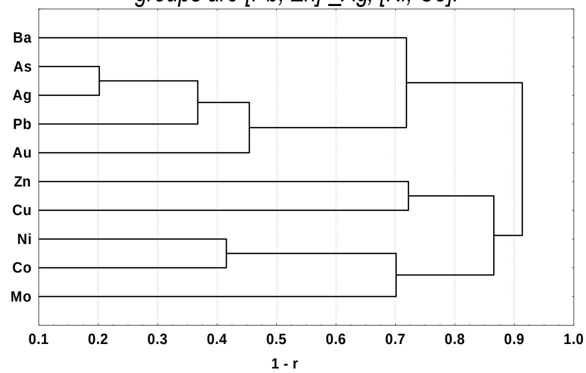

Figure 4. Cluster analysis on Chervena Mogila deposit data. Extracted groups are ([Ag, As] Pb, Au), [Ni, Co] ±Mo.

FACTOR ANALYSIS

Factor analysis (Thurstone, 1931) is used to present the structure of studied data by means of their grouping and classification as well as for space dimension reduction of the analyzed variables. It is the main procedure in this methodology for invoking groups of elements with similar spatial behavior, which are interpreted as geochemical associations. The main approach in factor analysis application is based on the idea to represent the data structure by factor communities extraction, based on the similarity between the elements.

The principal component analysis is the most popular variety of factor analysis in which new axes are defined with same number as input variables. The new axes, named principal components, are orthogonal, i.e. the condition for factor independence is accepted. This analysis is based on representation of the covariance matrix as a vector community describing data scattering ellipsoid. The ellipsoid's main axes are requested principal components and they are defined by eigenvectors and eigenvalues of covariance matrix. New axes obtained in this way differ from originally measured sample values, but they are linear combinations of particular variables. Their orientation is parallel to maximum data variance directions, which aims representation of existing "hidden" data structure. Thus, each of the resulting factor axes will account for the joint behavior of a group of dependent variables (if exist) or individual variation of a particular independent variable. The number of factor axes could be reduced as a result, so that only those factors remain which describe existing groups of elements.

R-method of factor analysis is used to represent data investigation for space dimension reduction and for elimination of useless factor axes, which describe single variables (J. Davis, 1973). This procedure analyzes the correlation data matrix, and relations between variables (chemical elements) are considered as correlations between each variable with new mutually independent (orthogonal) factors. Usually, the resulting factors are not well oriented with respect to the direction of regression dependency of a particular group,

Table 2. Factor analysis on data from three deposits.

	Tsar Asen deposit			**Radka deposit**			**Chervena Mogila deposit**		
	Factor 1	***Factor 2***	***Factor 3***	***Factor 1***	***Factor 2***	***Factor 3***	***Factor 1***	***Factor 2***	***Factor 3***
Ba	*0.356424*	-0.270438	-0.005634	**0.584817**	0.080681	-0.074527	**0.517654**	0.113013	-0.203637
As	**0.564405**	-0.150037	-0.097746	**0.548261**	0.040454	0.196027	**0.890475**	0.036145	-0.040895
Ag	**0.831592**	-0.019339	0.141586	**0.553641**	**0.615842**	0.217583	**0.826013**	-0.063165	0.073649
Pb	-0.012358	-0.111107	**0.913869**	-0.038171	**0.951301**	0.077332	**0.752217**	0.098799	0.147461
Zn	0.034869	0.226112	**0.893223**	-0.094317	**0.931630**	-0.083727	-0.033161	*0.318083*	**0.699382**
Cu	**0.710073**	0.149842	0.055786	0.142407	0.200609	0.010657	0.130129	-0.055779	**0.834445**
Ni	0.011791	**0.818641**	0.092808	**-0.812829**	-0.043390	0.124165	0.029211	**0.893558**	0.077196
Co	0.004689	**0.845982**	0.044145	**-0.851658**	0.025131	0.052812	-0.113072	**0.782778**	0.096433
Mo	*0.363490*	*0.344324*	-0.089243	0.019297	-0.039264	**0.708351**	***0.466447***	**0.557625**	0.020087
Au	***0.434278***	0.106800	-0.005758	-0.053381	0.096680	**0.733685**	**0.729855**	-0.115009	0.188704
Expl. Var.	1.963593	1.697769	1.684308	2.368985	2.213962	1.162687	3.090974	1.867477	1.307014
Prop. Total	0.196359	0.169777	0.168431	0.236898	0.221396	0.116269	0.309097	0.186748	0.130701

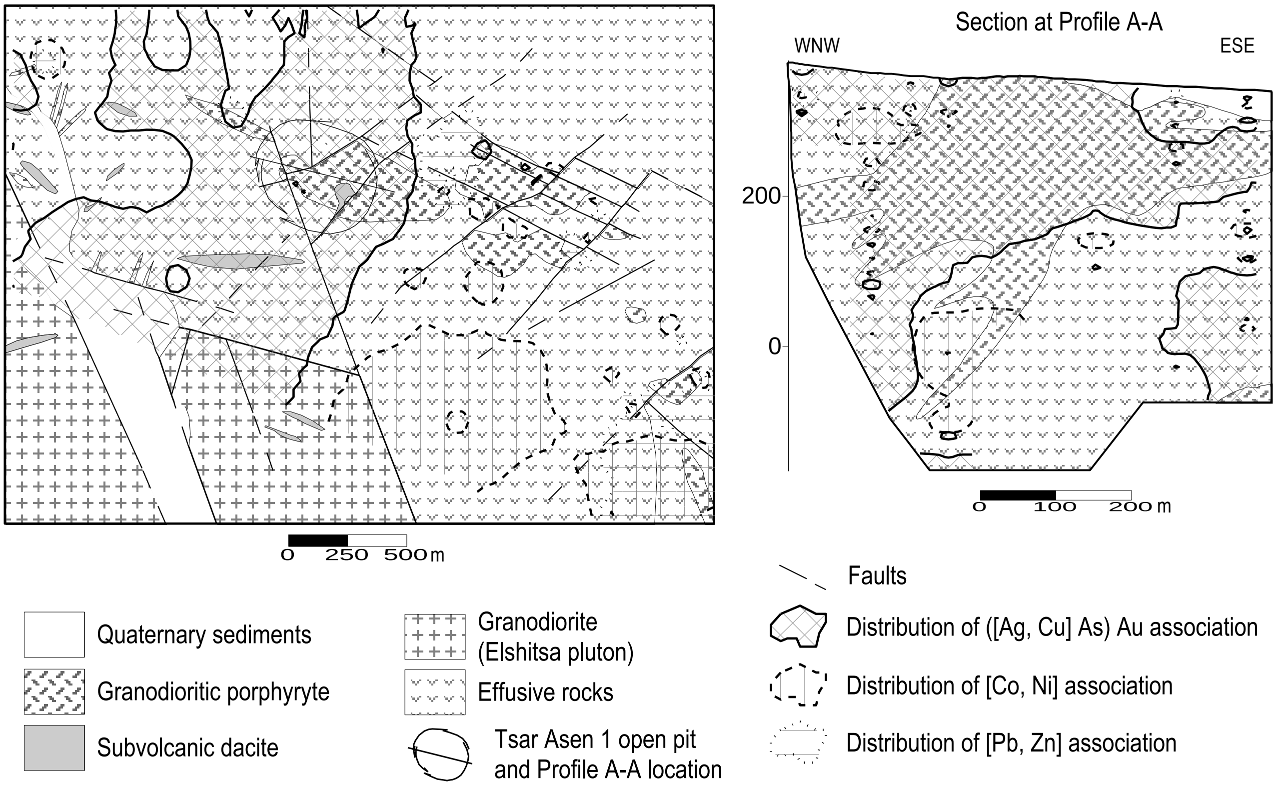

Figure 5. Spatial distribution of geochemical associations in Tsar Asen deposit.

because of the influence of independent variables and the observation of the factor orthogonality condition. Normalized “varimax” rotation is used for additional factor axes fitting to maximum group variances, which produce an additional increase of higher weights and a decrease of lower weights in every factor as well.

The lack of prior information about the necessary number of factors is a certain disadvantage of factor analysis. For this reason, cluster analysis is applied in the used methodology as a previous stage in order to obtain a concept for existing data correlation hierarchy and expected number of groups. Several extractions with different number of factors are commonly used in practice and the most convenient for interpretation variant is selected. Obtaining smaller number of groups with more elements in each group is the effect of using a small number of factors. An increasing number of factors leads to dividing groups into subgroups and appearance of factors representing individual elements. The possibility for calculating factor scores of each sample is a big advantage, which allows drawing of maps for the spatial distribution of each factor (Figs. 5-7).

The results from factor analysis of the used ten elements are shown in table 2. Different extractions at two to five factor axes are applied for derivation of the geochemical associations. The extractions of three factor axes, which was chosen as most representative, are presented below. The weights of elements which build the kernel of each group are bolded (weights higher than 0.5), the weights of elements possessing high tendency for integrating with a particular group are shown in bolded italic font (weights between 0.5-0.4) and the weights of independent elements which possess a slight tendency for joining with some group are shown in italic (weights between 0.4-0.3). The rates of variance explained from each factor in every deposit and their proportions from whole data variance are shown in the last two rows of the tables.

Table 3. Geochemical associations determined by individual factor axes at Tsar Asen, Radka and Chervena Mogila deposits.

Tsar Asen deposit
Factor 1: ([Ag, Cu] As) + Au, Mo, Ba Factor 2: [Co, Ni] + Mo Factor 3: [Pb, Zn]
Radka deposit
Factor 1: - [Ni, Co]; + (Ba, As, Ag) Factor 2: ([Pb, Zn] Ag) Factor 3: [Mo, Au]
Chervena Mogila deposit
Factor 1: ([As, Ag] Pb, Au, Ba) + Mo Factor 2: ([Ni, Co] Mo) + Zn Factor 3: [Cu, Zn] (-Ba)

The geochemical associations interpreted from the results of the factor analysis (Table 2) are shown in Table 3. The elements with highest weights (factor’s kernel) are enclosed in square brackets, similarly to the grouping by cluster analysis. The elements with lower weights are enclosed in ordinary brackets while independent elements, which possess some slight tendency for joining to a particular group, are added with “+” sign.

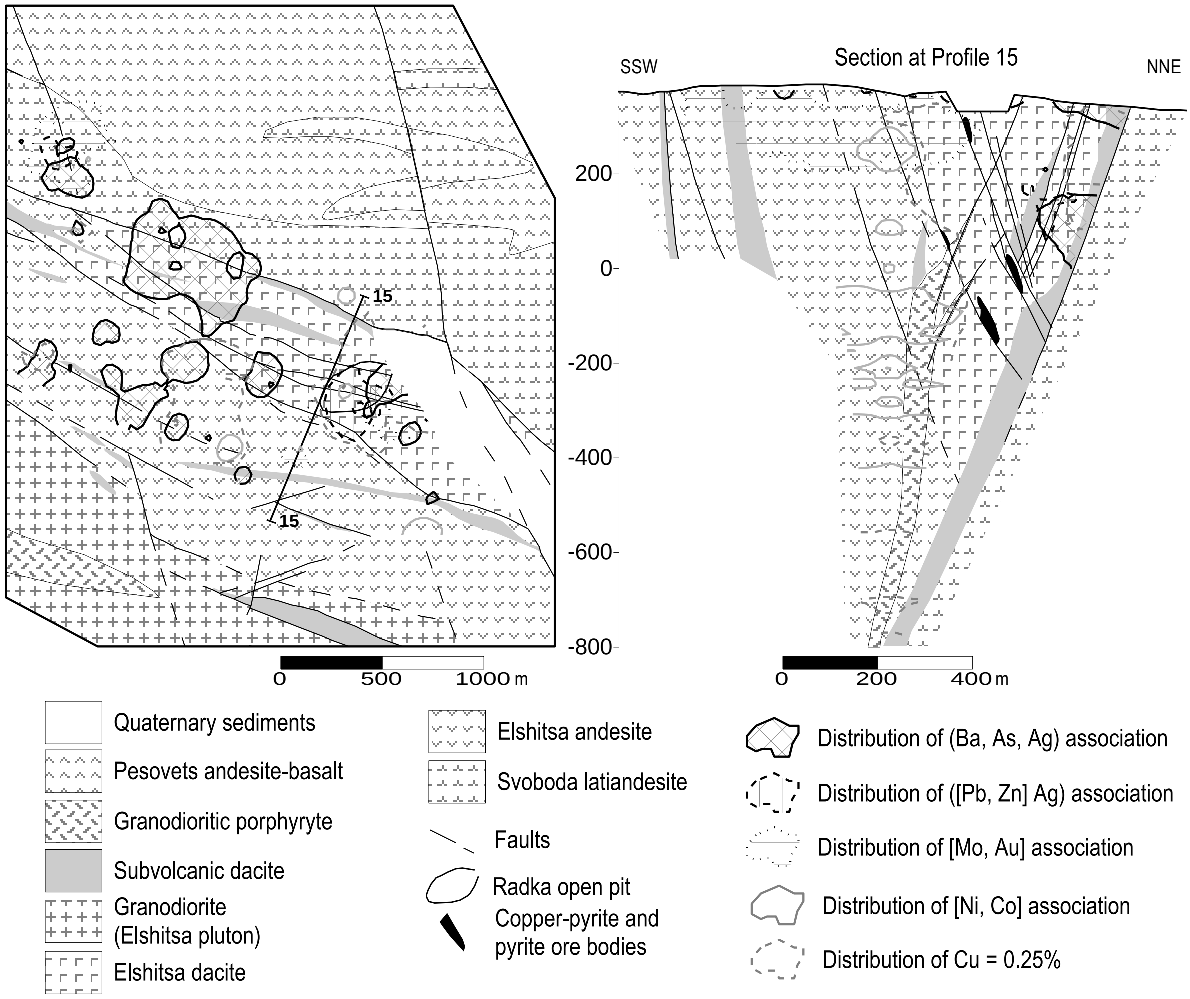

Figure 6. Spatial distribution of geochemical associations in Radka deposit

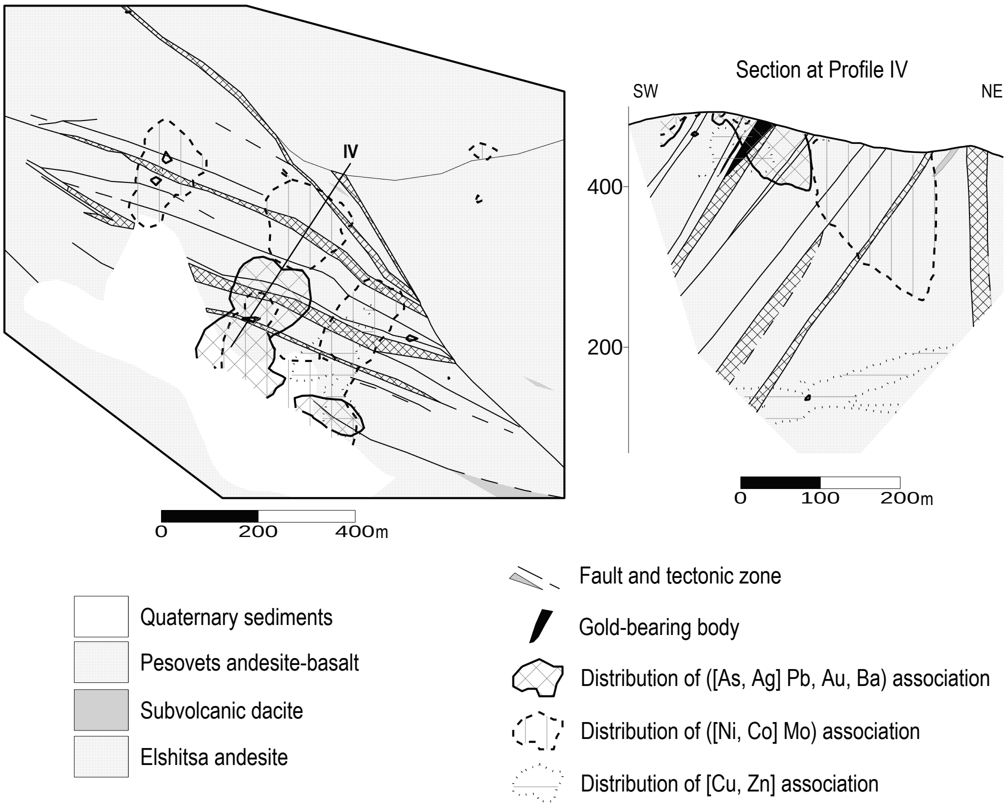

Figure 7. Spatial distribution of geochemical associations in Chervena Mogila deposit

CONCLUSIONS

The paper presents results from statistical processing of a large number of data form Tsar Asen, Radka and Chervena Mogila deposits. The information on the content and distribution of the studied elements is shown in Table 1. Generally, the elements demonstrate a typical for unequilibrium systems asymmetrical distributions, due to hydrothermal and ore forming processes superimposed on the host rocks. The geochemical associations derived from factor analysis are as follows:

in Tsar Asen deposit:
([Ag, Cu] As) Au, [Co, Ni] and [Pb, Zn], where Ba and Mo are independent elements,

in Radka deposit:
[Ni, Co], (Ba, As, Ag), ([Pb, Zn] Ag) and [Mo, Au], where copper is independent,

in Chervena Mogila deposit:
([As, Ag] Pb, Au, Ba), ([Ni, Co] Mo) and [Cu, Zn].

The spatial grouping of the studied chemical elements shows a tendency for differentiating such communities, that group elements related to low-, medium- or high temperature minerals. Thus, the extracted groups reflect the existing zonality in the deposits. A comparison of the results from the factor associations in the three deposits leads to the following conclusions:

1. The extracted associations reflect the existing zonality in the deposits. In Tsar Asen deposit, the distribution of the ([Ag, Cu] As) Au association is very close to the spatial position of the ore body as indicated by the high contribution of Cu in this group (Fig. 5). The second [Co, Ni] association develops around the first one and in depth. The third [Pb, Zn] association is located in the periphery of the first group and mainly on the surface, above of the deposit. The geochemical associations in Radka deposit are related to the periphery of those ore zones, which are located mainly within dacite effusives (Fig. 6). The [Ni, Co] association is located mainly in depth, while (Ba, As, Ag) and ([Pb, Zn] Ag) occur at higher levels and near the surface, surrounding the periphery of the copper ore. The [Mo, Au] association develops on the surface within andesitic rocks. In Chervena Mogila deposit, the first ([As, Ag] Pb, Au, Ba) association is related to areas of gold-bearing ore bodies and around them (Fig. 7). The second ([Ni, Co] Mo) is located along the periphery and near the first group, while the third [Cu, Zn] association tends to develop mainly in the SE areas and at lower levels. The spatial position of the associations in the three deposits reflect their genetic relation to the main ore-controlling tectonic structures.
2. Ag and As are grouped in all three deposits. Cu and Au associate with this group in Tsar Asen, while Pb and Au are joined in Chervena Mogila deposit. The Ag, As and Ba association is not so well developed in Radka deposit, where these elements show a distinct negative correlation with the Ni and Co group. "Inter-associative" behaviour of Ag is observed in Radka deposit as well, since Ag has significant weights in both the first and second factor axes.
3. The Pb and Zn association occurs in Tsar Asen and Radka deposits. Ag joins this group in Radka deposit. Pb and Zn belong to different associations in Chervena Mogila, where Pb associates with As, Ag, Au and Ba, while Zn is grouped with Cu.
4. Ni and Co are grouped in all three deposits. Mo joins these two elements in Tsar Asen and Chervena Mogila Deposit. This group has the highest proportion in the whole data variance in Radka Deposit.
5. The spatial behavior of Cu is specific in all three deposits. This element associates with Ag, As and Au, while it is grouped with Zn in Chervena Mogila and it possess an independent behavior in Radka (very slight tendency for joining to group of Pb, Zn and Ag).
6. Au and Mo show a somewhat specific behavior in each deposit. Au belongs to the group with As-Ag kernel in Chervena Mogila and Tsar Asen, while Mo exhibits a certain inter-associative behavior, because it is grouped with Ni and Co, but shows a tendency for joining the As-Ag association as well. Au and Mo form a self-contained association in Radka deposit, to which Ag shows a slight tendency for joining. The grouping of Au with Cu and Ag in the first factor in Tsar Asen deposit becomes more distinct when decomposition on a larger number of factors is used.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 65-69

PECULIARITIES OF Pb-Zn MINERALISATION IN DEPOSITS FROM YUGOVO ORE FIELD

Sergey Dobrev

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria; E-mail: sergey@staff.mgu.bg

ABSTRACT
Samples from quartz-galena-sphalerite mineralisation in Yugovo ore field have been studied (from ore occurrence Braikovitza and Komin dere). The mineralisation is related to small Early Alpine granitoid bodies, probably of Late Cretaceous age, intruded in metamorphic rocks from Dobrostan formation. The mineral composition of the ore is described and data on trace elements content in galena (atomic absorption analyses) are presented. Isomorphic presence of Ag and Bi in galena is proved through microprobe investigations. The composition of aikinite inclusions in galena is also studied. The temperature interval of mineral crystallisation (homogenisation of fluid inclusions in quartz from productive mineral paragenetic association) is in the range of 360 – 300° C.
Key words: – Pb-Zn mineralisation, fluid inclusions, trace-elements.

INTRODUCTION

The Yugovo ore field is situated in the northern part of the Central Rhodope ore district (Dimitrov, 1988) and according to some authors – within the confines of the so-called Yugovo-Narechen ore district (Maneva et al., 1989). The ore field is located from Yugovo road fork on the North to the town of Laki to the South and comprises molybdenite, lead-zinc and fluorite mineralisatons. The Mo mineralisation is of quartz-molybdenite type (ore occurrences Yugovsko hanche, St. Georgi, Laki), the Pb-Zn one is of quartz-galena-sphalerite type (ore occurrences Braikovitza and Komin dere) and the F mineralisation is of quartz-fluorite-sulphide type (deposit Yugovo, ore occurrences Gugliovo, Propula, Borovo).

The ore mineralisation is related to a small granitoid intrusive bodies of Late Cretaceous age – leucocratic granite and granodiorite (the so-called Yugovo granitoids – Stoynova et al., 1984; Nedyalkov et al., 1998).

Quartz-molybdenite veins are not of economic interest. Quartz-galena-sphalerite mineralisation is mainly of vein type – steep dipping veins with sub-equatorial and northeastern direction, cross-cutting schists and marbles of Dobrostan and Yavrovo formations (Fig. 1). Metasomatic replacement ore bodies are also present (in skarns of ore occurrence Komin dere). Ore veins could be traced on the surface to 700 m, with thickness usually not exceeding 1 m. Fluorite veins are mainly of sub-equatorial orientation and represent infillings of quartz, sometimes quartz plus carbonate with dissemination, nests and rarely lenses of barite-fluorite-celestine and sulphide mineralisation. Metasomatic lens-like fluorite bodies in marble layers also occur. The lead-zinc mineralisation could be assumed as a subfacies of fluorite-barite-sulphide mineralisation, well manifested in Yugovo deposit.

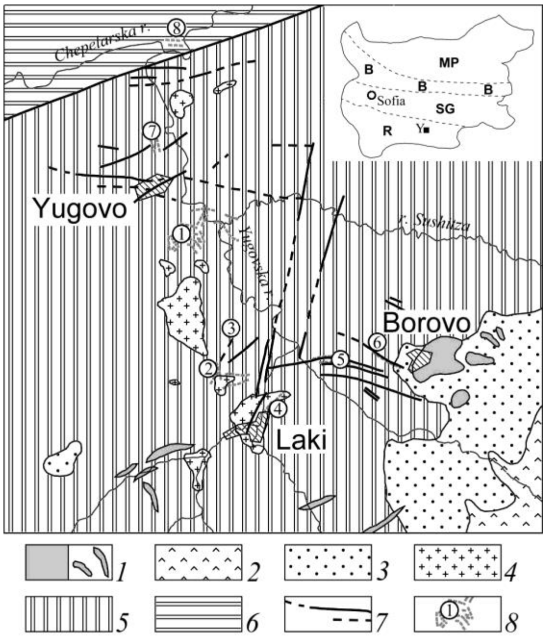


Figure 1. Schematic geological map of Yugovo ore field (after Stoynova et al. 1984, Ivanov et al. 2000).
Abbreviations on inset map: MP – Moesian Plate; B – Balkanides; SG – Srednogorie Zone; R – Rhodopes; Y – Yugovo ore field.
1. Oligocene trachyrhyolite and rhyodacite (a- subvolcanic bodies, b- dykes); 2. latite; 3. Eocene-Oligocene volcano-sedimentary unit; 4. Upper Cretaceous granitodes; 5. parametamorphites from Dobrostan and Yavrovo formations; 6. orthometamorphites from Bachkovo formation; 7. faults; 8. ore deposits and ore occurrences: 1- *Yugovo,* 2- *Braikovitza,* 3- *Komin dere,* 4- *Laki,* 5- *Propula,* 6- *Borovo,* 7- *St. Georgi,* 8- *Yugovsko hanche*

In quartz-molybdenite veins, main ore minerals are pyrite and molybdenite, arsenopyrite and pyrrhotite are abundant (Stoynova, 1988; etc.). The mineral composition of the quartz-fluorite-barite veins is quartz, fluorite, barite, calcite, manganocalcite (Todorov, 1989); rare minerals are bastnesite, gypsum plus small amount of sulphides – almost all of the established in the Pb-Zn mineralisation.

Pb-Zn MINERALISATION

Three mineral paragenetic associations (mpa) in the quartz-galena-sphalerite mineralisation can be distinguished: quartz-pyrite, quartz-sphalerite-galena (productive) and carbonate one. In the productive mpa besides quartz, galena and sphalerite, also fluorite, molybdenite, chalcopyrite, tetrahedrite, tennantite and aikinite are established and as rare ones bismuthinite, cosalite, galenobismuthite and tetradymite (Stoynova, 1988).

Typical for the ores is higher content of F, Ba and Mo and also presence of Sr. In the composition of quartz-galena-sphalerite mineralisation, lead strongly prevails (geochemical type Pb>>Zn). Galena usually is fine- to medium-grained, most often as nests and dissemination in quartz, rarely forming massive aggregates with coarse-grained texture.

Main trace elements in galena are Ag and Bi – established-in all analysed samples (Table 1). The content of Ag is in the range from 661 to 5610 ppm (average 4015 ppm), while Bi is from 942 ppm to 25400 ppm (average 15783 ppm).

Table 1. Trace elements in galena from ore occurrence Braikovitza (atomic absorption analyses of monomineral samples).

No	Sample No	Element content [ppm]												
		Ag	Sb	Bi	Te	Se	Cd	Tl	Sn	Zn	Fe	Cu	Mn	Co
1	1	1501	-	4155	41	42	49	-	20	1286	100	347	-	29
2	2	661	50	942	168		56	2	2	238	10	225	5	23
3	23 I	5610	30	24900			160	70	20	14700	900	3730	110	60
4	26 II	5570	-	17400	157	62	180	1	1	21200	1200	2630	140	60
5	34 II	5350	50	25400	130	3	130	100	7	310	160	3340	30	60
6	35 II	5400	10	22400	93	19	180	100	7	180	500	2430	15	60

The content of Cu is relatively high and correlates well with the content of Bi. It is in the range from 225 to 3730 ppm (average 2117 ppm).

Among the other trace elements, a relatively constant and high content of Te and Cd should be mentioned (no correlation between Cd content and presence of Zn is observed), as well as presence of Tl and Se.

Microprobe analyses of homogenous galena grains were provided (Table 2). The homogeneity of analysed galena grains was investigated – not only under optical microscope, but also in scanning electron microscope (Plate A). For the same area, data for regular distribution of Ag were obtained (Plate B), as well as for Bi, but with lower density. Ag and Bi were proved in all samples with average content 0.55% and 0.18% respectively while Te was found in two cases. Sb and Cd in analysed samples are in quantities under the threshold of response of the method. The contents of Ag correspond to those established by atomic absorption analysis, while the content of Bi is significantly lower. This could be explained by presence of numerous small aikinite inclusions in galena, the larger of them being observed in reflected light microscope.

Table 2. Microprobe analyses* of galena

No	Sample No	Element content [wt. %]					
		Ag	Bi	Te	Pb	S	Σ
1	23 I	0.62	0.54	-	85.33	13.87	100.36
2	23 I	0.40	0.09	-	85.08	13.70	99.27
3	23 I	0.47	0.18	-	84.14	13.63	98.42
4	35 II	0.57	0.02	-	83.79	13.74	98.12
5	35 II	0.51	0.13	0.04	84.51	13.33	98.52
6	35 II	1.30	0.13	0.06	83.75	13.24	98.48

* Sb and Cd not found

Balance of atomic quantities of Ag, Cu, Sb and Bi in galena shows atomic ratios Ag:(Sb+Bi) and Cu:(Sb+Bi) close to 1:2 (Table 3). Due to the low content of Sb, these are practically atomic ratios Ag:Bi and Cu:Bi. Atomic ratios (Ag+Cu):(Sb+Bi) are close to ratio 1:1, which correspond to bonding of Ag and Cu with Bi as matildite and aikinite (Fig. 2). The presence of Ag and Cu could be explained with limited solid solution matildite-galena, formed at temperature over 216° C (Vaughan and Craig, 1978) and inclusions of aikinite (probably even of submicronic size).

Table 3. Atomic quantities of Ag, Cu, Sb and Bi in galena from ore occurrence Braikovitza and atomic ratios (according to the analyses in Table 1)

No	Atomic quantities x 100 000				Ag:(Sb+Bi)	(Ag+Cu):(Sb+Bi)
	Ag	Cu	Sb	Bi		
1	139	55	-	385	1 : 2.77	1 : 1.98
2	61	35	4	87	1 : 1.5	1 : 0.95
3	520	587	2	1192	1 : 2.29	1 : 1.08
4	516	414	-	833	1 : 1.61	1 : 0.9
5	496	526	4	1215	1 : 2.46	1 : 1.19
6	501	382	1	1072	1 : 2.14	1 : 1.22

Presence of aikinite in ore from Braikovitza was reported by Gadjeva in 1972. Later Stoynova and Begizov (1982), using microprobe analyses and powder diffraction method, proved aikinite in mineralisations from ore occurrence Komin dere.

Investigation of polished sections from ore occurrences Braikovitza and Komin dere through reflected light microscope and microprobe analyses show presence of aikinite in the ore – most often at the periphery of galena grains (Plate C) or as cross-cutting veinlets (Plate D). Small aikinite inclusions with irregular shape in galena were also observed in some cases, but due to their small size, only one microprobe analysis of comparatively fine aikinite inclusion was provided (analysis 1, ChTable 4). Other analyses show the composition of larger grains or veinlets of aikinite in galena (analyses 9, 10, Table 4).aracteristic for the aikinite studied is almost absolute absence of impurities and constant crystallo-chemical formula, close to the theoretical one, with an exception of the last two analyses, made on aikinite veinlets that cross-cut galena.

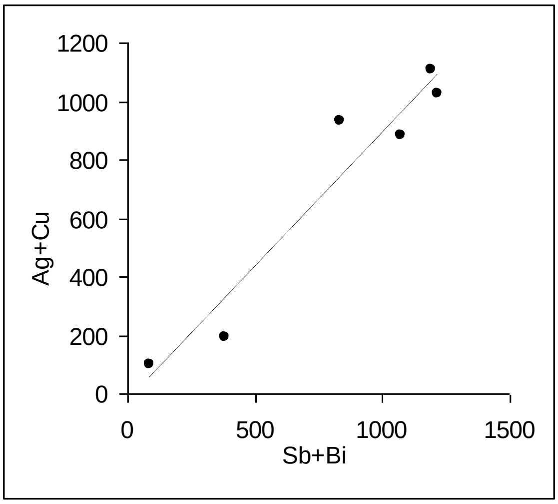


Fig. 2. Atomic ratios (Ag+Cu):(Sb+Sb) – according to Table 3

Fluid inclusion studies were provided using method of homogenisation of vapour-liquid inclusions in quartz from productive quartz-sphalerite-galena mpa. Fluid inclusions are relatively small in size (up to 20-30, rarely 50 μm) with ratio vapour : liquid from 1 : 8 to 1 : 3, rarely higher. All fluid inclusions studied homogenise in vapour phase in temperature interval from 250 to 370° C. Column chart showing distribution of temperatures of homogenisation of fluid inclusions for ore occurrences Komin dere and Braikovitza are given on figures 3 and 4.

Table 4. Microprobe analyses of aikinite from ore occurrence Braikovitza

No	Element content [wt. %]								Formula
	Pb	Cu	Fe	Bi	Sb	Te	S	Σ	
1	36.64	11.90	-	34.00	-	-	17.12	99.66	$Pb_{1.00}Cu_{1.06}Bi_{0.92}S_{3.02}$
2	35.46	11.12	-	36.71	-		16.17	99.46	$Pb_{1.00}Cu_{1.02}Bi_{1.03}S_{2.95}$
3	34.82	11.86	-	36.96	-	-	16.41	100.05	$Pb_{0.97}Cu_{1.07}Bi_{1.02}S_{2.94}$
4	33.04	11.84	-	37.17	-	-	17.29	99.34	$Pb_{0.90}Cu_{1.05}Bi_{1.00}S_{3.04}$
5	34.14	11.37	-	38.01	-	-	16.71	100.23	$Pb_{0.94}Cu_{1.03}Bi_{1.04}S_{2.99}$
6	34.71	11.94	-	36.01	0.50	-	16.15	99.31	$Pb_{0.97}Cu_{1.09}(Bi_{1.00}Sb_{0.02})_{1.02}S_{2.92}$
7	36.69	11.48	-	35.55	-	-	16.65	100.37	$Pb_{1.01}Cu_{1.04}Bi_{0.97}S_{2.98}$
8	33.83	11.05	-	38.20	0.39	-	16.68	100.15	$Pb_{0.94}Cu_{1.00}(Bi_{1.05}Sb_{0.02})_{1.07}S_{2.99}$
9	35.56	11.39	0.22	35.31	0.56	0.43	16.42	99.89	$Pb_{0.99}(Cu_{1.03}Fe_{0.02})_{1.05}(Bi_{0.97}Sb_{0.03})_{1.00}(S_{2.94}Te_{0.02})_{2.96}$
10	34.16	10.99	0.14	37.31	-	0.25	17.32	100.17	$Pb_{0.93}(Cu_{0.98}Fe_{0.01})_{0.99}Bi_{1.01}(S_{3.05}Te_{0.01})_{3.06}$

In ore occurrence Komin dere, a well expressed maximum is observed within the temperature interval 350–310° C. In ore occurrence Braikovitza, two maximums of homogenisation temperatures are present: 290–270° C and 350–310° C. The maximum at lower temperature is most probably connected with secondary inclusions. According to Krasteva and Todorov (1986), deposition of quartz-fluorite-barite mineralisation took place from 270° to 100° C, while deposition of late quartz and carbonate was within the temperature interval 150–50° C.

CONCLUSIONS

The Pb-Zn mineralisation in ore occurrences Braikovitza and Komin dere is quite different from the mineralisation in Tertiary Pb-Zn deposits from Laki ore field both mineralogically and geochemically.

The mineralisation in Yugovo ore field is genetically related to granitoid intrusive bodies and a magma chamber in depth – processes, which took place before the formation of the Tertiary Central Rhodope Dome (Ivanov et al., 2000).

Model ages, based on isotope composition of lead in galena, are in average as follows: uranogenic – 76 Ma, thorogenic – 68 Ma (Amov et al., 1993).

A genetic connection of the Pb-Zn mineralisation with Upper Cretaceous igneous rocks is proved by similarity in lead isotope composition both in granitoids and galena from ores.

Ratios $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ for granitoid rocks from Laki and Yugovo plutons are as follows: 18.624, 15.669, 38.800 and 18.641, 15.651, 38.738, respectively. The

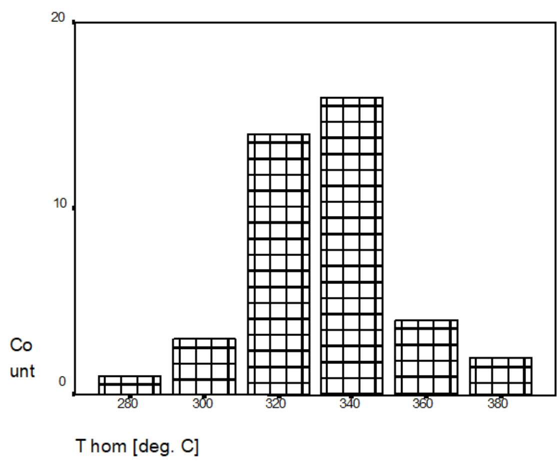
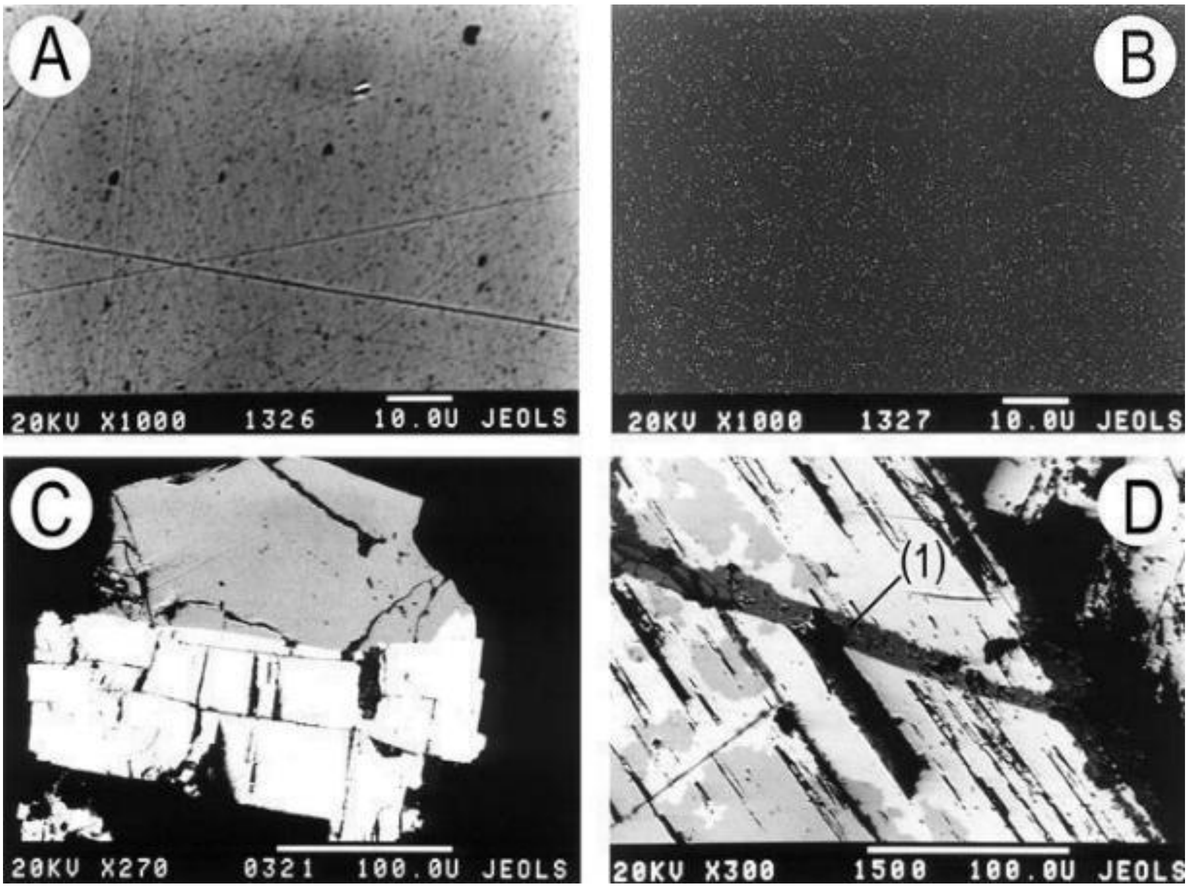


Figure 3. Histogram showing temperatures of homogenisation of fluid inclusions in quartz from productive mpa in ore occurrence Komin dere.



Plates:
Plate A. Homogenous galena. Backscattered electron image, COMPO regime. Plate B. The same observation field as on Plate A. Distribution of Ag in characteristic rays. Plate C. Galena-aikinite aggregate among gangue minerals (black). Aikinite is grey in colour, galena – white. Backscattered electron image, COMPO regime. Plate D. Aikinite veinlet (1), cross-cut galena (with different shade from light grey to white due to uneven carbon coating. Backscattered electron image, COMPO regime.

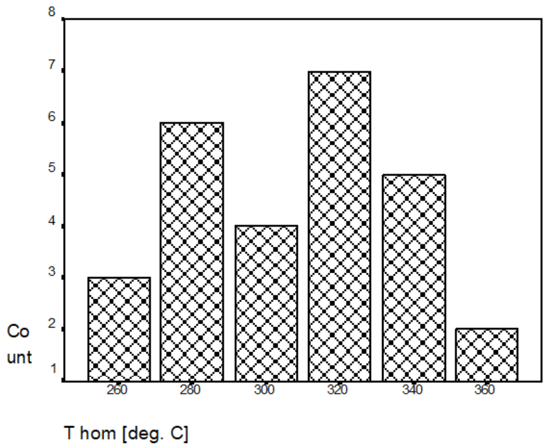


Figure 4. Histogram showing temperatures of homogenisation of fluid inclusions in quartz from productive mpa in ore occurrence Braikovitza.

same isotope ratios for galena from lead-zinc mineralisation and from quartz-fluorite one are 18.664, 15.680, 38.815 and 18.683, 15.661, 38.813 (Amov et al., 1993).

ACKNOWLEGMENTS

The author thanks to professor B. Kolkovski for the samples given up and for the disscussion on the article.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 71-75

VALUABLE MINOR COMPONENTS IN THE COMPOSITION OF PORPHYRY COPPER DEPOSITS

Margarita Tokmakchieva

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria; E-mail: tokmakchievi@mgu.bg

ABSTRACT
Porphyry copper deposits in Bulgaria are the main source for copper production. There are valuable minor components in the mined ores such as: gold, silver, molybdenum, platinum, palladium, selenium, tellurium, bismuth, cobalt, nickel. The subject of the present paper is to study their distribution and form of occurrence. The contents of minor elements in the mineral ore types in porphyry copper deposits are different. Most of these elements form their own minerals. Their main bearers are sulphide minerals which favors the concentration of these elements in the final product - the flotation concentrate. The correlation coefficients of the distribution of minor elements as compared to copper are: 0,77 for gold; 0,71 for silver; 0,48 for palladium; 0,12 for platinum; 0,54 for tellurium; 0,94 for bismuth and 0,82 for selenium. At present, in the process of production and processing of copper ores from these deposits, the attention is focused on the content of copper and gold. Our studies show, that the rest of minor components are a great potential for increasing the industrial value of the deposits and the competitive power of the mining product. The results obtained can be used for important technological solutions in the complex utilization of the ores.

INTRODUCTION

Porphyry copper deposits are the main source for copper production. Low contents of this useful component - less than 0,50 % are typical for them. They contain a number of minor components that exceed many times the price of copper. In spite of the low copper contents, porphyry copper deposits in the world are profitable due to the fact that a considerable amount of gold, silver, molybdenum and other useful components is being produced from them.

The object of the present paper are the minor components in porphyry copper deposits in Bulgaria, their distribution in mineral type of ores according to B. Bogdanov (1987) and form of occurrence. Scattered data have been published on this problem in the literature (Dimitrov, 1974-1975; Bogdanov et.al.,2000; Dragov et.al.,1996; Strashimirov et.al.,1994), but they do not allow to make a complete appraisal of the mineral deposits.

Methods

The samples were collected from ore that was produced during the last year from the working open pit mines "Elatzite" and "Assarel". Investigations at the level of mineral aggregates and minerals have been carried out. In "Elatzite" deposit, samples from the main mineral ore types have been analyzed: chalcopyrite - pyrite - molybdenum and from magnetite - bornite - chalcopyrite with vein-impregnated character of the aggregates and compact bornite mineralizations locally met in fault zones (Tokmakchieva, 1999). In "Assarel" deposit, samples from the chacocite - covellite mineral type have been analysed. Chemical and microbeam analyses have been carried out at the chemical Laboratory of the Mining and Geology University, Scientific and Research Center "Eurotest" and Hamburg University, Institute of Minerology and Petrography. Most of the analyses have been made with the help of Prof. M. Tarkian from the Hamburg University, Department of mineralogy and petrography for which I personally thank him.

PGE and Au have been analysed in Madington Laboratory, Australia. The sensitivity limit for Pd, Pt and Au is 1 ppb (1 mg/t). Most of the Ag, Te, Bi, Se, Mo, Ni, Co analyses have been carried out at the Ontario Laboratory, Canada by ICP method. The sensitivity limit is: 0,2 mg/t (for Te, Bi, Se); 0,5 g/t (for Ag); 1 g/t (for Ni, Co); 2 g/t for Mo. Part of the microbeam analyses have been made by Cameca Camebax Microbeam wavelength - dispersive electron microprobe at the Department of Mineralogy and Petrography at Hamburg University. The operational regime is 20 kV and 21-22 nA at used standards: native elements for gold, silver, palladium, bismuth, tellurium; pyrite for iron; chalcopyrite for copper and sulphur; synthetic PdSb.

Minor elements can be ranged according to their importance as follows: gold, silver, molybdenum, platinum, selenium, tellurium, bismuth, cobalt, nickel. At present, mining companies control only copper, gold and sulphur. The aim of the present study is to draw attention to the rest of the minor components. Their complex processing and utilization increases the value of the deposits and the efficiency of mining.

Results

The chemical content of the produced porphyry copper ores is different. High content of SiO_2 (between 59,16 and 61,98 %), of Al_2O_3 (between 17,18 and 18,45 %) is typical for "Elatzite" deposit. The content of K_2O (between 4,12 and 5,62 %) is higher than the content of Na_2O (between 3,87 and 4,29 %). A series of rare elements was established in the ore: V, W, Sr, Rb (between 100 and 700 g/t), Ce, Ga, La, Y, Zn, Zr (between 10 and 85 g/t) Cr, Cs, Pb, Th, U, Yb, Ta (between 0,5 and 4 g/t). In "Assarel" deposit, the SiO_2 content is between 60,97 and 78,65 %, Al_2O_3 - between 6,27 and 24,31 %, K_2O - between 0,14 and 5,11 % and Na_2O - between 0,18 and 3,95 %. The contents of these rare elements are 10 times smaller in comparison with those of "Elatzite" deposit. In "Assarel" deposit, the main ore minerals are: chalcocite, covellite, secondary bornite and djurleite (suppergenic) which replace the primary chalcopyrite and pyrite in the form of pseudomorphoses. Other rarely met hydrothermal minerals are: bravoite, thentite, tetrahedrite, molybdenite - 2H, siegenite, sphalerite, galena, arsenopyrite, gold, silver, electrum (Tokmakchieva, 1994). The produced ores from "Elatzite" deposit contain the following main ore minerals: chalcopyrite, pyrite (nickel pyrite, cobalt pyrite), molybdenum, bornite, and in smaller amount tennantite, tetrahedrite, pyrrhotite - 1C, siegenite, arsenopyrite, marcasite, sphalerite, galena, bournonite, electrum, platinum, hematite, linnaeite, carrollite, clausthalite, gold, hessite, naumannite, merenskyite (Tokmakchieva, 1999). According to the concentration of the main ore minerals, two mineral subtypes can be divided: chalcopyrite - pyrite - molybdenum and magnetite - bornite - chalcopyrite. The chalcopyrite - pyrite - molybdenum mineral ore type is widespread on the surface of the ore body while the magnetite - bornite - chalcopyrite mineral ore type is concentrated mainly in its southwestern part. The distribution of the minor components will be discussed on the background of these general data

In "Elatzite" deposit, the content of ***gold*** is 0,14 g/t. Its contents in the chalcopyrite - pyrite - molybdenum mineral ore type are from 0,2 to 0,8 g/t and for magnetite - bornite - chalcopyrite mineral type from 0,7 to 1,5 g/t (Table 1). In the concentrate from the processing plant, the contents of gold are between 10 and 14 g/t (at 25 % Cu). The coefficient of correlation of gold to that of copper is 0,77. Gold was established by microbeam analyses in the content of chalcopyrite, pyrite and bornite (Table 2). It was observed in its own mineral form: gold (Au = 90,45 g/t and Ag = 9,49 g/t) and electrum (Au = 57,7 g/t and Ag = 41,8 g/t). Grain sizes are from 1 to 10 microns and rarely 50 microns. In the ore produced from "Assarel" deposit, gold content is 0,06 g/t while in the concentrate it is 2,5 g/t (at 20 % Cu). By microbeam analyses it can established only in chalcopyrite (0,5 g/t). Chalcopyrite and bornite concentration in the vein - impregnated ores determines the variations in gold contents. The highest contents of gold 50 and 120 g/t are in compact bornite mineralizations having local distribution (Table 1) and being insignificant part of the ore mass.

Millions of tons of ore are being produced and processed from porphyry copper deposits. Although gold content is low, these deposits are an important source for its production. Gold content should be calculated at estimating the industrial value of perspective porphyry copper deposits. These recommendations concern other deposits of different genetic type that are not being discussed in this paper, such as: "Praveshka Lukavitza" - 0,10 g/t Au; "Karlievo" - 0,06 g/t Au; "Gorna Kamenitza" - 0,15 g/t Au; "Petelevo" - 1,31 g/t (M. Tokmakchieva, 1994).

Silver is another minor component. Its content in the chalcopyrite - pyrite - molybdenum mineral type from "Elatzite" deposit varies from 1 to 12 g/t in magnetite - bornite - chalcopyrite - from 1 to 5 g/t and in compact bornite mineralizations - from 10 to 100 g/t (Table 1). The coefficient of correlation compared to Cu is 0,71. Its distribution in the ore body has a coefficient of accumulation 40 reaching 1 in the outer zones. Its quantitative distribution directly depends on the chalcopyrite and bornite distribution reaching high contents (Table 2). In compact bornite mineralizations bohdanowiczite, naumannite (Ag = 73,93 %; Fe = 0,53 %, S = 22,83 %), hessite (Ag = 63,61 %; Cu = 1,25 %; Fe = 0,12 %; Sb = 0,23 %; Te = 36,71 %) can be found.

Table 1 Contents of valuable minor components in the composition of Bulgarian porphyry copper deposits - mineral types: 1 - chalcopyrite-pyrite-molybdenite (98 analyses); 2 - magnetite-bornite-chalcopyrite (21 analyses); 3 - compact bornite mineralizations (18 analyses); chalcocite (35 analyses)

Element	1	2	3	4
Au	from 0,2 g/t to 0,8 g/t	from 0,7 g/t to 1,5 g/t	from 10 g/t to 12 g/t	from 0,06 g/t to 1 g/t
Ag	from 1 g/t to 12 g/t	from 1 g/t to 5 g/t	from 10 g/t to 100 g/t	from 5 g/t to 20 g/t
Mo	from 50 g/t to 760 g/t	2 g/t	2 g/t	под 10 g/t
Pt	from 1 mg/t to 16 mg/t	from 11 mg/t to 55 mg/t	28 mg/t	-
Pd	from 6 mg/t to 27 mg/t	from 5 mg/t to 87 mg/t	73 mg/t	-
Se	from 20 g/t to 410 g/t	from 250 g/t to 600 g/t	800 g/t	from 3 g/t to 40 g/t
Te	from traces to 0,8 g/t	from 20 g/t to 106 g/t	380 g/t	from 0,5 g/t to 20 g/t
Bi	from traces to 1,5 g/t	from 79 g/t to 291 g/t	-	0,9 g/t
Co	from 21 g/t to 90 g/t	37-120 g/t	120 g/t	-
Ni	from 10 g/t to 48 g/t	47-100 g/t	260 g/t	-

Table 2. Microprobe analyses of: 1 - chalcopyrite (15 analyses); 2 - pyrite (12 analyses); 3 - bornite (9 analyses) from "Elatzite" deposit; 4 - chalcocite (8 analyses) and 5 - covellite (12 analyses) from "Assarel" deposit

Elem %	1	2	3	4	5
Cu	33,33	-	60,68	79,83	66,39
Fe	30,69	46,60	11,66	-	-
Au	0,09	0,03	0,09	-	-
Ag	0,003	0,001	0,11	0,001	0,001
Pt	0,0003	-	-	-	-
Pd	0,0001	-	-	-	-
Co	1,61	0,10	-	-	-
Ni	0,22	0,01	-	-	-
Bi	0,001	0,001	-	-	0,0001
Se	0,001	0,001	0,001	0,0001	0,0001
Te	0,001	0,001	0,001	0,0001	0,0001
S	33,61	53,28	26,85	19,85	33,45
Total sum	99,56	100,92	99,39	99,68	99,84

The dimensions of the inclusions are between 10 and 60 microns. The content of silver in the processed concentrate is 34 g/t. Djurleite is one of the main ore minerals in the mineral content of "Assarel" deposit. It is mixed with chalcocite and covellite and is the main silver-bearer. Its concentrations depend directly on the quantity of accumulation of this hypergenic mineral. The coefficient of silver accumulation in the ore body is 100 and in the outer zones and aureoles – from

0 to 1. The average silver contents in the produced chalcocite – covellite mineral ore type is 10 g/t and between 30 and 70 g/t in the concentrate from the processing plant.

Silver has not been calculated as an element in the balanced ores of porphyry copper deposits in spite of being a typical element for such genetic type deposits.

Irrespective of the low silver content as compared to lead-zinc and stratiform deposits, porphyry copper deposits can be an important source for production of this precious metal if we take into account the large amounts of mined ore (millions of tons).

Molybdenum is a minor component of industrial importance for porphyry copper deposits. According to P. Vassilev (2001), “Elatzite” is a molybdenum – bearing deposit, while B. Bogdanov (1987) considers it a copper – molybdenum – porphyry type. The average molybdenum content in the balanced ores of “Elatzite” deposit is 0,005%. Molybdenum content in outbalanced reserves of other deposits of this type is: "Karlievo – 0,005%, “Studenetz” – 0,005%, “Gorna Kamenitza” – 0,004% (P. Vassilev, 2001). For “Elatzite” deposit, molybdenum is a mineral of secondary importance. That is why the concentration coefficients of molybdenum in the ore body compared to its contents in the aureoles are between 80 and 90. Molybdenum is from 50 to 760 g/t in the chalcopyrite – pyrite – molybdenum mineral ore type and about 1 g/t in magnetite – in the bornite – chalcopyrite type (Table 1). Its content in the processed concentrate is 1300 g/t. Apart from molybdenum, molybdenite is a bearer of another valuable component – rhenium (up to 200 g/t in this mineral). The prices of both elements are several times higher than those of the metals produced from the deposit. Their calculation and utilization will contribute to a more efficient mining activity.

Molybdenum is not a typical element for “Assarel” deposit as well for the porphyry copper – allunite subtype (B. Bogdonov, 1987). The coefficient of accumulation in the ore body, compared to its concentrations in the aureoles, is 30. Molybdenum content in the chalcocite – covellite mineral ore type is less than 10 g/t.

Until recently ***platinum and palladium*** have not been considered as typical elements of this genetic type of deposits. Mineralogical studies in the last few years proved that considerable quantities of these valuable minor components can be found in the content of “Elatzite” deposit. The content of platinum in the chalcopyrite – molybdenum mineral ore type is between 1 and 16 mg/t and that of palladium – between 6 and 27,5 mg/t. In the magnetite – bornite – chalcopyrite mineral type, the content of platinum is between 5 and 87,5 g/t. In the compact bornite mineralizations, the quantity of platinum is 28 mg/t and that of palladium – 73,3 mg/t. (Table 1). Platinum and palladium are related mainly to chalcopyrite (Table 2). Inclusions of platinum, merenskyite (Pd = 17,66%; Pt = 13,73%; Cu = 1,82%; Ag = 1,40%; Te = 60,77%; Bi = 3,33%; Sb = 0,37%), palladium–arsenite, palladium, ramelsbergite (M. Tokmakchieva, 1999) can be found in chalcopyrite. Correlation coefficients of its distribution in the mineralization, as compared to copper, are 0,48 for palladium and 0,12 for platinum, respectively. Platinum 6,1 mg/t and palladium – 28,9 mg/t have been determined in the flotation concentrate. Earlier studies of M. Tarkian et al. (1999) show that platinum quantities in the flotation concentrate of “Elatzite” deposit are 0,23 g/t for 1996 and 0,15 g/t for 1998, and palladium quantities – 1,0 and 0,74 g/t, respectively. According to the same author, these values are among the highest as compared to other porphyry copper deposits in the world that produce both precious metals. The prices of both components are twice higher than those of gold and many times higher than those of copper. For the time being they have not been considered in the balanced reserves and in the content of the final product. Their utilization will contribute to its higher competitive power.

Selenium and tellurium are typical minor components in porphyry copper deposits. According to P.Vassilev (2001) balanced reserves have been calculated for “Elatzite” deposit containing 1463,5 tons of selenium metal in balanced and 243,2 tones selenium metal at average content 6 g/t in outbalanced reserves. Our studies prove that selenium from 20 to 410 g/t and tellurium to 0,8 g/t can be found in the chalcopyrite – pyrite – molybdenum mineral ore type. Selenium between 250 and 600 g/t and tellurium between 20 and 106 g/t can be found in the magnetite – bornite – chalcopyrite mineral ore type (Table 1). Correlation coefficients of distribution compared to copper are 0,82 for selenium and 0,54 for tellurium. The contents of selenium reach 800 g/t and those of tellurium – 380 g/t in the composition of compact bornite mineralizations. Selenium is found by in own mineral form in aumannite, bohdanowiczite, eucyrite, clausthalite (Pb = 77,45%; S = 5,07%; Se = 17,48%) and for tellurium – tellurium, weissite, hessite, merenskyite (Tokmakchieva, 1999). For “Assarel” deposit, selenium contents are from 3 to 40 g/t and those of tellurium – from 0,5 to 20 g/t. Selenium and tellurium are found in the composition of sulphide minerals as pyrite, bornite, taenite, tetrahedrite, sphalerite, molybdenite, chalcocite, covellite with trace contents to 100 g/t and 2400 g/t for chalcopyrite (Tokmakchieva, 1994). R. Petrunov et al. (1991) described goldfieldite in “Assarel” deposit. The distribution of the main ore minerals in “Elatzite” deposit (pyrite and chalcopyrite) and in “Assarel” (chalcopyrite, pyrite, chalcocite and covellite) controls the selenium and tellurium concentrations in the produced ore. These minor components are concentrated in the flotation concentrates.

Bismuth occurs in higher concentrations in the magnetite – bornite – chalcopyrite mineral ore type in “Elatzite” deposit in the limits 79 to 291 g/t. For the chalcopyrite – pyrite – molybdenum mineral type the contents are up to 1,5 g/t. About 20 g/t bismuth is contained in the concentrate. For “Assarel” deposit bismuth contents are up to 0,9 g/t (Table 1). Bismuth is related to the main sulphide minerals: in chalcopyrite – 0,0001% (“Assarel” deposit) and 0,001 % (“Elatzite” deposit); in pyrite – 0,0001 %; in tetrahedrite – from 1,34 to 2,03 %; in covellite and chalcocite – 0,0001% (Table 2). The variations of its content in the ore depends on the concentration of the sulphide ore minerals. For this reason the bismuth coefficient compared to copper is high – 0,94. There are inclusions of aikinite, wittichenite, merenskyite, bismuth, bohdanowiczite that are typical for late bornite mineralizations in chalcopyrite.

Cobalt and nickel are typical elements for the porphyry copper deposit of “Elatzite”. Their contents in the chalcopyrite – pyrite – molybdenum mineral ore type are from 21 to 90 g/t for cobalt and from 10 to 48 g/t for nickel, and in the magnetite – bornite – chalcopyrite type – from 37 to 120 g/t for cobalt and from 47 to 100 g/t for nickel (Table 1). Cobalt contents in concentrates are 94 g/t and nickel contents – 151 g/t. In the ore body the concentration coefficients of cobalt reach 50 and those of nickel – 20. Towards the outer zones in the aureoles these values decrease from 1 to 3 (Tokmakchieva, 1994). According to Strashimirov (1982) and P. Dragov (1972), the higher concentrations of cobalt and nickel are typical for porphyry copper deposits in the middle part of the Balkan Mountain. Cobalt and nickel occur in chalcopyrite and pyrite (Table 2). In separate microbeam analyses, cobalt and nickel are found in tetrahedrite, tennantite, bornite and sphalerite. In compact bornite mineralizations, in which the content of cobalt reaches 120 g/t and that of nickel – 260 g/t, inclusions of millerite, rammelsbergite, cobaltite, linnaeite can be observed (Ni = 9,53%; Fe = 0,73%; Co = 32,62%; Cu = 15,40%; S = 41,85%), carrollite, siegenite (Ni = 41,14%; Fe = 1,76%; Co = 15,13%; Cu = 0,38%; S = 41,82%) cobalt pyrite (Fe = 29,73%; Cu = 0,32%; Co = 14,90%; Ni = 0,11%; S = 53,65%) and nickel pyrite (Fe = 38,43%; Cu = 0,05%; Co = 0,09; Ni = 6,72%; S = 53,96%).

Other ***rare elements*** with higher contents can be also found in the mined ores: germanium – up to 0,6 g/t; mercury – from 1 to 8 g/t (in bornite mineralizations); antimonium – 0,6 to 5 g/t (270 g/t in concentrates). Arsenic is in the limits of 1,3 to 3 g/t in ores and 30 g/t in concentrate. The contents of lead in the flotation concentrate are 204 g/t and those of zinc – 128 g/t. We are not concerned with them in the present paper.

CONCLUSION

Bulgarian porphyry copper deposits are a source not only of copper and sulphur but also of a series of valuable components such as gold, silver, molybdenum, rhenium, platinum, palladium, selenium, tellurium, cobalt, nickel and bismuth.

The average contents of gold, silver, platinum and palladium in sulphides (Table 3) and in concentrates are among the highest as compared to other porphyry copper deposits in the world. Table 3 and 4 prove that fact giving results of other researchers. Unpublished data (Tarkian et al.) show that in the produced ore from “Elatzite” deposit gold is 14,2 g/t, silver – 72 g/t, platinum – 0,16 g/t and palladium – 0,55 g/t. Minor elements can be found in the main sulphide minerals due to which their contents are extremely high in the ores with concentration of sulphides. According to published data by M. Tarkian and B. Stribrny (1999) they are:
for “Elatzite” deposit: Au = 27000 mg\t, Pd = 1900 mg\t; Pt = 72 mg\t; Cu = 25.9 %; Au\Pd = 14; Pd\Pt = 26,4; Silicate content (vol %) = 20
for “Medet” deposit: Au = 5600 mg\t; Pd = 160 mg\t; Pt = 8 mg\t; Cu = 14,9 %; Au\Pd = 35; Pd\Pt = 20; Silicate content (vol%) = 40
for “Tzar Assen” deposit: Au = 130 mg\t; Pd = 8 mg\t; Cu = 15.9 %; Au\Pd = 16; Silicate content (vol%) = 20
for “Prohorovo” deposit: Au = 200 mg\t; Cu = 4,3 %; Silicate content (vol%) = 25.

Table 3. Average contents of gold, silver, platinum and palladium in sulphide concentrates from Bulgarian and some foreign porphyry copper deposits.

Name	Average contents of:			
country	gold	silver	platinum	palladium
Deposit				
Bulgaria				
*Elatzite	27000 mg\t	–	72 mg\t	1900 mg\t
Elatzite	14,2 g\t	72 g\t	0,16 g\t	0,55 g\t
*Assarel	8 g\t	–	12 mg\t	160 mg\t
Assarel	2,5g\t	70 g\t	–	–
Greece				
*Scouri	7300 mg\t	–	8 mg\t	160 mg\t
Serbia				
*Midanpeck	7000 mg\t	–	24 mg\t	240 mg\t
The Phillipins				
*Santo Thomas II	40 g\t	45 g\t	1,85 mg\t	2,67 mg\t
*Biga	2350 mg\t	–	8 mg\t	56 mg\t
USA				
*Bute	310 mg\t	–	–	–
*Bigman	1350 mg\t	–	–	–
Armenia				
*Kadjaran	3400 mg\t	–	84 mg\t	24 mg\t
Kazahstan				
*Sayak	25000 mg\t	–	–	–
Canada				
*Gibraltar	280 mg\t	–	–	–
Uzbekistan				
*Almalik	9800 mg\t	–	–	20 mg\t
Notes: * according to data of M. Tarkian and B. Stribrny (1999) (–) no data				

Table 4. Average contents of gold, silver, platinum and palladium in concentrates from Bulgarian and some foreign porphyry copper deposits

Name	Average contents of:			
Country	gold	silver	platinum	palladium
Deposit				
Bulgaria				
*Elatzite	7600 mg\t	–	170 mg\t	760 mg\t
Elatzite	14 g\t	34 g\t	155 mg\t	740 mg\t
*Assarel	4800mg\t	–	14 mg\t	54 mg\t
Assarel	2,5 g\t	70 g\t	10 mg\t	50 mg\t
Serbia				
*Bor	1700 mg\t	–	19 mg\t	40 mg\t
*Midanpeck	7,8 g\t	–	0,03 g\t	0,27 g\t
Malaysia				
*Mamut	18,7 g\t	–	0,57g\t	1,7 g\t
Papua				
*Oktedi	17 g\t	–	0,02 g\t	0,62 g\t
Chile				
*Chukvikamata	470 mg\t	–	–	36 mg\t
*El Salvador	1250 mg\t	–	8 mg\t	16 mg\t
Argentina				
*Elumbrella	31000 mg\t	–	8 mg\t	35 mg\t
Iran				
*Sar cheshme	840 mg\t	–	–	24 mg\t
Indonesia				
*Gresbig	1800 mg\t	–	15 mg\t	58 mg\t
Notes: * according to data of M. Tarkian and B. Stribrny (1999) (–) no data				

Similar results have been published by the present author about bornite compact mineralizations (Tokmakchieva, 1999). The data published by R. Petrunov et al. (1992) about a mineralization referred to as magnetite – bornite – chalcopyrite mineral type correspond to our results.

Flotation concentrates from "Elatzite" and "Assarel" deposits contain these valuable minor components. The results presented in this paper correspond to published data by M. Tarkian et al. (1999) as follows:
"Elatzite" deposit: Au = 7600 mg\t; Pd = 760 mg\t; Pt = 170 mg\t; Cu = 19,0 %; Au\Pd = 10; Pd\Pt = 4,5;
"Assarel" deposit: Au = 4800 mg\t; Pd = 54 mg\t; Pt = 14 mg\t; Cu = 27,9 %; Au\Pd = 88; Pd\Pt = 3,8.

The contents of minor components are higher (Table 3 and 4) as compared to the porphyry copper deposits Bor, Midanpeck (Serbia), Sar Cheshme (Iran), Sayak (Kazachstan), El Salvador (Chile), Bute (USA) and others (Tarkian and Stribtny, 1999).

The present studies show that the contents of minor components should be taken into consideration in the balance of the reserves of porphyry copper deposits, in the produced ore and in the flotation concentrates. This will allow to plan in advance the extraction technology and its value in order to increase the efficiency of mining works and to utilize the ores more completely. The studies carried out will help to undertake practical steps to extract these valuable minor components during the metallurgical processing of the produced concentrates.

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Recommended for publication by Department of Mineralogy and Petrography, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 77-82

DOLOMITE-GROUP FERROAN CARBONATES FROM KREMIKOVTSI DEPOSIT

Margarita Vassileva[1], Zhelyazko Damyanov[2], Vasil Atanassov[1]

[1] University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria, E-mail: marvas@staff.mgu.bg
[2] Central Laboratory of Mineralogy and Crystallography, Bulgarian Academy of Sciences, Sofia 1113, Bulgaria, Acad. G. Bonchev St., Bl. 107, E-mail: zdamyanov@mail.bg

ABSTRACT
The dolomite-group ferroan carbonates (ferroan dolomite, ankerite) are the main non-metallic component in the primary ores of the Kremikovtsi deposit. They (1) formed carbonate assemblages in the transition zones between the siderite ore bodies and the host Middle Triassic dolomitic limestones, (2) accompanied all sulfide assemblages, (3) constituted alteration zones in the carbonate rocks hosting the Pb-Cu sulfide mineralization, and (4) deposited as post-ore rhombohedral crystals in cavities within the dolomitic limestones. In the *non-sulfide mineral assemblages* these minerals are represented by micro-grained aggregates of ferroan-manganoan dolomite in a coarse-grained ankerite matrix. Zonal manganoan ankerites with decreasing Fe contents toward the rims are characteristic for the *sulfide assemblages*. In *cavities* within the host carbonate rock linings from coarse-grained manganoan ankerite are formed with the highest $FeCO_3$ content (up to 23 mol%) in the deposit.

INTRODUCTION

The dolomite-group ferroan carbonates (ferroan dolomite, ankerite) are the main associated non-metallic components of the polymetallic sulfide mineralization in the Kremikovtsi deposit (Atanassov, 1977). They are also widespread in the transition zones between the siderite ore bodies and the host Middle Triassic dolomitic limestones (Damyanov, 1998). So far this type of ferroan carbonates has not been an object of detailed studies in view of their characteristics in the different mineral assemblages they form.

The purpose of this work is to study the chemical composition, structures and mineral associations of the dolomite-group ferroan carbonates from the Kremikovtsi deposit. Because there are no commonly adopted rules of nomenclature differentiation of the minerals in the $CaMg(CO_3)_2$-$CaFe(CO_3)_2$ limited solid solution (even a proposal of quite conventional sharing of type "low-Fe = ferroan dolomite, high-Fe = ankerite" has been made by Reeder, 1983), in this paper the nomenclature, proposed by Minceva-Stefanova and Gorova (1967) is used as follows: ferroan dolomite – 10÷30 mol% $CaFe(CO_3)_2$; ankerite - > 30 mol% $CaFe(CO_3)_2$.

MATERIALS AND METHODS

Representative samples of dolomite-group ferroan carbonates from different mineral assemblages (host Middle Triassic dolomitic limestones, siderite ore, polymetallic sulfide mineralization and pale- to dark-gray recrystallized dolomites) were examined by electron microprobe (58 an.), optical and scanning electron microscopy, XRD, DTA, Mössbauer and infrared spectroscopy. The micromorphology, size and chemical composition of different samples and minerals were determined by a JSM–35–CF and a PHILIPS SEM-515 with an EDAX PV 9100 EDS system (with an operating voltage of 15 kV and electron beam diameter of 1µm). As the compositional variations in the distinct mineral assemblages and zonal grains are in the range of the experimental errors of the electron microprobe method and the apparatuses used, the data represented in Table 1 are summarized, as follows: № 14 – average of 11 analyses; №1 – of 6 an.; № 2, 3, 5, 6 – of 5 an.; № 17, 4, 15 – of 3 an.; № 7, 8÷11, 16 – of 2 an.; the rest are single analyses. X-ray diffraction (XRD) patterns were obtained with a DRON-1 diffractometer (CuKα radiation, Ni filter, I = 24 mA, U = 34 kV) and a 57.3 mm Debye-Scherrer TUR–M–60 camera. DTA and TG curves were recorded with a Derivatograph apparatus in static air, DTA = 1/10, DTG = 1/15, G = 200, sample weight – 1 g, rate of heating – 10^{o}/min, as well as with a Stanton Redcroft STA-780 series apparatus in the 18-1200^{o}C temperature range (10^{o}C/min). A Mössbauer study was carried out by using an UMS-3 spectrometer with a ^{57}Co (in Pd) source. Isomer shifts were always calculated vs. Fe metal. The infrared spectra were recorded in the 3800-400 cm^{-1} range with a UR-10 i.r. spectrometer. The samples were prepared as KBr disks by standard methods. Used are prisms of LiF (3800-2000 cm^{-1}), NaCl (2000-700 cm^{-1}) and KBr (700-400 cm^{-1}).

MINERAL ASSEMBLAGES

Host carbonate rocks and siderite ore

According to Kanurkov (1988), the earliest ankerite generation preceded the formation of primary Mn-siderite ore in the deposit. Its occurrence in the Kremikovtsi opencast workings may be established most often by indirect criteria based on the areal distribution of yellow to yellowish-brown low-Mn limonites.

In the transition zones between the siderite ore bodies and the host dolomitic limestones and rarely in the siderite ore, a *specific assemblage* of dolomite-group carbonates has been found. It forms massive, compact (porcelain-like), dark-gray aggregates, well differentiated visually on the background of the red Middle Triassic dolomitic limestones. Its textural features in the siderite ore are quite similar but the differentiation between the two mineral assemblages is very complicated because of the identical coloring. The ferroan dolomite-ankerite assemblage is represented by veinlets and nest-shaped aggregates of a coarse-grained ankerite matrix with inclusions of rhombic ferroan dolomite grains (Fig. 1a). Its textural relationships with the host rock/ore suggest that the assemblage was probably formed during the stage of advanced diagenesis according to the criteria proposed by Leeder (1982).

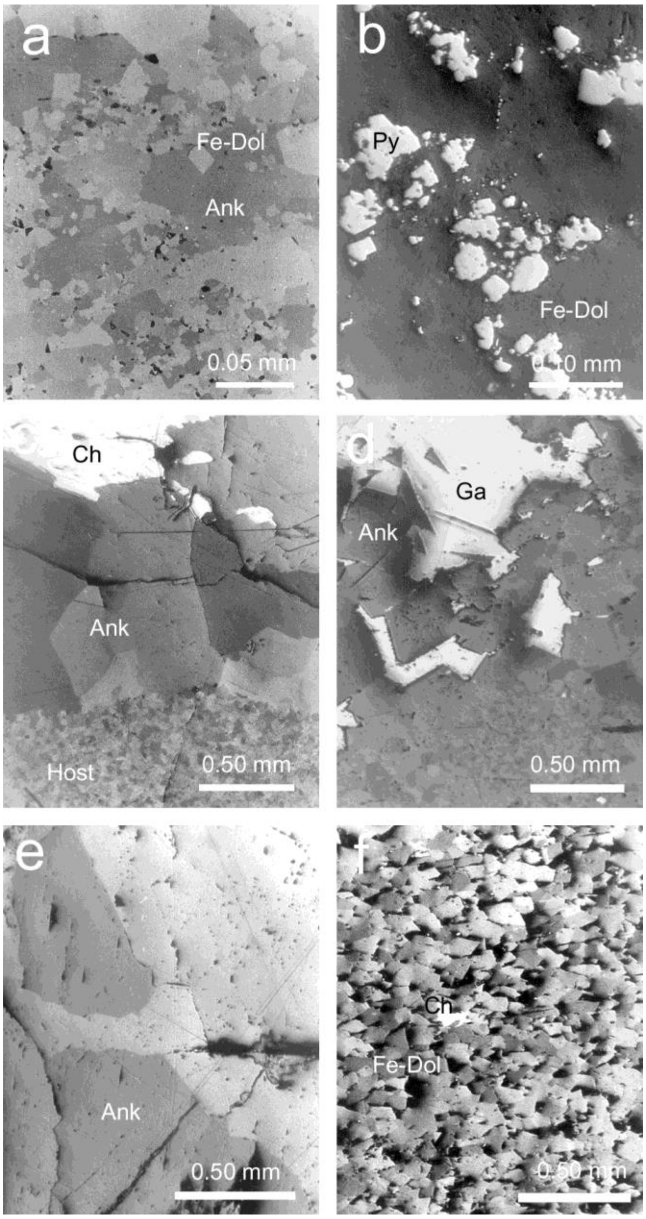


Figure 1. Textural features of dolomite-group ferroan carbonates from the Kremikovtsi deposit. a)fine-grained ferroan dolomite in an ankerite matrix; b) medium-grained ferroan dolomite impregnated interstitially by pyrite (recrystallized framboids); c) coarse-grained ankerite associated with chalcopyrite in a matrix of fine-grained dolomite (host dolomitic limestone); d) ankerite metacrystals in galena; e) coarse-grained ankerite lining solution cavities in dolomitic limestones; f) recrystallized ferroan dolomite from an alteration zone adjacent to the sulfide mineralization. Ank – ankerite; Ch – chalcopyrite; Fe-Dol – ferroan dolomite; Ga – galena; Host – host dolomitic limestone; Py – pyrite. Reflected light, II N.

Polymetallic sulfide mineralization

Several types of dolomite-group ferroan carbonates, accompanying the main sulfide assemblages (pyrite, chalcopyrite and galena) (Atanassov, 1977; Atanassov *et al.*, 1979, unpubl. data[1]), can be distinguished in the Kremikovtsi deposit. The first one is represented by ferroan dolomite, associated with

[1] Atanassov, V., Marinov, T., Sultanov, A., Vassileva, M., Petrov, I., Ganova, M. 1979. Mineral composition of the primary and secondary polymetallic mineralization in the Kremikovtsi deposit and petrographic chcrteristics of the host rocks. – Contract Report # 599/77, NIS MGU, 349 pp.

the earliest deposited sulfides (pyrite, marcasite, chalcopyrite) from the *pyrite assemblage*. Pyrite is one of the most widespread sulfide minerals in the deposit, but it is concentrated mainly in an ore body located at the 520 and 532 m levels in the opencast. Major components of this ore body are ferroan dolomite and fine-grained pyrite (recrystallized framboids) that are interstitially distributed in the carbonate matrix (Fig. 1b).

The next type is of ankerite, accompanying the deposition of copper mineralization in the deposit (*chalcopyrite assemblage*). It forms small veins and veinlets with nests of chalcopyrite in the host carbonate rock (Fig. 1c). The ankerite is coarse-grained (up to 1-2 mm crystals), dominantly idiomorphic with well-pronounced cleavage in two directions Interstitially of the carbonate grains are located sulfide inclusions (mainly pyrite) and organic matter. The main ore mineral in this assemblage, chalcopyrite, is coarse-grained, monomineralic or associated with tennantite. Galena and sphalerite are rarely observed.

Later type of ferroan dolomite-ankerites deposited in the *galena assemblage* which is the main sulfide assemblage in the deposit. The ferroan dolomite-ankerites form veins with nests of coarse-grained galena (up to 10 cm) within the carbonate host. Main ore mineral in this assemblage is galena, associated with tetrahedrite, chalcopyrite and rarely sphalerite.

The last type of ferroan carbonates is occasionally established as small *veinlets or cavity linings* in the dolomitic limestones. The ankerite is coarse-grained, white to translucent with up to 1-1.5 cm limpid sparry crystals (Fig. 1e) and associated with tabular barite, needle-like quartz and cube-octahedral galena.

The latest type of ferroan carbonate in the Kremikovtsi deposit is represented by post-ore ferroan dolomite. It is rarely established as fine rhombohedral crystals in solution cavities, associated with barite crystals and authigenic phyllosilicates (Damyanov and Vassileva, 2001).

The dolomite-group ferroan carbonates are not only associated minerals of sulfide mineralization, but also *a component of host rock alteration*. The sulfide ore-formation in the Kremikovtsi deposit is accompanied by local recrystallization (Fig. 1f) and ferroan dolomitization-ankeritization of the carbonate host. The recrystallized carbonate rocks are gray to dark-gray due to the impregnation with sulfides and organic matter.

Processes of ferroan dolomitization of the host carbonate rocks, preceding and accompanying the sulfide mineralization, have been established also in the Sedmochislenitsi-type polymetallic deposits from the Western Balkan (Minceva-Stefanova, 1988, 1989). These deposits are very similar mineralogically and petrographically to the sulfide mineralization in the Kremikovtsi deposit. In contrast to them however, the galena assemblage in the Kremikovtsi deposit is subsequent to the chalcopyrite one.

CHEMICAL COMPOSITION

Summarized microprobe data for the dolomite-group ferroan carbonates from the Kremikovtsi deposit are represented in Table 1. The results obtained show a pronounced tendency of compositional variations of the carbonate studied. The earliest formed sulfides (pyrite) are accompanied by ferroan dolomite.

Table 1. Representative microprobe analyses (mol%) and structural formulae of dolomite-group ferroan carbonates from Kremikovtsi deposit – summarized data.

№	Description		$CaCO_3$	$MgCO_3$	$FeCO_3$	$MnCO_3$
			Non-sulfide mineralization			
			Host carbonate rock			
1.	Medium-grained Fe-dolomite		52.22 (1.04)	38.48 (0.77)	6.04 (0.12)	3.26 (0.07)
			Siderite ore			
2.	Fine-grained Fe-dolomite		49.90 (1.00)	42.70 (0.85)	5.40 (0.11)	2.00 (0.04)
3.	Coarse-grained ankerite matrix		49.30 (0.99)	28.60 (0.57)	17.90 (0.36)	4.20 (0.08)
			Sulfide mineralization			
			Pyrite assemblage			
4.	Medium-grained Fe-dolomite		51.03 (1.02)	27.71 (0.55)	13.34 (0.27)	7.92 (0.16)
			Chalcopyrite assemblage			
5.	Zonal meta-crystals	c	49.60 (0.99)	29.57 (0.59)	15.83 (0.32)	5.00 (0.10)
6.		r	49.92 (1.00)	32.85 (0.65)	12.37 (0.25)	4.86 (0.10)
7.	Veinlets with chalcopyrite nests		50.84 (1.01)	21.39 (0.43)	21.87 (0.44)	5.90 (0.12)
			Galena assemblage			
8.	Zonal metacrysts with early PbS, host rock	c	52.47 (1.05)	39.45 (0.79)	5.92 (0.12)	2.16 (0.04)
9.		r	52.46 (1.05)	36.93 (0.74)	10.03 (0.20)	0.58 (0.01)
10.		c	49.29 (0.99)	29.51 (0.59)	18.26 (0.36)	2.94 (0.06)
11.		r	49.75 (0.99)	31.43 (0.63)	16.51 (0.33)	2.31 (0.05)
12.	Veinlets with galena nests	c	52.43 (1.05)	23.33 (0.47)	18.09 (0.36)	6.15 (0.12)
13.		r	51.21 (1.02)	26.35 (0.53)	16.42 (0.33)	6.02 (0.12)
14.	Coarse-grained ankerite in solution cavities		50.10 (1.00)	35.00 (0.70)	10.85 (0.22)	4.05 (0.08)
15.			49.85 (1.00)	24.05 (0.48)	19.71 (0.39)	6.39 (0.13)
16.			52.20 (1.04)	18.11 (0.36)	22.74 (0.46)	6.95 (0.14)
			Post-ore mineralization			
17.	Fe-dolomite rhombohedr. crystals		52.19 (1.04)	33.32 (0.67)	10.29 (0.21)	4.20 (0.08)

c – core, r – rim of zonal crystals

The later ones (chalcopyrite, tennantite, galena) are associated with high-ferroan dolomites to typical ankerites. During the final stage of sulfide mineral-formation once again deposited ferroan dolomite. The composition of late post-ore ferroan dolomite is distinguished from that of the earlier pyrite assemblage with higher Mg and lower Mn and Fe contents.

The highest Fe/Mg ratio is characteristic of ankerite from the chalcopyrite assemblage and the later galena assemblage (coarse-grained and cavity lining ankerites) (Fig. 2). In contrast to the Chiprovtsi carbonates (Dragov and Neykov, 1991), the Kremikovtsi ones are characterized by higher Mn contents

($MnCO_3$ up to 8 mol%). They are mostly represented by Ca-rich varieties ($CaCO_3$ > 50 mol%). Many authors noted variations as compared to stoichiometric composition and negligible excess of Ca in the dolomite-group carbonates (Deer *et al.*, 1966; Minceva-Stefanova and Gorova, 1967; De Grave and Vochten, 1985; Reeder and Dollase, 1989; Reksten, 1990). The higher Fe and Mn concentrations are considered to be a favorable prerequisite for formation of Ca varieties. Some authors (Deer *et al*., 1966; Minceva-Stefanova and Gorova, 1967; Reeder and Dollase, 1989) supposed an isomorphic substitution of a part of Mg^{2+}- cations by Ca^{2+} instead of the differences in their cationic radii.

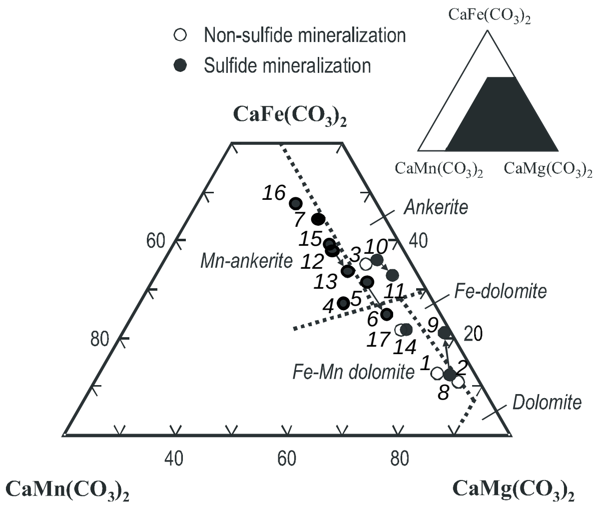


Figure 2. Compositional variations of the dolomite-group ferroan carbonates from the Kremikovtsi deposit in the $CaMn(CO_3)_2$--$CaMg(CO_3)_2$-$CaFe(CO_3)_2$ system. Zonal trends of type "core→rim" are marked by arrows. The numbers of analyses are as in Table 1. The fields of nomenclature differentiation are after Minceva-Stefanova and Gorova (1967)

According to Kucha and Wieczorek (1984), non-stoichiometric Ca-ankerites are characterized by a heterogeneous domain structure. Reksten (1990) considered the non-stoichiometric composition of some low-temperature Ca-ankerites as provoked by the microstructure features of the mineral and the presence of impurities. In contrast to the Ca-rich varieties, the stoichiometric ankerites, containing up to 66 mol% $CaFe(CO_3)_2$, are practically homogeneous (Reeder and Dollase, 1989). The splitting of some peaks in a part of diffractograms, obtained by the dolomite-group ferroan carbonates (Fig. 3), gives us a reason to propose a possible microheterogeneity in them.

Very often during the SEM studies of carbonate minerals, a compositional zoning is established, which provokes terminological difficulties. In the ankerites from the chalcopyrite assemblage e.g., pale-gray microlamellae with higher Fe contents have been observed. Heterogeneous zonality, represented by repeatedly alternating darker (ferroan dolomite) and lighter (ankerite) zones, has been established in some coarse-grained carbonates from solution cavities.

XRD, THERMAL AND SPECTROSCOPIC CHARACTERISTICS

The XRD studies of dolomite-group ferroan carbonates from the different mineral assemblages show a distinct increase of the d-values in accordance with the increase of the Fe contents in the minerals examined. In comparison with the standard data of ferroan dolomite (PDF # 340517), these of the Kremikovtsi ankerite have higher d-values probably because of the higher Fe and Mn contents (Fig. 3). The positive correlation between the cell parameters a_o and c_o and the Fe contents in the dolomite-ankerite series has been discussed by many authors (Reeder, 1983; Reeder and Dollase, 1989; Gil *et al*., 1992). The weak reflections with d-values (Å) at 3.03, 1.909-1.914 and 1.620-1.623 on the typical diffractograms shown in Fig. 3, are due to the presence of small quantities of calcite.

The DTA curve of ankerite (Fig. 4a) is characteristic for the mineral and has no visible differences in comparison with the standard one (Ivanova *et al*., 1974). It is characterized by the presence of 3 endothermic peaks at 740^o, 790^o and 890^{o}C. The first one reflects the ankerite decomposition and its dissociation of $FeCO_3$ and $MgCO_3$ and simultaneous oxidation of FeO toward Fe_2O_3. The second peak at 790^{o}C is considered to be a result of interaction between Fe_2O_3 and $CaCO_3$ and formation of Ca-ferrite. The third endothermic peak corresponds to the dissociation of the rest $CaCO_3$ quantity (Ivanova *et al*., 1974).

The Mössbauer spectrum of ankerite from the Kremikovtsi deposit consists of one quadrupole doublet with an isomer shift near 1.19 mm/s and quadrupole splitting – 1.49 mm/s (Fig. 4b). The results obtained conform to the data published in the literature (De Grave and Vochten, 1985; Reeder and Dollase, 1989). The experimental studies of ankerites with different Fe contents (17÷66 mol% $CaFe(CO_3)_2$) showed that the quadrupole splitting values decrease inversely proportional to the Fe contents. The Mössbauer data obtained testify to the octahedral position of the Fe^{2+}-cations and weak trigonal distortion of the (Mg, Fe)O_6 octahedrons. In comparison with the spectra of other ferroan carbonates (e.g. siderite), that of ankerite is characterized by a considerable decrease of the quadrupole splitting values while the isomer shifts amounts are very close. The distinctions in the Mössbauer spectra of ferroan carbonates with different structures (ankerite, siderite) can be used to distinguish them qualitatively and quantitatively in mixed aggregates.

The infrared spectra of Kremikovtsi ankerites are characterized by 3 main bands at 1445, 880 and 729 cm^{-1} indicating respectively the 3 normal vibrations (Y_3, Y_2 and Y_4) of CO_3^{2-}-group in the ankerite (Plyusnina, 1977). According to Dubrawski *et al*. (1989) and Gil *et al*. (1992) in parallel with the increase of the Fe content in the dolomite-ankerite series occurs an increase of the absorption bands frequencies of Y_4 and Y_2 vibrations of the CO_3^{2-}-group.

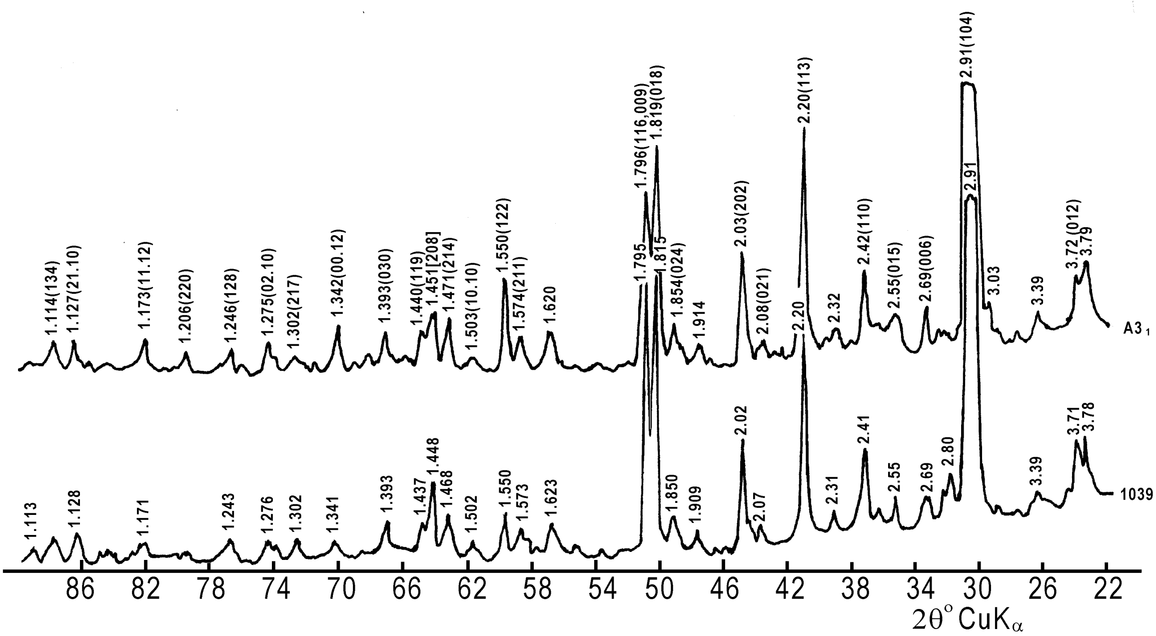


Figure 3. Diffractograms of coarse-grained manganoan ankerite from cavity linings in the dolomitic limestones (a) and from veinlets with chalcopyrite nests (b).

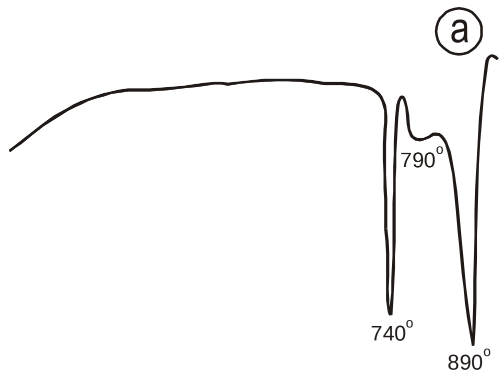
SUMMARY AND CONCLUSIONS

The dolomite-group ferroan carbonates are the main non-metallic component in the primary ores of the Kremikovtsi deposit. They (1) formed carbonate assemblages in the transition zones between the siderite ore bodies and the host Middle Triassic dolomitic limestones – the result of dolomitization of the host rock in the presence of Fe and Mn, (2) accompanied all sulfide assemblages, (3) constituted alteration zones in the carbonate rocks hosting the Pb-Cu sulfide mineralization, and (4) deposited as post-ore rhombohedral crystals in cavities within the dolomitic limestones.

In the *non-sulfide mineral assemblages* the dolomite-group ferroan carbonates formed micro-grained to medium-grained mosaic aggregates with massive, nest-like and veinlet textures. They are represented mainly by ferroan dolomite but within the siderite ore ankerite, as a coarse-grained mass with rhombic inclusions of ferroan dolomite is established as well.

In the *sulfide assemblages* predominate zonal ankerite metacrystals with decreasing Fe contents toward the rims – an indication of drop in temperature of the mineral-forming solution and exhaustion of its metal load in the process of crystallization (Minceva-Stefanova and Gorova, 1967).

Typical for the dolomite-group ferroan carbonates is the stable presence of Mn – a characteristic element for the deposit, the contents of which increase from the non-sulfide (2÷4 mol% $MnCO_3$ in the ferroan dolomite) to the sulfide (4÷8 mol% $MnCO_3$ in the ankerite) mineral assemblages. Thus, from a nomenclature point of view (Minceva-Stefanova and Gorova, 1967) the main part of the minerals studied should be referred to the varieties *ferroan-manganoan dolomite* and *manganoan ankerite*.



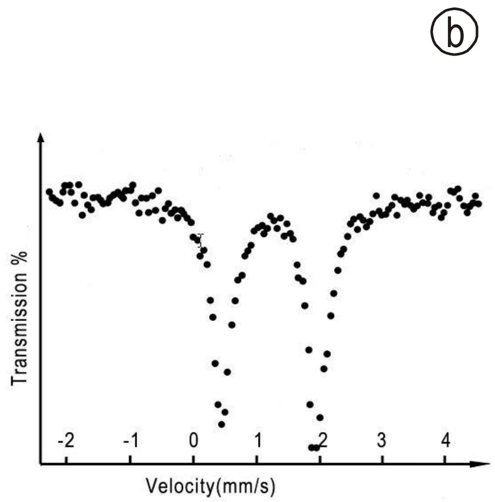


Figure 4. Representative DTA curve (a) and Mössbauer spectrum (b) of coarse-grained cavity lining ankerite.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 83-88

ROCK ABRASIVITY IN OPEN-PIT COAL MINES

Efrosima Zaneva-Dobranova[1], Peshka Stoeva, Evgenia Alexandrova[2]

University of mining and geology "St. Ivan Rilski", Sofia 1700, Bulgaria; e-mail:geoenergy@mail.mgu.bg[1]; e-mail:jogeni@yahoo.com[2]

ABSTRACT
A methodology has been developed for determining the abrasivity of different lithological varieties from the Pliocene complex of open-pit coal mines in the East Maritsa Coal Basin (Bulgaria). The relationships between the individual parameters are presented and described by their mathematical equations. Close relationships have been established between abrasivity and the moisture content, quartz and feldspar quantities which serve as qualitative parameters in selecting the material for manufacturing the bucket teeth, in predicting the rate of the bucket wheel motion and the conveyor belt service time. The results obtained can be used in other operations related to the geological and mining cycle on sites under similar conditions.

INTRODUCTION

Hard inclusions (sandy limestones, compact limestones, quartz sandstones, etc.), clays and sands of high abrasivity are encountered during the operation of bucket-wheel excavators in the Pliocene overburden complex of open-pit mines in the East Maritsa Coal Basin. As a result of that abrasivity, the cutting devices of the excavators (bucket teeth) and the conveyor belts wear out fast. Their replacement is very expensive thus raising the coal production costs. On the other hand, the negative effect on the overburden stripping rate is taken into account as well.

The different mineral composition of the overburden lithological varieties affects the abrasivity through the quantitative content of the individual constituents. The latter have been used as a basis for creating a methodology for analytical determination of the abrasivity coefficient.

INVESTIGATION METHODOLOGY

The abrasivity of hard inclusions was tested under lab conditions by the Baron-Kuznetsov method (1961). A steel cylindrical indenter (a pin of grooved silver steel) was introduced by dry friction on the non-polished surface of the hard inclusion. The abrasivity (A) is determined by the expression:

$$A = \frac{a}{N}\text{, mg/km,} \qquad (1)$$

where:
a - abrasivity index, mg;
N - correction coefficient for abrasivity determination, km.

Three values are used for the coefficient N – N=0,01 km; N=0,005 km and N=0,002 km. Coefficient N=0,002 km (Table 1) is accepted for theoretical and experimental reasons.

Table 1

Lithological description	Abrasivity index a, mg	Abrasivity, mg/km		
		0,01	0,005	0,002
Calcareous clay	19,40	1940	3880	9700
Varigrained sand with clayey-calcareous welding	63,30	6330	12660	31650
Coarse-grained sand with calcareous welding	44,90	4490	8980	22450
Fine-grained sand with carbonate welding	11,60	1160	2320	5800

For clays and sands the abrasivity is determined following the formula proposed by Kuntysh et al (1980) and improved by Stoeva, Zaneva-Dobranova et al (1992):

$$A = \frac{Vd\sigma_{on}}{100}\text{, mg/km,} \qquad (2)$$

where:
V - reduced volume content of a highly abrasive constituent (for this case quartz or feldspar), %;
d – grain size (diameter of prevalent sand or feldspar fraction), m;
σ_{on} – tensile strength, 10^5 Pa.

For the sand fraction (quartz) it is assumed that:

- fine-grained sand d=0,01 mm;
- small-grained sand d=0,25 mm;
- medium-grained sand d=1,00 mm (Table 2).

For the feldspar it is assumed that d=0,01 mm (Table 2).

Table 2

Lithological description	σ_{on}, 10^5 Pa	Quartz, %	Abrasivity, mg/km for			Feldspar, %	Abrasivity, mg/km for d=0,07 mm
			d=0,25	d=1,00	d=0,01		
Greyish-black clay	1,09	4	109	436	4,36	4	4,36
Greyish-black clay with coal inclusions	1,09	3	81,75	327	3,27	2	2,18
Bluish-green clay with dust-like carbonate substances	1,09	12	327	1308	13,08	9	9,81
Coarse-grained sand with clay welding	0,33	27	222,75	891	8,91	32	10,56
sandy rust-coloured clay	1,56	43	1677	6708	67,08	12	18,72

The abrasivity was determined for d=1,00 mm, a diameter proved to be most reliable.

RESULTS

Greyish-black clays with and without coal inclusions, bluish-green clays with dust-like carbonate substances and rust-coloured sandy clays were tested (Table 2). The hard inclusions were presented by: varigrained sand with carbonate welding, sandy or dolomitized limestone, calcareous clays (argillites), etc. (Table 1).

The tests proved that the abrasivity determination depends mostly on the terrigenous grain size, natural moisture content, etc.

The relationship between abrasivity (A) and natural moisture content (W_n) of the different clay varieties from the overburden horizons of the East Maritsa Basin mines is very indicative and permits future prediction assessments concerning the wear-and-tear of the bucket teeth and conveyor belts.

The greyish-black organic clays having up to 20% maximum content of organic substance are characterised by 1500 mg/km maximum abrasivity. In those clays, the abrasivity decreases considerably (up to 200 mg/km for W_n=60%) with increasing the natural moisture content (Fig.1, curve A). The limit value for W_n is approx. 60%. The rising branch of curve A shows an increase in abrasivity of up to 1300 mg/km with increasing the moisture content (W_n values above the limit ones). This can usually be observed in black clays with coal inclusions. The relationship between abrasivity and W_n is described by a hyperbola of the type:

$$A = 57674{,}2 - 2847{,}37W_n + 46{,}0849W_n^2 - 0{,}241466W_n^3,$$
mg/km, (3)

or a correlation coefficient r=0,72.

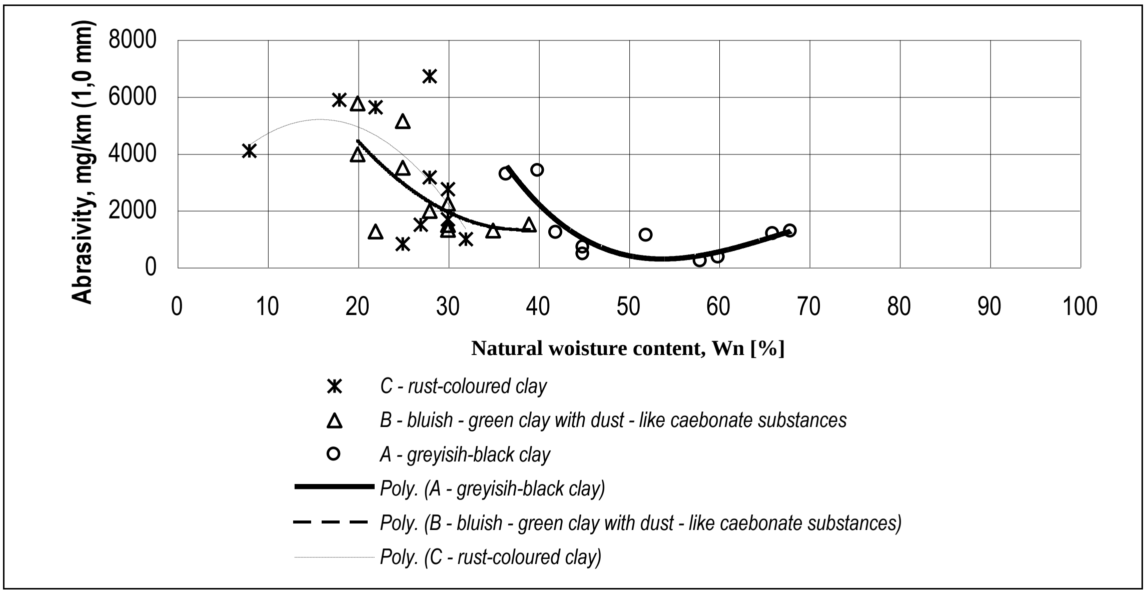


Figure 1.

The bluish-green clays are characterised by a very wide range of abrasivity variation determined not only by the quartz content but also by the different state of the calcareous constituent. Abrasivity values of up to 1200-1300 mg/km (Fig. 1, curve B) are related to the calcareous content in the form of dust-like carbonate substances. In lithological varieties containing up to 25% quartz and calcareous substance in the form of concretions, the abrasivity values increase up to 5200-

5700 mg/km. The relationship between abrasivity and natural moisture content for the bluish-green clays with dust-like carbonate substances is described by a parabola equation and has the following form:

$$A = 15190{,}3 - 729{,}199W_n + 9{,}57678W_n^2 \text{, mg/km, (r=0,47)} \quad (4)$$

The rust-coloured sandy clays are characterised by high data scattering (Fig. 1, curve C). The high abrasivity of up to 7000 mg/km is determined by the large-sized, uneven, sandy grains of the weakly welded sands which are insignificantly affected by the moisture content. Those results are typical of the East Maritsa Basin mines. Even in small-grained varieties the high abrasivity is not influenced by the moisture content. A proof of that is the low correlation coefficient (r=0,30) corresponding to the parabola equation:

$$A = 1478{,}82 + 467{,}692W_n - 14{,}7564W_n^2 \text{, mg/km, (r=0,30)} \quad (5)$$

The tests show that in hard inclusions the natural moisture content (W_n up to 5,6%) has an insignificant effect on the abrasivity. For instance, the low moisture content is due to the specific properties of the inclusions presented mainly by lumps of lithified varieties.

The reason for the wide range of abrasivity variation (from 1150 to 108100 mg/km) for the same lithological types can be accounted for by the broad variety of inclusions as regards their mineral composition, cementation structure and various strength characteristics.

The general trend of the relationship $A=f(W_n)$ is described by a hyperbola of the form (Fig. 2):

$$A = 62084{,}7 - 34092W_n + 6109{,}42W_n^2 - 245{,}523W_n^3 \text{, mg/km (r=0,48)} \quad (6)$$

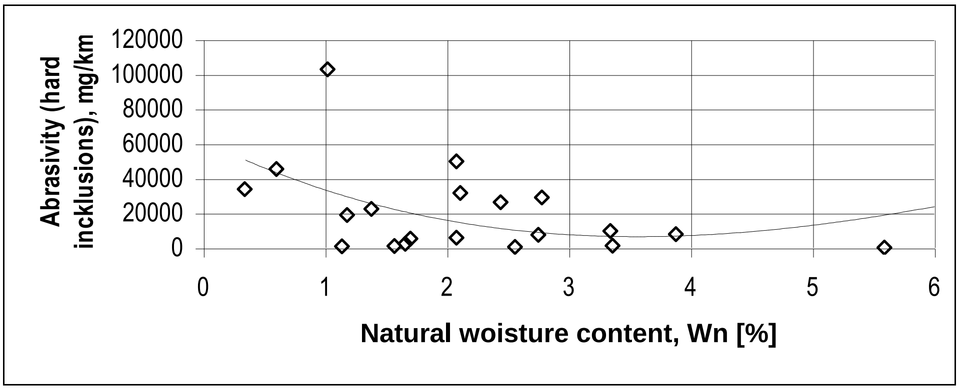


Figure 2.

The study on the effect of the proportional content of quartz on the abrasivity is of particular significance since it is the most abrasive constituent in the Pliocene overburden clays.

For the greyish-black clays having up to 18% quartz content, which form the first group of those clays, the abrasivity values are in the order of 50-1400 mg/km. For the second group of such clays, having coal inclusions and over 18% quartz content, the abrasivity values rise up to 3600 mg/km.

The relationship between abrasivity and quartz [$A=f(SiO_2)$] is described by the parabola equation (Fig. 3, curve A):

$$A = 142{,}59 + 85{,}477SiO_2 + 1{,}488SiO_2^2 \text{, mg/km (r=0,97)} \quad (7)$$

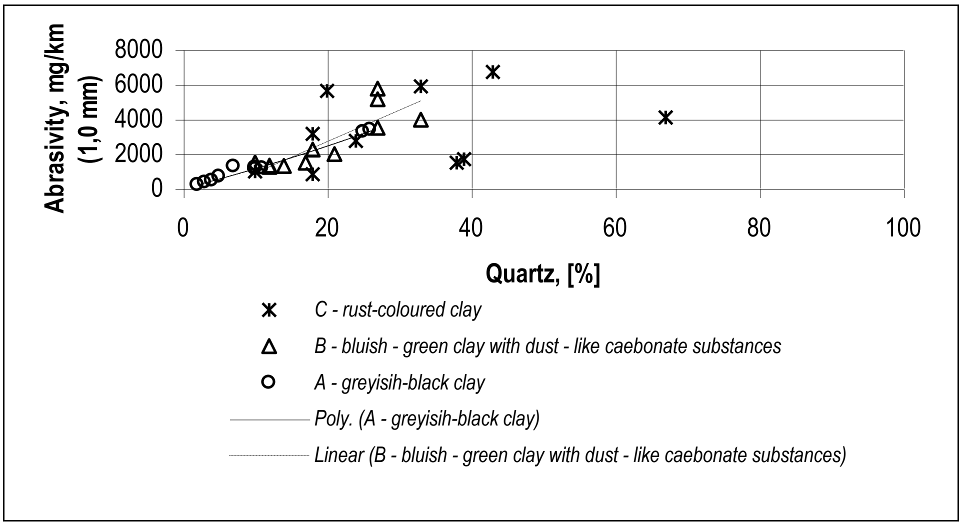


Figure 3.

The tendency towards changing the abrasivity depending on the quartz content in the bluish-green clays with dust-like carbonate substances is similar to that in the greyish-black clays (Fig. 2, curve B). For a quartz content of up to 10-15%, the abrasivity is 1300-1500 mg/km. Considerably higher values (5200-5800 mg/km) can be observed with increasing the quartz content over 15%. This is due to the presence of calcareous substance in the form of concretions.

The relationship between abrasivity and quartz for the bluish-green clays containing dust-like carbonate substances is described by a straight-line equation:

$A = -913{,}977 + 180{,}742 SiO$, mg/km, (r=0,71) (8)

Due to the small amount of data on the abrasivity of the rust-coloured sandy clays, the correlation coefficient is r=0,168. This makes it impossible to describe and analyse the relationship A=f(SiO_2) by using mathematical tools. The distribution obtained is shown in Fig. 3.

The relationship between the feldspar constituent and abrasivity has the same tendency (Fig. 4, curves A, B, C) for all three lithological varieties. When assessing the degree of wear of the bucket teeth and conveyor belts, it is necessary to take into account the maximum abrasivity values, namely:

- for the greyish-black clays - up to 2000 mg/km for 16% feldspar content;
- for the bluish-green clays containing dust-like carbonate substances - up to 4500 mg/km for 26% feldspar content;
- for the rust-coloured sandy clays - up to 5600 mg/km for 15% feldspar content.

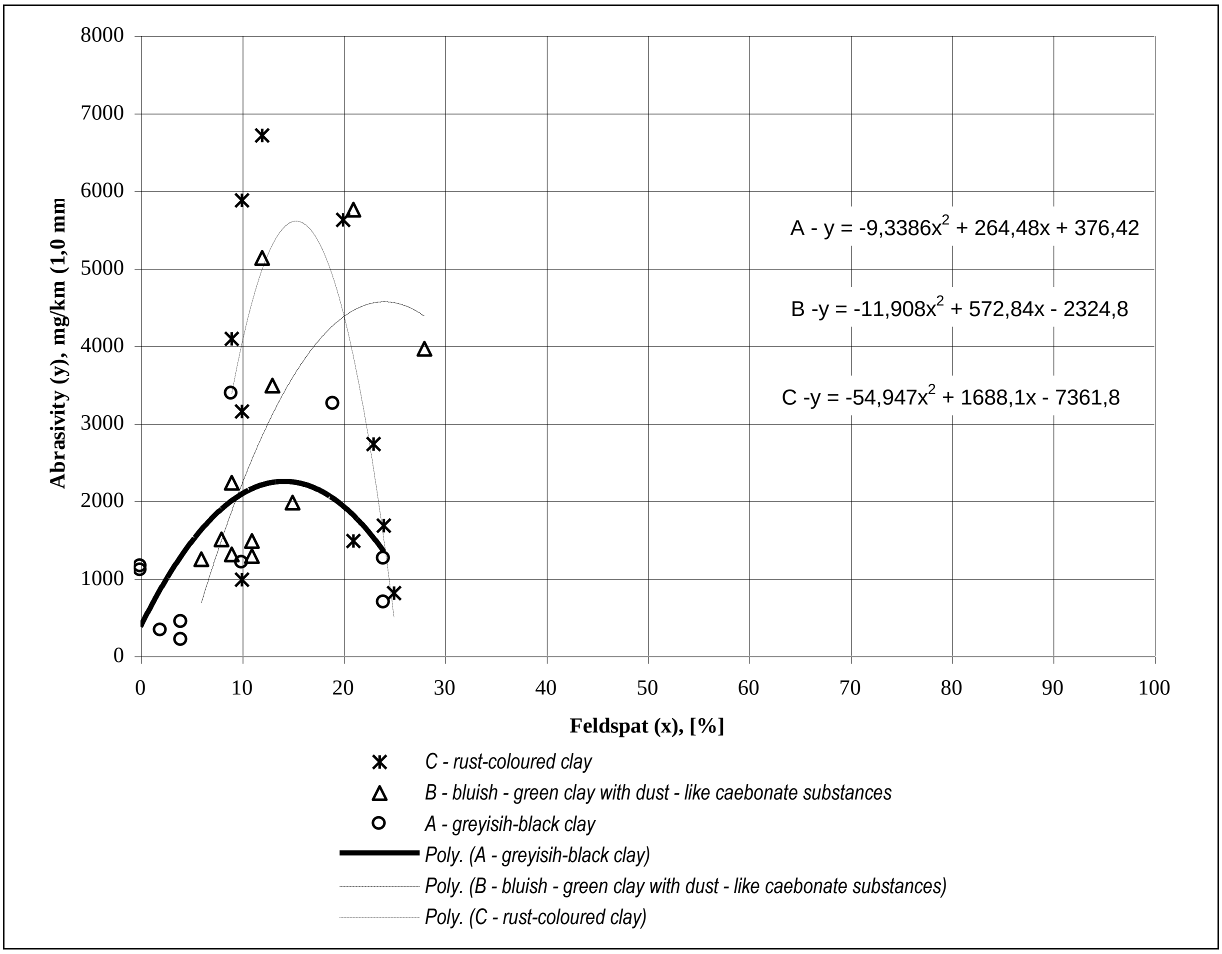
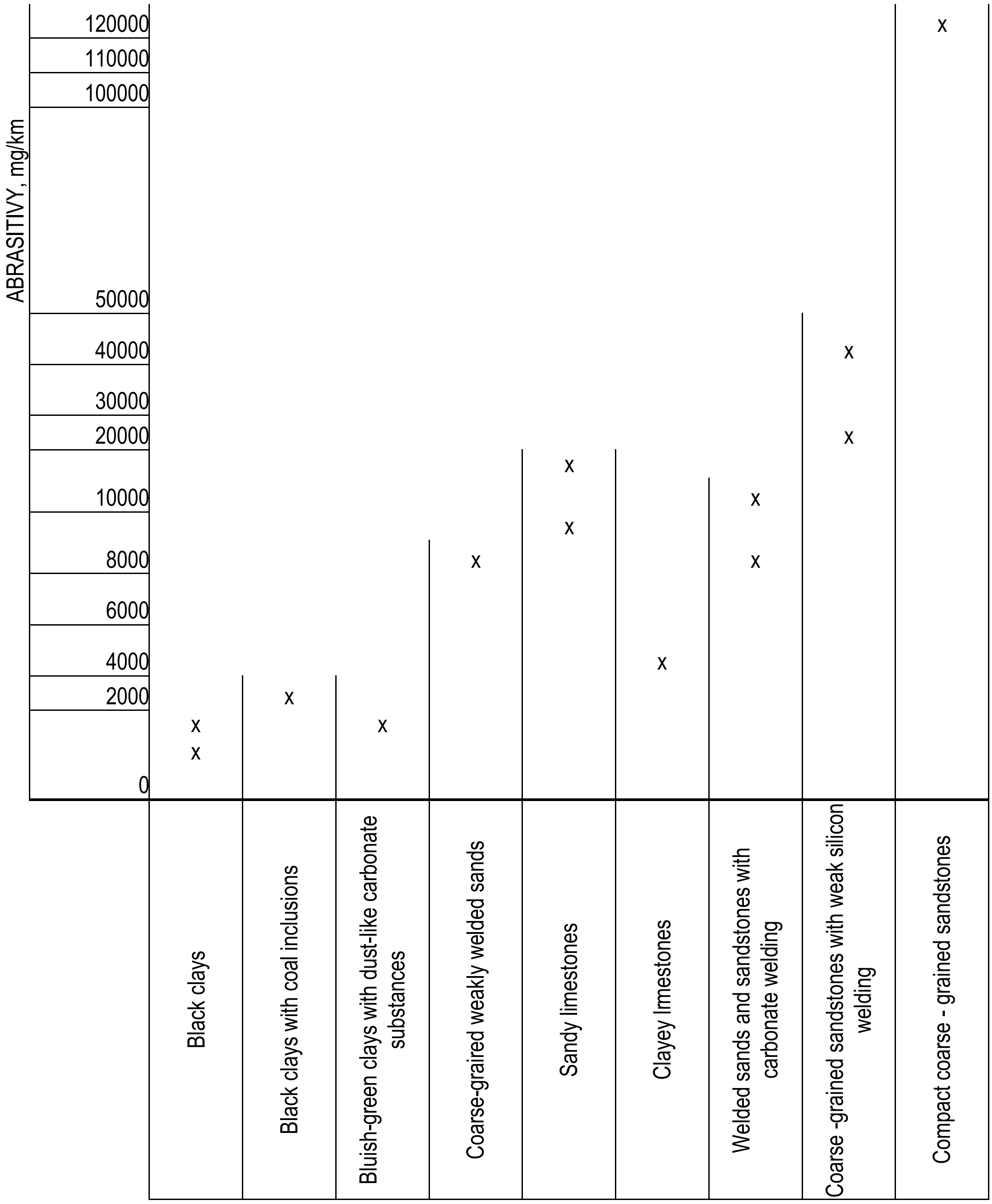


Figure 4.

The results of the tests carried out to determine the abrasivity of the different lithological varieties are summarised in Table 3. It can serve as a basis for a preliminary qualitative parameter in selecting the material for manufacturing bucket teeth and estimating their resistance capacities. Closely related to the latter is the rate of the bucket wheel motion (the excavator output, respectively) when cutting each coal web of the respective lithological variety.

Table 3



4. CONCLUSION

The relationships obtained between abrasivity and the natural moisture content, quartz and feldspar quantities in clays, sands and hard inclusions are of particular interest. They provide characteristics which can serve as criteria for the wear-and-tear of the BWE teeth and conveyor belts and can influence the technological process. The results presented have certain practical applications in:

- borehole explorations related to the annual planning of mining operations;

- predicting the overburden volumes for each subsequent year;

- geophysical exploration in zones of hard inclusion concentrations.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 89-96

THE ANCIENT GOLD MINE PERPERIKON NEAR THE VILLAGE OF STREMTSI, KURDZHALI REGION

Vasil Atanasov

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria

ABSTRASCT

Ten kilometers distant and bilaterally aside the road Kurdzhali-Haskovo there are tens of workings penetrating a small hill named Hissar Tepe. The nearest village is Stremtsi. All those workings are ancient adits, shafts, raises and open pit quarries. Until 1980 they have been recognized to be a unique Thracian sanctuary or tomb of a powerful Thracian king. On the 1:25 000 scale topographic and geologic maps they have been wrongly indicated as naturally formed caves. In fact, there are not any carbonate rocks in the Hissar Tepe hill.

Investigations performed from 1980 through 1983 show that Hissar Tepe hill near Stremtsi is built up of diagenetically hardened conglomerates, gritstones and sandstones. Locally they are interbedded with coal-bearing siltstones. All these are river and river-lake sediments of Priabonian age. They are horizontal or almost horizontal. At places vertical displacements at a distance of 0.5-1 m are seen. There are two main areas of concentration of galleries, shafts and raises - one of them on the SE slope and the other in the NW part of the hill. The distribution of most of the underground workings indicate that they follow conglomerate and gritstone layers.

Heavy concentration sampling of soil in the mining area has been performed and each of the samples yielded 20 to 135 grains of pure gold. Due to diagenetic alteration of the rocks all the gold grains are re-crystallized and the sizes are 0.05 to 1 mm. The content of gold in the conglomerates and gritstones is up to 4-5 ppm.

Beyond any doubt, the area of Hissar Tepe hill near the village of Stremtsi is a diagenetically altered placer deposit of gold and all of the workings in the area represent a remarkably large in size ancient gold mine. Fragments of ceramics have been found in the mine and they show two ages - 3-4 and 12-13 centuries A.D. There are no data that the mine has been in exploitation later than 14th century.

Four kilometers to the east of the mine there is the old castle Perperikhon, known from Antiquity up to the end of 14th century A.D. Similar are the names of the village and the river near the castle. The etymology of the names shows that they originate from the name perpera - gold coin, emited by Alexii Komnin (1081-1118) in Byzantium. And this is the reason why the name Perperikhon is proposed to name the gold mine and the gold deposit near the village of Stremtsi in SE Bulgaria.

The region of the Eastern Rhodopes is a gratifying and blessed land. We have to go back by centuries and millenniums in order to see it as it was, and what it may be - a centre of large economic and cultural progress, a cradle of flourishing civilizations which have gained world fame and glory. Here, in the BC centuries has arisen the kingdom of Odrisses, who surprise us by their skill to mine ores and metals. This rich in natural resources land has been a stronghold of the might of Sitalk and Seft, of Philip and Alexander of Macedonia, a source of the wealth of Rome and Bysantium, a corner in which swarmed the germs of the creative labour of the Bulgarians and the Bulgarian national spirit. The land of the ancient Odrisses is not just a peculiar crossroad of history and archeology, but also a knot in which are woven many secrets of the geology and the mineral resources of the Bulgarian lands.

The mining was an important profession of the ancient Thracians, could not be explained otherwise this rich archeology of metals and jewelry gold that they have left to us. This was noticed also by their neighbour states. "In the awareness of the Hellines at that time, as well as in earlier times, Thrace always has been a region with rich ore deposits and possibilities for exploitation and export of ores (especially gold, silver and copper ones)", writes V. Velkov (1973). The Hellines appreciated the skill of the Thracians to mine ores and metals, but were not let into the details of this profession. To them however, we owe the written about the mining skill of the Thracians, something that cannot be else but a slender description, missing technological and organizational details. The Thracians did not have writing to leave us descriptions of their professional skills in mining. And may be they did not want to let others in their findings in this craft which nobody can challenge even today. What they have left us, are the numerous old mines, which we find everywhere in our lands. There are so many of them, and they are so impressive in size, that one cannot imagine. But that are remnants of old mines which cannot be noticed and apprecieted by everybody. There are attempts of historians and archeologists, as well as of geologists, mining specialists and metallurgists, to study some of them. However the achieved in this respect successes do not go beyond an initial research phase.

To familiarize with and study adequately the history of the ancient Thracians without acquaintance with their main profession - the mining, is tantamount to absurd. To a great extent this applies also to our knowledge about the metallic and non-metallic raw materials. As far as our knowledge of gold deposits is concerned, this fact deserves stronger words. Provided about gold and its deposits we know as much as the Thracians did, we would save many errors and delusions, we would find a more direct rout to the wealth which is nowadays hidden in the bowels of our lands. During the last decades we made many efforts, but did not reach the desired successes. And we turned out to be only legitimate inheritors of their lands, but not of their prestige in the mining craft. But in the old mines an enormous information is buried, information that has to be read.

One of the long ago forgotten gold deposits is in the area of the town of Kurdzhali, between the villages of Rani List and Stremtsi, (Fig. 1). The interest toward it was provoked by a publication of B. Deribeev (Newspaper Anteni, 1980).

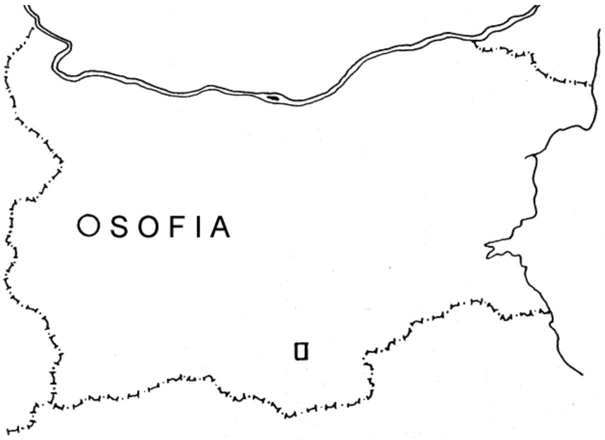

Figure 1. Location of the object

The organized by the newspaper special expedition that visited the site on 07.08.1980, did credit to the newspaper. In the expedition participated historians, archeologists, journalists. In the capacity geologist and mining specialist took part also the author. The expedition had to examine the object, to decide what it represents, and the newspaper's editors to inform the readers about this decision. The expedition examined the accessible for observation places, but to a final decision it did not come. Only an opinion of the author about what the object could be was expressed, an opinion that needed serious proves. An article with the final opinion that the object is an ancient gold mine appeared after three years of profound research (Atanasov and Yovkov, 1983).

What was known about the object? The place Hissar Tepe is a small hill between the villages Rani List and Stremtsi, (Fig. 2). It is located 10 km away from the town of Kurdzhali, along the road to the town of Haskovo. The asphalt road runs through the very object. There are exits of galleries, shafts and rises on both sides of the road. For the local population that are "the holes" or "the caves". Most frequently is used the name "Dzhenevis Inlar". And indeed, in many cases the investigated structures are considered as naturally formed caves. As such they are indicated also on the topographic and geological maps of the area (Fig. 2). So they are marked in the Tourist Guide for the Kurdzhali region (Strashimirov, 1981, page 85-86). There it is written " At a distance of 9 km (from the town of Kurdzhali, author's note), along the road is the fountain Gazlarchesmesi (The Geese Fountain). Above it, there is a small pine-clad hill. There are man-made caves".

There is a story, that chasing a fox, a hunting dog entered one of the holes, and went out as far as at the village of Shiroko Pole, which is 15 km away from there. For another of the galleries, which represents a perfect water siphon, it is said that behind the water, there is an iron gate guarded by an iron dog, and iron guardsman holding a drawn out sword. Legends. Such a gallery – siphon really exists. At present it is accessible, and is located at approximately 200 m after the Gazlarchesmesi, along the road Haskovo, at 20 m to the right.

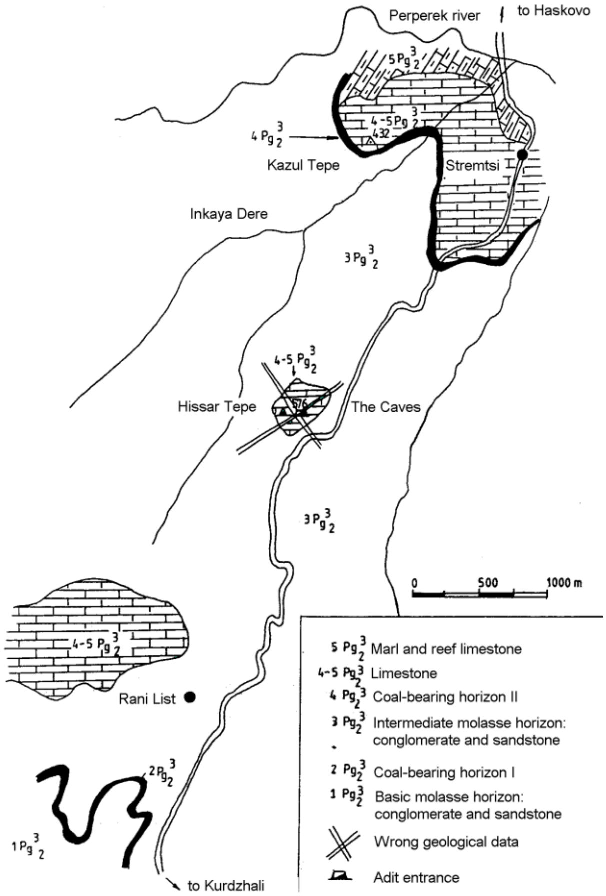

Figure 2. Geological map of the area (after D. Minchev et al., 1963, with supplements by the author)

The correct conclusion is that the object represents a large complex of man-made underground and surface workings. An opinion that this is an old mine was voiced even 80-90 years earlier, but it did not find convincing support. It was visited by our and foreign geologists and mining specialists. They however did not find traces of the traditional for the Eastern Rhodopes mineral deposits. And indeed it is so. There are not even traces of lead-zinc, iron and other ores. Absent are also the traditional for this area non-metal mineral resources: trass, talc, asbestos, etc. Then came the categorical, but wrong conclusion that the object is not a mine and remained the curious puzzle, what it is anyway. During the period before 1980 this question interested mainly historians and archeologists. They assume the existence of certain connection between the numerous rock tombs and niches from the Early-Iron epoch, located along the Arda river valley and in other places in the Eastern Rhodopes, with the "underground labyrinths" next to the village of Stremtsi - in the sense that both are deeds of the ancient Thracians, but underline that such thing may not be seen anywhere in Bulgaria. In the publication of B. Deribeev (1980) is assumed that the object represents a rock necropolis of a powerful Thracian ruler or a sanctuary of the Odrisses. It is mentioned that the hill is build up of "volcanic tuff that has cemented gravel and sand in a conglomerate". There is no tuff. The rocks represent strongly cemented Tertiary clastic rocks belonging to the so called Priabonian coal-bearing group. It is not important that we do not share the conceptions of the author concerning the essence and the purpose of the object. Thanks to him we have a scrupulous description of that "labyrinth of mysterious galleries".

The body of the Hissar Tepe hill is formed of clastic rocks of the intermediate molasse horizon of the Priabonian. In its composition participate continuously and repeatedly alternating poorly sorted and quickly thinning out layers and lenses of conglomerates, gritstones and sandstones. In some places also presence of thin coal-bearing strata and siltstones is observed. The total thickness of the molasse horizon is about 300 m. The sandstones are medium- to coarse-grained, the conglomerates - of medium to large rocks fragments. The fragments are of gneisses, mica schists, amphibolites, diabases, pegmatites. There are plenty of compact gray and milky quartz fragments. The layers and lenses of conglomerates and gritstones are horizontal or almost horizontal. The fragments and grains they contain are very rounded due to prolonged transportation by water. In the crest of the hill, where the numerous and best preserved mine workings are located, the gritstones and the conglomerates are strongly cemented. At the lower levels of the same horizon, the cementing of the rocks is relatively weaker. The deposits of the horizon represent typical river to river-lake sediments. From here came the initial assumption that these are lithified gold-bearing alluvium.

In the rocks that build the hill are observed minor faults with amplitude 0.5-1 m, dipping at 80 - 85°. The thickness of the tectonic zones rarely exceeds 10-20 cm. Locally, some of the fractures are filled by interrupted veins of gray or white fine-grained quartz. Sulphide mineralization visible to the naked eye is not observed, but the material from and around the tectonic zones after being exposed to air for a longer period obtains a rust-brown colour. The reason is the weakly expressed pigmentation from iron oxides and hydroxides, a result of weathering processes. During the weathering of the rocks inside the mine, on the walls of some of the galleries were formed minor gypsum crusts, up to 0.5 cm thick. Such type of secondary mineralization suggests the presence of primary disseminations of sulphide impregnation of sulphides minerals. The carried out later microscopic and X-ray studies confirmed the presence of fine-grained impregnation of pyrite and marcasite.

It is important to note, that in the geological 1:25 000 map of the object, the crest of the Hissar Tepe hill is given as built up from limestones (Fig. 2), what is not true. There are no limestones, but only sandstones and gold-bearing conglomerates and gritstones. As an underground structure, the mine represents a complicated complex of isolated or mutually connected horizontal, inclined and vertical workings, located predominantly in the crest part of the hill, on an area of about 1 km^2. On the surface are found several places of especial concentration of galleries, shafts and rises (Fig. 3. (The topographic map and the plans of the underground workings are made by K.Yovkov). Found were more than 30 entrances of horizontal and inclined mine workings, more than 20 vertical workings (vertical shafts and raises), places with remnants from open-pit quarrying of material and old dump-sites with abandoned broken-off material.

The system of mutually connected galleries and raises located on the SE slope of the hill has an impressive appearance (Fig. 3). They enter the massif through 10 adits and reach inside to 60-70m (Fig.4). From them detach a multitude of branches which form a complicated labyrinth. The workings follow mainly the conglomerate and gritstone layers, as well as the fault zones. From the geology of the sedimentary gold deposits is known, that rich in metals and other heavy minerals are usually the layers of coarse rocks. Many of the galleries are built to follow the faults zones in the rocks. Obviously the tectonized material along the faults facilitated the drowing of the workings. Along them most frequently the connections between the workings on different levels were accomplished. At the same time it was found that partial re-deposition of metals, related to notiseable enrichment of gold occured along the fault zones.

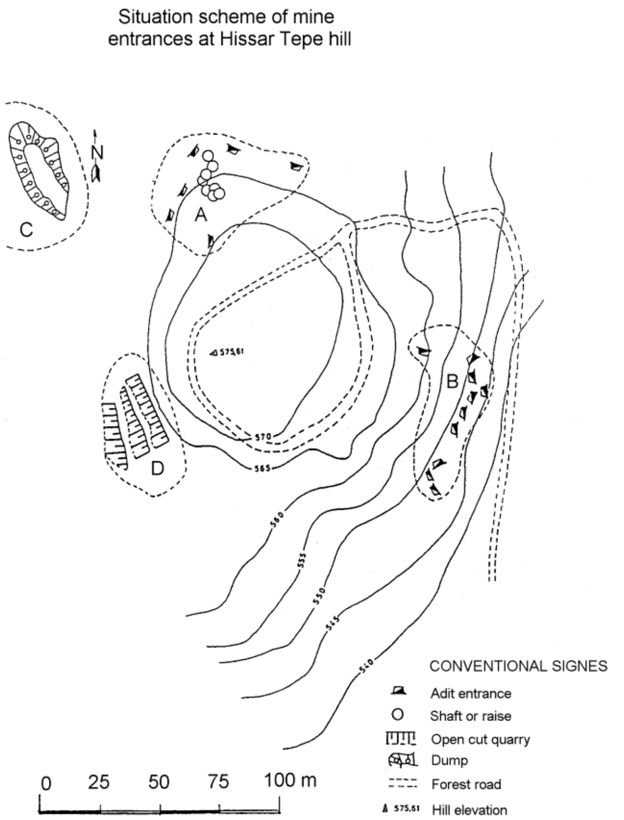

Figure 3. Schematic location of the entrances to the mining workings: A. Shafts; B. Galleries; C. Dump sites with broken-off material; D. Open –cut quarry

The connection of the galleries with the surface was carried out also by building raises up to 10-15m high. The galleries that penetrate deepest into the hill are intentionally barred by broken-off rock material. From the general vew of the mine is visible the desire of its last inhabitants to restrict the access of visitors to the most inner parts of the massif, to where the labyrinth of galleries most probably penetrates. As barriers against penetration most frequently raises were used. Usually they are full with especially prepared broken-off material. The so prepared barriers are a serious obstacle to clear the mine even nowadays.

A typical feature of the horizontal workings is that in their upper parts they are perfectly arcaded. Despite the fact that they pass through coarse-grained and pebbly rocks, the ceilings and the surfaces close to the arch are impressively smooth. Especially impressive in appearance are the arcaded galleries with large cross section, the chamber widenings and the crossing places of several galleries. In these places the arches have a regular oval shape and their surface is plain and smooth. At first glance the smoothing of the arches of the galleries is perceived as a deed of human hand. The truth is that the arcaded shape and the smoothing of the arches is a result of the action of the mining pressure exerted during many centuries. The interesting in this action is that the shearing stresses act through the same cylindrical surface in the same manner through the cementing matrix and through the much harder pebbles of the conglomerate, regardless of whether they are rock fragments or pieces of dense and compact quartz. Due to the action of the mining pressure, the typical for such conditions rock peeling from the walls of the galleries takes place - at the arches and areas close to them. In this respect the mine is an exceptional object for carrying out observations on the real action of the mining pressure forces during a period or 1000 to 1700 years. This fact is of importance not only for mining experts, but also for specialists from other fields in order to prevent them from wrong conclusions. The floors of the galleries and the lower portions of the walls however have kept the roughness remained from the time of their laying. It is well known, that according the rock mechanics laws, here the forces of the mining pressure do not manifest themselves in rocks with such degree of consolidation. Owing to this reason, the marks of the chisels of the ancient miners are well visible. Their examination certainly would lead to disclosure of interesting data related to the methods and organization of the work of the ancient miners, something important for the archeology, as well as for the history of the mining.

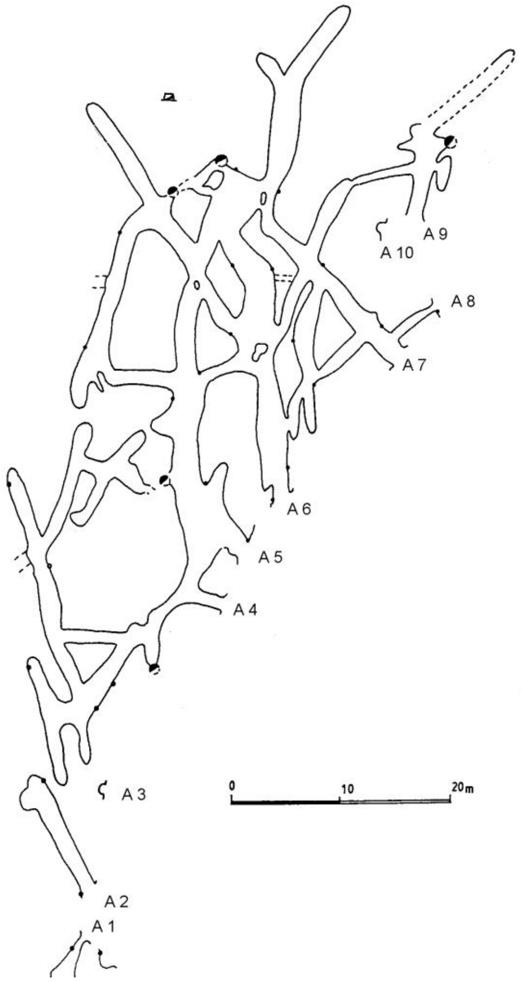

Figure 4. Plan of the mine workings (galleries) in the SE slope of the Hissar Tepe hill

Interesting is the system of shafts, galleries and raises at the NW part of the hill, (Figs. 3, 5 and 6). On a surface of about 100 m^2 are located 8 shafts which penetrate to a depth of 10-15m. From them, at three levels, are laid horizontal and inclined galleries. Followed are also layers of conglomerates, gravelites and tectonic zones. The galleries built aside of the shafts are also connected, and are in the same manner intentionally blocked by broken-off rock material, either by raises up to the surface, or by careful burying of the very workings. Fig.6 shows the mouth of one of the shafts. In the monolithic and hard rocks around the mouth of this shaft hemispheric depressions with diameter 10-15 cm are clearly seen (Fig. 7). Most probably they are remnants of near-shaft structures - nests for pillars for hoisting devices, sheds and other auxiliary surface devices. And maybe this is a system for underground orientation, a plan of the mine, or something else related to it.

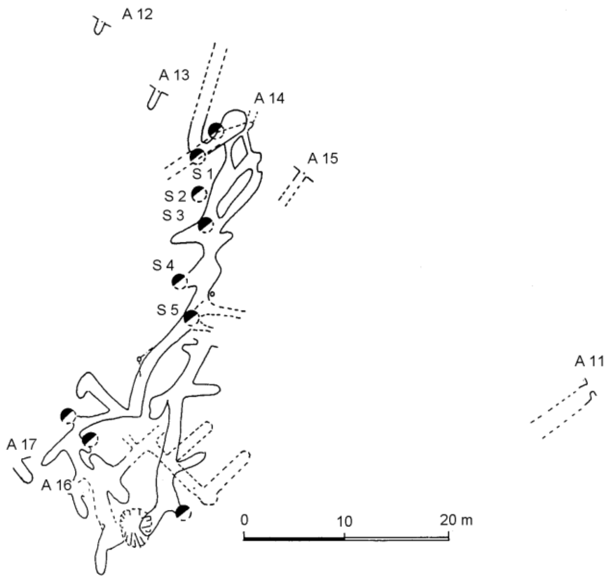

Figure 5. Plan of the workings (shafts, galleries and rises) in the NW part of the Hissar Tepe hill

The above described two major systems of underground workings - the galleries at the south-eastern slope and the shafts at the north western part of the hill, for the time being are isolated from each other. A direct link between them was not found. Presumably, such underground link between them exists, but has been intentionally blocked. Here is the prove for this. To the system of shafts, galleries and raises goes the whole amount of rain water that is coming from the wide crest of the hill. The rocks are difficult for penetration, and each depression in the rocks is holding the water even during the driest months of the year. As a whole however, the mine remains dry during the whole year. That means, the mine is adequately drained. The draining of the water probably is accomplished through galleries at lower levels. They have to be searched down the slope, but they are covered by slope embankment.

On the north-western slope of the hill, on a level 25-30 m below the mouth of the shafts, but not less than 200-300 m away from them, there are well preserved old dump-sites with piled broken-off material (Fig. 3). The amount of the material at the largest dump-site was about 3000 m^3 . This is already rather low down the slope of the hill, and exits of galleries, close to the dump sites, are not seen. It is logic to assume that there are such exits , but they are buried by material from the slope. It is possible that they are the draining units of workings developed around the shafts. It is very possible that the very Gazlarcheshmesi has as a source the draining gallery of the gallery system at the south-eastern slope of the hill. The ancient miners did not have water pumps at their disposal and they have solved the draining problems of their mine on the principle of gravitational self-drying. Surprisingly, this system keeps on working even today, more than 6 centuries after the mine stopped working. And besides Gazlarcheshmesi (which by now is completely distroyed) on the slopes of the Hissar Tepe hill there are catchings of several more water sources. Maybe, together with the Gazlarcheshmesi they are the key of the mine's draining system.

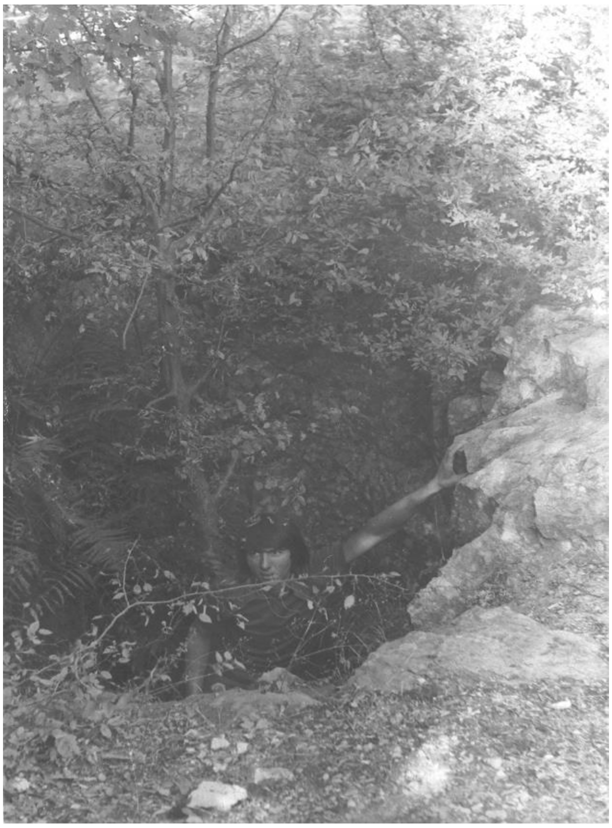

Figure 6. The mouth of one of the shafts at the NW part of the Hissar Tepe hill

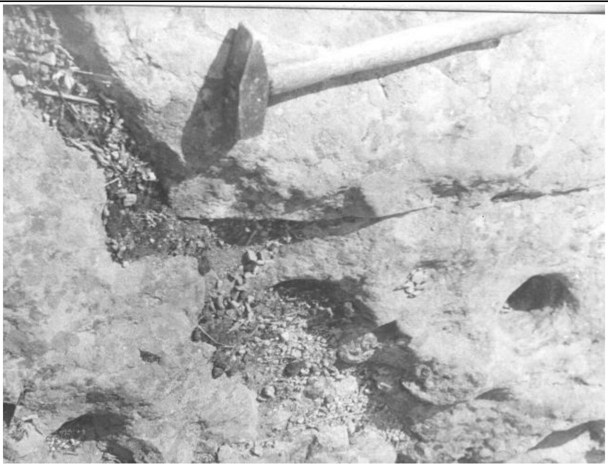

Figure 7. Hemispheric depressions in the layer of sandstone at the site close to the main shaft at the NW part of the Hissar Tepe hill.

The available at the dump-sites broken-off material witnesses for a large - scale mining activity in the remote historical past. And this is just a portion of the material excavated from the mine. A large amount of it was transported away and used as pebbly cover of the road Kurdzhali-Haskovo. For this purpose to the dump-sites a special forest road was laid, which exists now. The builders of the road did not realize that they are carrying away material from old dump-sites. Nowadays, when needed, the local inhabitants are using material from the dump-sites for construction purposes. To produce construction material needed for building the asphalt road Kurdzhali - Haskovo the mouths of two galleries on the south-eastern slope of the hill were hurt. Blown up and irretrievably disappeared the first 3-4m of their entrances (Fig.8).

Figure 8. The entrances of galleries No-s 9 and 10 on the south-eastern slope of the Hissar Tepe hill. The original mouths of these galleries were blown up and the obtained material used for pebly cover of the Kurdzhali - Haskovo road.

Special attention deserve two of the galleries at the south-eastern slope of the hill. They also belong to the structures envisaged to restrict the access to the mine's inside.They are built as artificial water siphons. In one of them, located near the crest of the hill, the siphon consists of a gallery sloping inside and other sloped gallery laid on a lower hypsometric level. This siphon was discovered by carrying out minor clearings of its almost closed entrance.The other siphon is located considerably lower down the slope and is outside the scope of Fig. 3. It was already mentioned in the legend for the iron gate barrier. The siphon is very well preserved and the portion before the water barrier is easily accessible. It consists of horizontal galleries on two levels, both of them dry. Next follows a vertical shaft full with water. The water is clear. At the bottom of the shaft is visible one more gallery, located on a lower level and also submerged under the water. This structure is suitable for penetration into the mine since evacuation of the water may be easily accomplished.

At the western part of the hill there are few entrances of galleries only. There is however a place of open cut quarry (Fig. 3). In the rocks several benches are formed and terraces of broken off material near to them are made. The benches of the quarry reveal and follow well expressed conglomerate beds.

There is no doubt that the whole system of underground and surface workings represents a very large for the time of its development gold mining complex.

During accomplishing of the mine surveying and geological documentation of the underground part of the complex, in two of the galleries fragments of ceramic utensils were found. The dating indicates two ages - one of between 3rd and 4th century, the other - between 12th and 13th century AD (The age of the ceramics is determined by D. Mitova-Dzhonova).

A purposeful sampling of the soil layer near the entrances of some of the galleries, shafts and raises of the mine was carried out. In all samples grains of native gold were found. In a 20 kg sample, taken near the quarry, (Fig. 3), were found 135 grains of native gold (Fig. 9). The sizes of the grains vary between 0.05 and 1 mm. The larger of them reprecent, intricately branched three-dimensional dendrites, built up of comparatively well shaped gold crystals. Many of the grains are aggregates of gold still not freed from the non-metalliferous minerals and this picture completely corresponds to the local geological situation: a stage of weathering, with not completed disintegration of the rocks and without transportation of the material away from the place of weathering.

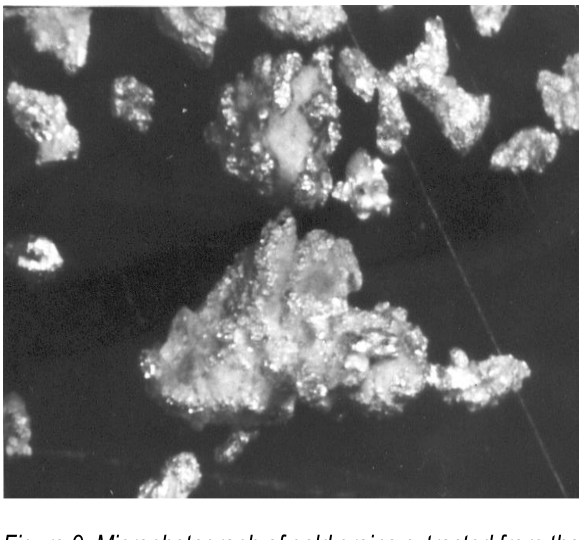

Figure 9. Microphotograph of gold grains extracted from the soil layer of the Hissar Tepe hill. Magnification 100 x

An observation of polished sections taken from the Hissar Tepe hill was carried out. In them were also found grains of native gold, with dimensions and sizes as above mentioned. The preliminary sampling of the gold-bearing conglomerates gave gold content from 1-2 to 4-5 ppm. The above stated indicates that the placer gold in the clastic Priabonian rocks near Stremtsi was affected by serious diagenetic alteration. It has caused a general re-crystallization of its grains. Apparently, the extraction of gold from souch ore may by realized by preliminary desintegration. And probably this way of extraction has been used by the ancient miners.

Concerning the essence of the object in study as a man-made creation, a link between it and the old castle Perperikon (Perperakion), located at about 4 km eastwards of Hissar Tepe, should be searched. The castle is situated on a neighbouring hill, next to the village of Gorna Krepost. The names of the river Perperek and the village of Perperek are derivatives of this word. The etymology of the word indicates a connection with the name "Perpera" - name of a gold Byzantine coin from the 11th to 13th centuries. This coin was introduced by emperor Aleksii I Komnin (1081 - 1118), weighs 4.4-4.5 g and is with purity 20.5 carats. It was in use during the Byzantine domination on Bulgaria, but was also in circulation during the Second Bulgarian Kingdom. That is a name which survived the broken thread of the time.

According to the data of B. Deribeev (1980), in the 1891 Year Book of the Odrin Vilayet (Province of the Ottoman Empire), in the section for the Kurdzhali's Kaasa is mentioned that between the villages of Rani List and Stremtsi "are located two underground buildings that are worthwhile to be seen". By these words the Turkish chronicler actually declares that he is not aware about any information related to operation of the mine after the Turkish invasion in our lands. According to the Byzantine chronicler Georgi Akropolit (1217 - 1282), Perperikon was one of the largest fortresses of Achrida (Mora). There is a description of the fortress and the near-by located town of Perperakion made by the Byzantine Emperor Yoan Kantakousin (1347 - 1355). It is obvious that to a certain degree the history of the civilizations around the archeological object Perperikon, located near the village of Gorna Krepost, since pre-historical times is related to the gold mining in the Hissar Tepe hill.

The mine Perperikon is not unique, but is one of the numerous gold mines in the lands of the Thracians, and later, in the Byzantine and Bulgarian lands. After the break-down of the Roman Empire a considerable drop in the ore mining took place. A great number of mines were abandoned. The mining skills of the Thracians were somewhat forgotten. The Thracian tribes rarefied and intermingled with the newly arrived populations in their lands. And it is not before the time of Aleksii I Komnin that Byzantium again becomes a mighty power. Many of the ancient mines were recovered and brought into exploitation. A general upsurge of the mining and production of metals occurred. It is difficult to prove that the mine near Stremtsi was an unique miracle at the Empire. What I know about it at present, does not allow me to support such assertion. Whether there was a break in the ore mining at the Stremtsi mine during the period between the Antiquity and the time of Aleksii I Komnin, for the time being is not clear. There is no doubt however, that this upsurge in the ore mining was not a privilege of Byzantium only. It is obvious that it affected also the neighbouring Bulgaria. Everyone knows that the Bulgarian king Ivan Asen II also began to make gold coins. And that is a fact which was not profoundly discussed in the Bulgarian history. It is not clear why, but written knowledge concerning the ore mining and gold production during this period and during the time of the First Bulgarian Kingdom is missing. For the time being, this extremely interesting secret is locked within the numerous old mines that can be found everywhere in our lands. Of course one of them is the Perperikon mine near Stremtsi. For this reason, in the paper of Atanasov and Yovkov (1983) was stated that many more secrets are hidden there. It is known that the fortress Perperikon was a reason for disputes between Bulgaria and Byzantium. In the middle of the 13th century it was taken away from Byzantium and conquered by the Bulgarian ruler Mihail II Asen. Actually, what about was the dispute? Was the gold mine near the fortress included in the dispute? Is it just a chance that so many names in the neighbourhod have in their root the word "Perpera"?

There is no doubt that the activity of the mine was ceased just before the coming of the Turks in the Balkan peninsula. It is logical to look for a link between both events. The previous possessor of the mine, Byzantium, obviously did not want to allow the invaders to penetrate in its deepest inside. Before withdrawal he has built the above described barriers of broken-off rock material, as well as the water barriers - the siphons. There were things left in the most inside parts of the mine, ones that solely he knew about them. Provided this assumption is true, than even now there is available an extremely rich archeological material, carefully hidden by the Empire. There is no other way to explain the building of such complicated system of barriers.

New data about the gold mine near Stremtsi were obtained during the period 1994 through 1998 (Ivanov and others, 1998). By the former Committee of Geology a large-scale geological research programe of drilling, exploration trenches and clearings was accomplished. The opinion of the authors is that the gold mineralization in this place is epithermal in origin, and is closely attached to the faulting of the rocks. It is in the form of **ore veins** along two main directions of faulting, **ore shoots** formed on the places of fauld crossings, and **metasomatic widenings** near to the faults. The sampling of the deposit provided during the exploration programme gave gold content of 0,1 – 8 ppm. The calculated prognostic reserves in terms of amount of gold and silver are 6.992 t and 5.638 t respectively, the average of gold content being 1.03 ppm. The final conclusion for Stremtsi as gold deposit it does not satisfy the conditons to be used as current sourse of commercial ore, but is just a low grade gold occurence. Of course this conclusion is far from the truth. Apparently this is a blazing mistake done by the explorers. They have searched for vertical or almost vertical veins, ore shoots and widenings near to the faults, but here at Stremtsi they have had horizontal and layered ore bodies. This makes a big difference and for this reason the mistake was of the similar degree. The ancient miners did not make such mistakes. There is no evidence for an elapsed large-scale epithermal process after faulting of the rocks. Really there was only a partial re-deposition of gold, that has happened mainly within the limits of the initially formed by sedimentation ore bodies. The consolidation of the rocks and their lithification is an event that took place before the faulting process.

The accomplishment of a research programme, based on the defended by us concept for a sedimentary gold deposit with horizontal or almost horizontal layered and lens shaped bodies would lead to radically different results. The expectations are to establish more ore reserves with higher metal content. There is no answer to the question: what was the metal content in the ore the ancient miners have produced? They would not be satisfied by a content around 1 ppm.

The idea for vein type, epigenetic hydrothermal mineralization in Stremtsi is shared also by V. Stamatova (1996). This however contradicts the results she obtained for the chemical composition of the gold. Its hallmark is 837.7. According its composition, the native gold from the Stremtsi is within the range hypo- to meso-thermal or is sedimentary (Bilibin, 1955; Petrovska, 1973). But it cannot be hypo or meso-thermal because in the area there are no data for a previous high- or medium-temperature hydrothermal process. At the same time it cannot be epithermal, because its hallmark is above 800, but not below 700. By all signs, the Stremtsi gold deposit corresponds to sedimentary mineralization of alluvial type. It is not logical to assert that it is just an insignificant ore occurrence, neither that is completely exhausted by the ancient miners. It is areal gold deposit that deserves serious examination and competent assessment from geological and archeological points of view. The problems related to it are neither solely geology, nor solely history and archeology - they are both of them.

There is still no evidence for a direct link between the gold mine near Stremtsi and the near fortress Perperikon, but their close neighbourhod and the existence in approximately the same time is obvious. Indisputable is also the closeness in the physical dimensions and the historic significance of both objects. It is difficult to prove that they have existed independent of each other.

And after all that is written here, it is difficult to believe to the information in the newspapers Monitor and Troud, dated 28.02.2002, that a few days ago, a team of archeologists, with leader Nikolai Ovcharov, has discovered the "only antique gold mine in Europe" near the village of Stremtsi, region of Kurdzhali. Indeed, the gold mine is unique, but it is neither the only one, neither the largest, nor the richest one. Only in the Balkans decades of them can be listed. The team of archeologists discovered for itself something that was discovered 22 years earlier and published 19 years ago. Besides, by letter # 374, dated 31.01.1984, of the National Institute for Monuments of the Culture at the former Committee for Culture, the mine is declared to be an archeological Monument of the Culture. Both newspapers have used too strong expressions to make people believe them. "Starting are excavations in the Bulgarian Klondyke of the Antiquity". "From the legendary mines were obtained the largest gold outputs in the Antiquity and the Middle Ages". "The money reform in Byzantium is made by our gold" etc. It is maintained that "the mine is a deed of the Thracian tribe Bessi". It is interesting how the Bessis managed to build a mine in the lands of the Thracian tribe Odrisses. And why should somebody say things that later has to deny by himself?

The studies carried out until now on the ancient mine near to the village of Stremtsi (most of them mainly geological, than historical or archeological) give reason to make the following conclusions:

1. The object under study represents a huge for its time mine, and deposit of alluvial gold in the Priabonian conglomerates and gritstones near the village of Stremtsi. Its development is linked with the history of the civilizations around the archeological object Perperikon, near the village of Gorna Krepost - since the time of the Odrisses Kingdom, and probably before this time. It is expedient to designate it as **Perperikon gold mine and Perperikon gold deposit.** It is a Monument of the Culture with international significance which needs additional studies in three main directions.

- As a deposit of alluvial gold in the clastic sediments of Priabonian age, presenting a wide range of non-clarified issues concerning its mineral composition, content of useful components, productive rocks, ore deposition processes, character of diagenetic processes, amount of commercial and non-commercial ore reserves, possibilities to organise current production of gold from the deposit, presence of other gold deposits in the clastic rocks of the Paleogene, presence of river gold in the contemporary alluvium of the river system in the regions of Kurdzhali, Haskovo and other places in SE Bulgaria.
- As a well preserved ancient mine, presenting a wide range of problems concerning the method of cutting the mining workings, technology of ore production and extraction of gold, drying and water draining, history and archaeology of the mine and its connection with the historical fate of the fortress Perperikon near the village of Gorna Krepost.
- As an unique Monument of the Culture, with all problems connected with its clearing, study, restoration and preservation. Subject of preservation is not only the underground part of the mine, but also the surface one: dump-sites, open pits, terraces etc.

2. It is obvious that during the last stage of its existence the mine has served also as a hiding place, possessing especially prepared equipment to resist penetration of unwanted visitors. It should be expected that in its inaccessible and liable to clearing part, deep inside the massif, an abundant amount of archeological material is available. The time of transformation the mine into a hiding place most probably coincides with the decades preceding the arriving of the Turks to the Balkan peninsula.
3. It is necessary to carry out a purposeful complex study of the object in geological, archeological and historical aspects.
4. It is necessary to provide timely measures to protect the object. To stop the taking away of material from the dump-sites. To stop the development of new quarries for production of stones for construction purposes. To ban visits into the underground part of the mine by speleologists and treasure hunters. Huge damages were inflicted to the mine by military detachments which during the last decades have made many ditches for hiding of people and equipment. Huge damages were inflicted also by the Committee for Geology at the accomplishment of exploration programme during the period 1994 through 1998.
5. Even at this early stage of the ancient mine study, the making of a popular science film is appropriate.

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Recommended for publication by Department of Mineralogy and Petrography, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 97-100

RELATIONSHIP BETWEEN THE REFLECTANCE OF THE MACERAL GROUPS FROM COAL WITH DIFFERENT RANK

Anton Sotirov[1], Thomas Rainer[1], Jordan Kortenski[2]

[1] Institut für Geowissenschaften Montanuniversität Leoben, A-8700, Leoben, Austria

[2] University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria

ABSTRACT

The main purpose of the study was the determination of the ratios between the reflectance of the maceral groups of coal with different rank and the range of the reflectance of each maceral group with changing of the coal rank. The coal from different basins from Bulgaria and Slovenia were sampled and studied. The samples from each type of coal were studied and 60 points were measured of each sample. The following relationships between the reflectance of the maceral groups and the following ranges of the reflectance of each group were observed: 1) In the studied lignite the Liptinite macerals have reflectance, which vary in short interval and that interval is widest for the bituminous coal. The ratio of the reflectance Vitrinite/Liptinite (V/L) and Inertinite/Vitrinite (I/V) is equal (4.5). 2) The intervals of variation of maceral reflectance in the sub-bituminous coal are similar to the lignite, but the V/L=3.5 and I/V=3.5. 3) The intervals of variation of the reflectance of the macerals (especially Inertinite) for the bituminous coal are wider than the lignite and sub-bituminous coal and the ratios V/L=3.5 and I/V=2.5. 4)The intervals of variation of the reflectance of the Vitrinite and Inertinite macerals are largest in the anthracite and the ratio I/V = 1.5. The Liptinite macerals have most short interval of variations of the reflectance and this interval increase with the increasing of the coal rank. The Inertinite macerals have the widest interval of the reflectance values for each coal type. The Vitrinite maceral reflectance has middle settled values, but they are more similar values to the Liptinite macerals reflectance. The interval of variation of the reflectance increases for the Inertinite and Vitrinite macerals with the increasing of the rank (especially for the bituminous coal and anthracite). The average reflectance of the Huminite (Vitrinite) and Liptinite macerals is similar, especially for the lignite and the sub-bituminous coal. The graphics of the changing of the reflectance with the increasing of the coal rank is similar for the three maceral groups. The ratio I/V decreases with the increasing of the rank of the coal and its value decreases from lignite to anthracite with step of 1.0. Similar linear relationship is established for the ratio V/L from lignite to sub-bituminous coal, but the ratio V/L is not changed from the sub-bituminous to the bituminous coal.

Key words: reflectance of different macerals, reflectance ratios, lignite, sub-bituminous coal, bituminous coal, anthracite.

INTRODUCTION

Coal with different rank from Bulgarian and Slovenian basins was studied. The lignite from the Sofia Neogene basin, the sub-bituminous coal from the Pernik basin with Late Miocene–Early Oligocene age, the bituminous coal from Vremski Britov (South-East Slovenia) with Upper Cretacerous age and the anthracite from Drenov Griz (Central Slovenia) with Upper Triassic age were sampled.

The main purpose of the study was the determination of: 1) the relationships between the reflectance of the maceral groups of coals with different rank and 2) the change of the reflectance of each maceral group with the increasing of the rank of the coal.

MATERIALS AND METHODS

The coals from each type were sampled. They were prepared for microscopic investigations. Sixty points were measured for reflectance of the macerals of each sample. A microscope "Leica" with reflective light (λ=546 nm), objective 50x/0.85 (oil) and a computer program "Leica mpv_meas" was used. Gadolinium-gallium-granat with reflectance Ro=1.699% was used as a standard.

RESULTS AND DISCUSSION

The reflectance of the macerals from all groups increases with the increasing of the coal rank (Taylor et al., 1998). The reflectance of the Vitrinite macerals is intermediate (Stach et al., 1982). The ulminite and telocollinite show relatively gradual change with increasing rank of the coal (Veld et al., 1994) and usually they are the most measured macerals for the determination of the Vitrinite reflectance in the present study. The sporinite is most measured maceral from the Liptinite group. He is the prevailing maceral from that group in the studied samples. The fusinite reflectance is the most determined from the Inertinite group. Some samples are poor of Inertinite or Liptinite macerals. Alpern et al. (1970) report a diagram for the reflectance of different macerals of coal with different carbon content (respective different rank). This diagram shows that the reflectance of the macerals from the Liptinite and Inertinite groups (with an exemption of the semifusinite) not varies. The Vitrinite reflectance varies in coal with higher rank only. Hoover&Davis (Taylor et al., 1998) report similar diagram, which shows linear relationship between the reflectance of the vitrinite, macrinite, semifusinite and sporinite and the coal rank. The fusinite reflectance is very varied only. The reflectance of the macerals from all groups increases from lignite to anthracite (Fig. 1). The relationship in the ranges of reflectance for each maceral group in the coal with different rank is established in the present study (Fig. 1).

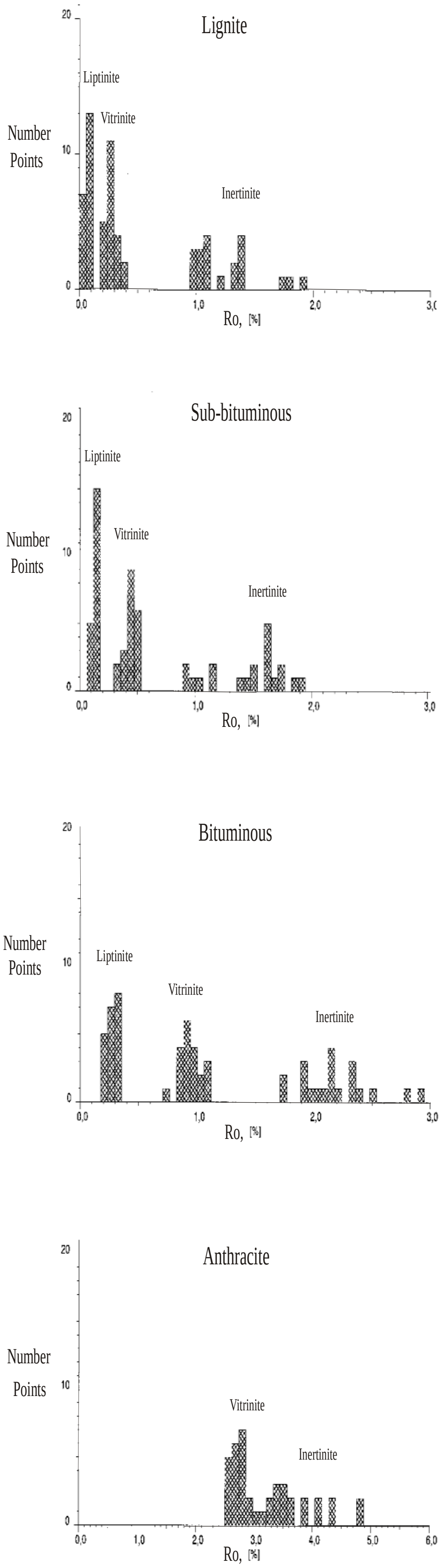

Fig. 1

Figure 1. Histograms of the reflectance Ro (%) of the macerals from the Liptinite, Vitrinite and Inertinite groups in coal with different rank.

Lignite. The reflectance of the Liptinite macerals varies from 0.03 to 0.11% (Fig. 1). The maximum value is higher than the minimum value about 3.7 times. The reflectance of the Huminite varies between 0.21 and 0.4%. The more measurements have low values (Fig. 1). The difference between the maximum and minimum value is about 2 times. The reflectance of the Inertinite macerals varies in wide interval (0.96-1.94%), but the most of the values are grouped at the interval 0.96-1.5% (Fig. 1).The maximum value is higher than the minimum value about 2 times. The average reflectance value of the Huminite is 4.5 times higher than the Liptinite and 4.5 times lower than the Inertinite (Fig. 3).

Sub-bituminous coal. The reflectance of the Liptinite macerals varies from 0.08 to 0.17%. The interval of the variation is short and the most of the measured points have higher reflectance (Fig. 1). The maximum value is higher than the minimum value about 2 times. The reflectance of the Huminite is higher than the same of the lignite and it varies from 0.33 to 0.54%. The rank of the Pernik coal is sub-bituminous A and the most of the measurements have higher values of the reflectance (Fig. 1). The interval of variation of the values is 0.19% (as much in the lignite) (Fig. 2) and the maximum value is about 1.6 times higher than the minimum. The Inertinite macerals have nearly the same interval of the reflectance (0.93-1.94%) as much in the lignite, but more of the measurements are grouped about 1.7% (Fig. 1). The maximum value is nearly 2 times higher than the minimum value. The average reflectance of the Huminite is about 3.5 times higher than the Liptinite and 3.5 times lower than the Inertinite (Fig.4).

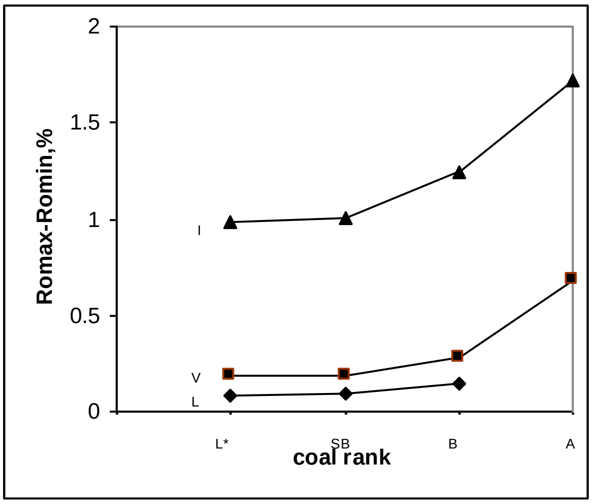

Figure 2. Plot for changing of the interval of reflectance values ($R_{o\,max}$-$R_{o\,min}$, %) of the maceral groups Liptinite, Vitrinite and Inertinite in coal with different rank.

Bituminous coal. The reflectance of the Liptinite macerals changes in wide interval (0.19-0.34%) and the most measurements have high values (Fig. 1). The maximum value is about 1.8 times higher than the minimum value. The Huminite reflectance is wider in comparison with the lignite and sub-bituminous coal (Fig. 1). The most of the values are below 1%. The ratio max/min value is about 1.5. The reflectance of the Inertinite is significantly higher and the interval of change of the values is very wide (1.76-3% - Fig. 1). The maximum value is higher than the minimum 1.7 times and the difference between them is higher than the lignite and the sub-bituminous coal (Fig. 2). The most of the measurements establish reflectance about 2% (Fig. 1). The Vitrinite macerals reflectance is 3.5 times higher than the Liptinite macerals and 2.5 times lower than the Inertinite macerals (Fig. 4).

Anthracite. The Liptinite macerals may not be observed with the traditional methods in the anthracites (Taylor et al., 1998) and they are not measured in the present study. The interval of the Vitrinite reflectance is wider (2.53-3.2%) and it has significantly higher value than in the other coals (Fig. 3). The most measurements are grouped in the interval (2.5-2.8% - Fig. 1). The maximum value is higher than the minimum value 1.3 times only. The Inertinite macerals have reflectance in wide interval – from 3.18 to 4.9%. (Fig. 2) and the measurements have uniform distribution into that interval (Fig. 1). The average value of the reflectance is much higher than the studied bituminous coal (Fig. 3). The ratio max/min value is 1.5 times. The average reflectance of the Inertinite macerals is about 1.5 times higher than the Vitrinite macerals (Fig. 4).

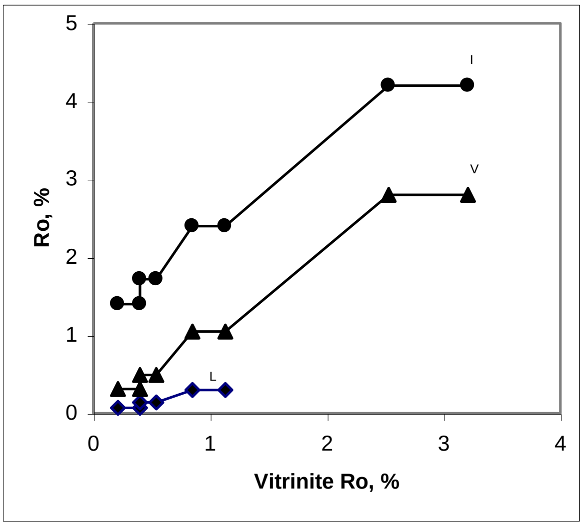

Figure 3. Plot for the changing of the average reflectance value of the maceral groups Liptinite, Vitrinite and Inertinite for coals with different rank.

The following relationships between the reflectance of the maceral groups in the coal with different rank are established. The differences between the maximum and minimum values of the maceral groups reflectance are similar (Fig. 2). The change is smaller for the lignite and sub-bituminous coal and it increases in the bituminous coal and anthracites.

The change of the average reflectance value of the three maceral groups with increasing of the coal rank is shown on the Figure 3. The graphics are similar. The reflectance values of the Liptinite and Vitrinite group are near. The Inertinite macerals have much higher reflectance and Taylor et al. (1998) were established this too. It is valid for coal with lower rank and the reflectance of the Vitrinite and Liptinite are very different. The difference between the average values of the Vitrinite and Inertinite reflectance is constant for coal with different rank.

The Figure 4 illustrates the relationship between the average reflectance of the three maceral groups with coals with different rank. The value of the ratio between the Inertinite and Vitrinite (I/V) is decreasing from lignite to anthracite and the relationship is linear. The relationship between the reflectance of the Vitrinite and Liptinite (V/L) is similar, but the ratio V/L is not changed from the sub-bituminous to the bituminous coal.

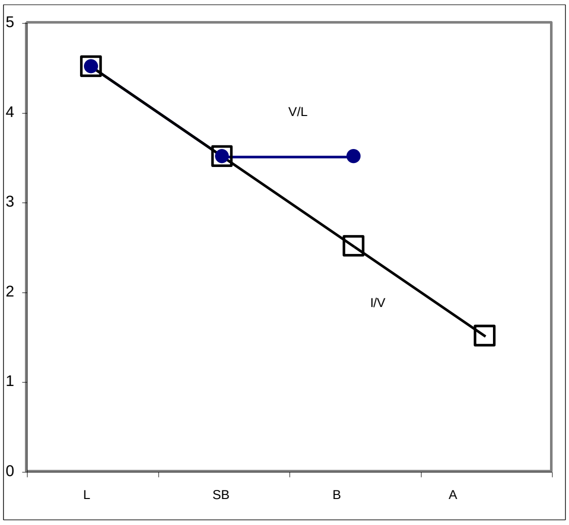

Figure 4. Plot for the ratios between the average reflectance values Vitrinite/Liptinite (V/L) and Inertinite/Vitrinite (I/V) for coals with different rank.

CONCLUSIONS

The following relationships between the maceral reflectance and the intervals of variation of their values were established:

1. In the studied lignite the Liptinite macerals have reflectance, which vary in short interval and that interval is widest for the bituminous coal. The ratio of the reflectance Vitrinite/Liptinite (V/L) and Inertinite/Vitrinite (I/V) is equal (4.5).
2. The intervals of variation of maceral reflectance in the sub-bituminous coal are similar to the lignite, but the V/L=3.5 and I/V=3.5.
3. The intervals of variation of the reflectance of the macerals (especially Inertinite) for the bituminous coal are wider than the lignite and sub-bituminous coal and the ratios V/L=3.5 and I/V=2.5.
4. The intervals of variation of the reflectance of the Vitrinite and Inertinite macerals are largest in the anthracite and the ratio I/V = 1.5.

The Liptinite macerals have most short interval of variations of the reflectance and this interval increase with the increasing of the coal rank. The Inertinite macerals have the widest interval of the reflectance values for each coal type. The Vitrinite maceral reflectance has middle settled values, but they are more similar values to the Liptinite macerals reflectance. The interval of variation of the reflectance increases for the Inertinite and Vitrinite macerals with the increasing of the rank (especially for the bituminous coal and anthracite). The average reflectance of the Huminite (Vitrinite) and Liptinite macerals is similar, especially for the lignite and the sub-bituminous coal. The graphics of the changing of the reflectance with the increasing of the coal rank is similar for the three maceral groups. The ratio I/V decreases with the increasing of the rank of the coal and its value decreases from lignite to anthracite with step of 1.0. Similar linear relationship is established for the ratio V/L from lignite to sub-bituminous coal, but the ratio V/L is not changed from the sub-bituminous to the bituminous coal.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 101-103

PHYSICAL ASPECTS OF OIL-RECOVERY IN SELANOVTSI TYPE OIL FIELDS

Vassil Balinov, Efrossima Zaneva-Dobranova

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria, E-mail: geoenergy@mail.mgu.bg

ABSTRACT
The Middle Triassic section in the eastern part of Lom depression (Selanovtsi, Marinovgeran) contains oil accumulations related to a specific type of natural reservoir. It was defined as "Selanovtsi" type. A typical representative is the homonymous Selanovtsi oil field. The general principles which characterize the mechanism and kinetics of oil extraction from fractured media are valid in the conditions of the "Selanovtsi" type oil field. There are a number of specific features arising from the particular geological setting and the characteristics of the stratified system; the model of the host space; the fluid saturation of different types of cavities and their communication; the behavior of bed energy; the expected phase transformations of the hydrocarbon system; the molecular nature of the hard surface, etc. The recovery of oil from the fracture system is controlled by the pressure gradients. The main driving forces in the matrix system are related to capillary phenomena, interbed depressions, the elastic properties of the fluids and the separation of gas from the oil. The possibilities to recover oil from "Selanovtsi" type oil fields are extremely limited and are controlled exclusively by the fracture system. The analysis and conclusions inferred from Selanovtsi field attain a more general significance and may be used for prognostication purposes.

INTRODUCTION

The Middle Triassic section in the eastern part of Lom depression (Selanovtsi, Marinovgeran) contains oil accumulations related to a specific type of natural reservoir. It was defined as "Selanovtsi" type (Balinov et al., 2002) on the basis of characteristic lithogenetic and petrophysical features which determine a considerable capacity and filtration potential of the reservoir (Balinov et al., 2002). Since the hydrocarbon accumulations are of industrial significance, the recovery efficiency of the petroleum resources in the "Selanovtsi" petroleum reservoir is of great practical interest. From this point of view, the physical aspects of the mechanism and the kinetics of the processes, which accompany the exploitation of the oil field, are of essential importance. The prognosis of these processes is based on detailed knowledge of important characteristics related to the particular geological setting and to a number of factors that control the stratified system.

The Selanovtsi oil field is a typical representative of hydrocarbon accumulations related to natural reservoirs of "Selanovtsi" type. It may be assumed that the mechanism of the processes, related to the recovery of oil, will in principle not differ from other fields which were formed in analogous or close geological setting. From this point of view, the analysis and conclusions inferred from Selanovtsi filed attain a more general significance.

SHORT NOTES ON THE SELANOVTSI OIL FIELD

The Selanovtsi oil field is located in the eastern part of Yarlovo-Selanovtsi swell and is related to a horst-brachianticline. The productive horizon is a complex, 20-25 m thick stratified body located in the upper part of Opletnya Formation (Anisian). This body comprises beds, interbeds and lenses of dominantly pelleted, pelleted-biodetrital and locally micritic limestones in complex spatial interrelations. The considerable lithogenetic diversity and specific development of post-depositional processes control the formation of cavities of diverse genesis, morphology and dimensions. They form two relatively autonomous fluid-saturated systems: fracture and matrix system (Balinov et al., 2001).

The fracture system is of general occurrence within the productive horizon. It is formed of micro- and macro-fractures of different generations, orientation (dominantly vertical) and scale (short, medium and long). Commonly, the fractures are complicated by open or partially mineralized irregular extensions. They form the filtration potential of the productive horizon (the permeability grades to several tens of md) but their capacity is relatively low. Their effective (oil-saturated) volume is estimated to be approximately $1,6.10^5$ m^3.

The matrix system comprises intergranular, fragmentary, intercrystall, relictic-peletted (moldic), relictic-fragmentary (vagues) cavities (pores and caverns) that link subcapillary pore canals and microfractures (partially or totally mineralized). They show irregular spatial distribution and specific relations to different rock types. Their capacity varies in a wide range ranging to 26% and more. At the same time, the matrix system is characterized by extremely low filtration properties (the permeability is rarely over 0,1 md). This indicates that there are no effective links between the matrix cavities and the filtrating fracture system (Balinov et al., 2001). The matrix forms the basic capacity potential of the productive horizon. Its effective (oil-saturated) volume is approximately 2,05.10^6 m^3.

The basic properties of the formation oil were estimated on the basis of the initial thermobaric conditions of the field: initial bed pressure – 29,63 Mpa and initial temperature – 95^{0}C. Under these conditions, the initial gas content (gas factor) is assumed to be 280 m^3/m^3; the saturation pressure – 265 Mpa and the volume oil formation factor – 1,88. Under the same conditions, the molecular weight is 215, the density – 596 kg/m^3, the dynamic viscosity – 0,520 cP, the compressibility factor – 3,3.10^3 1/Mpa.

According to molecular nature, the surface of the rocks, which form the productive horizon, is heterogeneous (Yordanov et al., 2001). The rocks with high oil saturation are dominantly hydrophobic and those with low saturation – dominantly hydrophilic. The high oil saturation of the fractures indicates that their walls are highly hydrophobic.

In hydrodynamic respect, the natural reservoir of the oil field is a closed system of relatively small dimensions. This controls its limited energy potential, the possible sources of bed energy and their interrelations in time. From this point of view, two periods of exploitation of the oil field may be conventionally divided: 1) a period of decreasing bed pressure, from the initial value (29,63 MPa) to the saturation pressure (26,5 Mpa); 2) a period of further decreasing bed pressure below the saturation pressure. During the first period, the bed energy is controlled by the elastic properties of the reservoir system. The regime of the oil accumulation is elastic-water drive controlled. During the second period, the gas dissolved in the oil contributes to the energy balance and the regime transforms into mixed.

MECHANISM OF OIL RECOVERY

The modern approach to appraise oil and gas recovery is based on the physical essence of the mechanism and kinetics of the processes which accompany the exploitation of the hydrocarbon accumulations. Their forecast suggests detailed knowledge of the specific features and characteristics of the reservoir systems as well as the role and significance of the diverse factors that control these processes.

These specific features, applied to the conditions of Selanovtsi oil field, are as follows: the model of the hosting space; the fluid saturation of the different types of cavities and their interlinks; the behavior of bed energy; the expected phase transformations of the hydrocarbon system; the characteristic molecular nature of the rock surface, etc. The model of the capacity volume (Balinov et al., 2001) is of decisive importance. According to this model, the productive horizon comprises two incorporated into each other, relatively autonomous and at the same time interacting systems – fracture and matrix system. In principle, the mechanisms of oil recovery from both systems is different and for this reason they will be discussed separately.

MECHANISM OF OIL RECOVERY FROM THE FRACTURE SYSTEM

During the first period of production, when the elastic properties of the bed system (elastic-water drive controlled regime) are the basic energy source, a process of displacement of the oil from the fracture system initiates as a result of the invading water. The limited capacity potential of the fractures creates conditions for a relative active inflow of sub-oil water into the oil accumulation. The process progresses with different intensity in fractures of different size (width). This creates favorable conditions for an dominate displacement into zones of higher filtration properties where macrofractures dominate (wells P-3, P-9, P-10, P-13, P-14). In other parts of the accumulation, where microfractures dominate (P-6, P-11), the rate of motion of the fluid system is lower. In this case, the capillary processes play a negative role due to the small width of the microfractures and their highly hydrophobic walls.

The oil recovery from the watered part of the fracture system, at optimum drainage conditions, is high and probably exceeds 90%. Some time later, depending on the hypsometric position of the well depth with respect to the oil/water contact and the specific features of the fracture system, conditions for water inflow may develop and later – the water content in the production of the wells may increase, including partial or complete watering. Consequently, in the end of the first period of exploitation of the oil field, the productive horizon will be irregularly drained due to the unequal displacement rate of the oil from different in size fractures.

The second period marks the beginning of gas breakout and transformation of the regime of the field into mixed. The gas, initially expanding in free space, is now in discrete state, under the form of gas bubbles. With increasing volume, they displacement part of the oil into the production wells. At the same time the displacement effect of the gas-containing water below the water/oil contact rapidly decreases due to the numerous capillary effects in the oil-gas dispersion system. This negative effect is very strong in microfractures in which the motion may practically stop. After the expansion of the volume of the gas phase, the latter becomes mobile and involves part of the less mobile oil in its dominate displacement motion to the production wells. The displacement effect of the oil-gas mixture from the water below the oil/water contact continues to be small due to the rapid decrease of the mobility of the fluid system under the conditions of three-phase filtration. The combination of unfavorable factors leads to worsening of the production characteristics of the wells, including water cut and as an end effect – to a decrease of oil production from the fracture system.

MECHANISM OF OIL RECOVERY FROM THE MATRIX SYSTEM

This mechanism is in principle different from that described for the fracture system. Due to the low conductivity of the matrix, the latter does not participate independently in the filtration processes but interacts with the fractures. In this interaction, lower rates of the pressure gradient in the matrix should be expected as compared to the fractures and as a result – late separation of gas from the oil in the matrix.

If we take into consideration the specific features of Selanovtsi oil field, it may be assumed that the main forces which provoke or hinder oil recovery from the matrix are: capillary processes; inerformation depressions; elastic properties of the fluids and the rock; separation of gas from the oil.

The processes of capillary displacement may develop after watering of the fluid system at high oil saturation of the matrix and dominantly hydrophilic hard surface. The possibilities to extract oil by capillary way are extremely limited for the following reasons: dominantly hydrophobic properties of the matrix in domains of high oil saturation and its relatively low oil saturation in domains with dominantly hydrophilic properties; different size of the cavities, forming a system of complex morphology in which the capillary displacement is not effective; negative influence of the expanding free gas phase.

The inerformation depressions are a result of higher rates of bed pressure drop down in the conducting fracture system as compared to those in the heavy-permeable matrix. For this reason, an increasing in time depression forms between the two systems. This creates conditions for “outflow” of part of the oil towards the fractures. Relatively better possibilities for this process exist in domains with high oil saturation of the matrix, the permeability of which is relatively higher or in case of the presence of linking local micro fractures. After the beginning of the liberated from saturated oil of gas from the formation oil, the process is hampered or impossible.

With decreasing bed pressure, the elastic energy of the matrix system becomes the main factor. The existing imperforation depression favors the outflow of additional quantities of oil corresponding to the elastic resource. Also in this case, the separation of gas from the oil has a negative influence on its mobility.

In the course of the development of the oil field, the above mentioned moving forces occur simultaneously, with different and variable intensity but as a final result they will not lead to extraction of considerable quantities from the matrix (the oil recovery coefficient hardly could exceed 10%). Due to the low conductivity of the matrix, the gas which separates from the oil hinders the processes of oil extraction to its full stop in the conditions of a three-phase fluid system.

Consequently, the major extractable quantities of oil from Selanovtsi oil filed are contained in the fracture system. The contribution of the matrix system is extremely limited and will come into effect within a considerable period of time during the development of the oil field, including also the period after the full drainage of the fracture system.

CONCLUSIONS

The general principles which characterize the mechanism and kinetics of oil extraction from fractured media are valid in the conditions of the “Selanovtsi” type oil field. However, there are a number of specific features arising from the particular geological setting and the characteristics of the stratified system. The above analysis leads to the following conclusions.

1. The fracture system forms a unified in hydrogeodynamic respect conductive medium of relatively low capacity. The displacement of the oil is a result of the influence of sub oil water and the existing pressure gradients. The behavior of the bed energy and the related phase transformations hinder the full realization of the capacity potential.
2. The matrix system has a high capacity potential which is controlled by the presence of cavities, commonly with large dimensions. Its realization, however, is insignificant due to the low effectivity of the bed energy, the hindered communication between the cavities and the fracture system, and the specific mechanism of oil extraction.
3. The possibilities to extract oil from oil fields of “Selanovtsi” type are extremely limited and are related exclusively to the fracture system. Consequently, taking into account the effective (oil saturated) volume of this system, the volume coefficient of the oil and the possible coefficient of oil recovery, the extractable quantities in the period of effective production will not exceed 50-60 thousand tons which is approximately one third of its effective volume.

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Recommended for publication by Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 105-108

COMPREHENSIVE APPROACH FOR 3D SIMULATION BY MATHEMATICAL MODELING OF GROUNDWATER CONTAMINATION

Nikolay Stoyanov, George Ajdanlijsky

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria, E-mail: nts@staff.mgu.bg; ajdansky@staff.mgu.bg

ABSTRACT

Development of precise models for predicting and managing processes of groundwater contamination as a result of a number of natural and technogenic factors (mining activity, industry, agriculture, sanitary landfills, etc.) requires more detailed knowledge on the structure and morphology of aquifers. Some of the aquifers are located in sediments and sedimentary rocks of significant heterogeneity of the lithological properties, causing a rather high heterogeneity of porous medium. Past practice of mathematical modeling has not considered realistically enough the rate and specifics of this heterogeneity.

In recent years, sedimentology of aquifers acquires higher importance in the compilation of 3D prediction models. This comparatively new approach allows the application of a set of direct and indirect "in situ" and laboratory sedimentological, stratigraphic and geophysical methods, which allow the correct differentiation and definition of lithofacial and architectural-element units of different rank and scale. Each of them is characterized by relative inner homogeneity of hydrodynamic and migration properties. Thus, the differentiation of zones and layers simulating the correct hydrogeological conditions is allowed easily and precisely enough by compilation of numerical 3D models.

The comprehensive approach was successfully tested at the Plovdiv sanitary landfill.

INTRODUCTION

Groundwater is the main object of technogenic contamination and potential carrier of different contaminants. Hydrogeological conditions in the area of potential (or real) source of contamination are the major factor, limiting the behaviour of contaminants within the underground hydrosphere. For that reason good recognition and correct simulation of particular hydrogeologic medium is so important.

HETEROGENEITY OF POROUS MEDIUM AND OPPORTUNITES FOR ITS CORRECT SIMULATION

Aquifers (groundwater reservoirs) are often formed in non-homogeneous sediments and sedimentary rocks. Lithologic heterogeneity determines the significant variety in dimensions and geometry of porous medium and regularly brings to area variation of hydraulic and migration characteristics of water-bearing (saturated) medium. Unfortunately, simulation approaches for compilation of flow and mass-transport models has not considered yet the rate and specifics of this heterogeneity realistically enough. This fact predetermines the inaccuracy of prediction models and subsequent efforts for their elimination.

Recent practice widely applies several approaches for modeling the movement of contaminants in aquifers: simplified, stochastic and deterministic.

The simplified approach is based on the adoption that saturated medium is relatively homogeneous (quazihomogeneous) in the aspect of hydrogeological parameters. Each of the water-bearing layers, consisting of several aquifers and aquitards is considered quazihomogeneous and horizontal. In the simplified approach the distribution of conservatives (inert) contaminants in the aquifers is described well by the convection-disperse equation (Bear, 1972). Behaviour of contaminants with water-bearing medium is modeled by mathematical dependencies, describing the kinetics of processes of reversable and non-reversable elimmination (Bear, 1979; Freeze and Cherry, 1979). The reversible elimination (sorption-desorption) is described by the linear isoterm of Henry and is characterized by the coefficient of distribution K_d, with sorptional porosity n_S, respectively. Non-reversible elimination (hydraulitic decay and precipitation) is determined by the reaction of non-reversible elimination of first order and by the elimination constant γ. It is worth mentioning that this approach, widely applied in the past, may be used (with a sufficient precision) in a very limited number of cases and significant schematization of the hydrogeological background. It is valid within a local scale and a homogeneous media only.

The stochastic approach is developed and widely used in practice in the last 20 years. Movement of contaminants in the non-homogeneous medium is described by area correlation of random fields (Dagan, 1989; Gelhar, 1993) or by fractal distribution, laid over homogeneous or slightly varying trends (Wheatcraft and Tylor, 1988). Considerations are based on the adoption that area variation is small. This brings to the negligence of real existence of lithofacial and architectural-element units of different rank and size, which in fact determine the inner and outer boundary conditions in the flow area and strictly frame the possible ways for distribution of contaminants. No doubt, possible movement of contaminants is correctly modeled mathematically only after precise determination of sedimentologic interconnection of different scale.

The deterministic approach pretends to simulate the real heterogeneity of natural objects with a maximum reliability. 3-D objects, homogeneous with respect to hydraulic and migration characteristics (layers and zones) are differentiated and described in the subsurface area. Objects, determined by this approach are treated as main architectural elements of the water-bearing structures. Movement of contaminants is described precisely enough by the mathematical means, applied by the simplified approach within each quazihomogeneous object. In the compilation of regional mathematical models for prediction of groundwater contamination, each element is included as a 3-D object with established geometry and properties (hydraulic conductivity k, dispersivity α, effective and sorptional porosity n_0 and n_S, elimination constant γ etc.). In this case software packages MODFLOW and MT3D, standardized by USGS and EPA and widely applied in the world practice may be used (Andersen, 1993; McDonald и Harbaugh, 1988; Zheng, 1990 et al.).

The application of traditional hydrogeological means and vehicles to the deterministic approach most often brings to difficulties. The attempts to determine 3-D objects based on statistical processing of results from “in situ” and laboratory filtration (hydraulic) tests (Боревский и др., 1973, Мироненко и Шестаков 1976, etc.) showed that investigations of that kind might have only theoretical importance and did not reveal any specific meaning for practice as statistical methods required performing of numerous tests in different points of the subsurface area which would bring to unreasonably high financial cost.

A modification of the deterministic approach, new for hydrogeological practice and recognized in specialized references as aquifer sedimentology (Huggenberger and Aigner, 1999) has recently shown its advantages. This sedimentological approach comprises a set of direct and indirect “in situ” and laboratory sedimentological, stratigraphic and geophysical methods, which allow the direct determination of lithofacial and architectural-element units of different rank and scale (size). Each of those units is characterized with relative homogeneity of hydrogeological characteristics. The approach allows compilation of a good and rather precise 3D model, showing the natural heterogeneity of medium by a limited number of laboratory and field hydrogeological tests. Reliability of prediction model depends much on precise correlation between hydraulic and migration characteristics and existing 3D variation. However, cost efficiency and other practical concerns usually limit the number of exploratory and hydrogeological tests, which reduces the precision of simulation. This fact may not decrease the importance of suggested approach as the ratio of (financial cost)/(precision of prediction) may be optimized for each specific object depending on its significance. In some cases, below suggested dependence of correlation between hydraulic conductivity and size of grains of prevailing fraction and rate of sorting may be used purposefully for preliminary assessments and predictions.

SEDIMENTOLOGY OF WATER-BEARING STRUCTURES

As it has already been mentioned, the sedimentological approach has been successfully applied to hydrogeological issues. Often, especially when located in fluvial deposits, aquifers reveal a wide spectrum of lithological and lithofacial variability, which significantly predestinates the hydraulical and migration properties of medium. Recently many attempts to characterize and systematize qualitatively and quantitatively those heterogeneity by the form of a hierarchic system have been done (for example van de Graaff and Ealey, 1989; Dreyer, 1993). According to Huggenberger and Aigner (1999), within such hierarchic scheme of the degree of the lithological heterogeneity, the individual subdivisions could be treated as both genetic sedimentologic units and hydrogeologic units, for exapmle:

- Giga-scale lithological heterogeneity, determined by development of sedimentary basin. It controls the confinements and inner structure of entire water-bearing basins;
- Mega-scale lithological heterogeneity, determined by the type of sedimentary environment. It characterizes the area interrelations of aquifers and complexes in the water-bearing basins;
- Macro-scale lithological heterogeneity, determined by local facial dynamics of sedimentary accumulation. It determines the morphology and inner structure of individual aquifers and aquitards;
- Meso-scale structural and textural variations, related to sedimantary dynamics. It subdivides aquifers into zones of different hydrogeologic characteristics;
- Micro-scale differences in petrology, porosity and permeability, related provenance and diagenesis. They control the processes of filtration and mass-transport at a micro level (in the pore channels).

The architectural-element analysis is among the main tools for implementation of macro- and mezo-scale investigations in sedimentology of aquifers, located in fluvial sequences. The method is based on the comprehension that fluvial sedimentary sequences are composed of eight constructive units, nominated as “architectural elements” (Allen, 1983; Miall, 1985, 1988). Their identification and characterization is possible in large two- and three-dimensional outcrops. The definition of these architectural elements is based on both their outer morphology, determined by the character of their confining surfaces, and organization of their inner structure. Those features reveal the different style and dynamics of sedimentary body generation and in most cases are related to morphologic features of dimensions of the complex sedimentary macroforms. Despite of some variations in their characteristic, it is accepted that most fluvial depositions are composed of those eight elements in different proportions.

The architectural element description and definition comprise:

- Nature and morphology of confining surfaces;
- Unit scale: thickness, lateral (parallel and perpendicular to the direction of the sedimentation paelotransport) development;
- Outer unit geometry;
- Inner structure of the unit: lateral and vertical lithofacial assemblages and sequences, presence and orientation of low-rank erosion surfaces, orientation of the indicators of the sedi-

mentary paleotranspot, interaction of bedding in respect of the limiting surfaces.

The application of architectural-element analyses to the study of fluvial sequences simplifies significantly their sedimentological modeling thus increasing precision and sustainability of prediction mathematical model.

COMPREHENSIVE APPROACH FOR SIMULATION OF 3D MEDIUM IN THE MATHEMATICAL MODEL OF GROUNDWATER CONTAMINATION IN THE AREA OF PLOVDIV SANITARY LANDFILL

The sanitary landfill of Plovdiv is developed in Quaternary and partially Neogene loose, mainly alluvial sediments. The uppermost part of the sedimentary section in and around the landfill is represented of four fluvial cycles, located one above the other. The thickness of the separate cycles is within the range of 8-13 m showing lateral variations. Only the uppermost of these cycles outcrop on the surface, however, due to the character of sediments its exposure is rather limited. That is the reason, instead of the standard approach for architectural-element analysis, in a larger part of the area the acquiring of the necessary for the analysis data to be reduced to:

- Studying the vertical lithofacial sequences;
- Systematic measuring of all types of indicators in the direction of sedimentary paleotransport;
- Detailed study of morphology and orientation of limiting surfaces of individual lithofacial units.

As a result 10 lithofacial varieties and 6 types architectural elements are identified and characterized. The description of architectural elements in the present study is based on the proposed by Miall (1996) scheme with some changes and additions.

Groups of carefully correlated outcrops, located in a cross and longitudinal direction of dominating paleotransport trends are studied for achieving of correct model of the fluvial depositions. The acquired data have been used for interpreting the results of numerous exploratory boreholes in the area. A network of profiles, which illustrate the area distribution of separate fluvial cycles and comprise the entire territory of the landfill, is developed. Within each fluvial cycle the spatial interrelations of constructing architectural-elementary units are illustrated.

Based on numerous grain-size analyses, the degree of sorting of the sediments in each separate lithofacial unit is determined, and hence – in the architectural-elementary units that they compose. The representation and analysis of grain size data in standard phi-scale allows hydraulic and genetic interpretation of the studied sedimentary bodies.

A correlation diagram (Fig. 1) is compiled on the base of the relations between granular characteristics and rate of sorting of sediments, on one hand and hydraulic conductivity on the other, which many authors have obtained, (according to Виссмен, и др., 1979; Де Уист, 1969; Daly, 1982; Davis and DeWiest, 1966; Morris and Johnson, 1967,etc). It allows interpreting of lithofacial and architectural-elementary units as hydrogeological units (aquifers and zones of particular geometry and characteristics). At first approximation, two aquifers and one aquiclude are determined in the subsurface area of the Plovdiv sanitary landfill area. Zones of different penetration are differentiated in the aquifers, and a number of interruptions, so called hydrogeological windows, are localized in the clayey aquiclude.

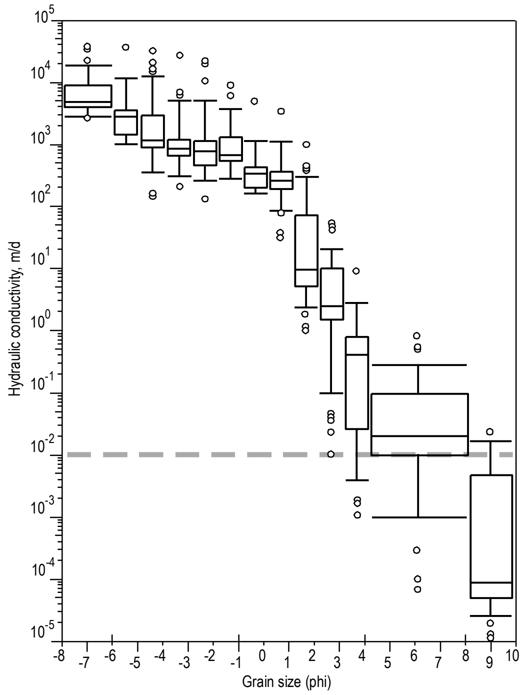

Figure 1. Correlation box-diagram of the type of sediments and hydraulic conductivity. Dotted line shows the boundary between permeable and practically impermeable sediments. Circles show the values, typical for well-sorted and poorly sorted varieties.

Each layer and zone acquires values of characterizing hydraulic and migration parameters based on data from laboratory and "in situ" filtration and traser tests. Thus, a rather precise 3-D model of subsurface area in the region of Plovdiv sanitary landfill is compiled. This model is successfully applied by the authors for precise simulation of aquifers and zones (potential medium for distribution of contaminants) in the filtration field for compilation of mathematical models for prediction of processes of groundwater contamination in the landfill.

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Recommended for publication by Department of Hydrogeology and Engineering Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 109-116

ELEMENTS OF THE GEOLOGIC STRUCTURE OF THE BELASITSA-OGRAZHDEN BLOCK ACCORDING TO GEOPHYSICAL DATA

Stefan Dimovski, Sergei Sevdanov

University of Mining and Geology “St. Ivan Rilski”, Sofia 1700, Bulgaria, E-mail: dimovski@staff.mgu.bg; sergo@staff.mgu.bg

SUMMARY

In the territory of Bulgaria, to the Belasitsa-Ograzhden block as a part of the Serbian-Macedonian block, are related parts of the Belasitsa Mountains, the Ograzhden Mountains and the Malashevska Planina Mountains. The block is limited to the east by the Strouma fault system, to the north and northeast - by the Kadiytsa-Breznitsa fault zone, to the south - by the Middle-Mesta fault zone which controls the south edge of the Belasitsa horst in Greece. To the west the block continues in Macedonia, where it is bounded by the Sasa-Toranitsa fault zone.

A negative background characterizes the observed gravitational field of the territory under study. The Belasitsa-Ograzhden block is bounded by two very well pronounced gravity transitions. It is limited to the east by the Strouma gravity transition, tracing the western edge of the Strouma rift structure. This transition is striking S35°E and has a stable horizontal gradient of 8-10 mGal/km along its entire length of about 30 km. The block northern border is the Breznitsa gravity transition B-B, that is almost perpendicular to the Strouma one.

The studied area gravitational field is characterised by a regional trend positive to the south, starting from the Breznitsa gravity transition towards the two opened to Greece anomalies. The presented field distribution rose-diagram (excluding the areas of the Strouma and the Breznitsa gravity transitions) shows three dominant directions : a subequatorial one, one striking N(45°-60°)E and one striking S35°E. These three directions correlate well with the concept of development of longitudinal and transverse fault deformations along the rift structures periphery.

The local field characteristics are analyzed according to the residual fields derived from the regional transforms and according to the variation anomalies compiled from the center-point and ring method of Griffin using a circle of radius R = 5 km.

The observed geomagnetic field of the studied territory is characterised by negative background values within the limits of -100 and -150 nT. On this background two anomalies can be separateded. A pronounced positive anomaly is very obvious in the northern part. A negative anomaly is present in the southwestern part of the map. It has an intensity of about -300 nT, and remains opened to the south. The subequatorial direction (90-110°) is predominating on the presented rose-diagram. The two other directions observed are one striking roughly S45°E and one striking roughly N45°E.

The compound analysis and systematization of the studied geophysical fields and other characteristics is the reason for some basic conclusions. The Strouma gravity transition is pronounced without ambiguity in all regional and local gravitational fields. The transition characteristics in the regional maps, which are reflecting the depth interval 3-10 km, are showing that it dips west. In the local fields maps, this gradient zone is tracing the Ograzhden fault limiting the Strouma fault zone to the west The fault-block tectonics have predominant influence in the depth interval 3-10 km. The Lebnitsa, the Southern-Ograzhden, the Podgoritsa, the Kolarovo and the Petrich gravity transitions are forming the block division of the studied territory. The Northern-Igralishte and the Klyuch negative anomalies are mapping relatively deep granitoid plutons. The geophysical fields main characteristics in the depth interval down to about 3 km are mapping the near-surface disposition of plutons, reflected by the Northern-Igralishte, the Igralishte, the Nikoudin and the Klyuch negative anomalies. The areas having increased thickness of the metamorphites are separated by positive anomalies. The Stroumeshnitsa graben and especially the areas having increased thickness of the decompressed sedimentary rocks that are filling it are mapped very well by negative anomalies. In the studied near-surface interval, gradient transitions are tracing faults of two main systems - the Lebnitsa system and the Stroumeshnitsa one. The analysis of the main elements of the geologic-geophysical structure in the Belasitsa-Ograzhden block is showing that the studied block has been developing under the direct influence of the rift processes in the regional Strouma rift structure. These processes and their performance are reflected mainly in fault deformations transverse and oblique to the Strouma rift system. In the Bulgarian territory the Belasitsa-Ograzhden block has been developing under the direct influence of the rift processes in the regional Strouma rift structure. These processes and their performance are reflected mainly in fault deformations transverse and oblique to the Strouma rift system, which are successfully mapped by well-pronounced gravity transitions.

INTRODUCTION

In the territory of Bulgaria, to the Belasitsa-Ograzhden block as a part of the Serbian-Macedonian block, are related parts of the Belasitsa Mountains, the Ograzhden Mountains and the Malashevska Planina Mountains (Boyadzhiev, 1971; Ignatovski, 1968; Ignatovski, 1969a; Ignatovski, 1969b; Zagorchev, 1970a; Zagorchev, 1970b; Zagorchev and Dinkova, 1991; Zagorchev, 1992).

The block is limited to the east by the Strouma fault system, to the north and northeast - by the Kadiytsa-Breznitsa fault zone (the Breznitsa fault or the Gradeshnitsa fault), to the south - by the Middle-Mesta fault zone which controls the south edge of the Belasitsa horst in Greece. To the west the block continues in Macedonia, where it is bounded by the Sasa-Toranitsa fault zone.

The Belasitsa-Ograzhden block is composed mainly by the Archaic structural complex. The Caledonian-Hercynian intrusive complex has a relatively small participation. During the Upper-Alpine stage, in the Stroumeshnitsa graben and the Strouma graben, respectively in the southern and eastern block flanks, the Neogene-Quaternary substage is superimposed.

The Archaic structural complex builds almost entirely the situated in the Bulgarian territory parts of of the Belasitsa

Mountains, the Ograzhden Mountains and the Malashevska Planina Mountains. It is presented by the Archaic metamorphic complex, that is divided into three suites composed mainly by gneisses, granite-gneisses, shales and amphibolites.

The Ograzhden-Malashevski anticlinorium and the Belasitsa horst are well pronounced in the Precambrian structural plan.

The Ograzhden-Malashevski anticlinorium has a monoclinal character. It consists of rocks of the Archaic metamorphic complex, among which are intruded the Igralishte pluton and many other smaller granitoid apophyses.

The Belasitsa horst is also a monoclinal block, built by rocks of the Archaic metamorphic complex. Among them are intruded metamorphosed granitoids. The development of stock-wise apophyses of granites of the Southern-Bulgarian type, as well as the presence of small bodies of granitoids of the Pirin type are observed in the northwestern portion of the horst.

The Caledonian-Hercynian intrusive complex is composed by the Southern-Bulgarian granites and the relatively younger Pirin granitoids. The Southern-Bulgarian granites are building the Igralishte pluton and many smaller apophysic bodies situated along the northern border of the Belasitsa horst. The Pirin granites are building some small stock-wise bodies in the northern slope of the Belasitsa Mountains.

Neogene-Quaternary sediments are presenting the Alpine structural stage and fill entirely the Stroumeshnitsa graben and the Strouma graben. They consist of Pliocene deposits (of molasse character) which have a thickness of over 1000 m in the Strouma basin, of Pliocene volcanics (trachyandesites, andesite and dacite vein-bodies, tuffs), and of Quaternary eluvial, alluvial, proluvial and hybrid sediments.

The fault structures in the Belasitsa-Ogralden block are presented by the Lebnitsa fault zone, which has a predominant direction of 330^{o} and by one relatively smaller cross-fault zone having direction of 90-100^{o}, which has the Petrich fault and the Stroumeshnitsa fault as typical members.

The Lebnitsa fault zone is a direct continuation of the southern branch of the Sasso-Toranitsa deep-seated fault zone. Many volcanic bodies and zones of big hydrothermal changes, situated along the northeast flank of the Igralishte pluton, are connected to it.

Between the Ograzhden-Malashevski anticlinorium and the Belasitsa horst is situated the Stroumeshnitsa graben, which is formed during the Upper-Alpine stage and consists of Pliocene-Quaternary sediments.

The performed studies, presented in this report, include a detailed analysis of the gravitational field and its transforms and of the magnetic field, aimed mainly towards determination of the density and magnetic inequalities distribution in the surveyed territory.

The basic rock types building the geological section of the Belasitsa-Ograzhden block are well differentiated with respect to their density (Dobrev , *et al*., 1989).

The different types of gneisses, which are widely spread in the studied region, have increased density. By the relatively lowest density are characterized the granitizated gneisses (2,62-2,65 g/cm^{3}), the density of the biotite-gneisses is higher (2,66-2,68 g/cm^{3}), and the highest density have the amphibolite-gneisses (2,69-2,81 g/cm^{3}). The granitoids are characterized by relatively low density having values within the limits of 2,58-2,66 g/cm^{3}. The density of the sedimentary rocks building the graben structures is decreased - 2,35-2,53 g/cm^{3}.

The outcropped gneisses, granitoids and sedimentary rocks are non-magnetic. The magnetic susceptibility of the Pliocene volcanics, presented mainly by trachyandesites and vein-bodies composed of andesite, is increased and has values up to n.10^{-3} SI.

CHARACTERISTICS OF THE GRAVITATIONAL FIELD AND ITS RELATIONSHIP TO THE GEOLOGIC STRUCTURE

A negative background (Fig.1) characterizes the observed gravitational field of the territory under study.

The studied Belasitsa-Ograzhden block is bounded by two very well pronounced gravity transitions.

It is limited to the east by the Strouma gravity transition A-A, tracing the western edge of the Strouma rift structure. This transition is striking S35^{o}E and has a stable horizontal gradient of 8-10 mGal/km along its entire length of about 30 km. The northern border of the Belasitsa-Ograzhden block is the Breznitsa gravity transition B-B, that is almost perpendicular to the Strouma one.

The studied area gravitational field is characterised by a regional trend positive to the south, starting from the Breznitsa gravity transition towards the two opened to Greece anomalies. The presented field distribution rose-diagram (excluding the areas of the Strouma and the Breznitsa gravity transitions) shows three dominant directions : a subequatorial one, one striking N(45^{o}-60^{o})E and one striking S35^{o}E (Fig.1). These three directions correlate well with the concept of development of longitudinal and transverse fault deformations along the rift structures periphery.

The gravitational field regional characteristics are analyzed according to the upward continuations at height H = 3 km and H = 10 km, and according to the average values for circle radius R = 15 km.

The regional fields are reflecting the predominant influence of the depth interval under about 10 km (the upward continuation at height H=10 km), under about 7 km (the average values for circle radius R = 15 km), and under about 3 km (the upward continuation at height H = 3 km).

The regional gravity background of the Belasitsa-Ograzhden block in the Bulgarian territory is expressed by a negative gravitational field that includes the peripheral parts of the gravity transitions limiting the Rila-Western Rhodope megablock.

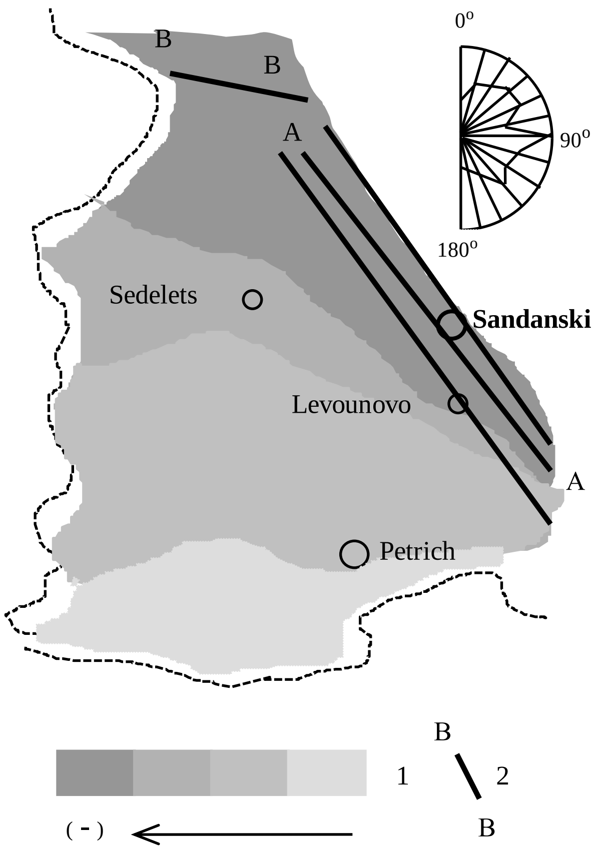

Figure 1. Compound scheme of the observed gravitational field distribution with included elements of the regional fields and a rose-diagram of the field isolines orientation.
1 – field distribution zoning – the arrow shows the direction of increase in the negative intensity;
2 – axes of regional gravity transitions:
A-A - Strouma regional gravity transition mapped at the following depths starting form east to west respectively:
under about 10 km,
under about 5 km
under about 3 km;
B-B – Breznitsa regional gravity transition

The compound regional scheme for the studied block is illustrated in Fig.1. The eastern border is the Strouma gravity transition A-A, that is tracing the Strouma fault zone. This regional gravity transition has a length of about 30 km and stands out boldly on all regional field maps. According to the field of average values for circle radius R = 15 km, it is characterized by a horizontal gradient of 2 mGal/km and a width of about 6 km. The analysis of the transition behavior in regional maps, reflecting depth interval 3-10 km, shows that it dips west about 70-80°.

The northern border of the Belasitsa-Ograzhden block is the Breznitsa gravity transition B-B, that is almost perpendicular to the Strouma one.

The studied area regional gravitational field is characterised by an increase in the gravitational force to the south of the Breznitsa gravity transition. This is a reflection of the depth decrease towards the regional density boundary – the Moho discontinuity.

The local field distortions are due to the structural-tectonic non-uniformity of the studied block.

The local field characteristics are analyzed according to the residual fields derived from the regional transforms and according to the variation anomalies compiled from the center-point and ring method of Griffin using a circle of radius R = 5 km.

The residual anomalies derived from the upward continuation at height H = 10 km (Fig.2) show, on a negative background, the distribution of the differentiated with respect to their density media to a depth of about 10 km.

The Strouma A-A, and the Breznitsa B-B gravity transitions are mapping without ambiguity the deep-seated fault zones. The field values are increasing to the south with about 22 mGal. Many relative anomalies can be isolated on this background.

The positive anomaly 1 is situated in the central part of the area. It is opened to the west and is mapping rocks having increased density. In the southeastern portion of the studied territory is separated the positive anomaly 2 that remains opened to the south. The positive anomalies 1 and 2 are situated along an axis that is almost parallel to the Strouma gravity transition. Southwest of these anomaly zones, two smaller positive anomalies 3 and 4 are formed.

In the most western part of the area, the Klyuch negative anomaly 5 is located. It remains opened to the west and to the southwest, and most probably is related to the intrusion of granites having relatively lowered density among the gneisses.

Local gravity transitions are mapping the fault tectonics characteristics.

In the northern part of the area, the gravity transition a-a is tracing the Brezhani fault. Next to Levounovo, northwest of the Strouma regional gravity transition A-A, is formed a gravity transition of a lower order b-b. It reaches Sedelets, and is tracing the Lebnitsa fault.

The Southern-Ograzhden gravity transition c-c is striking N80°E and is separating the central anomaly 1 from the southern ones 2, 3 and 4. This transition, compared to the Strouma one, is of a lower order, and is mapping a fault almost transverse to the rift. It divides the Belasitsa-Ograzhden block into two parts – a northern and a southern one.

The Petrich gravity transition f-f is tracing a fault separating the two southern positive zones. Gravity transitions of the lowest for the studied depths order – d-d and e-e – are detailing the internal faulting of the southwestern block into two parts – positive anomalies 3 and 4.

The compound analysis of the residual field distribution derived from the upward continuation at height H = 10 km indicates that, in the depth interval down to about 10 km, the faults and the separation of the Belasitsa-Ograzhden block are connected to the processes in the Strouma rift structure. The transverse faults of Lebnitsa b-b and Southern-Ograzhden c-c, and the oblique one of Petrich f-f, are forming the main internal-block faulting of the studied territory.

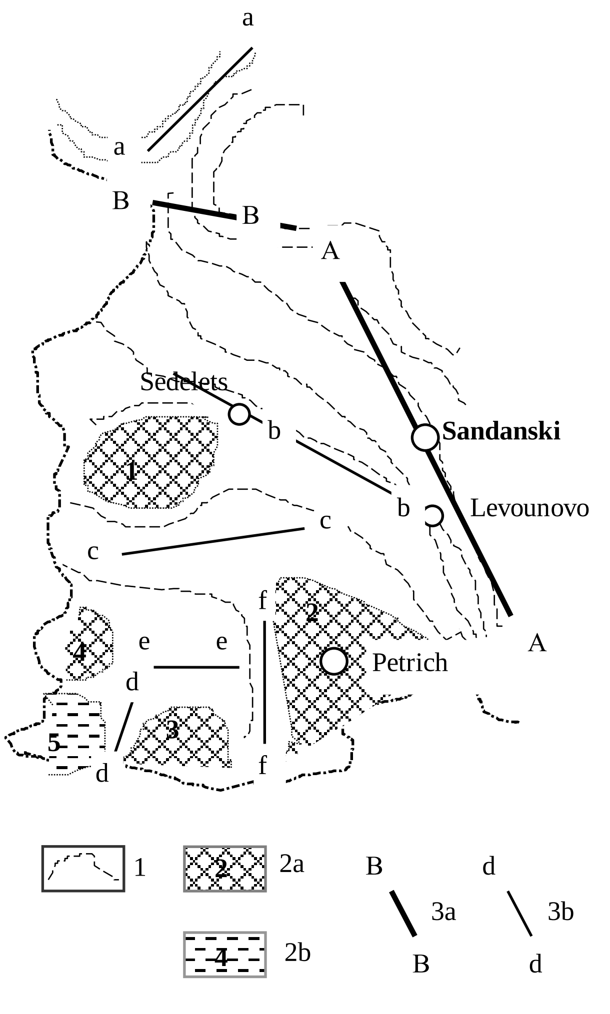

Figure 2. Scheme of the residual gravitational field distribution, derived from the upward continuation at height H = 10 km
1 – field isolines (negative);
2 – relative field anomalies:
2a - positive;
2b - negative;
3 – axes of gravity transitions:
3a - regional;
3b - local

The residual field derived from the upward continuation at height H = 3 km is illustrated in Fig.3. It reflects the density distribution in the depth interval down to about 3 km.

The Strouma gravity transition A-A is mapped very well, and is moved about 2,0-2,5 km to the west, in comparison with the residual field derived from the upward continuation at height H = 10 km. In this map, the transition is tracing the western border of the Strouma fault zone – the Ograzhden fault (Zagorchev, 1992).

The Breznitsa gravity transition B-B has no distinct presence, but only distorts the field distribution. This fact shows that at small depths the fault mapped by this transition has a weaker performance as density non-uniformity.

The well-pronounced Lebnitsa gravity transition b-b is very obvious in the map. The Southern-Ograzhden gravity transition c-c is also confidently traced. It isolates a well-expressed negative anomaly 6. Most probably, this anomaly maps a granite core.

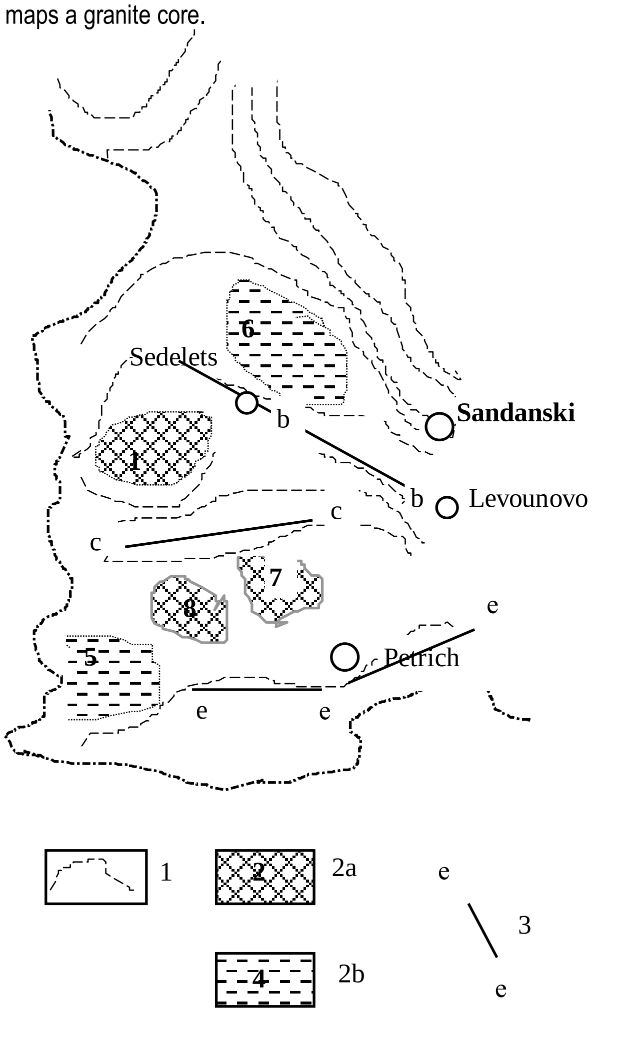

Figure 3. Scheme of the residual gravitational field distribution, derived from the upward continuation at height H = 3 km
1 – field isolines (negative);
2 – relative field anomalies:
2a - positive;
2b - negative;
3 – axes of local gravity transitions

In the southern block, the density distribution at the studied depths down to about 3 km is quite modified. A common positive zone, which has two maximums – 7 and 8, is formed.

To the south it is limited by the Stroumeshnitsa gravity transition e-e. This transition is mapping well a fault situated at a depth of about 3-4 km.

In the most southwestern part of the territory, the Klyuch negative anomaly 5 is broader and larger at these shallower depths.

Some extra information about the density distribution in the near-surface geologic section can be obtained from the map of the variation anomalies compiled from the center-point and ring method of Griffin using a circle of radius R = 5 km (Fig.4).

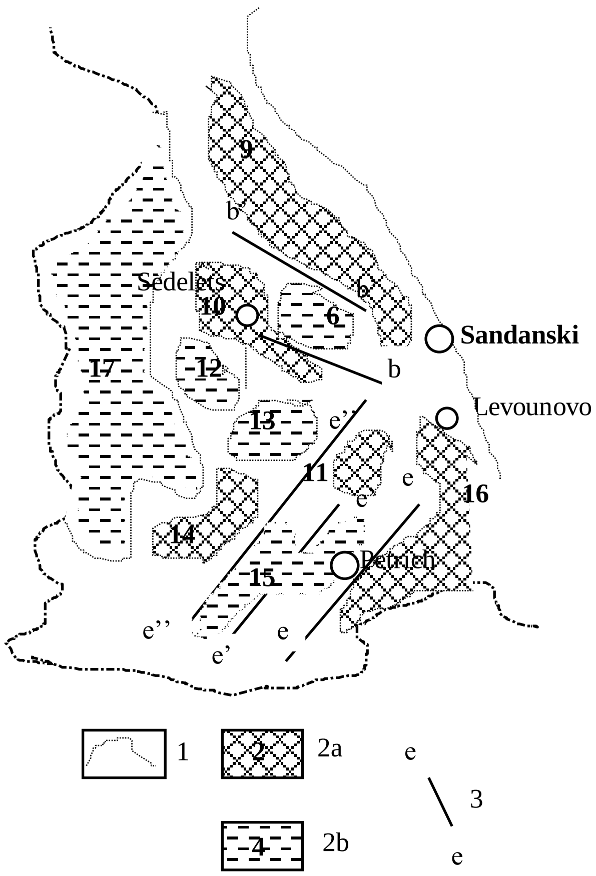

Figure 4. Scheme of the gravitational field variation anomalies distribution, compiled from the center-point and ring method of Griffin using a circle of radius R = 5 km
1 – field isolines mapping the variation anomalies;
2 – field anomalies:
2a - positive;
2b - negative;
3 – axes of local gravity transitions

This transform is reflecting the predominant influence of the density-geologic section at a depth of about (0,6-0,7).R, i.e. down to 3-4 km. But it is suppressing in a higher degree the regional background in comparison with the upward continuations residual field. Like this, the influence of the near-surface density distribution is increased.

Well-pronounced anomalies are present on the variation anomaly scheme.

The zero-line on the map is limiting the Belasitsa-Ograzhden block to the west. This line is tracing the Strouma (Ograzhden) gravity transition.

The vast Ograzhden-Malashevska Planina zone 17 has negative field values and remains opened to the west. It is mapping near-surface formations having lowered density.

The negative, almost isometric, local anomaly 6 is well pronounced in this map as well. South of it is situated the Igralishte negative anomaly 13, and to the west – the Nikoudin negative anomaly 12. They are mapping the Igralishte and the Nikoudin plutons respectively (Ignatovski, 1969a; Ignatovski, 1969b).

In the eastern portion of the area, on a negative background, can be separated the positive anomalies 9 and 16 – to the east, and 10 and 11 – to the west. These anomalies are reflecting the presence of metamorphites having a bigger thickness.

It can be summarized, that in this map, the anomalies in the eastern and central part of the studied territory are creating an alternation of zones having increased and decreased density, and orientation close to the one of the Strouma gravity transition.

The pronounced Stroumeshnitsa negative anomaly 15 is very obvious in the southern part of the area. It has two local minimums – a western and an eastern one. This anomaly is mapping very well the Stroumeshnitsa graben.

A positive anomaly 14, which is striking SE-NW, is located in the southeastern part of the studied territory and is connected with the gneisses increased thickness.

Several local gradient transitions can be isolated in the analyzed map. In the northern part, the Lebnitsa b-b and the Tsaparevo b'-b' gravity transitions are most pronounced. They are striking S45°E and are tracing faults of the Lebnitsa system. To the south, the gradient zones e-e, e'-e' and e"-e" are reflecting faults of the Stroumeshnitsa system.

The compound analysis of the regional gravitational fields (Fig.1) and the local transforms (Fig.2, Fig.3 and Fig.4) shows that they are differentiating very well the geologic section of the Belasitsa-Ograzhden block with respect to its density characteristics.

CHARACTERISTICS OF THE GEOMAGNETIC FIELD

The observed geomagnetic field of the studied territory (Fig.5) is characterised by negative background values within the limits of -100 and -150 nT. On this background two anomalies can be separateded.

A pronounced positive anomaly 1m is very obvious in the northern part. Its position is correlating well to the Breznitsa fault zone B-B (Fig.1). Most probably along this zone are intruded rocks having increased magnetic susceptibility.

A negative anomaly 2m is present in the southwestern part of the map. It has an intensity of about -300 nT, and remains opened to the south. This anomaly correlates well to the Klyuch negative anomaly 5, pronounced in the local gravity transforms schemes (Fig.2 and Fig.3). It is mapping intruded granites having relatively lower magnetic susceptibility in comparison with the Neogene volcanics of the Stroumeshnishki graben.

The subequatorial direction (90-110^o) is predominating on the presented rose-diagram (Fig.5). The two other directions observed are one striking roughly S45^{o}E and one striking roughly N45^{o}E.

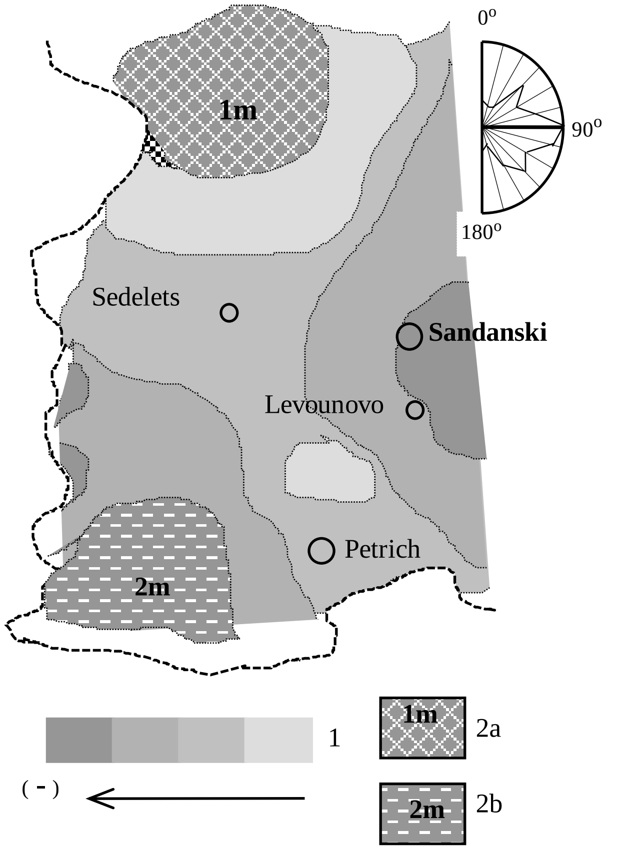

Figure 5. Compound scheme of the observed magnetic field distribution with included elements of the regional fields and a rose-diagram of the field isolines orientation.
1 – field distribution zoning – the arrow shows the direction of increase in the negative intensity;
2 – field anomalies:
2a - positive;
2b - negative

MAIN ELEMENTS OF THE GEOLOGIC-GEOPHYSICAL STRUCTURE OF THE BELASITSA-OGRAZHDEN BLOCK

The compound systematization of the studied geophysical fields basic characteristics shows a complex interrelation between the deep fault-block tectonics of the Belasitsa-Ograzhden block and the near-surface distribution of rocks having different density. This fact is justifying the development of two compound schemes of the geologic-geophysical structure of the studied territory.

In Fig.6 is illustrated the scheme reflecting the main elements of the fault-block tectonics, dominating in the depth interval 3-10 km, and in Fig.7 - the scheme reflecting the main elements of the near-surface geologic-geophysical section, predominating down to a depth of about 3 km.

The analysis of the geophysical fields in the studied part of the Serbian-Macedonian massif shows generally a good correlation between the established anomalies and transitions and the main geologic structures described in the region.

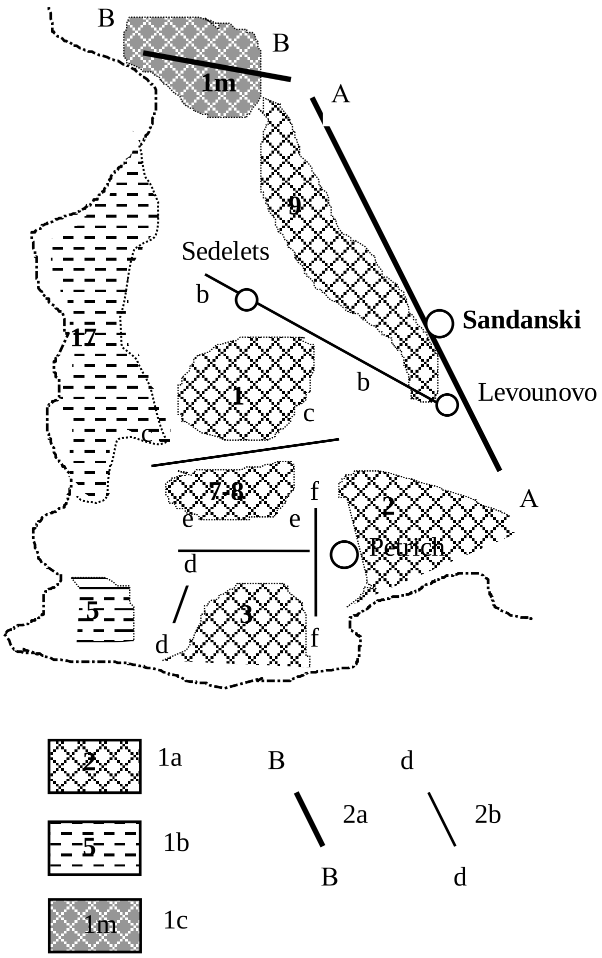

Figure 6. Compound scheme reflecting the main elements of the Belasitsa-Ograzhden fault-block tectonics, dominating in the depth interval 3-10 km
1 –structures mapped by geophysical anomalies:
1a – positive gravity anomalies;
1b - negative gravity anomalies;
1c - positive gravity anomaly;
2 – gravity transitions tracing fault structures:
2a – regional gravity transitions expressed down to 15 km and more;
2b – gravity transitions expressed in the depth interval 3-10 km

The Strouma gravity transition A-A is tracing the deep-seated Strouma fault zone. It is limiting the Belasitsa-Ograzhden block to the east.

At relatively shallower depths the Strouma gravity transition is mapping the Ograzhden fault (Zagorchev, 1992), as a western border of the Strouma fault zone. The transition is striking S30°E. The interpretation data are showing that at bigger depths it displaces to the west. This fact confirms the concept of rotation in the Strouma zone faults during the Pont-Pliocene (Zagorchev, 1992).

The Breznitsa gravity transition B-B is tracing a deep-seated fault and is bounding the Belasitsa-Ograzhden block to the north. Most probably along the fault were intruded rocks having increased magnetic susceptibility. They are mapped by a very well pronounced positive magnetic anomaly.

The Lebnitsa gravity transition b-b is striking approximately N60°W and is traced very well from the village of Sedelets to its intersection with the Strouma gravity transition near the village of Levounovo. It is mapping the Lebnitsa fault zone (Boyadzhiev, 1971) – a continuation of the Sasa-Toranitsa fault zone second southern branch (striking approximately N30°W).

The Southern-Ograzhden gravity transition c-c is transverse to the Strouma fault zone and is tracing a fault that separates the central block 1 from the southern ones.

In the most southern part of the territory are situated the Kolarovo d-d and the Petrich f-f gravity transitions. They are tracing the Kolarovo and the Petrich faults respectively (Ignatovski, 1968) and are dividing the Belasitsa block structure reflected by two positive anomalies - 2 and 3.

The Northern-Igralishte and the Klyuch negative anomalies 5 and 6 are mapping granite plutons, intruded among metamorphites.

The Podgoritsa gravity transition e-e is mapping the Podgoritsa fault (Ignatovski, 1968; Zagorchev, 1992) and is separating a block structure having two local highs 7 and 8.

In the scheme, reflecting the main elements of the near-surface geologic-geophysical section predominating down to a depth of about 3 km (Fig.7), the studied territory is differentiated very well with respect to the density.

The positive zones 9, 10, 11, 14 and 16 are separating the areas where are dominating gneisses having bigger thickness and relatively higher density.

The Igralishte negative anomaly 13, the Nikoudin one 12 and the negative anomaly 6, caused by a deeper structure, are mapping granitoid plutons having relatively low density.

The Stroumeshnitsa negative anomaly 15 is tracing the biggest thicknesses of the decompressed sedimentary rocks that fill the Stroumeshnitsa graben.

The gradient transitions are mapping faults of two main systems – the Lebnitsa system, situated in the northern part of the area and striking S45°E, and the Stroumeshnitsa one, situated in the southern part and striking N45°E.

Analyzing together the two compound schemes one can see that in the depth interval 3-10 km are predominating the fault-block tectonics main elements, while the near-surface distribution of rocks having different petrography and respectively density characteristics is predominating in the depth interval down to about 3 km.

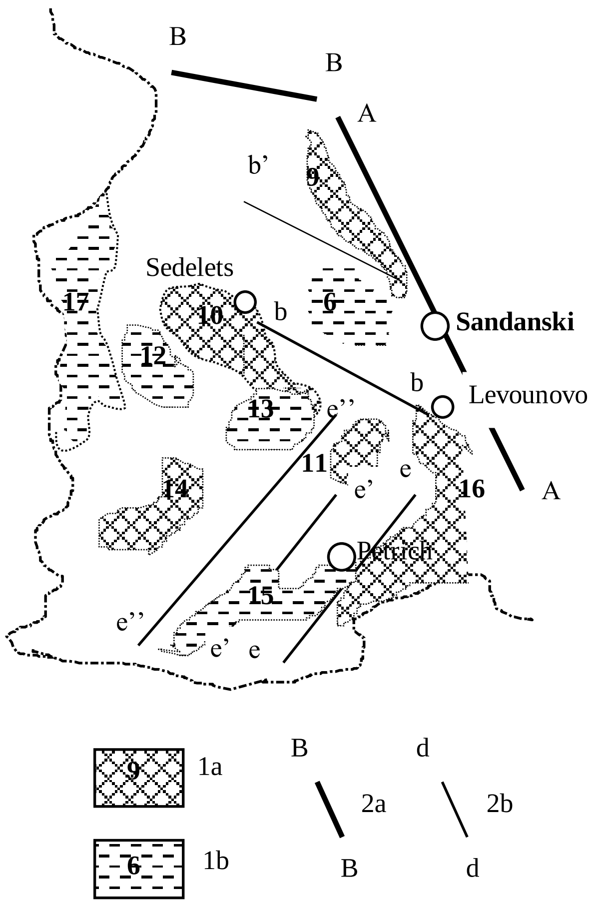

Figure 7. Compound scheme reflecting the main elements of the Belasitsa-Ograzhden near-surface geologic-geophysical section predominating down to a depth of about 3 km
1 –structures mapped by geophysical anomalies:
1a – positive gravity anomalies;
1b - negative gravity anomalies;
2 – gravity transitions tracing fault structures:
2a – regional gravity transitions expressed down to 15 km and more;
2b – gravity transitions expressed in the depth interval 3-10 km

CONCLUSIONS

The data of the Belasitsa-Ograzhden block geophysical fields analysis and interpretation are confirming and enriching the knowledge of the geologic-geophysical structure in this territory. The compound analysis of the gravitational fields (Fig.1, Fig.2, Fig.3 and Fig.4), the magnetic field (Fig.5) and the developed two compound schemes (Fig.6 and Fig.7) is the reason for the following conclusions:

- The Strouma gravity transition is pronounced without ambiguity in all regional and local gravitational fields. The transition characteristics in the regional maps, which are reflecting the depth interval 3-10 km, are showing that it dips west about 65-80^o. In the local fields maps, this gradient zone is tracing the Ograzhden fault limiting the Strouma fault zone to the west (Zagorchev, 1992). It strikes N35^{o}W and dips west about 70-80^o.
- The fault-block tectonics have predominant influence in the depth interval 3-10 km. The Lebnitsa, the Southern-Ograzhden, the Podgoritsa, the Kolarovo and the Petrich gravity transitions are forming the block division of the studied territory. The Northern-Igralishte and the Klyuch negative anomalies are mapping relatively deep granitoid plutons.
- The geophysical fields main characteristics in the depth interval down to about 3 km are mapping the near-surface disposition of plutons, reflected by the Northern-Igralishte, the Igralishte, the Nikoudin and the Klyuch negative anomalies. The areas having increased thickness of the metamorphites are separated by positive anomalies. The Stroumeshnitsa graben and especially the areas having increased thickness of the decompressed sedimentary rocks that are filling it are mapped very well by negative anomalies. In the studied near-surface interval, gradient transitions are tracing faults of two main systems - the Lebnitsa system and the Stroumeshnitsa one.
- The analysis of the main elements of the geologic-geophysical structure in the Belasitsa-Ograzhden block is showing that the studied block has been developing under the direct influence of the rift processes in the regional Strouma rift structure. These processes and their performance are reflected mainly in fault deformations transverse and oblique to the Strouma rift system.

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Recommended for publication by Department of Applied Geophysics, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 117-120

COMPLEX GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS IN ANTARCTICA

Boyko Ranguelov

Geophysical Institute – BAS, Sofia 1113, Bulgaria, E-mail: bkr@geophys.bas.bg

ABSTRACT
The results of the complex geological and geophysical investigations on the Livingstone Island, Antarctica during the campaign 2000-2001 are presented. Seismic signals, tsunamis generated in the South Bay, destructive geodynamic phenomena – landslides, rockfalls, deep erosion, etc., are investigated. The UV radiation, wind and temperature changes, humidity and hydrology regime have been observed as well. Some preliminary results of the geological probing, gemstone deposits and fossils are presented as well. The results obtained support the proven facts that Bulgarian Antarctic Base and its surroundings are suitable place for complex natural investigations.

INTRODUCTION

The complex geological and geophysical investigations have been done during the expedition 2000-2001 for about 40 days – 1st December till 10th January in the area of the Bulgarian Antarctic Base (BAB) on the Livingstone Island – Antarctic South Shetlands. Several projects have been under the execution: seismological – with MINEDU, Tsunamis – with Geophysical Institute and a project on geodynamics – with New Bulgarian University (NBU). Many samples of rocks and minerals have been collected for Mining and Geology University and NBU collections and sampling of soils, waters, organic materials has been performed.

SEISMOLOGICAL OBSERVATIONS

The main purpose of the seismological observations was to establish the first Bulgarian seismological station on Antarctica. It was successfully executed and since 4th December the measurements started. The coordinates of the station measured by GPS were as follows [Ranguelov, 2001]: 62 38'25.4"S and 60 21'55.1"W, height - 12.5 m.

The station was equipped by a GVB device produced by GeoSIG, with a three component geophone with own frequency – 4.5 Hz. The records have been interrupted by different reasons – electricity interruptions, memory limits, other duties etc. As a result more than 250 records from different sources have been recorded. Natural seismic emissions are generated by ice cracks, icefalls, surf, rockfalls, wind, rock cracks and possibly earthquakes. Artificial seismic signals have been generated by hammering, electric generator, human and animal's activity. For the signal identification different criteria have been used. Base method was the spectral analysis in both forms – Fast Fourier Transformation (FFT) and power spectrums (PS). Other method applied was the 3D representation of the vector sum of the signal on the three components – a vertical and two horizontal. Additional criteria – the signal envelope, and velocity, acceleration and displacement have been applied as well as filtering windows (Hemming, Hening, Bartlett, etc.) for the same purposes. The software is included in the device options. The results of the signal classification are as follows: 7 signals from icefalls, 21 – ice cracks, 3 – rockfalls, 12 – surf (wind and tsunami influence), 121 – wind noises, 2 – probable local earthquakes, more than 80 – artificial. The normalized spectral characteristics are presented on fig.1.

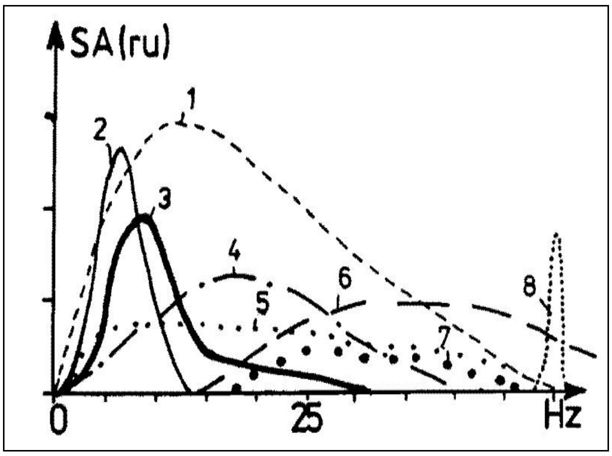

Figure1. General spectral characteristics of the seismic signals registered on the Livinstone Island.
1 – earthquakes(?); 2 – icefalls; 3 – surf;
4 – artificial signals; 5 – wind microseisms;
6 – rockfalls; 7 – ice cracks; 8 - 50 Hz.

The active experiments show the attenuation of the wave amplitudes twice for about 50 meters on the soft soil and the same for about 300 meters for the hard rock. Very often the attenuation is extremely high – more than 10 times for the local moraines' deposits formed by the glaciers.

TSUNAMI INVESTIGATIONS

The icefalls generated huge local tsunamis in the South Bay. They have been described in Ranguelov [2001]. For the whole time period more than 20 cases have been registered. A lot of data are missed due to the different reasons – bad weather, night time, other duties of the observer, etc. The run-ups and their maximum amplitudes have been registered by primitive equipment – marked rope and a chronometer. That's why the reliable results must be considered for the amplitudes greater than 50-60 cm. An exceptional case of an extremely high tsunami has been registered due to the big ice block (more than 300 meters) fall. It generated huge tsunami with amplitude of about two meters. The generating mechanism is different. Usually the icefalls are connected with a big acoustic noise. The travel time from the source to the BAB beach is different, but in the range of 10-15 seconds. This time is enough to avoid the dangerous influence of the wave on the researchers. The wind waves very often reach 3-4 meters high. The time pulses for them are in the range of 8-14 sec. The tides are estimated by the data for the Spanish base. The maximum values reached 2 meters.

Table 1. Parameters of the observed tsunami waves

№	Month day	time h.min.	H [m]	T [sec.]	Tr.time [min.]	No
1	12.03	10.21	0.8	23	6.2	2
2	12.04	20.40	1.2	30	6.5	2
3	12.05	14.20	1.0	25	7.2	1
4	12.09	16.30	2.0	16	5.5	4
5	12.09	12.36	0.8	21	7.5	2
6	12.13	11.13	1.1	20	8.2	3
7	12.17	10.05	0.7	18	5	3
8	12.17	14.15	0.8	19	6.5	4
9	12.17	15.36	0.7	20		3
10	12.17	16.15	0.9	21		3
11	12.17	17.47	1.0			3
12	12.25	18.36	0.9		7.5	2
13	12.29	11.15	0.7	22	5.5	2
14	12.29	12.18	1.0	24	6.5	3
15	12.31	19.31	0.6	30	4.5	3
16	01.02	12.16	0.6		4.2	2
17	01.05	19.16	0.8	22	5.5	2
18	01.06	13.36	0.6	21	2.5	2
19	01.06	13.40	0.6	26	2.5	2
20	01.08	11.46	0.8		2.3	2
21	01.08	11.56	0.8		2.3	2

H – run-up; T – wave pulse; Tr.time – travel time; No – number of the waves.

The specific hydrology regime nears and around the BAB, suggested an idea to measure the underground water level changes. The experiment shows a negative connection. Due to the water level height generated by the snow melting process, the transmission is not possible. The underground water table is stable on the beach and no influence from the sea is detected. The dominant is the hydrology regime from the land to the sea due to the snow and ice melting process.

GEODYNAMIC PHENOMENA

Near the base other geodynamic effects could be observed – erosion, rockfalls, active volcanoes, glaciers with all accompanying events they are able to produce (ice falls, ice cracks, moraines transport, etc. [Рангелов, 2001]. The big gravel and stone blocks on the beach are very dangerous for the people due to the wetness and slippery surfaces producing frequent traumas on the people.

Erosion

The erosion is deep and often reaches 3-4 meters due to the continuous cycle of the melting and freezing waters in the rocks' pores. The erosion together with the sharp relief are the main generators of the rockfalls and the rock's cracks. Similar effects on the relief have the surface faults. Most of them are of a listric type due to the extensional tectonic regime. In a crack of such fault an elementary experiment was establish, measuring the movement on the surface. About 1 mm was detected in a left (west) lateral displacement. This means very active fault movement. Usually the cracking and the erosion are orientated by the cleavage. This leads to a slices parallel to the cleavage. There are as well block perpendicular cracks, which formatted block image of the rock surface, especially on the basic rocks. Sometimes due to the reach quartz zones some rocks formatted clearly expressed cliffs. Special measures against the erosion are not necessary. The base is on the hard rock of the basaltic dyke.

Abrasion

The abrasion is strongly developed in the surf zone. The main dynamic factors are several – erosion, big tide amplitudes, ice movements with the morenas transportation, temperature changes, etc. The most exposed to the abrasion forms are the cliffs and the vertical rock walls. The abrasion effects are clearly expressed as well on the formations with the tectonic origin. A natural cave due to the abrasion of the fault planes is located near (about two kilometers) southeast of the base.

Glaciers

The glaciers are located everywhere and near surroundings the base. The biggest (Johnson, Perunica, etc.) have very large dimensions (tens of kilometers) and sometimes depths reach more than 300 meters, according the Spanish researchers. They have very active dynamic movements, in some places more than 25 meters per year.

The glaciers are main source of the moraines, other ice materials (such as glacier's "milk") and deposits. The most dangerous event for the researchers is to fall down in the ice cracks (frequently deeper than 30-40 meters). It can bring fractures, contusions even deaths. The icefalls are also dangerous because they can splash the researchers or to generate tsunamis in the South bay. The main way of protection is the alpine equipment and tracks in couples with continuous radio connection with the base during the tracking sessions. The small ice pieces generated by the glaciers are also main dangerous component during the debarking phase. The velocity of the wind movement of this active agent is extremely high during the windy time – the whole bay (more than 5km. length) can be covered for about 30-45 minutes.

Rockfalls

The rocfalls are due to the deep erosion. The sharp relief formatted different volumes of rocfalls. They have different dimensions – from several up to thousands of tons [Рангелов, 2000]. They are very sensitive and often started their movements due to different triggers – strong winds, steps, etc. The rock pieces of the rockfalls have different dimensions - from centimeters to meters. In the near BAB surroundings more than 25 different rockfalls have been investigated and mapped. The seismic signals generated by them have been registered and can have practical implementations for the seismic hazard purposes about the vulnerability and stability of the different structures affected by such events. The careful watch and approaching to the rockfall places can help to avoid negative effects and dangerous behavior of the falls to the researchers. The recommended measures are – good weather, careful measurements and safety equipment to prevent the negative effect of these phenomena.

Active volcanoes

The active volcano Disseption is located to the 40 km northeast. This is a very active volcano. The last eruption was reported 1974. Traces of its activity are clearly visible on the Livingstone Island – volcanic bombs, ash and pyroclastites are usual view on the glaciers and the beaches. The volcanic rocks are basic – basalt and andesite basalts. [Рангелов, 2001]. On Livingstone Island local recent volcano is reported [Kamenov 2000]. It is located SW of the base but is difficult for the investigations. Can be dangerous in case of under ice eruption, which can bring heavy floods. The volcano is relatively far from the base that's why the preliminary effects can be observed earlier. The local dykes have been investigated and prove the idea that the local volcanic activity can be expected [Kamenov 2000].

OTHER NEGATIVE PHENOMENA

Ultraviolet rays

This is the most dangerous environmental phenomenon observed on the Island. It acts on the eyes and the skin and can produce heavy damages and burning. Due to the ozone hole the daytime quantity is too big [Рангелов, 2001]. A simple indicator for the comparative measurements between (UVA-soft) and (UVB-hard) rays has been used for the observations. During the clear sunny days (not very frequent event) the UV index reaches about 12. The UVA and UVB rays attack the surface layers of the skin. The danger is a result of the possible lightening effects on the eyes and burning of the skin. 2-3 hours stay on the open air is equivalent of the III degree burning effects. Clothes, hats and protective glasses can do the protection. For the open skin – the protective foam can be used with a high UV factor.

Strong winds and temperature changes

These are the most dangerous meteorological elements. Very often strong, impulsive winds can be observed. The velocity reaches up to 150 km/h. Similar winds and storms can "blow" the person and the instrumentation in the bay. Directly connected with the windstorms are the temperatures. There is clearly expressed so-called "feeling temperature". Frequently the temperature of about –2-3 C according the wind and the humidity can be felt as –20C. Vice versa – the temperatures of +2C can be felt as +20. Sounds of the cracking stones are frequently observed during such days [Рангелов, 2001]. The temperature variations during the astral summer are not big – most frequently in the range +/- 3-4C. Measurements made by the extreme thermometer show that during the winter the temperature goes below up to –25-30C. Everyday variation can be observed cycling around the zero. This process brings the effects of the deep erosion due to the freezing and melting cycle. The most natural phenomena acting on the Livingstone Island are schematically presented on fig.2.

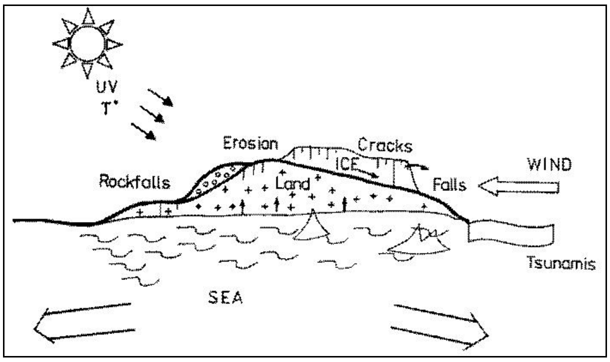

Figure 2. Main factors generating the geodynamics on the Livingstone Island

GEOLOGICAL INVESTIGATIONS

The results obtained from these investigations are preliminary and not yet completed. The interpretations will follow by the investigations of the respective specialists.

Petrochemical contents of the rock samples

Table 2. Results of the chemical analysis for some selected rock samples

№	SiO2	Al2O3	Fe2O3	MgO	CaO	Na2O
A1	55.10	17.10	9.31	4.24	6.37	3.16
A2	75.10	10.91	3.97	1.47	0.56	3.05
A3	66.30	11.48	2.71	0.38	0.89	3.61
A4	54.10	15.04	10.89	4.20	7.10	6.65
A5	62.00	15.04	8.69	1.94	2.11	4.14
A6	77.10	11.01	2.18	0.80	0.38	2.84
A7	70.00	13.76	5.72	1.88	1.62	1.72
A8	77.40	11.47	2.29	0.18	0.93	3.24

The petrochemical analysis has been done according the AES-ICP standard. In table 2 the values for some selected sample are presented: A1 – gabbro; A2 – pyroclastic tuff; A3 – andesite; A4 – dolerite; A5 – trahite (Ca); A6 – sandstone; A7 – argillite; A8 – granite-porfir. On the island due to the intrusions the thermal metamorphism is very frequent, especially near the gabbro-dioritic body of the Hesperides point, as well as near the dyke's intrusion. [Kamenov, 2000].

Precious and semiprecious stones

Near the base, up to now, only semiprecious stones have been discovered. A small deposit of onyx (brown-red sliced agate sometimes including pyrite) and a lot of veins of amethyst with different sizes (from several centimeters up to several meters) have been described. The onyx is rare mineral, sometimes have nice properties and can be polished well. The amethyst has larger distribution. Usually appears as aggregates, very rare – like crystals or inclusions in the quartz veins. The color is light violet, sometime – dark violet. The samples have jewelry properties. Epidote is another frequently discovered mineral. The magmatic rocks very often looks useful for decorative purposes. Very often the findings of manganite, pyrite, chalcopyrite, galenite, sphalerite, etc. can be recognized. Quartz crystals are also discovered. In the sediments microscopic crystals of garnet, olivine, epidote, hematite, sometimes circone can be found. The collectors can collect all described minerals.

Fossils

For the first time near the BAB fossils from belemnites have been found. The specialists from New Zealand have made the analysis on the eight samples. The identification show two types dated – Belemnopsis (Berias-Valangine) and Hibolites (Titonian). All specimens have been discovered on the beach, included in dark sandstone' gravel similar to the Maiers-Bluff formation. The dimensions of the detrituses are between 2 and 5 cm. The fossils themselves are light white, because of the Ca dominance. This is due to the posformation changes. Only one sample is bigger. The samples are firmly included in the mother's rock and to extract them mechanically is impossible. The sample can be found everywhere on the beach and formed large fans. This is may be indicator that they are coming with the glacier's materials. The frequency of the findings is about 10% from all dark colored rock gravel. Up to now there are no information about the discoveries of the fossils on the basement rocks.

CONCUSIONS

The results obtained gives a light idea about the large possibilities for the geological and geophysical investigations on the Livingstone Island. The BAB appears as a test site for the geology, geophysics and the geodynamic investigations. The results are preliminary and even in this case show the large improvement for the observed facts and phenomena. All described phenomena can be observed in natural environment due to the lack of different anthropogenic noises. The large possibilities provided by the Bulgarian Antarctic Base, can and must be in use for the increased geological and geophysical investigations in Antarctica.

Acknowledgments

GeoSIG provided the seismograph for the seismic station. Dr. Challinor and Dr.Briggs from the Waikato University – New Zealand executed the fossils investigations. NBU provided support for the Antarctic project 24/08.01.2002. Dr. Tokmakchieva investigated the rock samples. MGU labs – made the petrochemical analysis.

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Recommended for publication by Department of Applied Geophysics, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 121-126

NUMERICAL MODELLING OF DRILL WELL PACKER BY USING FINITE ELEMENT METHOD

Nikolay Tchervenakov

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria, E- mail: cherv@mgu.bg

ABSTRACT
Construction and operation of cone packer for small diameter drill wells is examined. Its advantages and disadvantages are analyzed. By using finite element method and ANSYS program is investigated stress- strain condition of the packing element of the packer. Matter of modeling is deformed condition of the cylindrical element for different drill well diameters and the intrusion of a cone stem in it. Occurring forces, stresses and deformations in packing element of the packer and at the border "packing element- drill well" are defined. Influence of basic constructive parameters and working conditions on serviceability of the packer are analyzed.

Prospecting drilling for minerals in general is in hard, strong rocks in which faulting structures are met very often. Above-mentioned zones are usually presented by hydrothermally altered rocks and quartz layers with different degree of cavities. In such conditions if drilling is from the earth surface water losses occur, and if drilling is from underground, water inflow with 20 l/s rate and 2 MPa pressure are observed. Drilling from underground workings is additionally obstructed because of the fissuration and jointing of rock mass as a result of blasting. The classic way of drill well cement grouting (by pouring out cement grout into the well) as a matter of fact is ineffective because the low pressure of the grouting agent and as a result of it low penetration of the grout into fissures of rock mass. For obtaining better results from grouting in Department of Drilling, Oil and Gas a complex of units is elaborated (V. Arisanov, N. Tchervenakov and all, 1985, 1986,1988). The principal element of this complex of units are the two packers: cone packer (V. Arisanov, N. Tchervenakov, 1985) and cylindrical packer (N. Tchervenakov, V. Arisanov, 1986).

The structure of cone packer is shown on fig. 1. Its function is to insulate zone of grouting from upper- positioned drill well intervals, and by this way to permit to force grout under high pressure. Packer consists of back- pressure valve pos. 1, 2, 3, cone body 4, stopping washer 5, screw spindle 6, elastic packing element 7, pressing washer 8, washer 9, and combined upper adapter- safety adapter 10. The packing element diameter is some bigger of the drill well diameter (60 mm for drill well diameter 59 mm). Excluding washers 5 and 8 and upper adapter 10, diameter of all other elements of the packer are smaller of inner diameter of diamond core bit for the respective well, and for this reason they can be taken out as a core and used many times.

Cone packer must be screwed in lower part of drilling pipe and is descended to required depth into the well without any rotation. Because of the friction with the well wall during dropping down, the packing element rests immobilized. To operate the packer we slowly take up and rotate at the same time the drilling rods. The cone part of the body 4 enters into the opening of packing element, deforms it and press it more strong to drill well wall.

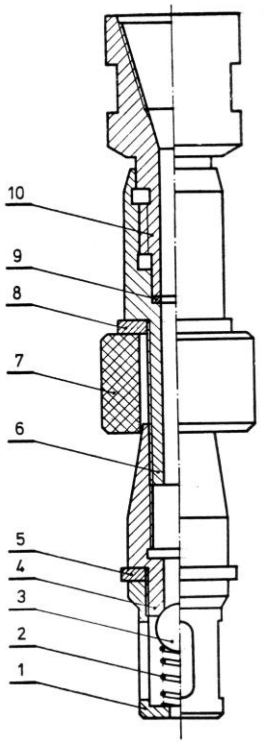


Figure 1. Cone packer

Friction force between the cone 4 and packing element 7 tends to move up the packing element 7, but against it is acting friction force between packing element 7 and well wall. Coming into packing element 7, cone 4 magnifies the friction force between cone and packing element, but in the same time deformation of packing element is increasing and respectively the force, pressing it to well wall is increasing too, i. e. we have an autowedging effect. If the angle of cone is suitable, friction force between packing element and the well wall is always bigger than the friction force between the cone stem and packing element and packing element rests fixed to the rock. Turning right, screw spindle 6 is screwing into the body 4 and by pressing washer 8 additionally deforms packing element 7 and press it to well wall. Stopping washer 5 prevents packing element 7 from falling down. After putting the packer into action, we are forcing the grouting mix by using circulating drilling fluid pump. After finishing cement grouting, we are taking out the drilling rod from the well by turning it carefully left and in the same time easy lifting it up. As a result of this action, safety adapter 10 is unscrewed from screwing spindle 6. We are taking drill rod together with adapter 10 of the packer out of the well, and other packer elements rest in the well until cement hardens. By this way is prevented cement washing out and ensure high quality of grouting. After cement hardening we lower down diamond core drilling bit and drill again grouted interval. Because the outer diameter of back pressure valve 1 , 2, 3, body 4 and screw spindle 6 are smaller than inner diameter of diamond core drilling bit, we take them out of the well as a core and after cleaning we could use them again. Stopping washer 5, packing element 7 and pressing washer 8 should be drilled with the diamond core drilling bit, that why they must be produced of easy drilling matter.

In known packer constructions for fixing the packer to well wall at predetermined depth cone jaws are used. In the above-described construction this action is done by the packing element of the packer. For the purpose its outer diameter is bigger from the drill well diameter and the effect of autowedging occurs when the cone stem is entering into the packing element. This leads to a very simple construction of the packer. In the same time removal of jaws gives the possibility the greater number of details to be elaborated with enough small diameter and to be used as “drilled packer”, i. e. to stay in the well until grout becomes hard, and after that to take them out and use them again. Letting the packer to stay in the well during cement hardening is quite effective when grouting zones are with abundant water inflow because it prevents cement grouting to be washed out or forced out from fissures of the rock. But this construction has some disadvantages, part of them removed from later constructions. One of the main disadvantages is if it is put into the well it can’t be positioned at upper place, taken out or rotated, because this leads to put it in action. Because of the small difference between packing element diameter and well diameter it can’t be used in cavernous zones because of the unavoidable enlargening of well diameter. But we must say that such zones are met not too often in prospecting drilling for minerals.

In this article modeling of packing element deformations of the packer are made during the time in its putting into action. For the purpose, by means of program ANSYS v.5.3 finite element method is used. Occurring forces and deformations of two main stages of packer putting into action are investigated:

- initial deformation of cylindrical packing element as a function of drill well diameter;
- packing element deformation during entering of cone stem into it.

For technologic reasons the packing element is divided into two separate elements. As an packing element is used cylindrical rubber sleeve with outer diameter 60 mm, inner diameter 31 mm and height 40 mm from the lower outer part on which chamfer 3 mm is made. Cylindrical part of the central stem is with a diameter of 30 mm. The angle of cone part of the body is 5^{o}, the small cone diameter is 30 mm, the bigger one is 38 mm, and the height of the cone is 45 mm. For simplification of calculations axial symmetry of the model is used, and later is operated with radiuses. Cylindrical packing element body is divided to 200 finite elements with total sum of 241 nodes and elements type HYPER56 are used with parameters as follow: axially symmetric model, hyperelasticity, nonlinear large deformations, Mooney- Rivlin coefficients 0.8 and 0.2 MPa, temperature 20 deg. and Poisson’s ratio 0.49. For modeling the contact “packing element- rock” and “packing element- cone” type CONTAC26 elements with linear contact and Coulomb friction law were used. Friction factor is one of the basic parameters, which influence is investigated into the interval 0- 0.5.

During first stage, preliminary deformation of packing element was investigated in function of drill well diameter and friction factor between well wall and packing element. This is of great Importance, because it is initial force that holds packing element 7 immobilized during cone stem 4 enters into it. Influence of the change of drill wall diameter from 60 to 59 mm was investigated (5 steps of 0.2 mm) for friction coefficient between the packer and well wall 0; 0.3; 0.5. Results of every step are saved in a file and for every node the information saved is as follows: node number, node coordinates X and Y, displacements on X and Y, vector sum of the displacements, stresses values for SXX, SZZ and SXY. In addition for every step two- dimension graphs with isograms of this parameters are saved. Of particular interest are this parameters for the surface of the packing element and for the contact “packing element - cone”, that why they are saved as separate files. On fig. 2 is shown stress distribution into the packing element in radial deformation 0.5 mm (i. e. the packer is positioned in a 59 mm diameter drill well and friction coefficient between the packing element and well wall 0.3)

From fig. fig. 3, 4, and 5 could be seen distribution of radial stresses SXX on the contact “outer diameter of the rubber packing element- drill well”. The influence of packing element radius decreasing is investigated in the interval from 0.1 to 0.5 mm, and it corresponds with the change of well diameter from 60 mm to 59 mm with a step of 0.2 mm. Modeling is made for friction factor on the contact “well wall- packing element” 0; 0.3 and 0.5.

From comparisons made is evident, that if friction factor in contact “packing element- rock” increases, compressive stress SXX between packing element and rock increases too. Higher stress concentration is typical for the lower part of the packing element, their values in its upper part are some lower, and the stress values are proportional to friction factor.

The explanation of the fact is as follows- the radial deformation of the packing element causes its longitudinal deformation. In lack of friction there is not anything to obstruct this longitudinal deformation and stresses of the packing element are relatively small. With the increasing of friction factor a friction force occurs and it obstructs the longitudinal deformation and that why radial stresses raise. Because

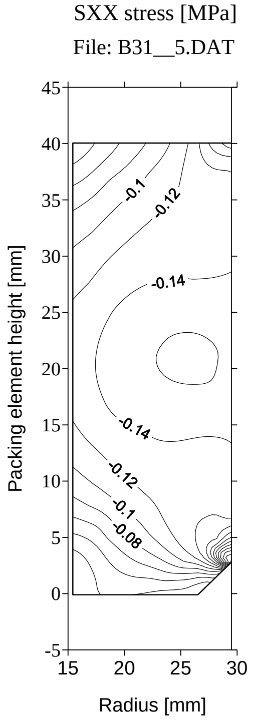


Figure 2. Radial stresses SXX into the packing element (radial deformation – 0.5 mm, friction coefficient 0.3)

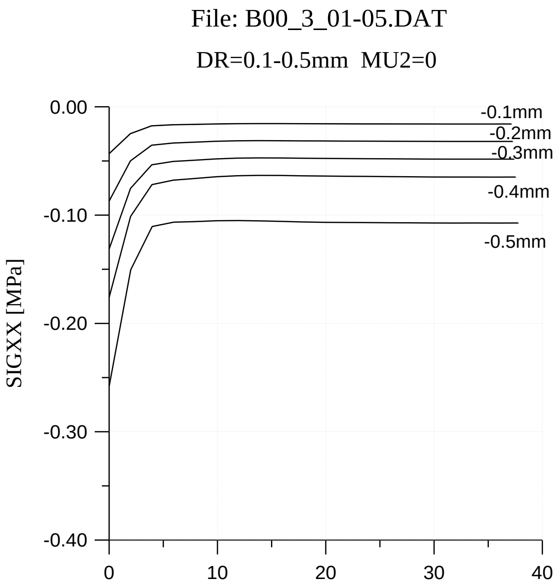


Figure 3. Radial stresses SXX on the contact "packing element- drill well" (radial deformation 0.1- 0.5 mm, friction factor with the rock 0)

packing element deforms comparatively symmetrically from the middle to the two ends, stresses from friction force are higher at the two ends of the packing element, and where the greatest longitudinal deformations are. This is evident and from fig. fig.6, 7 and 8 too. Investigations are made at friction factor between the packing element and rock 0; 0.3; 0.5. In presence of friction at the middle of the packing element it is clearly seen a zone, where friction force obstructs longitudinal deformations and with growth of friction factor this zone is magnifying.

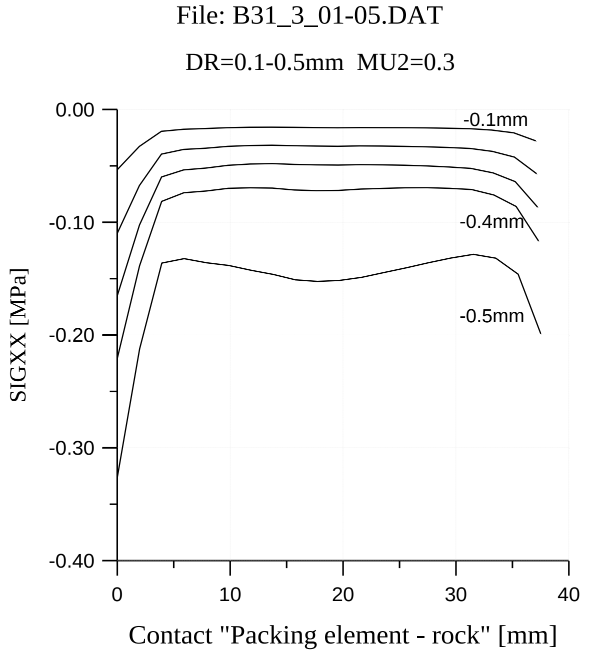


Figure 4. Radial stresses SXX on the contact "packing element- rock " (radial deformation 0.1- 0.5 mm, friction factor with the rock 0.3)

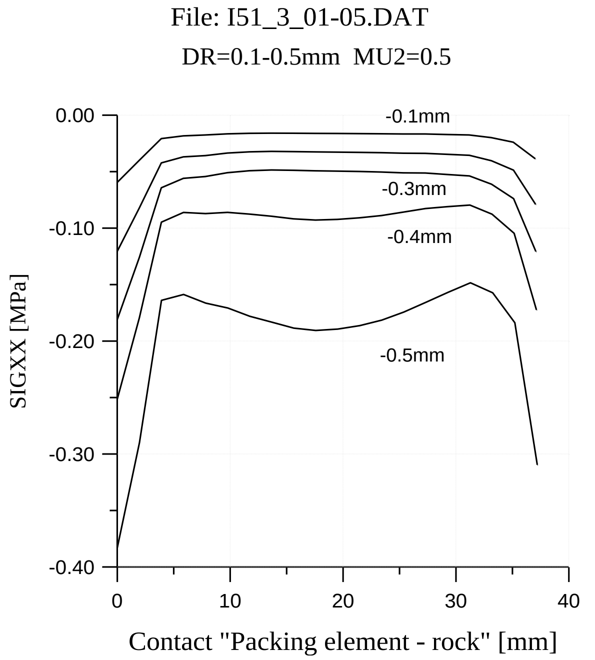
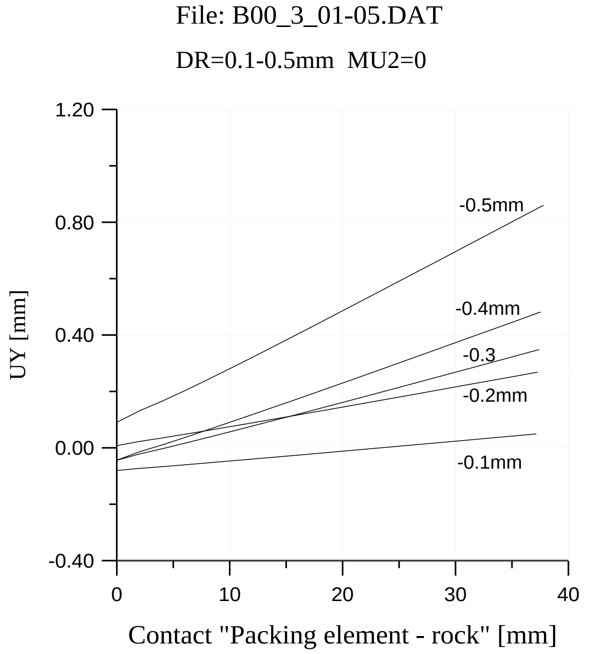


Figure 5. Radial stresses SXX on the contact "packing element- well" (radial deformation 0.1- 0.5 mm, friction factor with the rock 0.5)

Next stage of packer putting into action is cone stem entering into the hole of cylindrical packing element. The stem causes radial deformations of the packing element, by pressing it to well wall and packer body. At the same time cone stem is trying to push up the packing element, and against it acts friction force between well wall and packing element. The most unfavorable case for putting packer into action is when friction factor between packing element and cone stem is maximal and friction force between the packing element and rock is minimal



Fiure 6. Longitudinal deformations on outer diameter of the packing element (radial deformation 0.1- 0.5 mm, friction factor with the rock MU2=0)

i.e. we have minimal friction factor between packing element and rock and minimal preliminary packing element deformation. For such case investigations for zero packing element initial deformation DR=0, friction factor between packing element and cone stem MU2=0.3 and friction factor between packing element and rock MU3=0.3 are made. Cone stem has 40 mm total way up and it is divided into 10 steps of 4 mm.

On fig. fig. 9; 10; 11 are shown the radial stresses SXX in the packing element when cone stem has entered 8; 24; and 40 mm into it. On fig. fig. 12; 13; 14 vertical stresses SYY into the packing element at the same conditions are shown. The simulation of cone stem entering into cylindrical packing element shows stability of packer putting into action even in the most unfavorable conditions- near to zero initial deformation of the packing element and equal friction factor for the two contacts: packing element- rock and packing element-cone. Using the above- discussed method, 34 numerical experiments were made at different values of input parameters with 560 total steps of change of input parameters. Input parameters varied as follows:

- friction factor of packing element with the rock and with the cone stem- 0.3 and 0.5;
- initial deformation of the packing element- from 0 to 0.5 mm with 0.1 mm step i. e. it was simulated well wall diameter 59- 60 mm;
- vertical pass of the cone stem from 0 to 40 mm with a step of 4 mm;
- rubber elasticity modulus 2; 4; 6 and 8 MPa.

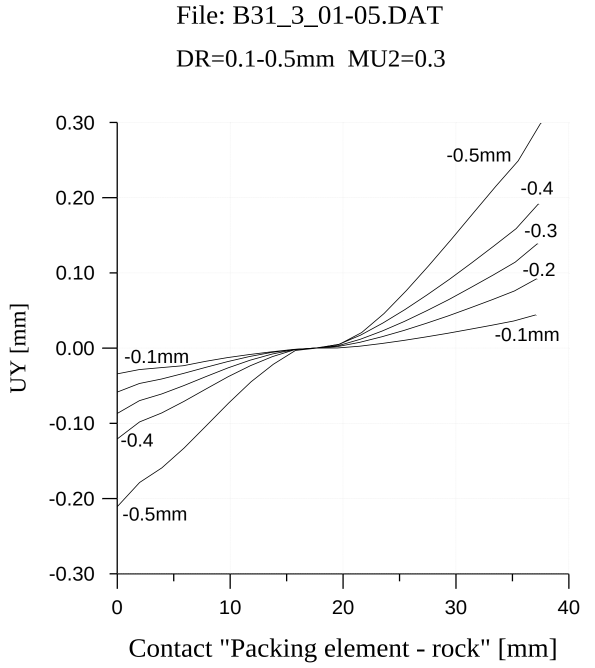


Figure 7. Longitudinal deformations on outer diameter of the packing element (radial deformations 0.1- 0.5 mm, friction factor with the rock MU2=0.3)

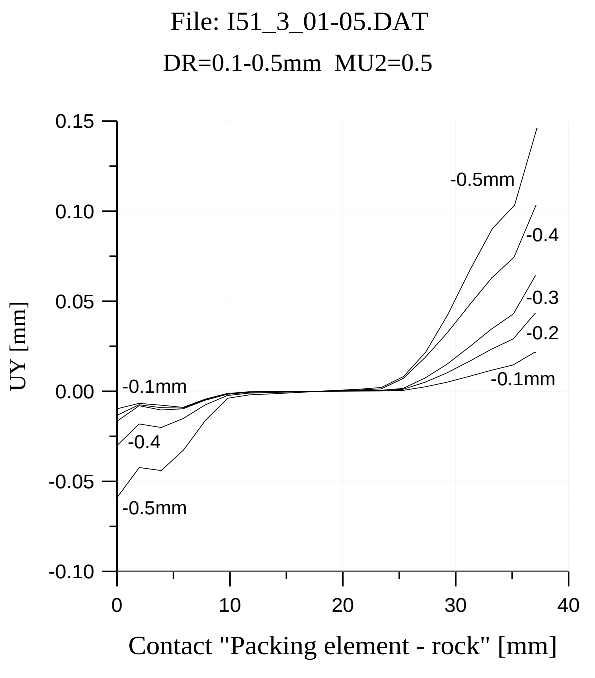


Figure 8. Longitudinal deformations on outer diameter of the packing element (radial deformations 0.1- 0.5 mm, friction factor with the rock MU2=0.5)

The packer reacted safely for all combinations of input parameters. Construction discussed is tested in practice and it sowed definitely sure action.

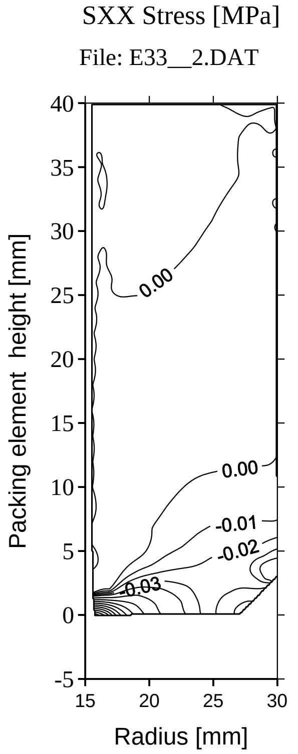


Figure 9. Radial stresses SXX in packing element (cone stem pass DH=8 mm)

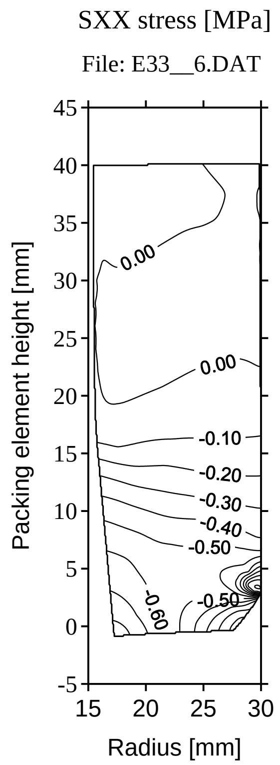


Figure 10. Radial stresses SXX in packing element (cone stem pass DH=24 mm)

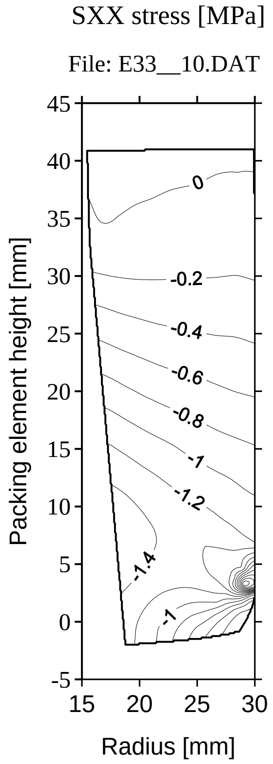


Figure 11 Radial stresses SXX in packing element (cone stem pass DH=40 mm)

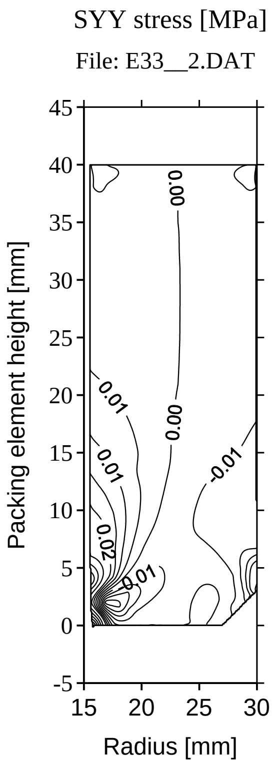


Figure 12. Longitudinal stresses SYY into the packing element (cone stem pass DH=8mm)

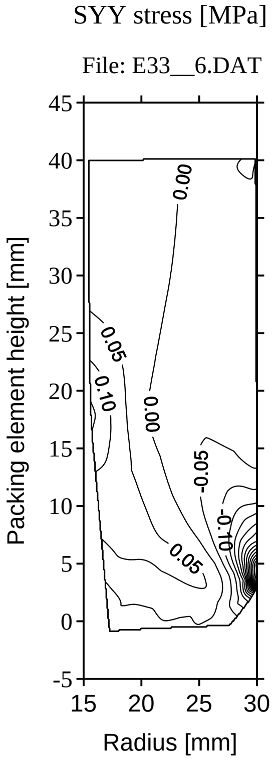


Figure 13. Longitudinal stresses SYY into the packing element (cone stem pass DH=24mm)

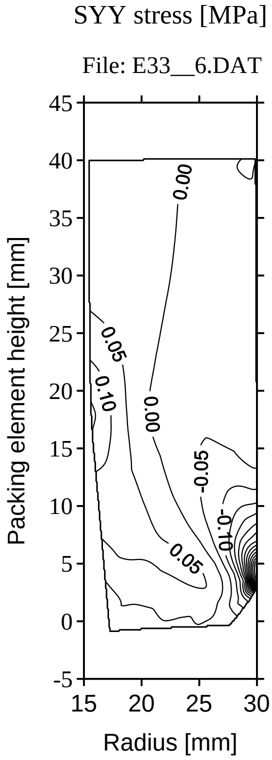


Fig. 14. Longitudinal stresses SYY into the packing element (cone stem pass DH=40mm

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Recommended for publication by Department of Drilling and Oil and Gas Production, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 127-128

NEW TECHNOLOGY AND TOOLS FOR GAS WELL TESTING CHIREN UNDERGROUD GAS STORAGE

Rumen Kulev

University of Mining and Geology “St. Ivan Rilski“, Sofia 1700, Bulgaria

ABSTRACT
This article describes the technology and equipment for carrying out a complex of geophysical studies and well testing of wells in the underground gas storage of Chiren. A test unit is mounted in the testing line from the well. Data obtained and registered by the measuring unit are used by PC on the well site to calculate the test parameters. The system is reliable and robust. It easy to operate, saves time and money.

A great number of gas wells testing have been carried out in the underground gas storage of Chrien. Most of them are during the period of exploitation of the gas field and in the period of setting up of underground gas storage.

At the period 1992-1993 a extensive gas well testing was performed at the gas storage field. The results of this study were published by Mincheva, Belchev, (1993). In their report the authors presented productivity curves for most of the wells used in the gas storage. The testing equipment for study includes test line, separator, measuring block, diaphragm, valves, and pressure gauges. The measuring block was mounted on the test line from the well. During the test the well flow rate was controlled by the manifold valves installed on the test line. Due to pressure rating of the valves on the separator line (6 MPa) the testing of the wells during injection was not possible (the manifold is rated to 16 MPa). During well testing pressure and temperature data are measured. The obtained data were used to calculate the well coefficients A, B as well as the permeability and the mobility. The curve of the productivity obtained from the calculations did not pass through the origin of coordinate system. In order to account for the unsteady state of the formation/bottom hole pressure coefficients for correcting are involved.

The review of the well testing studies and the analysis of the applied technology lead to the following conclusions:

- All gas well tests carried out in 1992-93 missed out direct measurements of reservoir and bottom hole pressures;
- The well testing reported in excludes measuring of the bottom hole pressure during the test;
- The reservoir pressure was determined by the barometric formula using values of the static head pressure;
- The bottom hole pressure was calculated by the formula of Adamov using the well head pressure. The measured manifold pressure was used to calculate the later;
- The temperature was not measured during the well testing;
- The formation and bottom hole pressure during the testing were not measured but calculated, which lead to erroneous interpretations and bad control of the testing.

An extensive geophysical, well testing and workover program for some of the wells in the storage of Chrien started in 1993. This program included a complex of geophysical studies in order to check the technical state of the casing as well as a well testing. The gas-testing program was aimed to evaluate the reservoir performance, formation characteristics and well damage after well stimulation. The workover program included tubing inspection and change and well stimulation.

The equipment used in this study consists of two units: technological and measuring. It’s shown in figure 1.

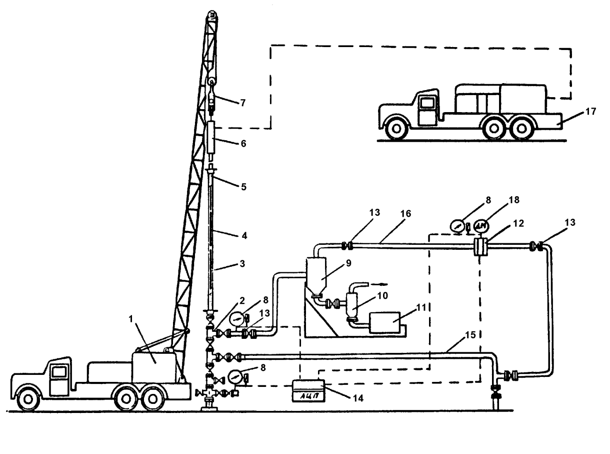

Figure 1

The technological units includes the following: drilling rig 1; geophysical devices 3 and 4; lubricating device 5; traveling block 7; test line 15; cyclone separators for high and low pressure – 9,10 and collecting and separating liquid and debris vessel 11. The cyclones 9 and 10 and collecting vessel 11 are not used during injection testing.

The measuring unit included geophysical devices 3, connected to the geophysical station 17 by means of geophysical cable; measuring line 16 fitted up with measuring diaphragm 12, absolute-and differential-pressure gauges 8,18; control PC fitted up with analogue-to-digital converter 14, regulating and closing valves 13.

The pressure of the tubing annulus and well head was measured with pressure gages 8 (Hottinger Baldwin - 1000 bar) and high accuracy manometers (0,4%), calibrated in testing laboratories. After calibration the pressure gages are mounted on a test bench simulating the real test conditions and tested again. A pressure membrane converter "Sapphire" was used to measure the differential pressure. Diaphragms of various sizes were used according to the flow rate of well. The temperature measurements were performed by two thermocouples mounted in the test line. The pressure and temperature data was measured by HP Data Acquisition and Control Unit and stored in PC for further manipulations. This arrangement of the testing line with the measuring devices and the use of the PC enabled the continuous calculation of the flow rate at the well site. Thus it was possible to distinguish the steady state during test regime. Printout from two well tests; well P-2 and E-27 is shown in figure 2. The gas well testing was performed in stabilized and non-stabilized regime of filtration.

The geophysical complex consisted of radiometric study and flow, humidity and noise measurements performed by geophysical station.

The described above equipment was used to study eight wells in the Chiren underground gas storage. The equipment showed robust and reliable work allowing performing different testing regimes. All data obtained during the well testing was used for the necessary calculation.

The following advantages have been observed:

- The schedule enables to study the wells in a several different regimes;
- The loop used for the testing allows determining the effect of the neighboring wells on the well performance;
- Information about the working flow rates, pressures and temperatures is provided by the measuring system during the well testing on the well site. It allows controlling the study;
- The surface manifold loop enables to avoid the possible gas leaks from the manifold's valves, which can influence the results obtained from the testing;
- The testing equipment setup allows simultaneous running geophysical studies and gas well testing.

The study of the eight wells showed that the equipment and setup used are reliable and robust. The testing program used and nesting some of the operations saved considerable amount of time and money.

сондаж P-2	сондаж E-27
3:24:03.24 PM	1:22:43.13 PM
PDIA=63.570742ATA	PDIA=66.896112ATA
TCHL=25.8C	TCHL=19.3C
TBUF=39.6C	TBUF=31.2C
PBUF=64.16ATA	PBUF=66.87ATA
DP=0.03322MPA	DP=0.00768MPA
Q=118.3XM3/D	Q=59.6XM3/D
3:29:18.67 PM	1:26:32.74 PM
PDIA=63.359763ATA	PDIA=66.349082ATA
TCHL=25.8C	TCHL=19.9C
TBUF=38.6C	TBUF=26.3C
PBUF=63.78ATA	PBUF=66.75ATA
DP=0.03332MPA	DP=0.00768MPA
Q=118.5XM3/D	Q=60.1XM3/D
3:34:27.16 PM	1:32:19.63 PM
PDIA=63.274494ATA	PDIA=66.731538ATA
TCHL=28.1C	TCHL=20.1C
TBUF=37.6C	TBUF=29.5C
PBUF=63.61ATA	PBUF=66.83ATA
DP=0.03322MPA	DP=0.00765MPA
Q=118.5XM3/D	Q=59.7XM3/D

Figure 2. Real – time printout from well testing

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Recommended for publication by Department of Drilling and Oil and Gas Production, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 129-132

THE MINERALOGICAL EDUCATION IN BULGARIA AS EXPOSED IN TEXTBOOKS FROM THE XIX AND FIRST HALF OF THE XX CENTURY

Ruslan Kostov

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria, E-mail: rikostov@staff.mgu.bg

ABSTRACT
A periodization of the mineralogical knowledge and education in mineralogy has been made as exposed in the textbooks and other books during the XIX and first half of the XX century. Published mainly abroad, in the first (revival) period the natural history works of Dr. I. Seliminski, Dr. P. Beron, Dr. D. Mutev as well as of Dr. N. Planinski can be included. The second period from the late XIX century and the first decades of the XX century is related dominantly to the publishing of textbooks for secondary state schools – among translations, some Bulgarian textbokks can be mentioned as those of M. T. Brakalov, Z. Boyadjiev, I. Mavrov and V. Bogdanov, G. Markov, Ch. Yarumov, B. Mitov, N. Dospevski, A. Toshev, V. Stanchev, G. Bonchev and D. Tzonev, I. Tomov and P. Nedkov, D. Tzonev and K. T. Kuzov. The third (academic) period starts with the university textbooks in mineralogy (1929; 1936) of Acad. Georgi Bonchev and can be traced to the middle of the century with the textbooks of Acad. Strashimir Dimitrov (1939; 1948) and Acad. Ivan Kostov (1948; 1950). Some other publications related to the education of mineralogy in secondary schools and in the university have been reviewed as well including their structure, scientific level and type of illustrations. A conclusion has been made for a relatively higher mineralogical knowledge at the discussed periods compared to the contemporary stage in the beginning of the XXI century because of the lack of secondary school textbooks with geological and mineralogical content.

INTRODUCTION

Mineralogy is supposed to be one of the most ancient sciences not only in the complex of all of the Earth sciences. Natural history knowledge can be considered as a irreversable part of the complete contemporary knowledge. From a practical point of view the development of human civilization can be described as a strugle for the search and processing of natural non-metallic and metallic raw materials. From a historical point of view it is of interest to trace the development of mineralogical knowlenge in Bulgaria together with the mineralogical education. In the present study an attempt has been made for describing textbooks as well as other publications related to mineralogy in the XIX and the first half of the XX century.

THE REVIVAL PERIOD

Natural historical and particularly geological-mineralogical knowledge has a definite place in most of the familiar Medieval treatises, for example the so called 'Miscellany of Simeon' and the 'Six Days' by Ioan the Exarch (Р. Костов, 1988). The first original Bulgarian works in hatural history can be attributed to our educators and scholars Dr. Ivan Seliminski (1799/1800 – 1867) and Dr. Petar Beron (1800 – 1871). The second person has published the famous 'Riben Bukvar' ('The Fish Primer') for the first time in 1824 (Division 7 – Physical stories).

The published mainly abroad during the XIX century (before the Liberation in 1878) in Bulgarian language primers contain certain geoknowlegde. Such is the primer by the teacher Hadji Naiden Jovanovich which has been published in Bucharest in 1846 and the 'Primer with Usefull Notions' by Constantin T. and G. M. Vladikin which has been published in Budapest in 1847 (with a division on 'mineral deposits' with description of some minerals) (Галчев, 1981).

The well known scholar Dr. Dimitar Mutev (1818 – 1864) includes in his 'Natural History' which has been published in 1869 in Plovdiv a special third division devoted to minerals. They have been systematized in four classes, being characteristic for the European tradition since the time of Agricola: 1 – earths and stones; 2 – salts; 3 – metals; 4 – inflammable minerals. Among the first class, for example, the following minerals and aggregates (rocks) have been listed: barite, lime earth, lime, gypsum, clays, mica, serpentine, asbestos, lapis lasuli (lasurite), quartz, jasper, diamond and other precious stones. Among the second class he describes alums, natron, salt (halite), Glauber's salt (mirabilite), niter and other salts. In the third class more of the common metals are described including the noble metals and semi-metals. In the last forth class inflammable products have been listed, sulphur, graphite and amber among them. The textbook of Dr. Mutev can be considered as the first competent mineralogical guide for the corresponding epoch published in Bulgaria. During the next 1870 year Dr. Nacho Planinski published a textbook in geology and zoology.

THE SECONDARY SCHOOL PERIOD

After the Liberation from the Otoman yoke in 1878 the educational system in Bulgaria is engaged with ensurance of Bulgarian textbooks for the primary and secondary schools. In some cases translations of foreign textbooks have been used and in other cases – new adapted textbooks have been published.

In 1882 in the 'Periodic Journal of the Bulgarian Scholarly Society' (predecessor of the Bulgarian Academy of Sciences) is published the original work 'Materials on the Geology and Mineralogy in Bulgaria' by the first Bulgarian mineralogist-geologist professor Georgi Zlatarski (1854 – 1909). About 45 mineral substances (mineral species and varieties) have been described in this article. At the same time Hermengild Skorpil (1858 – 1923) publishes a booklet concerning the mineral wealth of Bulgaria with two editions (1882; 1884). These pioneer reviews make the basis for further studies on minerals in Bulgaria.

Some secondary school Bulgarian textbooks with mineralogical and geological-mineralogical content can be mentioned from this period in the late XIX century: by Minko T. Brakalov with three editions (1881; 1889), Zakhari Bojadjiev (1889), I. Mavrov and V. Bogdanov with two editions (1889; 1892), N. G. Markov in two parts (1892), Christo Yarumov with four editions (1892; 1894; 1896; 1908), Nikola Dospevski with two editions (1894; 1896) and Andrei Toshev (1897). All these textbooks have been prepared for the lower classes of the secondary schools. Most of them are over 100 pages in volume and have been compiled according to the newest foreign textbooks.

The 'Textbook in Mineralogy' from 1881 by the teacher in the Plovdiv real state secondary school Minko T. Brakalov is the first specialized textbook with such a title in Bulgaria. In Plovdiv have been published also the textbooks by Mavrov and Yalumov, by Dospevski, by Yarumov, in Turnovo – by Boyadjiev, as well as by Markov, and in Sofia – by Toshev.

The most voluminous (456 pp.) and ambitious textbook from that period is 'Textbook in Mineralogy and Geology' by Christo Yarumov and Boris Mitov (1896) published in Plovdiv. The textbook which has been probably compiled as model from German sources has the quality of an university course, but not that for the secondary schools. The mineralogical division (more than half the volume within 270 pp.) is structured in two parts: 1 – general mineralogy, including morphological (crystallography), physical and chemical properties of minerals; 2 – 'special mineralogy' or systematic mineralogy, in which the minerals are descibed in the following sequence of mineral classes: native elements, sulphides, halides, oxides, other oxi-salts and minerals of organic origin. The textbook is richly illustrated with crystallographic forms and sketches of mineral aggregates. This textbook has been 40 years the most comprehensive guide in mineralogy in Bulgarian language until the publishing of the official academic edition by G. Bonchev in 1936 (with its second part).

In 1897 professor Georgi Bonchev under the order of the Ministry of People's Education writes an opinion-review on the textbooks of Markov (1892) and Yarumov and Mitov (1896), in which he says: 'Until a few year no textbooks in mineralogy and geology were available for the sixth classes of the secondary schools and a hollow place existed in the school literature, which has been kindly overtaken for the first time by the dear authors of the cited textbooks' (Костов, 1988). Never-the-less Bonchev criticized the huge volume and poorly placed material in the textbook of Yarumov and Mitov which as such is difficult for the pupils in secondary schools.

Among foreign authors the translated in Bulgarian as well as in other languages textbook by A. Pokorny and P. Elhichka (1884) has to be mentioned. The translation from Czech language has been made by G. Belchev. The mineral kingdom is described in division B with five groups of minerals being separated: 1 – group of atmospheric minerals with air and water; 2 – group of non-metallic minerals distributed into seven subgroups - salt, lime stones, heavy stones, micas, steatite, clays and hard stones including common stones, quartzites and precious stones; 3 – metallic minerals distributed into five subgroups of pure metals, ores, fire-stones, stones that glisten and variegated stones; 4 – group of inflammable stones with two subgroups including earth resins and coal; 5 – group of rocks subdivided into five subgroups with monomineral, polymineral non-layered, polymineral layered, clastic and clay rock varieties.

In this group of foreign translations can be also included the work by M. Kishpatich about the most important mineral raw materials (1884; in translation from Croatian by V. N. Ikonomov from Rousse, who is also the publisher). Of interest is the guide of A. Weissbach (1899) for determination of minerals according to their outer properties in translation from the forth German edition by S. Karavelov (the first edition is from 1866). The minerals are arraged in the following sections: 1 – with metallic luster and distributed according to their colour to red, yellow, white, gray and black; 2 – with semimetallic and common luster and distributed according to their colour to minerals with black, brown, yellow, green or blue streak; 3 – with common luster and non-coloured streak distributed according to their hardness to very soft, soft, semihard, hard and very hard. In a tabular manner are described the following peculiarities of the minerals: name, chemical formula, luster, colour, hardness, crystal system, crytal habit, cleavage, type of the aggregates, fracture, comments for determinatioin with the blowpipe method and associated minerals.

THE ACADEMIC PERIOD

The founder of Bulgarian mineralogy and petrography is academician Georgi Bonchev (1866 – 1955). He has obtained his doctorate in Zagreb, later on, since 1895, he has been elected as an associate professor in the High School (University), since 1905 he has been elected as a full professor and since 1911 - member of the Bulgarian academy of sciences. He has integrated in the University of Sofia a group of young and talented assistants, which have specialized in different towns and countries abroad – Iliya Stoyanov (1875 – 1920), Petar Andreev (1879 – 1912), Naum Nikolov (1889 – 1972), Strashimir Dimitrov (1892 – 1960) and Vassil Arnaudov (1889 – 1946).

In 1895 Bonchev as an associated professor in the High School published as linotype 'Key for Determination of the More Important Rock-forming Minerals', and in 1899 'Detertminative Crystallography (Crystallonomy)'. The second work appeared as an university textbook in 1921 (University Library, N12). The two parts of his lectures in mineralogy have been published a bit later as two textbooks, corespondingly

'General Mineralogy' (1929) with 374 pages (University Library, N85) and 'Special Mineralogy' (1936) with 368 pages (University Library, N175). He published also two textbooks in petrography, the first one in 1928 for agronomists, foresters, geographers and technicians (University Library, N77), and the second one in 1938 for students in natural history (University Library, N188). Among the university aids one can point out also to the 'Guide for Determination of Minerals' by Fuchs-Brauns (1932) translated by N. Nikolov and S. Dimitrov from the seventh German edition (University Library, N112).

In 1923 in the 'Annual of the Sofia University' has been published the large article 'The Minerals in Bulgaria' (in a volume of 212 pages), which is the first major and fundamental review in regional mineralogy after the work of Zlatarski. During these 2-3 decades Bonchev has written a lot of articles on the mineralogy of different mountains or regions. His extraordinary capacity for work, talent of observation and precision of decriptions, as well as the knowledge of the science of his day placed him among the best European professors in the field of natural history sciences. He has also contributed for popularizing mineralogical science. Among his popular science articles a specific place has been occupied by the series 'Precious stones' in a few numbers of the 'Estestvoznanie' ('Natural History') journal in 1912 with over 100 pages of total volume. As a matter of fact this is the first guide on precious minerals and thus he can be declared as the founder of gemmology in Bulgaria (Р. Костов, 1992).

Bonchev writes in the preface of his university textbook in mineralogy as a pathetic pedagogue: 'Because mineralogy is studied in the first semesters, the matter has to be teached in an accessible for everyone manner. That is why it will start with the common, the visible and gradually will transfer towards the more unknown matter, and the study and determination of mineral species being the final aim'. In his 'General Mineralogy' the following main subdivisions have been included: outer peculiarities of minerals (including crystallogrophy); physical properties of minerals; chemical properties of minerals; genesis of minerals; mineral deposits; systematics and nomenclature of minerals.

In 'Special Mineralogy' 450 mineral species and varieties have been reviewed arranged in classes according to Dana's (USA) classification, but the author knew and has used in his work the monographs and the reference books of the most famous European mineralogists as Naumann-Zirkel, Tschermak, Bauer, Hintze, Dufrenoy, Lapparent, Beudant, Bombici, Descloiseau, Pisani and others: 1 – native elements; 2 – sulphides, selenides, tellurides, antimonides; 3 – sulphosalts; 4 – halides; 5 – oxides; 6 – oxisalts (with groups and numerous subdivisions for the silicates and other minerals); 7 – organic salts; 8 – hydrocarbons.

During the first decades of the XX century the publishing of textbooks for the secondary schools continues. Professor Dr. G. Bonchev and D. Tzonev (teacher in the Ist Sofia secondary school for girls) have published in 1909 'Textbook in Natural History. Mineralogy and Geology", which is addressed for the third class and has been approved by the Ministry of Education. The text has been illustrated with 100 figures (among them a lot of prints form photos) and two coloured tables.

A 'Methodical Textbook in Chemistry and Mineralogy' has been published in 1906 in Turnovo by V. Stanchev. The last edition of the textbook of Yarumov has been published in Plovdiv in 1908. Ivan Tomov and Pavel Nedkov are authors of 'Geology and Mineralogy' (1909) for the third class of the boys and girls secondary schools. D. Tzonev published 'Natural History. Mineralogy and Geology on Pure Genetic Basis for the Secondary Schools' (1911), with its second edition with Ch. Kantardjiev as a co-author (1927). 'Mineralogy and Petrography' (1926) is the title of the textbook by Kyril Kuzev, who published later on also a 'Mineralogy' (1946) for the sixth mining class in the State technical secondary school 'Christo Botev' in Sofia.

The pocket field guide for determination of minerals intended for pupils and amateurs by Zhivko Lambrev (1937) and the translation from Russian language of one of the classic works 'Entertaining Mineralogy' by academician A. E. Fersman can be poited out in this period among the scientific popular literature.

From academician Georgi Bonchev the educational relay-race has passed to professor Strashimir Dimitrov (later academician) who published as lithoprint in 1939 his lectures in mineralogy (being read during the winter 1938-1939 semester), and in 1948 as a textbook in mineralogy.

In 1950 appears the first part 'Mineralogy (Special Part)' by professor Ivan Kostov (later academician), which is going to be included within the next editions in one of the best monographic textbooks 'Mineralogy', translated in English and Russian languages (the latest Bulgarian edition is from 1993). He also published in 1948 an uninversity appliance for students 'Crystallographic Tables', a predessecor of the later textbook 'Crystallography', which has been also translated abroad and undergone several editions (the latest Bulgarian edition is from 1978).

CONCLUSION

The review of the textbooks and related scholar aids in mineralogy for the secondary schools and universities in the end of the XIX century and the first half of the XX century displays a concern and wishfullness for educating the population in the best European traditions. This tendency is in contrast with the contemporary situation at the end of the XX century and the beginning of the XXI century when neither geology, neither mineralogy are studied in secondary schools with the exception of a few specialized technical schools. The described three educational periods (revival, secondary school and academic) are in a logical sequence of the social-political and concrete educational situation in Bulgaria.

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Recommended for publication by Department of Mineralogy and Petrography, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 133-135

INTERDISCIPLINARY RELATIONS IN TRAINING IN PHYSICS AT THE UMG

Julia Ilcheva

University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria

ABSTRACT
Implementation of informal didactical process leads to necessity of planning and methodical elaboration of academic knowledge. This necessity causes a lot of actual problems, which require deep practical and scientific importance. One of the problems is creation of optimal syllabuses in all education disciplines. There are not concrete clear and accurate requirements in modern didactics for compilation of syllabuses. The traditional improvement of syllabuses to a great extent has a casual pattern.
The problem of creation of optimal syllabuses in physics in order to realize an informal training permits solution by investigation and analyzing of interdisciplinary relations with mathematics, Earth sciences and some engineering sciences.
Existing interdisciplinary relations between physics and disciplines that are studied in two specialities at the Faculty of Geology (FG) "Applied Geophysics " (AG) and "Drilling and Air and Gas Production" (DOGP) are investigated. (These specialties were selected because of the fact that they could not be obtained in other institutes of higher education (IHE). 19 syllabuses are considered for the subject AG and 22 syllabuses are considered for DOGP. Consideration of the syllabuses is based on investigation of included in them educational elements.
More complete perfection of subject syllabus presumes "optimal including of the subject in curriculum context, i.e. its coordination and integration with other subjects and with general aim of training - the specialist's model".

The accelerated development of modern society is in need of mobile education that leads to a dynamic qualification. The secondary education is not enough to practice certain professions. That is why the young people enter IHE, motivated by inner needs - to master a specialty. With regards to this arises the effect of selective activity of the student, which finds expression in different sharing out of student forces between subjects.

The investigations show that two of a lot of facts, which have an effect on successfully mastery of knowledge, are of great importance: motivation and structure of the didactic process. It is supposed that students, who enter IHE, are motivated concerning their selectivity and themselves are responsible for their education. And because the education is teaching and learning, the teachers are the persons, who are obligated to keep up and to strengthen this motivation during the different degrees of training.

A didactical process is: student activities, conducted and managed by the lecturer for mastering a system of knowledge and skills in a particular field. Implementation of informal didactical process leads to the necessity of planning and methodical development of academic knowledge. This necessity causes a lot of actual problems, which demands deep scientific and practical solution. One of these problems is creation of optimal syllabuses for all subjects, differentiated in four groups - Mathematical, Fundamental, Engineering and Additional, according to the accreditation requirement of the Canadian Accreditation Bureau for Engineering Degree - Bachelor of Engineering.

There are not fully concrete requirements for working out syllabuses in modern didactics and unfortunately lecturers are not able to use concrete methods in the creative work for creation of syllabuses. The lecturers searches are based mainly on experience and intuition. That is why their traditional improvement to a great extent has a casual pattern.

In the ordinary syllabus, which puts content of educational discipline in a nutshell, there is a lot of disadvantages:

a) Selection of the matter, included in the syllabus, is made not on criteria or rules and often depends on the opinion of the author(s) or on not enough representative group of experts.
b) In the syllabus a lot of things are supposed, but not all is clearly formulated, for example it is unclear what must to be the quantity of subject acquirement.
c) The syllabus is not comprehensible for all and is realized in accordance with the subjective opinion of particular lecturer.
d) There is no differentiation between important and secondary information and this makes the teaching process difficult.
e) The syllabus volume rarely is harmonized with the time, necessary for its learning. The way for most effective construction of the training process is not determined.

A method for solving of this problem is proposed in the specialized literature [1]. Application of this approach guarantee primary perfection of the subject syllabus – for organization of the discipline in order to its study.

Every problem needs some kind of solution. "Man now is concerned with such problems, that makes a conquest of his spirit..." (N. Bor). The problems are more important than solutions. The solutions could become out of date, but problems stay [2, p. 25]. One solution of this problem – creation of optimal syllabus in Physics for educational and qualification degree Bachelor – is made by Prof. Ph.D. N. Djerahov, Prof. Ph.D.V. Lilkov and Prof. Ph.D. L. Drajeva, Department of Physics, Faculty of Geology, UMG.

There are three flows at the UMG, which studied Physics – a fundamental science and that is why it is necessary to use three syllabuses in Physics. The syllabuses were actualized in the first semester of the academic year 1998/99. The syllabuses are structured in separate modules according to the module principle of organization of the educational content in differentiated parts (according to Art. 40 of the Law of Higher Education). They are conformed to requirements both for specializing and general departments.

The problem of creation of optimal syllabus in order to realize an informal training permits another solution, which could be carried out by analyzing the investigation of interdisciplinary relations between physics and higher mathematics, Earth sciences and some engineering sciences.

Subject syllabuses for two specialties obtained at MGU - Applied Geophysics (AG - engineering science and design) and Drilling and Oil and Gas Production (DOGP - engineering science and design) are investigated.

19 syllabuses of corresponding disciplines are investigated for the speciality AG and for the speciality DOGP - 22.

Consideration of the syllabuses is based on investigation of the included in them educational elements. According to V. Bespalco educational elements are:

a) Objects, sites and things from a detrained field of reality;
b) Phenomena, processes or other observed interactions between objects;
c) Methods, which man uses to have an effect on objects and phenomena, i.e. man's skills and habits.

According to Prof. Ph.D. P. Galanov (Galanov, 1992; Galanov, 1994), educational elements are all compound parts of a particular educational matter - facts, experiments, phenomena, concepts, terms, physical quantities, statements, hypotheses, laws, conclusions, solutions and application of physical knowledge. Founded on these educational elements, it could be maintained that there are the interdisciplinary relations between different educational disciplines and relations could be classified into tree groups: synchronous, asynchronous and methodical. This differentiation is made with regard to the time of initiation of educational elements, which are used in different educational disciplines. The implemented investigation emphasis on relation synchronism and asynchronism, where:

There are synchronous relations when a particular educational element is initiated first in the subject, in which it is logically defined and then is used in another one.

- there are asynchronous relations when a particular educational element is used in a subject and it is not initiated in the subject to which it logically belongs.
- the conclusion about the kind of existing relations between physics and educational disciplines, studied in both specialties AG and DOGP (selection of specialties is based on the fact, that this qualification cold not be obtained in other IHE), is made on the base if investigated educational elements logically defined in physics.

The conclusion is: all investigated educational disciplines (with the exception of higher mathematics) follow in time studying the physics and therefore for existed interdisciplinary relations could maintain that they are synchronous. A new problem concerning repetition of educational elements arises In the process of relation analysis, i.e. is it necessary? Recapitulation on one hand leads to assimilation of knowledge, but on the other hand to loss of time, that could be utilized more rationally for obtaining of new knowledge and skills for their implementation in order to obtain the desired specialization. The application of knowledge shows the degree of intelligibility, as an ancient Chinese proverb says:

"What I hear - I forget.
What I see - I keep in mind
What I make - I understand."

Implementation of high effective education needs not only accumulation of academic knowledge, but gaining skills and competitions with applied and practical significance.

If a whole university course in a particular specialization will be considered, it will be found out that it is build on the base of linear and spiral system, i.e. some educational elements are studied for the first time and another are repeated. If the repetition is necessary, the differences in terms and symbols must be eliminated because the differences cause unnecessary embarrassment for students.

Mathematics as a subject is studied in three educational disciplines, respectively: Mathematics part I and part II during the first semester and Mathematics part III during the second semester. The cases, when the synchrony is breached, are established by investigation of relations between physics and mathematics.

Learning of Higher Mathematics must get ahead of teaching the disciplines, in which the obtained knowledge is necessary for learning of new knowledge and skills. The following example is conformation of that.

The following two equations are given:

$$a_1x_1+b_1x_2=c_1$$
$$a_2x_1+b_2x_2=c_2$$

About this problem mathematician will give the most common answer, that it is a system with two linear algebraic equations with two unknowns, but what exactly it expresses he can only guess.

But different specialists will answer as follows:

1. Electrical engineer - these are equations of voltage or amperage in an electric circuit with active resistance.
2. Mechanical engineer - These are equations of forces balance of levers or springs systems.
3. Civil engineer - These are equations of forces of connections and deformations of a building structure.
4. Supervising engineer - These are equations of distribution of loom loading.

In order to give such right answers it is necessary the students to be able to apply mathematics in time and quality in physics and specialized educational disciplines. This necessity is prompted by the fact that a real importance of mathematics is in its application in other sciences.

Investigation of interdisciplinary relations is a necessary precondition for perfection of syllabuses. The carried out investigation (Dimitriva, 2001) of educational loading volume in most disciplines in the higher engineering institutes in Western Europe shows that not only the number of hours is an indicator of the volume and content of studied educational disciplines. Preparing of optimal syllabuses, conformed and in detail considered on collective experts level will have an effect both on concrete training and on the complete education, the general principles, aims and takes of which must to be in the spirit of the European requirements and standards.

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Syllabuses - UMG.

Recommended for publication by Department of Physics, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 137-141

INNOVATIONS IN PHYSICS LABORATORY PRACTICE IN UNIVERSITY

Julia Ilcheva[1] Petar Galanov[2]

[1] University of Mining and Geology “St. Ivan Rilski”, Sofia 1700, Bulgaria
[2] Sofia University “St. Kliment Okhridski”, Sofia 1164, Bulgaria

ABSTRACT
In the conditions of developing market economy, the Bulgarian higher education should be equivalent in quality and quantity to the world and especially the European one, as well as convertible; the foreign companies and institutions should recognize i.e. the Bulgarian university education. A special research about the implementation of innovations in the field of the pedagogical technologies is needed so that the pedagogical process be enriched with ideas, methods and answers, with the help of which we could talk about integration of the Bulgarian education in the European and world research programs.
For the Bulgarian higher education (engineering in particular) the technology for formulation and implementation of the testing system is an innovation. Along with the laboratory practice in the University of mining and geodesy, multiversion tests, based on many kinds of exercises, have been worked out. The purpose of these tests is to examine the skills and the knowledge of the students, related to the carried out laboratory practice. This goal is consistent with the studied material and the time needed for the examination. The tests include problems, checking up the 6 knowledge levels, according to the taxonomy of the American psychologist Benjamin Blum. Their structure varies, so that the possibility of guessing the correct answers is minimized. The problem with cheating has also been solved with the help of the multiversion didactical test and the possibility given to the student to show knowledge obtained from reading additional science literature.

During the last few years new concepts as “reform”, “reforming pedagogy”, “competitive education”, “innovations in education”, “provocations in educational process”, etc. (Bishkov, 1992; Bishkov, 1995; Guirova, 1997; Kostova, 1998) have been entering the Bulgarian pedagogical press. This is based on the fact that, although fixed European standards in the system of higher education don’t exist, the basic principles, goals and problems of our education should be harmonized with the European and world requirements, disregarding the national, ethnical and political differences. Especially today, in the conditions of developing market economy, the Bulgarian higher education should be equivalent in quality and quantity as well as convertible, i.e. mobile, to the world and European one.

The prolonged isolation of the Bulgarian education (and that of the former communist countries) from the world experience demands a careful study of all the western educational achievements and their successful adaptation to the Bulgarian conditions.

A special research about the implementation of innovations in the field of the educational technologies is needed, so that pedagogical process be enriched with ideas, methods and answers. On the base of these methods and answers we could talk about integration of the Bulgarian education in the world and European research programs.

For the Bulgarian education (engineering in particular), the technology for formulating and implementing of a test system is an innovation.

By a decree from 1936 tests were not used in the former Soviet Union, also affecting former European communist countries (Bulgaria, the Czech and Slovak republic, Poland, Hungary). Scientists were forced only to translate and use popular western tests, without standardizing them towards the requirements of the educational process in their own countries.

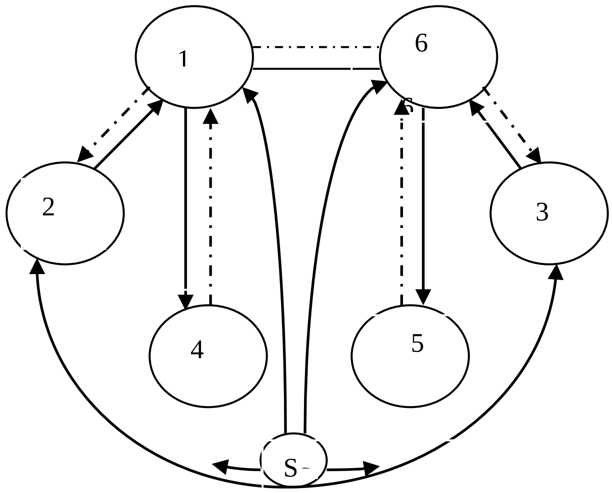
In the 70s, articles and developments of didactical tests, as well as publications of tests in some subjects, appeared in the local press, but they were intended for students in High Schools. Tests meant for the education in physics in University did not exist yet.

If we examine the specific character of the pedagogical system in the University we’ll find that its structure, according to V. Bespalko (1982), may be presented in the following way:
1. Goals;
2. Students;
3. Teachers;
4. Contents of the educational program;
5. Organizational units;
6. Didactical process;

Didactical tests are included in 5, like all the other elements of the pedagogical system.

If 4 is the subject Physics in a University, then 5 will include:
1. an extra cathedra method of teaching;
2. practical method (physics demonstrations and physics laboratory practice);
3. problems solving;

4. tests;
5. didactical tests;



Studying these methods, i.e. the didactical process, the problem of their effectiveness comes forward. This problem relates to the ability to follow and control the process of learning and has great importance for students and instructors. It helps students improve their learning and teachers – their teaching.

The methods that allow quantitative measuring have higher objectivity in the final result. The didactical tests in this way of thinking have standard – "with the standard we can reach the conclusion about the quality of the test carried out, i.e. the uncertainty of the different instructors about the students' mark is eliminated. The students themselves can use it as a technique for self-estimation. The more exact the students' expectation about his/her mark, the higher the quality of their work.

The result from the test has a positive effect on the students' motivation, because it does not depend on the personality of the teacher and is just a function of the students' knowledge. The opinion of the instructor about students' knowledge and skills does not matter in this case. The important thing is how many of the problems in the test have been correctly solved. This fact creates the feeling that the mark is objective and does not depend on personal opinion of a teacher, who uses "the method of estimation by sight".

Along with the laboratory practice in physics multiversion tests, based on many kinds of exercises, have been worked out. These midterm tests are a necessity in the process of education, because achieving higher results in physics needs not only objective method of estimation, but also a way "the cheating" to be avoided. To solve this big problem an average mark is advisable, one that reflects the results from the following: work with physics instruments and measuring tools, the carried out didactical tests and written protocols.

Doing tests for estimating the skills and knowledge of the students does not eliminate the possibility of using them along other methods. Achieving a better objectivity in the process of estimation and successful realizing of its basic forms need sensible combining of different methods that should be consistent with the studied material and its position in the structure of teaching.

The main advantages of didactical tests are:
1. the difficulty of the test problems can be controlled;
2. time can be saved;
3. objectivity of the mark;
4. positive motivation;

The good understanding of the potential of different tests suggests their correct usage, i.e. in the most appropriate way. Methods by PhD P. Galanov (Galanov, 1992; Galanov, 1994) have been used in formulating the midterm multiversion tests in the physics laboratory practice. The purpose of these tests is to examine the skills and the knowledge of the students during the process of their education. This goal is consistent with the studied material and the time needed for the examination. The material consists of themes that have been studied in other Universities such as Sofia University. Thus, a standardization of the physics tests and a possibility for comparing the achievements of students from different Universities is achieved.

The formulated didactical tests are in fact an effort to estimate the students' capability of doing research with the help of the studied material. Requirements for the tests (validity, exactness, simplicity and synonymity) have been met. The tests problems examine 6 knowledge levels, according to the taxonomy of the American psychologist Benjamin Blum. Their structure varies, i.e. there are problems with given answers, and the student should choose the correct one, and there are problems for finding logical mistakes; problems with diagrams that should be completed and discussed; problems for planning a result under the operation of another factor; problems checking the meaning of physical quantity; problems for checking up the understanding of the whole material; problems for examining the skills needed for finding physical quantities using an algorithm, i.e. examining the ability to use a physical law to create problems. With the help of problems like these, the possibility for guessing the right answer is minimized, and with formulating essay problems this possibility does not exist.

The system "n from 5", formulated for the needs of the extramural University of Hagen (West Germany), that has been used for examination, is a new answer for the multiple-choice problems. Tests about the studied material have been worked out. They consist of questions and problems that have 5 possible answers. The students know that they have to choose minimum 1 and maximum 3 answers. The pint of this test is to minimize the possibility of guessing the right answer, because the student has to think about all the given choices. Every right answer gets 1 point, and the highest result for a problem is 5 points, when all the choices are correct and the wrong ones are not chosen. (Bishkov, 1992).

This system is used for formulating multiple-choice problems, i.e. there are 5 answers for each problem. There is either 1 correct or 1 wrong answer, depending on what is asked in the text of the problem. The estimation is not according to the "points" method, but to the number of operations needed for the problem to be solved. Although the possibility for guessing the right answer is less than the one for problems with alternating character, it still exists (in our case with 5 given answers this possibility is 1/5, and for n problems it is 1/5*n).

The following example shows how multiple-choice problems are used in two of the choices of test N2.

N14 Electrical microscope

N15 Characteristics of a semi-conductoral diode

N16 Characteristics and parameters of a transistor

N18 Thermo electrical phenomenon

VERSION 1

Problem 10

Peltie's heat does not depend on:

a) magnitude of the electricity, passing through the solder;

b) direction of the electricity, passing through the solder;

c) resistance of the conductor;

d) magnitude of the electrical charge, passing through the solder;

e) time, needed for the electrical charge to pass through the solder.

VERSION 2

Problem 10

The sign of Peltie's heat depends on:

a) direction of the electricity, passing through the solder;

b) the sign of the emitted Jaul's heat in the conductors;

c) the sign of the Peltie's coefficient;

d) contact metal – metal;

e) contact metal – conductor.

The right answer to both of the problems is only one. The purpose is : the students should be able to tell apart and show the physical quantity that define Peltie's heat. This goal checks up the 4th knowledge level from the taxonomy of Blum.

The difficulty of the test problems is equal to the knowledge needed for solving it. For both of the versions it has been estimated theoretically, according to P.Galanov (Galanov, 1992; Galanov, 1994, Galanov, 1994).

Estimating the objective difficulty of a physics problem (that can be used for a test too) means estimating how difficult it is for the particular problem to be solved. Dividing the process of solving the problem into separate operations does this. By operation we mean every brain work that can be looked at as a specific and is done for the sake of solving the given physical problem.

Using the common instructions for solving physical problems and the algorithm for estimating their difficulty, it can be concluded that for solving problem N10 we need 12 operations. That means both of the problems are equally difficult.

The technology suggested by PhD P. Galanov (Galanov, 1992; Galanov, 1994, Galanov, 1994) allows us also to estimate a complete answer by using the number of the right operations.

The experimental defining of the difficulty of the test still has to be done. The problems need also to be tested about their quality, validity, reliability, and formulating the test versions.

Besides multiversion didactical tests certain help is offered to the students. It's called "a gun" and consists of literature, materials, protocols and reference books. (Bespalko, 1982) Creating such a situation along with the carrying out of the didactical test helps avoiding the competition between students and teachers, a normal psychological climate will be created and it will influence the education of the students, i.e. it will help bringing up character features like responsibility, independence, active behavior and so on.

Carrying out a test like this one requires the formulation of the problems to be different from the one in the textbooks, in order to avoid learning the material by heart and not understanding it.

The open book test gives the students the chance to think about the material and to test their understanding of it.

The most important skill in cases like this is to be able quickly and effectively to use the necessary information for solving problems. A criterion about the creativity of a problem exists. It's called Fuller criteria and suggests that a problem is creative if two or more physics laws should be used for its solving. For example problem N3, test N2, version N3:

1. The resistance R, which is an unknown quantity, can be estimated with the help of an oscilloscope.

By using data from the figure, estimate and choose the right answer.

a) 282 Ω;

b) 470 Ω;

c) 32 kΩ;

d) 282 kΩ;

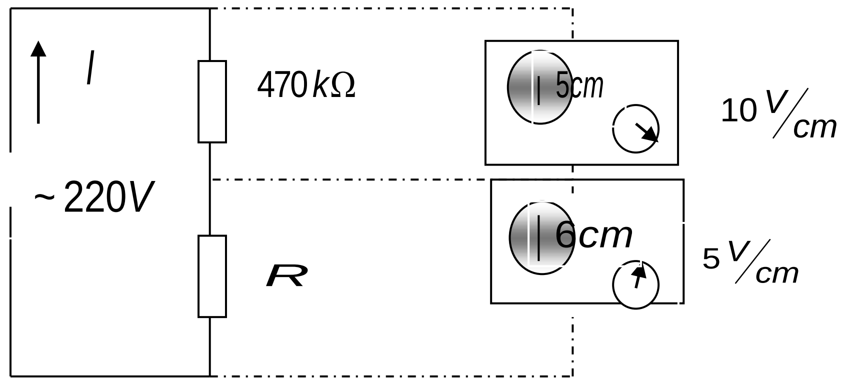
e) 470 kΩ.

The correct answer to this problem and choosing it (answer E) takes 29 operations to be done, which is relatively more than the number of operations needed for solving an algorithmic problem, such as problem N7, test N2, versionN1

Simple transistor amplifier with common base has coefficient of amplifying 50. What entering pressure is necessary in order to obtain outgoing signal 1 V:

a) 0,02 V

b) 0,5 V
c) 1 V
d) 50 V
e) 100 V



Solving this problem requires using one physical law and 15 operations.

Finding appropriate scale for translating percentage marks into examination marks is a serious practical and technical problem. If there are more students that have passed an exam thanks to the scale, they should be able to continue their study and this is a basic requirement for these skills.

To work successfully in many engineer fields like: electrical units, knowledge for the materials; nuclear electricity, one needs to understand the basics of contemporary physics. Physics is an important knowledge for an engineer and is "the door" towards technique and different technologies. That's why the scale for translating percentage marks into examinational ones is very strict in its requirements fir the students and has excellent prognostic validity, concerning their future knowledge

Table N1. Scale for translating percentage marks into examinational ones.

If a student gets the following percentage marks

between	100% - 90%	gets	Excellent (6)
between	90% - 80%	gets	Very good (5)
between	80% - 70%	gets	Good (4)
between	70% - 60%	gets	Satisfactor (3)
under	60%	gets	Poor (2)

Good understanding of the possibilities given by tests as a method of examination and estimation of students' knowledge and skills will provide their thorough implementation into the process of education and objectivity of the final grade. The exam gives the student a chance to show in a systematic and thorough way his/her knowledge and demonstrate his/her skills.

In its traditional version, however, the exam (written or oral) focuses on reproduction of the studied material. Overcoming this disadvantage can be accomplished by using some versions of an exam and elimination of others as separate phases of the final estimation.

The formulated didactical midterm tests consistent with the physics practice at the University can be used as a phase of the exam. They'll provide correct information floe from students to teachers about students' progress and will make them able to examine themselves alone.

This opportunity to control your own grades and progress creates the necessity for the students to accept the tests as an objective estimation. As a result, the relationship student/teacher will be changed. The teacher will no more be just a person who demands and instructs but an assistant who helps students realize the objective requirements of the didactical test.

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Recommended for publication by Department of Physics, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 143-147

THE GEOLOGICAL EXPLORATION ACTIVITY (GEA) AND THE COAL MINING INDUSTRY (CMI) AS ENVISAGED IN THE ENERGY STRATEGY OF BULGARIA

Jordan Jordanov[1], Christo Kazandjiev[2], Vassil Belogoushev[3]

[1] MGU
[2] MEER
[3] MEW

INTRODUCTION

The Bulgarian Government declared that the industrial policy it would follow highlights 5 priority areas one of which is the energy. Based on the Government program the Ministry of Energy and Energy Resources (MEER) worked out a strategy for development of the energy industry (MEER web-site, www.doe.bg). An essential portion of it is devoted to production of fuels (energy resources) and more specifically of crude oil, natural gas and coal. The attending exploratory, geological, appraisal and commercial appraisal works have not been subject to strategic planning, however, these are understood as necessary.

The present paper makes a review of the operations anticipated in the sphere of GEA and CMI. These issues have been discussed many times in the specialized literature, on forums of NGOs, industry organizations and specialists. The subject sector, however, develops with extreme dynamics that calls for timely response aiming at supporting the administration in managing the sector of the national economy. This in fact is the key task of the authors – to outline the main trends in the development of the sector and formulate recommendations towards its more successful management with the following clearly defined goals in mind:

- to keep the coal mining industry alive, with its servicing activity;
- rational utilization of national energy resources;
- to balance the employment in the coal mining regions;
- to secure energy independence of the country through volumes of produced energy resources;
- to reduce to minimum the negative trade balance formed mainly by imports of energy resources.

THE ENERGY STRATEGY OF BULGARIA AS SEEN IN THE EUROPEAN ENERGY AND LEGAL ENVIRONMENT

The economic environment within which the energy strategy is considered to be implemented is described by several important features among which are the accelerating globalization, market liberalization and unification of the energy legislation of the European countries. These particularities lead to integration processes that urge Bulgaria to pursue and achieve harmonization with the EU energy legislation in view of successful accession to the European Union and more specifically to its energy and energy legislation framework. The fundamental documents of the energy legislation in Europe regulating the public relations include the following:

- Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity;
- Directive 98/30/EC of the European Parliament and of the Council of 22 June 1998 concerning common rules for the internal market in natural gas;
- Directive 94/22/EC of the European Parliament and of the Council of 30 May 1994 on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons (from the subsurface).
- Declaration of 25 June 1999 on the role of the coal in Europe in the 21st century.

The particular community legislative framework for the GEA may be found in Directive 94/22/EC, however, the practice of the member candidates is still regulated by the legislation of the respective countries.

COAL MINING IN THE REPUBLIC OF BULGARIA

Current status and problems

Presently the coal mining sector includes 21 commercial entities 13 of which are involved in mining, processing and sale of coals; 6 are announced for closing down and 2 are announced insolvent (Table 1). Coals are produced from 22 mines in total 9 of which are open and the remainder are underground. For 2001 the total production amounts to 27 364 thousand tons of coal, after cleaning the figure is 26 586 thousand tons; the producers are shown in Table 1. Based on data by Markov (2001) and data by the authors the total production shows trends to reduction compared to previous years. The reasons for this tendency are generally known to the specialists, as more significant are: reduced electricity consumption; reduced purchase power, reduced labour productivity, insufficient investment to open new mining units and for maintenance of facilities, out-of-date and worn-out mining equipment and machinery for extraction and processing.

Table 1. Main indices of the coal industry and the coal mines announced in liquidation (based on data by Markov /2001/ and data by the authors)

Total annual coal production (in thousand tons)	1989	1990	1992	1994	1996	1998	2000	2001
	35 801	33 060	31 423	29 782	32 363	30 962	26 278	26 586
Coal producing	State Companies		Announced in liquidation		In liquidation with production restored			
Maritsa East EAD	*							
Beli breg AD								
Chukurovo EAD								
Staniantsi EAD								
Christo Botev EAD								
Vitren EAD								
Bobov dol EAD	*							
Cherno more-Burgas EAD	*							
Pirin EAD	*							
Zdravets EAD	*							
Balkan - 2000 EAD	*							
Lev EOOD								
Antra EAD	*							
Toplofikacia – Pernik EAD	*		*		St.Anna mine, section “Central”			
Balkan EOOD			*					
Marishki basein EOOD	*		*					
Ivan Roussev EOOD	*		*		Iv. Roussev mine, sections III, VII			
Kolosh-BD EOOD	*		*		Minior mine, section V			
Kanina EOOD	*		*		Kanina mine			

A common feature of the active coal mines is the insecure financial standing. At present only Mini Maritsa-East EAD show relatively stable financial parameters. The financial standing of the remainder of the mines, esp. the underground ones is poor to very poor. Although the prices are liberalized, the monopoly position of the thermal-power plants prevents any optimistic forecasts. A typical example of this situation is Mini Cherno More EAD, where despite the satisfactory level of restructuring and optimization of the personnel, the poor collection of receivables from consumers is a major hindrance to enduring stabilization of the company. Without any in-depth analysis of the main reasons for these conclusions, developed quite in detail by Rizov (1998), Dimitrov (2001), Markov (2001) and others, we will only point out that the limited individual incomes of the population appear to be one of the most essential element in overcoming the constant shortage of cash flow in the companies. Most of the mines follow a negative trend of decapitalization, which on the other hand reduces the interest of potential strategic investors to null. These problems are reflected in the Energy strategy of the country and it is expected these to be remedied by applying the measures as listed below.

1. With respect to open coal mines
- to mobilize financial resources for rehabilitation and modernization of the heavy mine machinery;
- to introduce new equipment and facilities in the coal mining operations to improve the labour productivity;
- to protect the environment along with restoration and recultivation of the mining areas.

2. With respect to the underground coal mines
- to develop a strategy to improve the financial standing of the coal mines;
- to develop schemes to improve the effectiveness of the mining activity;
- to develop schemes to gradual reduction of due payments to null;
- to formulate and justify schemes to improve the collection from debtors;
- to optimize all levels of operations in order to achieve competitive cost of production, thus allowing broader market opportunities;
- to optimize the personnel along with adequate financial funds for social protection and re-qualification of the dismissed personnel.

In line with the above measures it is planned to apply conventional instruments to revitalize the sector relating to its restructuring and privatization following a model that will secure the activity, the investment programs on behalf of the buyer, as well as effective post-privatization control to prevent from the negative trend to withdraw the resources and subsequent compulsory liquidation of the company at lack of liquid assets.

The above stated considerations are based on the projected macroeconomic indices for medium- and long-term development of Bulgaria. Based on data from the World Bank and the Economic Analyses and Forecasts Agency with the Ministry of Finance it is envisaged the GDP will grow from 29 618 bln BGL in 2001 to over 50 bln BGL in 2010 which is by 3.5-4.5 per cent average per year. This growth is anticipated to be reached through secured production of primary energy by the end of the period of up to 500-600 PJ. Forty to forty-five per cent of the production will be due to fossil fuels. However, we need to point out the "negative" estimations of the World Bank that outline reduction of the fossil fuels' share at the expense of liquid fuels and eventual growth of nuclear energy. The World Bank experts expect the fossil fuel portion of 45 per cent in 2010 to decrease to 43.7% in 2015 which in volumes appears to be a reduction of more than 30 mln tons. The authors of the paper are not inclined to accept these forecasts and anticipate increase in domestic coal consumption and the production of around 27 364 thousand tons in 2001 will gradually rise to 30-34 mln tons by 2005-2008 and will retain that level for the period 2010-2015. This conclusion is supported by the analysis of expected growth of power generation on local energy resources and briquette production for households. Extensive household gasification is not envisaged for this period and the pricing and tariff policy of NEK is oriented towards more effective utilization of electricity in the industry.

The above presented model of macroeconomic development is assessed as more favourable or "maximum scenario". Under the minimum scenario the growth rate of GDP is projected to be 3-3.5 per cent which prevents strongly any prognoses with respect to the coal mining industry and it is most probable to expect reduction to termination and further liquidation of the underground coal mining and concentration of the mining operations only in the open mines of the Maritsa basin. In such situation the state financing institutions will not be able to support the industry at sufficient levels and the government will be forced to privatize the coal mines at utterly unfavourable conditions. The practice shows that in such privatization only few companies manage to keep the activity, and the sector, respectively.

Measures to optimize the management of the coal mining industry

The national Energy strategy stipulates a series of measures in several directions. In the first place it is anticipated to introduce appropriate legislation in order to optimize the public relations in the energy resources extraction sector as well as in the attending areas that render services to the industry. Improvement of the secondary legislation to facilitate the regulation procedures on behalf of DKER (the State Commission on Energy Regulation), the procedures under the Public Commissions Act, the Law on Structure of the Territories and the subsidiary regulatory documents. Also of crucial importance appears to be the declared willingness to develop and adopt a pricing and tariff policy that would most adequately correspond to the real incomes of the population and particularly of the lowest income population. The practice to support the lower income households in covering their energy costs will continue in a way to secure that funds will be distributed to eligible households on the one hand, and to achieve regular load of the capacities (i.e. the briquette plant) on the other.

The second trend is development of models to mobilize resource support in a liberalized competitive energy market environment. The estimations for the rehabilitation and modernization of coal mining industry indicate that by 2010 the required investment amounts to USD 400-500 million. The mobilization of such financial resource is beyond the capacity of the national economy. Therefore, it is more expedient to look for alternative sources. Up to now interest is shown only to Mini Maritsa – Iztok EAD while for the other companies no strategic investor is identified. The public is aware of the foreign companies' interest to Maritsa basin, however, the intersection of both parties' interest is still not found.

Certain resource to overcome the critical situation is tied to the intentions for economically justified privatization. The privatization is envisaged to proceed by stages. Initially the companies are to be restructured to become more attractive for the market followed by privatization. The accumulated experience suggests that the direction is correct but financial stability is achieved through a package of measures some of which are rather restrictive and unacceptable for the people. Regardless of some difficulties the orientation is steady and is perceived both by the practitioners and the European consulting structures as the only viable approach.

GEOLOGICAL EXPLORATION ACTIVITY IN THE REPUBLIC OF BULGARIA

The geological exploration activity in principle is not projected in the Energy strategy but it takes indirect part in formulating the general policy in resources provision of Bulgaria and that is why the authors discuss it as an element of securing the sustainable development of the energy system of the country.

The state policy in the field of geological exploration and production of underground resources is implemented mainly by the Ministry of Environment and Waters in the legal framework of several laws the leading documents being the Underground Resources Act (URA, state Gazette, No 23 of 12.03.1999). In 1995-1999, in parallel to the new URA, several strategies on the metallic and non-metallic ores, decorative rocks were developed, as well as national program for development of ore production. But only in 2000 a thorough document known to the public as "Strategy for development of geological exploration activity and protection of subsurface to 2010" was elaborated and adopted by the Council of Ministers Ordinance No 519 of 03.07.2001. The approved strategy is based on common efforts by a team of distinguished experts led by Prof. Dr. Christo Dabovski (Sofia, October 1999) supplemented with the views and recommendations additionally introduced prior to its approval by the Council of Ministers. The principles laid down in the documents with respect to the leading role of the market rules in the geological exploration, production and processing activities in the framework of the recent international requirements for protection of the environment and the subsurface were perceived positively. They were also successfully projected in the legislative regulation of the public relations (URA and the elaborated draft for amendments thereto) and indicated successful initial implementation. We will only point out that by 8 April 2002 the Ministry of Environment and Waters (MEW) registered and issued certificates for 26 discoveries.

Particularly encouraging is the applied participation of RAMCO to assess the petroleum-bearing potential of the East Balkan tectonic zone. It is also intended to re-arrange blocks in the offshore Black Sea aiming to attract strategic investors. It will be correct, however, to mention the negative trends of dramatic reduction of prospecting and exploration activities. This fact as well as the main reasons behind it are well known to the public. The authors expect that following the standstill as a result of the gradual imposition of the market principles in the sector, it will mark a rise in the GEA substantiated by the company interests of the legal entities holding permits for prospecting and exploration or concession rights to produce. At this stage, however, a greater portion of the financing for GEA comes from the state budget with the MEW being the primary organization in distributing the funds. For 2002 the state budget subsidy for projects in the field of regional geology, underground resources and waters amounts to 1 562 569 BGL. The sum is distributed among the directorates as follows: Directorate on Subsurface and Underground Resources – 1 277 466 BGL and Directorate on Waters – 285 103 BGL. The internal distribution of the funds by departments and divisions is shown in Table 2.

Table 2. Distribution of the state budget subsidy for 2002 by research programs and projects in the field of geology and underground resources (web-site of MEW)

Directorate	Division	Department	Programs (in number)	Tasks (Projects)	Total Sum (in BGL)
					85 000
Subsurface and Underground Resources	Geology and Exploration Permits	National GeoFund and GeoInformation	2	11	284 297
		Geology	4	7	607 815
	Protection of the Subsurface, Appraisal and Balance of Reserves		3	8	300 354
Waters	Utilization of Waters			4	285 103
				TOTAL:	1 562 569

According to the strategy for development of the national policy in the field of geology, underground resources and waters the key financial resources are oriented towards implementation of a broad range of tasks of regional character mainly. The available funding, however, is rather insufficient which resulted in the current status of a number of spheres in the underground resources and regional geology sector. This will have negative impact on the plans of the country to adequately participate in potential cross-border projects (e.g. appraisal of the opportunities to utilize the resources of gas-hydrates in the offshore Black Sea). The attitude to have mainly commercial companies involved in prospecting and exploration is acceptable since the "transitional" type of economies are not in a position to secure large amounts of financing. In the opinion of the authors it would be expedient to invest even more rigorously in regional studies and more specifically in studying the deep structure of certain areas of the territory of the country. This type of investment is assessed as potentially redeemable because such results are highly informative and sought by the companies, therefore, they are a marketable product. The areas may cover the economic zone of the offshore, parts of south-west Bulgaria, completion of the seismic projects for the S Bulgaria section and others.

At present no state budget financing is provided for new coal prospects. This position is also estimated as a substantiation of the term of strategic planning (2005-2010). The authors consider as an essential task in the geological exploration for fossil fuels the attraction of strategic investors and perfect compilation of the privatization contracts along with precise negotiation of the exploratory and appraisal operations, including effective post-privatization control on the commitments taken.

The experts in the field of geology quite often discuss the issue on the institutional consummation in supporting the GEA and the production of underground resources. Without getting in too much details we will mention that in our opinion it is more weighty to clearly define the competencies and the institutions charged with the implementation thereof. According to URA (Article 7) MEW is the institution that is to develop and propose to the Council of Ministers the state policy and strategy in the field of prospecting, exploration and production of underground resources and protection of the subsurface. This way MEW appears to be a regulatory, coordinating, supervisory and information state body and to solve the following two key issues:

- development of the legislative documents on the procedure and conditions to acquire rights to prospect, explore and produce underground resources; this is a function of a state regulatory body, independent at maximum settled by law;
- management of regional scientific and applied studies to acquire more complete notion of the underground resources of the country and to compile and maintain a national data base of the composition and the studies of field geophysical surveys and well logs.

At the same time it is expected the Ministry to achieve the following political goals in the most favourable for the society way:

- To provide the society and the economy of the country with sufficient in type and quality information;

- European and global integration in the field of geology, expansion and protection of Bulgarian interests worldwide;
- To stimulate the private initiative in prospecting, exploration and production of underground resources and to attract foreign investment in this sector;
- To utilize and protect the subsurface as a non-renewable resource.

The complete realization of these goals will be achieved by the implementation of 16 long-term programs. The Ministry of Environment and Waters will introduce for the first time in Bulgaria, starting from 2003, program- and goal-oriented budgeting instead of the mere compilation of the annual budget as practiced until now. This will allow the implementation of all programs, as concentrated in one body, to be secured with the required human and financial resources. Currently the work on some parameters of the budget to 2005 is ongoing. Thus the National geological survey of Bulgaria (a directorate within MEW) will dispose of the necessary resources to carry out its intrinsic functions. Of enormous significance to the country is that Bulgaria became an associated member to EuroGeoSurvey, first among the "new democracies in Europe".

CONCLUSION

The views of the authors presented here are far from exhausting the issues of the coal industry and the geological exploration activity. It is envisaged that in the dynamic environment of the economic life of the country the market principles will be more strongly imposed to stimulate the expected growth of production. The growth will be inevitably attended by increased demand for energy resources and raw materials. And our efforts will be worth if we have even partially contributed towards achieving this goal.

Recommended for publication by
Department of Economic Geology, Faculty of Geology

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 149-152

SOME INTSTITUTIONAL ISSUES RELATED TO ENVIRONMENTAL IMPACT OF MINING AND INDUSTRIAL ENTERPRISES

Detelin Dachev[1], Kristina Marhova[2]

[1] University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria
[2] "Kristina M" Ltd., Sofia 1505, Bulgaria

ABSTRACT
Some institutional issues related to estimation of the impact of mining and other industrial enterprises on the environment are disputed in the present paper. The list of the Council of Ministers, concerning Regulation No 50 of 1993 about areas industrially contaminated with heavy metal as well as the inadequate policy of the Government in respect of re-cultivation of contaminated lands is also commented. Examples of irrational strategy are also given in respect to the restoration of the ecologically clean status of the environment.

INTRODUCTION

The idea of a balanced economic development under a sustainable ecological condition in some Bulgarian areas has been rather deformed for the recent years. This refers not only to high institutional levels but also to subordination of local authorities of municipalities of extreme negatives environmental conditions.

Worth mentioning is the fact that according to our investigations hyperbolizing the ecological status in some "hot points" of the strategy is a result of the following factors:

- Insufficient professional knowledge and in some cases incompetence of some representatives of the high departmental institutions;
- Inadequate legislation and regulations, established in the last years;
- Comprehensiveness of the issue of real estate properties and in particular ownership of the agricultural lands. These are the consequences of the reforms concerning restoration of private ownership restoration of these lands. A lack of information is quite characteristic in a scale concerning issues such as natural (geo-genetic) soil contamination with geonoxes (poisonous agents of geological origin) and separation of areas of such contamination from areas of a technogenic ecological harm.

INVESTIGATION AND METHODOLOGY

Our detailed review of recent Bulgarian and world investigations in the field of land ecological status, geoecology and the legislation for the real estates in our country concluded that institutional information in Bulgaria is inadequate in respect of problems of negative impact of natural and technogenic factors on nature and public environment. Based on a review of methodologies, applied all over the world, which concern the separation of human contamination from the geogenic one, it was established that soil science and geological methodologies of early 60ties had been applied to environmental protection even in the most developed countries. Only in Bulgaria, after a period of a geoecology development (in a collaboration with French, Russian and Serbian scientists – Frolov, 1991) the so-called *Discrete Point Geoecological Profile Method* was developed (Dachev, 1996, Dachev, Theoharov et al., 1997, Dachev and Uzunov, 2000, Dachev and Borisova, 2000, Borisova, 2001, Theoharov and Dachev, 2001). The environmental contamination (auto-contamination zones) caused by technogenic invasion into soils could be determined by the above methodology. This method is a priority for Europe is practically interesting and is applicable for:

- Expert estimations of private and state-owned real estates in the sale of real estates, for assessment of ecological, market and the strategic risks;
- Assessment of former technogenic and self-geogenic contaminations;
- National and regional ecological programs.

RESULTS AND INTERPRETATION

In this case, an application of the so-called multidisciplinary approach to the effect of the mining and the industrial plants on environment as well as the role of the institutions is necessary for adequate assessment of the issue. That means all the mentioned above factors should be taken into account: competency of institutional experts, legislation basis and the integrated character of real-estate interrelations.

On competency of institutional expert. It should be noted that regardless of the endorsed international standards and operating legislation concerning the problems of Environmental

Impact Assessment (EIA), there are a number of EIA procedures in Bulgaria practiced in a usually by reduced by number expert boards. As a rule, they consist of chemists, biologists, geographers, and economists and rarely of geologists and geoecologists. This goes on despite the fact that there are highly qualified specialists exactly in the same area – in specialty of "Geoecology" trained and educated at the University of Mining and Geology (UMG) "St Ivan Rilsky" in Sofia.

Reasons for not including geologists from the University of Mining and Geology into the commissions is the lack of information of high level officials from Ministry of Environment and Waters as well as the badly formulated legislation.
For example, recently operating Environment Protection Act and relevant regulations say that only graduate professional of at least five years of experience possess the right to take part into EIA commissions.

This is obviously unadvisable as the University of Mining and Geology "St Ivan Rilski" in Sofia and the University of Forestry train professionals in the field of environmental sciences for a term of five years. So, the new Environment Protection Act should regulate the right of geoecological specialists to take a part in expert commissions.

An inadequate juridical treatment of the legislation and regulations concerning environmental issues. The disorientation role of certain laws and regulation documents for environmental issues was repeatedly underlined (Dahev, Theohranov, 1995; Dahev, Kiosev et al., 1997; Dahev, Uzunov, 1997). For example, a decisive disorientation role in the agricultural (soil) environmental issues played para 10 of article 10 of the Law for Agricultural Land Management and Usage (LALMU) of 1991 where the following is written: " The lands in the ecologically contaminated areas should be given back to the owners and the expenditures for their ecological restoration should be assumed by the government". The Council of Ministers determines the ecologically contaminated lands as well as the order and the way of their ecological re-cultivation. There are not comments about the lands and even whole regions with extreme natural geochemical anomalies that impact negatively on the ecological status. It is not clear how the state may re-cultivate such lands in an ecological condition that is again not specified.

That is why an entire series of subsequent laws and regulations were generated, which treated the problem of the ecologically harmed lands in the same wrong direction. For example: Law for agricultural land protection, Law for infrastructure of territory as well as relevant regulations and the number of rules generated by them, etc. Now a new Law for the Cadastre will be discussed and it will be considered in the same way. A working group of UN experts on a base of cadastral investigations and land development systems accepted the following definition (UN bulletin, 1985), quotation: "The cadastre is methodologically ordered governmental list of data about the real estate in a given country or area".

The word DATA, of coarse, includes also a full set of geomorphological and lithogeochemistry facts. At present, in our country the geological information is neglected. It is shown in an undoubted way by the notorious list (appendix 2 of the Decree № 50 of 1993) of contaminated lands in Bulgaria, which still is neither cancelled nor at least corrected. That list (table 1) includes hundreds of hectares of Bulgarian lands, industrially contaminated, where "the competent experts" – soil scientists and agronomists included the zones of extreme values of geochemical heavy metal anomalies in the sampling (the dark marked in the text – a. n.) which is unacceptable.

It is known today why that list was neither annulled nor corrected and the answer is:

- Purposefully, the competent specialists in ecology from the University of Mining and Geology "St Ivan Rilski" in Sofia are not drawn into the commissions;
- Authors of the list, due to their undoubted economic interest, started a re-cultivation of those lands, i.e. tried to clean the uncleanable and spent significant amounts of money from the funds of European and United States Organizations in the most unadvisable way.

The clarifying of the problem of the lands contaminated by the mining and industrial enterprises is not referred only to the Land Fund Authority and the other real estates. It is also exclusively important in respect of former contamination and agricultural ecological restructuring. For example, growing of tobacco in the whole Rhodopes is nor advisable because this same plant is a concentrator of heavy metals and radionuclides. A realization of such project, which is obviously stimulated by interested companies of that branch, will render at the end a negative ecological influence on people of the region.

Separation of the natural contamination from the industrial one needs relatively low funds, a little times and not extended teams. It should be a process of re-mapping of the well-known (and already mapped) metalogenic zones with a separation of the minimums and maximums of genoxy content.

Some aspects of taking into account the geoecological risk. The Geoecology is a science for a 3D and polycomponent influences (geological and soil) on the ecological status of the soil, waters, air and the human factor. Generally, the environment contamination, however, is not only of geochemical anomalies and heaps resulting of mining and metallurgical industry. An attention to other geological phenomena, harming the environment and society, is also necessary, as: landslides, earthquakes, strong rain fans, erosion and cumulative processes, etc.

Those are risk factors as of an economical as well as of a health-ecological meaning. Their prognosis is a matter of a system, devices, monitoring and control activities but most of all they are a matter of a principle position in respect of endorsing of the dynamical geoecological systems (Dachev, Uzunov, 1999).

There is no case for underestimation of these geoecological factors, or the environmental contamination.

Table 1
List of environmentally contaminated agricultural lands from industry of heavy metals (Appendix 2 of the Decree of Council of Ministers № 50)

№ Region	Location	Contaminated areas above the Threshold Permissible Concentration - decares		Elements contaminants	Source of contamination
		Total	More than twice the TPC		
1. Vidin including:	Total:	1002	673	-	-
	Bregovo town	671	508	copper. zinc	Timok river (Bor mine, Yugoslavia, Serbia)
	Balley village	45	45	lead, arsenic	
	Vrav village	286	120	lead, arsenic	
2. Vratsa including:	Total	1310	635	-	-
	Ochin dol village	390	15	arsenic, lead	MMP - Eliseina
	Zverino village	300	-	lead	MMP - Eliseina
	Oselna village	300	300	arsenic, lead	MMP - Eliseina
	Eliseina village	280	280	arsenic, lead	MMP - Eliseina
	Zli dol village	40	40	arsenic, lead, copper	MMP - Eliseina
3. Kardjali including	Total:	33500	11500	-	-
	Kardjali town	9000	5000	lead, zinc, cadmium	LeadZincP – Kardjali
	Gledka village	1500	1000	lead, zinc, cadmium	LeadZincP – Kardjali
	Shiroko pole vill.	2700	1000	lead, zinc, cadmium	LeadZincP – Kardjali
	Vishegrad vill.	1000	500	lead, zinc, cadmium	LeadZincP – Kardjali
4. Sofia - district including	Total:	47400	11000	-	-
	Pirdop town	15000	5000	copper, arsenic	CopperPlant –Pirdop
	Zlatitsa town				
	Tsarkvishte town	12000	4000	copper, arsenic	CopperPlant –Pirdop
	Karlievo vill.				
	Anton vill.	6000	2000	copper, arsenic	CopperPlant –Pirdop
	Chelopech vill.	5000	-	copper, arsenic	CopperPlant –Pirdop
	Dushantsi vill.	1500	-	copper, arsenic	CopperPlant –Pirdop
	Grigirevo vill.	1900	-	lead	"Kremikovtsi" Co.
	Eleshnitsa vill.	2100	-	lead	"Kremikovtsi" Co.
	Stolnik vill.	1800	-	lead	"Kremikovtsi" Co.
	Musachevo vill.	2100	-	lead	"Kremikovtsi" Co.

CONCLUSIONS

1. An intensive intervention on behalf of scientific geoecologic and soil science society is required to change the style and methods applied to issues of institutional factors for re-cultivation of clean Bulgarian environment from geogenic and technogenic contamination.
2. The comprehensive approach toward environmental impact assessment for mining and industrial enterprises should be applied and geologists and mining engineers should be involved in it.
3. A support should be requested in the Parliament and within the Government for corrections in the regulations, relevant to the most important trends of environmental expertise and environmental status of real estates.

- Change in the Environmental Protection Act in the part of required professional experience for enrolling experts in the register of Ministry of Environment and Waters for assessment of environmental impact. Experience of the graduates from the "Geoecology" specialty of the University of Mining and Geology – Sofia and other similar specialities should be one year instead of quoted in the law five years;
- Change in the same law, in the part concerning paying of expenses for the procedure of EIA, according to recent law these expenses are paid by the investor, which is illogic and unmoral. Owner of land, where the project will be implemented (as it is in Germany and other west-European countries), should pay those expenses;
- Cancellation of the list of contaminated lands to Decree No 50 of the Council of Ministers of 1993 and organizing by the Ministry of Environment and Waters, teams of geologists and soil scientists for reviewing the metallogenic zones with extreme geochemical anomalies and geochemical heaps of heavy metals and radionuclides;

4. Organizing by the University of Mining and Geology "St. Ivan Rilski" of seminars, conferences etc. at a national and international scale for reviewing the economic role of geoecological investigations for assessing the risk of real estate sales, santary and other operations, national and regional strategies for extreme geological situations.

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Recommended for publication by the Editorial Board of part "Mechanization, electrification, automation in mines"

Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.45, part I, Geology, Sofia, 2002, pp. 153-156

GRANITE – THE ETERNAL DECORATIVE ROCK MATERIAL

Nikola Murhov[1], Pavel Milev[2], Nikolai Petrov[2], Kiril Papadopulos[3]

[1] University of Mining and Geology "St. Ivan Rilski", Sofia 1700, Bulgaria
[2] Techmi Ltd., Sofia, Bulgaria
[3] Papadopulos Co., Sofia, Bulgaria

ABSTRACT
General information on granite is presented and its role in the history of human civilizations is discussed. The technology and mechanization of extraction and processing of granite materials in Bulgaria are described and assessed to be on a modern level. Definitions of special concepts such as 'rock materials' and 'decorative rock materials' are given. The term 'granite material' is defined and its main parameters considered.

GENERAL INFORMATION ON GRANITE

Definition. The concept 'granite' is not a clear notion to many people in the modern high-tech and computerized world. It is still a common belief that every polished stone is marble. In fact, the difference between marble and granite is very big.

Marble is a carbonate rock that is easy to grind and polish but has lower hardness compared with granite. The products made of this material are not resistant to the adverse weather conditions, which makes them suitable mainly for enclosed spaces. However, marble is much more richly colored and patterned than granite.

Marble is associated with the exquisite sculpture of Venus Miloska, with the spiritualization of the Carrara stone by Michelangelo and the polished slab at home.

Granite is a symbol of hardness, strength and durability. The products made of granite materials are practically eternal.

Granite (from the Latin word *granum* grain) is a granular rock formed by the crystallization of magma in the crust. It is composed of the minerals: quartz, feldspar and mica. Granite has physico-mechanical properties that characterize it as an excellent structural, decorative-facing and monumental material. It has a density of 2700 kg/m^3, hardness 7 by Mohs' scale and 150 to 250 MPa compressive strength. It is cold resistant and highly resistant to aging and weathering. Polished granite preserves its luster for centuries and millennia.

On our planet granite occurs in inexhaustible quantities and humanity will never feel short of it.

Granite rocks are differently colored, varying between the white Norwegian granite and the black African one, coming in a wide range of various colors such as bluish, pearly-gray, cream, pink, red and green granites. Some of these are unique in color and have a highly decorative value.

Granite is the history of human civilization. Natural stone has always been a crucial part of the material culture of the human race. Mankind faced the need to process stone as early as the beginning of its development.

During the earliest cultural-historical period, the stone age (approx. from 800 to 5 thousand years BC) stone was the main material used to make tools (axes, hoes), weapons (arrow tips, spears), ornaments and attributes symbolizing the meaning of human life, dwellings and religious monuments. The great importance of stone for human life during the time of the primitive community gave the name of that age, the Paleolithic Age (from the Latin *paleo* old and *lith* stone), which started with the appearance of the first stone tools and ended with the discovery of copper during the Bronze Age.

Stone processing during the Paleolithic Age passed through a long evolution from the use of rough unprocessed implements to the invention of various cutting tools. During that period man gradually acquired the manual operations for stone processing in the following technological-chronological sequence:

- dislodging and breaking off during the Early and Middle Paleolithic (800 –35 thousand years BC);
- splitting and rough hewing during the Late Paleolithic (35 – 10 thousand years BC);
- cutting, grinding and drilling holes during the Neolithic (10 – 5 thousand years BC);

As late as the Bronze (4 – 2 thousand years BC) and Iron Ages (2 – 1 thousand years BC), when metal tools were invented, man managed to master the skill of processing the hardest rock material, i.e. granite. The Egyptians, whose civilization leads us 7 – 8 millennia back from modern world, gave the first data about granite processing. During the dynasties, in the course of centuries, hundreds of thousands of people worked on the construction of pyramids and creation of pharaohs' sarcophaguses. The truth is that the Egyptian pyramids were built up of numulite stone but Mycerin's pyramid was faced from base to top with pink syenite tiles.

As far as the technological and technical level of granite processing practiced by the ancient Egyptians is concerned, it should be noted that the Luxor obelisk, 25 m high and approx. 250 t in weight, was made of pink granite. Nowadays this monument decorates the Concord Square in Paris. The pharaohs' people were precise and methodical. An example of that is the granite sarcophagus of Senizert II, whose sides were made with 0.2-mm differences in dimensions. Even today we can admire that marvel of precision.

The processing of granite monuments was carried out by thousands of people for centuries but the time factor played no decisive role since the aim was to make beautiful, precise, monumental and grandiose products.

The Greek civilization left a small number of granite products since marble was the Lord in ancient Hellas. It was used to build the world famous monuments in Athens. And yet, we have to mention Agamemnon's tomb in Mycenae made of green porphyry.

The Romans, who used the knowledge and experience of their ancestors, improved granite processing and left many monuments and temples in Europe that have been preserved until the present day.

During the Medieval Age and Renaissance no considerable progress was made in granite processing but that period was characterized by intensive construction. It was the time when the Saint Michel monastery in Bretan in France and the 15th century abbey were built up of granite elements.

It is necessary to note that in the 18th century, during the construction of Saint Petersburg, gracefully worked-out large-scale granite products were created. In 1782 a monument devoted to Peter the Great was raised with a basement of polished pink granite of weighing 1500 t, overlaid by a bronze group of horses.

The most spectacular granite monolith ever to have been raised by a human so far is the polished column of red granite, 3 m in diameter, 25 m in height, weighing 500 t and placed on a basement of polished granite with 6.5 m sides, 1.5 m in height and 150 t in weight. This monument is an exquisite work of art and decorates the Winter Palace Square, inspiring respect in modern man with its large scale.

TECHNOLOGY AND MECHANIZATION FOR EXTRACTION AND PROCESSING OF GRANITE MATERIALS IN BULGARIA

The present technology and mechanization used in extracting and processing granite materials in Bulgaria measures up to the most advanced countries in the world.

Extraction. Explosives are not used any more in extraction thus preserving largely the integrity of the extracted blocks. A combined extraction method is now used. Transverse slots, spaced 5 – 8 m, are cut in the bench by a thermal saw. The slots can be as deep as the bench width, the depth being equal to the bench height, though these dimensions usually reach up to 3 – 4 m. The technological width of the slot reaches 12 – 15 cm and the thermal saw output varies between 1 – 1.2 m^2/h. The vertical and horizontal contouring between the slots is performed by rock drills making holes of 36 – 41 cm in diameter, spaced 10 – 15 cm. The monolith thus contoured is dislodged from the bench mass by wedge-splitting devices placed in the vertical holes. The monolith is then cut out by slitting the rock block into the required dimensions.

Processing. The granite block is processed by different techniques depending on the dimensions of the billets and products.

The cutting of granite blocks for making large-sized slabs (2x3÷4 m), 15 – 50 mm wide, is technically possible to perform by using several techniques but the most economical technology is cutting by gang saws with smooth blades and cast iron or steel shot. This technology is applied in Bulgaria, at the plant of the Bulgranite Ltd., Gara Iskar in Sofia, using one of the most advanced gang saws in the world, Masterbreton HG120, for cutting blocks of up to 3300 mm in length, 3000 mm in width and 2000 mm in height. The gang saw is provided with 120 blades and, at a maximum allowable feed rate of 80 mm/h, a fairly high operational output of up to 25 m^2/h is achieved.

The cutting of granite blocks for making thin slabs with the so-called foot sizes (30.5x30.5x10÷15mm) is carried out by orthogonal disc saws with diamond segments allowing to process the block in a stepped manner.

The edges of the billets and large-sized slabs are cut out by machines of various design equipped with diamond segment discs.

The grinding and polishing of the granite products in a flow process is performed entirely by abrasive grinding and polishing tools. These operations are also performed by diamond tools but only at private companies when grinding single granite products. The specific prime cost of the operations is higher but they are carried out by smaller machines.

ROCK MATERIALS

It is a well-known fact that there are no commonly accepted terms and concepts in the Bulgarian science and practice that characterize the materials extracted from various types of rock and their purposeful technological alteration in view of using them properly in construction or for architectural and monumental products. This ambiguity of terms and concepts is inadmissible. The difference between rock and rock material is often blurred and in some cases misunderstandings occur as a result. For instance, even experts sometimes use the term 'decorative rocks', not making it clear whether they have in mind the outer decorative shape of the rock (e.g. the

Belogradchik Rocks or the Pobiti Kamuni/Fossil Forest), or the potential decorative properties that will be manifested provided that rock is used to extract material and process it in the appropriate manner.

This is the reason why we suggest that we discuss our views on those issues.

Rock. Rock is a geological concept meaning natural material aggregates of relatively constant composition and structure and considerable volume, formed as a result of a complete geological process. The rock should always be associated with its natural state in the ground.

Rock materials. The materials extracted from the rock mass by some technical impacts (mechanical, blasting or thermal) are called **rock materials**. These materials result from their artificial separation from their natural state in the ground and not from various weathering and other processes.

Types of rock materials. Modern industry and construction use numerous materials extracted from various types of rock. According to the purpose of use they are classified into the following groups:

- nonmetal building materials used for obtaining artificial construction material (cement, lime, etc.)
- building stone used for constructive building material;
- decorative rock materials.

Decorative rock materials. The name of these materials comes from the Latin word 'decoro" meaning decorated. This concept involves natural rock materials which, due to their aesthetic qualities, revealed by means of different processing methods, are suitable for making various decorative-functional products needed for the construction industry and everyday life or products of purely decorative or monumental character.

There is still no generally accepted and standardized term in the Bulgarian technical literature for those materials, which can give accurate and full information about their nature and use.

The term 'decorative stone', used in the past, is incomplete since it refers only to the feature 'decorativeness' and does not give any information on whether the stone has been broken out of the rock as a result of natural destructive processes or produced by artificial separation.

The term 'rock facing material' has begun to gain ground lately because the decorative rock materials are increasing being applied as facing material in construction. However, this concept is inaccurate and limited since it does not reveal the decorative nature of the material and neglects its use for high volume structural elements or for purely decorative purposes (sculptures, monuments, etc.).

On the basis of the above reasoning we propose the term 'decorative rock material', which, firstly, reveals the character (decorative) and nature (rock) of the materials, and secondly, one definition of 'material' is the raw material for making products (according to the dictionaries of the Bulgarian language).

At present many types of decorative rock materials are being extracted but granite and marble materials are of particular importance for the construction industry, architectural products, monumental plastics, etc.

GRANITE MATERIALS

The unspecified concept 'granite materials'. The terms 'marble materials' and 'granite materials' are used in the practice of processing decorative rock materials in Bulgaria and other industrially developed countries. While the concept 'marble materials' is clear enough, the problem with the term 'granite materials' has not so far been defined accurately and is to a large extent more complicated to solve.

This circumstance causes certain difficulties in the production and, particularly, trades relations between business partners as regards the type and quality of these materials.

It is a well-known fact that every company, which exports some decorative rock material to the market, gives it a name that serves to advertise the product in view of raising its price. On the international market of decorative rock materials there is no institution that obliges the producers to use the correct petrographic term for the material offered. However, the producers and traders sometimes designate the material in such a way that the name often contradicts its real nature. For example, rock materials are offered on the international market, which are not related to granite in terms of either genesis or mineral composition. And yet, they are called granites. Here we will point out only two firmly accepted misleading names: black Swedish granite and Belgian granite.

The "Swedish black granite", also known by the symbol "SS", is an excellent material for making monuments. It is black in color and composed of plagioclase and pyroxene but does not contain quartz. Nevertheless, this material is not granite and neither does it belong to the intrusive rocks which granite materials are usually referred to. The "Swedish black granite" is an effusive rock composed in the so-called fissure effusions and should be named 'basalt'.

A more striking case is the so-called "Belgian granite" which is not even an igneous rock but coquinoid purple limestone advertised and sold on the market as a granite material.

Definition of the concept 'granite materials'. It is obvious that the precise petrographic terminology for the various types of rock is not applicable to the practice of processing decorative rock materials. This is due primarily to the specific scientific character of treating the rocks, classified according to genetic, age, deformation, mineral, chemical and other features which have no direct relationship to the practical aspects of processing decorative materials and their application.

It is a fact that there are terms in petrography such as granite, granitoids, granodiorites, granite gneiss, etc., but these have not been identified and classified by genetic and mineral features. The materials extracted from these rocks are involved in the concept 'granite materials', used in practice, though only as one essential part which, nevertheless, does not cover the whole content of that term.

Having in mind the technological specificity of processing granite materials and their application, we can formulate the definition of that concept in the following way:

Granites are such rock materials that have three basic properties: high hardness, durability and decorativeness.

These conditions are fully met by granite, which logically gives the name to the whole group of materials. Granite materials generally involve a great part of the materials extracted from igneous rocks and, in particular, most intrusive and fewer effusive rocks. The only rock material, which is not of igneous but metamorphic origin, is quartzite which occupies a well-deserved place in this group.

In case more information is required when using the term 'granite material', it can be provided by its genetic and mineralogical characteristics or by its main parameters, viz. hardness, durability and decorativeness.

Main parameters of granite materials. The basic identification properties of granite materials are actually the main parameters by which they are assessed.

Hardness is the property of granite material to resist the penetration of a solid body of higher hardness. This parameter depends on the density, location and size of the mineral grains composing the material as well as their cohesion. The hardness of the material is determined by the constituent minerals. They should have a hardness of 6 or higher by Mohs' scale. Hardness is mainly a technological parameter of granite materials and determines largely the technology and labor consumption of their processing. The rock blocks are most economically cut by sawmill cutters and free abrasive (shot). Sometimes the blocks can be cut by cutting machines with orthogonal disc saws. Granite materials are best cut by percussive tools.

The durability of granite material is defined as its capacity to preserve the physico-mechanical and decorative properties of the processed surfaces depending on the service life. This parameter is determined by the strength, structure, mineral composition and cracking of the material. The larger the mineral grains, the lower the strength and durability of the material. Therefore, fine-grained materials are most durable. Besides, the more homogeneous the material, the higher its durability. The most durable material is quartz whose polished surface starts to destroy after 600 – 700 years. Less durable is granite of high quartz content, then come gabbro, labradorite, etc.

Decorativeness is the most important parameter of granite materials and the main factor determining their prices. At present, the price of highly decorative granite materials in the form of 2cm thick polished slabs on the Bulgarian market varies from \$120 to \$160 for 1m^2.

The granite material decorativeness is determined by expert assessment according to the color and structural-textural properties. The decorativeness of the granite materials is assesses in 4 classes: class 1 – highly decorative; class 2 – decorative; class 3 – low decorative; class 4 – non-decorative.

The highly decorative granite materials of class 1, which are world-famous, are "Shikshinskiy" quartzite (Russia); "Capustino" granites (Russia); "Elberton" dove-gray-colored granite (USA); Nordmjarkit" (Norway); "Golovinskiy" labradorite (Ukraine), etc.

Most granite materials are of class 2. Of these more famous are "Impalla" gabbro (RSA), "Norway" silver-gray labradorite, etc. No granite deposits of class 1 and 2 have been explored in Bulgaria so far.

Granite materials of class 3 are extracted and processed as local raw materials and those of class 4 are extracted in exceptional cases.

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