50 Years University of Mining and Geology "St. Ivan Rilski"
Annual, vol. 46, part I, Geology and Geophysics, Sofia, 2003, pp.47-51

ON THE GENETIC MODEL OF CHELOPECH VOLCANIC STRUCTURE (BULGARIA)

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

STRUCTURAL SETTING

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

PREVIOUS IDEAS

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

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

SCOPE AND APROACH

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

RESULTS AND PROBLEMS DISCUSSION

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

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

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

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

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

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

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

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

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

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

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

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

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

ESSENSE OF THE NEW GENETIC MODEL

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

PROSPECT IMPLICATION

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

ACKNOLEGEMENTS

We are much obliged to the Directory Board of Navan Chelopech AD both for the sponsorship of the study and for the permission to publish part of the data.

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