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THE STRUCTURAL-METALLOGENIC MAPS OF ORE DISTRICTS OF F.Y.R. OF MACEDONIA

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Abstract: The metallogenic characteristics, tectonic setting, and structure of F.Y.R. of Macedonian territory, Kozuf-Aridea and Kadica-Bucovic ore districts and its specific formation features are discussed in this paper on the basis of new results and data obtained by previous investigations. The interpretation of satellite images and morphostructural analyses were employed successfully for revealing the ore-concentrating structural features. The tectonic elements of the present-day topography were marked out and compared with the structural features that existed during the period of ore formation. The use of the present-day structural landforms of F.Y.R. of Macedonia for reconstruction of the tectonic elements of ore-bearing periods became possible after substantiating their inherited evolution. The ring structure occupies a special position in southern F.Y.R. of Macedonia and ore districts are controlled. Geological, geochemical, and morphostructural attributes allow interpretation of this structure as a center of long-term endogenous activity that evolved since the Jurassic-Cretaceous time.

Keywords: structural-metallogenic maps, morphostructural analysis, ore district, F.Y.R. of Macedonia, fault zones.

1. Introduction

The structural-metallogenic maps are traditionally a result of studying tectonics and metallogeny of large regions. In the Laboratory of Metallogeny of Ore Districts of IGEM RAS, various complex methods for verifying the geological structures in relation to metallogenetic ore districts on maps of 1 : 50 000, 1 : 200 000 and 1 : 500 000 scales are developed (Tomson et al., 1992; Volkov et al., 2006a).

When drawing up structural-metallogenic maps of orogenic districts, first of all, it is necessary to allocate potentially the ore-bearing structures, and the relation with the tectonic-magmatic episodes with the formation of ore mineralization. Recently, a Russian-F.Y.R. of Macedonian scientific team has carried out a comprehensive study of F.Y.R. of Macedonian territory, including Kozuf-Aridea and Kadica-Bucovic ore districts, under the agreement between the faculty of Geology and Mining of Stip, F.Y.R. of Macedonia, and the IGEM RAS.

2. Methods of map construction

The morphostructural analysis and the interpretation of satellite images are the most important methods of revealing the arch raisings. The methods of studying the relief become very effective in the paleoreconstructions of the inherited development of arch raisings. With the help of the interpretations of tectonic elements of a modern relief, the radial and concentric systems are the main indicators of arch raisings (Figs 1 and 2). Besides, for this purpose, interpretations of geochemical and geophysical data are also used. The various elements of the maps are important in discovering new metallogenic ore districts: intrusive-dome structures of various types reaching a diameter of 100 km, and break "through" zones, as systems of geological and tectonic anomalies (Fig. 3). Intrusive-dome structures are allocated with the same methods, as arc raisings. They are characterized by the radial-concentric forms of a relief created by complex combinations of new tectonic raisings and hollows, fixing intrusive-dome structures and depressions. In satellite pictures the break "through" zones are distinguished by linear anomalies of photo-tones. At the final stage, the special metallogenic analyses will be carried on, which will be based on the discrimination of the ore-formations ore complexes and series, which are in space and time with the certain types of arch raisings, intrusive-dome structures and break “through" zones (Fig. 3). In addition the nature of metallogenic provinces related to tectonic structures of mineralization will be especially studied.

tural features, including superimposed ring and graben-like depressions, were outlined on the basis of interpretation of satellite images and morpho-structural analyses. The F.Y.R. of Macedonian Arch, which practically embraces the whole country, was recognized together with “daughter” ring

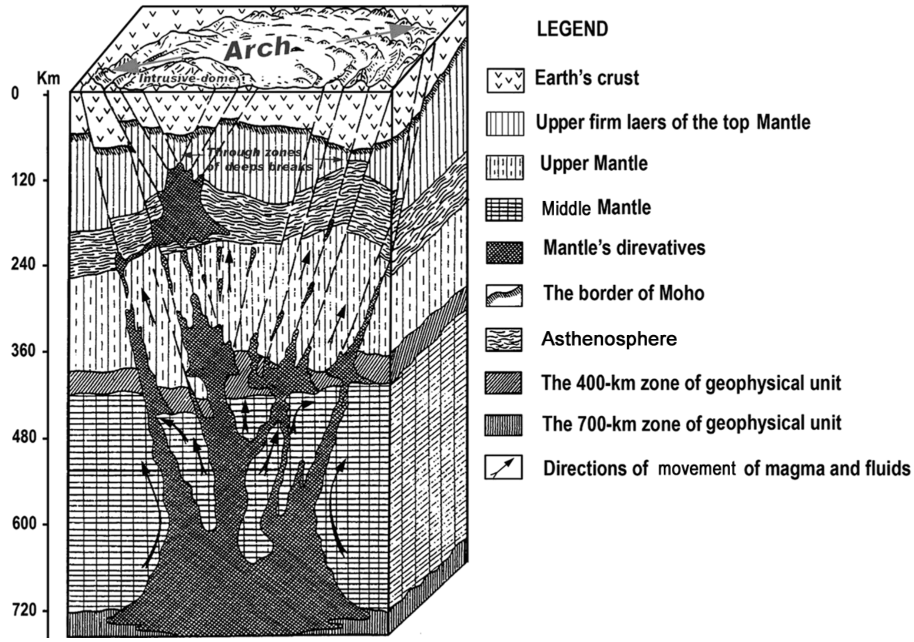

Fig.1. Genetic model of orogenic arched structure (Soloviev, 1978).

3. The structural-metallogenic map of the Republic of F.Y.R. of Macedonia

The F.Y.R. of Macedonia is located in the Serbo–Macedonian Massif of the Eurasian Tethys metallogenic belt (Fig. 4). The mineralizations are related to Cenozoic magmatic activity which is represented by volcanic and plutonic rocks in a dispersed spreading setting (Jankovic, 1993). Our previous joint studies with F.Y.R of Macedonian geologists concluded that the present-day tectonic structure of F.Y.R. of Macedonia reflects dislocations closely related to Cenozoic magmatism, which are connected with the formation of ore deposits (Tomson et al., 1998). A considerable part of the study area (Fig. 4) belongs to the Serbo-Macedonian and Pelagonian crystalline massifs separated by the Mesozoic Vardar Graben and to the reworked margins of these massifs: the West and East F.Y.R. of Macedonian margins, which were reactivated during Caledonian-Hercynian times and the Cenozoic, respectively.

According to our joint studies, F.Y.R. of Macedonia comprises fold-block systems, as well as superimposed and through-type structural features. A new structural work on the ore-controlling structures and through fault zones with important ore-controlling implications (Kochneva et al., 1997; Tomson et al., 1998).

In the present-day topography, the Cenozoic arched structure (250 x 300 km) has an oval to rounded shape. Its central part is relatively subsided (down to 1000-1500 m) and filled with Upper Cretaceous, Paleocene and Quaternary sedimentary rocks. The marginal part of the F.Y.R. of Macedonian Arch is uplifted to a height of 2000-2800 m on average. The dislocations within the arch are emphasized by the radial arrangement of the main tributaries of the Vardar River, which crosscut this structure. The main structural features of the arch are reflected in the isometric zoning of the anomalous gravity field: the central maximum is encircled by ring zones of gravity minima.

The comparison of the present-day structural features of the territory with geological and paleo-structural data shows that the main features of the F.Y.R. of Macedonian Arch are traceable since the Caledonian time. The presence of geological units of different ages suggests that the marginal belt of the arch, which consists of volcanic rocks and includes the largest ore deposits, is the most active and long-lived part. Noteworthy is the widening of the marginal belt at the contrary of “daughter” ring structures of the second rank, as is observed in the vicinity of the Kratovo-Zletovo, Taimishte, and Alshar deposits (Fig. 4).

F.Y.R. of Macedonia: Kratovo-Zletovo, Sasa-Toranica, Buchim, Taimishte, Rzanovo, and Alshar are controlled by such meridional zones.

The Oligocene-Miocene metallogenic zones recognized in the metamorphic sequences of the Ser-

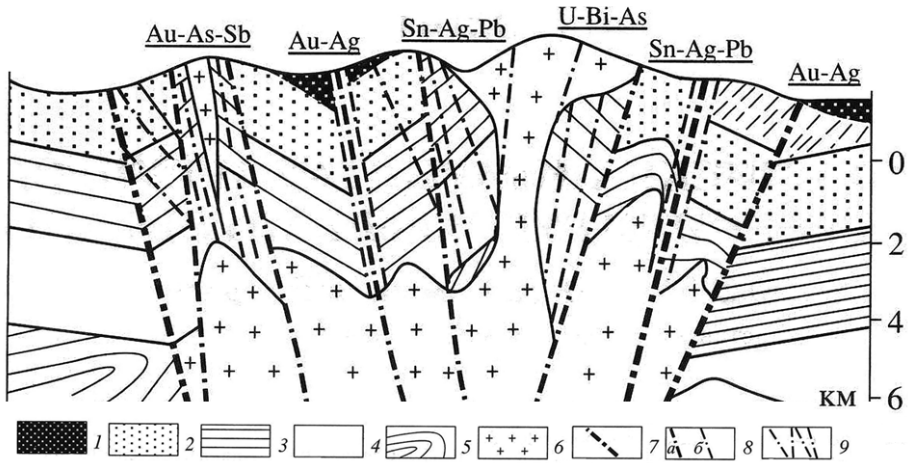

Fig. 2. Geological schematic section of the Maisk ore district showing an intrusive-dome structure of the Central Chuckotka, Russia. 1 - Relicts of volcanic rocks (Upper Cretaceous); 2 - Upper Triassic flysch sandstone-aleurolite deposits; 3 - Middle Triassic terrigenous aleurolite members; 4 - Lower Triassic greenschist members; 5 - Paleozoic terrigenous-carbonate basement rocks; 6 - Upper Cretaceous granite; 7 - Boundaries of the tectono-magmatic metallogenic zone; 8 - Deep-seated faults of the tectono-magmatic zone; 9 - Ore-localizing faults zones.

The Cenozoic reactivation involved mainly the eastern part of the F.Y.R. of Macedonian Arch (Tomson et al., 1998) and is reflected in the formation of the two faulting systems: NW-trending fault system relative to the Vardar Zone and the NE-trending transverse fault zones, which were active at the final stage of magmatic activity. Three NW-trending systems that control graben-shaped troughs, filled with Cenozoic sedimentary rocks, and one NE-trending fault zone, have been outlined from the interpretation of satellite images. Chains of local concentric central-type structures, many of which correspond to outcrops of Tertiary igneous rocks, are present along these NW- and NE-trending zones. The northwestern system controls the Cenozoic metallogenic zones (Fig.4).

The special implication of meridional fracture zones for localization of large ore deposits has been demonstrated by many researchers. Tomson et al. (1998) traced such meridional ore-controlling systems throughout Europe. The active role of such systems in localization of ore deposits was pointed out in neighboring Bulgaria (Vaptsarov et al. 1986). It is notable that such intersections provide zones of maximal permeability and cause ascent of mantle material. All economic deposits of

bo-Macedonian Massif are largely composed of Cenozoic tuffaceous-sedimentary and volcanic rocks and intruded by granitoid bodies and intermediate dikes. In total, three metallogenic zones make up an ore belt that extends westward to Serbia and southeastward to Greece and Bulgaria (Fig. 4). The characteristics of the metallogenic zones change and the igneous complexes and ores become progressively younger from southwest to northeast. There is a distinct correlation between age and composition of the ores. In addition, the ore mineralization changes in this direction from high- to low-temperature and from relatively low-sulfide to polysulfide types. The change in the ore composition may be associated with differentiations in the deep-seated magmatic chambers. Across the strike of metallogenic zones, the types of ore deposits change from magnetite skarn (Damian) to porphyry copper (Buchim) and further to copper-base metal (Kratovo-Zletovo) and base metal deposits (Sasa-Toranica). The age of the igneous rocks in the ore districts also changes towards the northeastern direction from 28.0-24.5 Ma (Buchim) to 27.2-16.0 Ma (Kratovo-Zletovo) and 24-12 Ma (Sasa-Toranica). Thus, the progressive change in the composition of the ore mineralization is a consequence of rejuvenation and differentiation. These relationships suggest that there is a close link between the metallogenic zones.

alkaline intrusions are confined to NE-trending neotectonic faults. Igneous rocks are represented by calc-alkaline andesite and quartz latite. All sub-

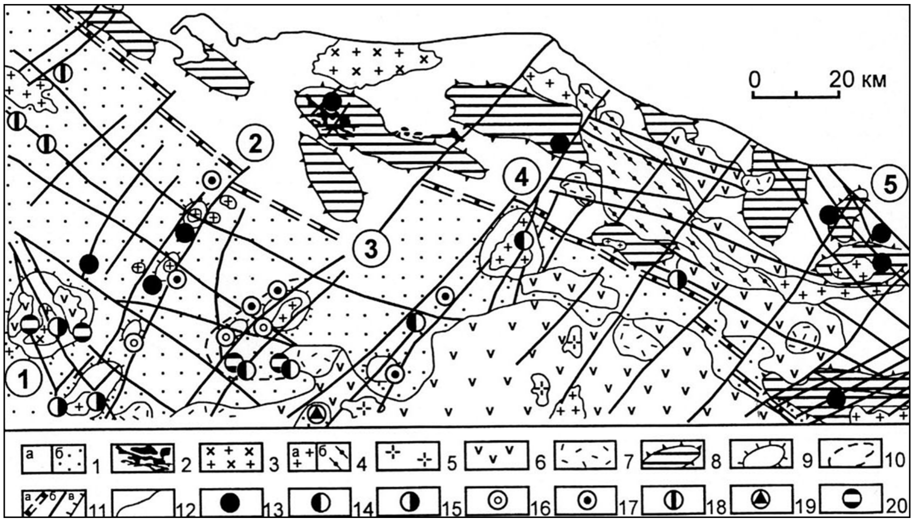

Fig. 3. Structural-metallogenic map of the Central Chukotka ore district. 1 – Mesozoic terrigenous sedimentary rocks (a), Paleozoic terrigenous-carbonaceous sedimentary rocks (b); 2 – Triassic dykes and sills of gabbro-diabase; 3 – Cretaceous granodiorites ; 4 - Cretaceous granites (a), granito-gneisses (b); 5 – Upper Cretaceous syenites, rhyolite-porphyries; 6 - Cretaceous andesite; 7 - Upper Cretaceous ignimbrite ; 8 - nucleus of Paleozoic tectonic raisings; 9 - intrusive-dome structures and separate domes; 10 – Maisk intrusive-dome structures; 11 - faults: a - Kuvet deep fault, b - slip-shifts, c - thrust; 12 - geological and geographical borders; 13 - 20 - deposits and occurrences: 13 – Au-quartz, 14 – Au-intrusion-related, 15 – Au-Ag-epithermal, 16 – Au-sulphidic disseminated, 17 – Sn-Ag-sulphidic, 18 - Sn-silicate, 19 – Cu-Mo-porphyry, 20 - Hg; *Figures in circles* – metallogenic zones: 1 - Palian; 2 -Karpung, 3 - Maisk; 4 - Matenvunay; 5 - Ruveem.

A model of this system at a depth may be viewed as a low-angle common seismic focal zone inclined southwestward (Tomson et al., 1998). The hypothetical focal zone could have served as a feeding channel for injection of magmas towards in northeast direction. Each new portion of magma and associated ore mineralization experienced compositional differentiation at a certain level of the seismic focal zone. The hanging wall of the zone moved southeastward. Particular blocks were detached along impaired zones with formation of grabens. The deep faults that bound the grabens could have reached the magmatic channel of the seismic focal zone to provoke the eruption of magmas and to stimulate ore formation.

The Kozuf-Aridea ore district which hosts a Pliocene mineralization, extends along the Greek - F.Y.R. of Macedonian border and is a significant ore deposit in southern F.Y.R. of Macedonia (Fig. 4). Volcanic structures and subvolcanic calc-volcanic intrusions of the Kozuf district are of the same age; intrusions at the Alshar deposit belong to the youngest phase, dated at 5.1-3.9 Ma (Boev and Serafimovski, 1998). The Kozuf-Aridea metallogenic zone is characterized by the development of a complex Au-As-Sb-Tl mineralization.

It is known that metallogenic zones in orogenic domains of fold systems are linear and oriented in two directions: along the strike of sedimentary sequences and across them. The metallogenic zones conformable with folding control plutonic bodies and deposits of the early orogenic stage, while the transverse metallogenic zones are accompanied by late orogenic mineralization and magmatism (Tomson and Polyakova, 2000). Thus, the system of northwestern zones in the F.Y.R. of Macedonian Arch may be referred to the early orogenic structural features, whereas the transverse Kozuf-Arid Zone is related to the late orogenic stage.

The Kadica–Bukovik ore district is located in the easternmost Surdulica–Osogovo–Pasos metallogenic zone characterized by the wide development of lead–zinc mineralization (Fig. 4). The zone incorporates systems of sheeted bodies and discordant dikes of quartz latites with an absolute age within 24–12 Ma. Recent discovery of the gold-bearing porphyry copper mineralization in the eastern Kadica ore district is inconsistent with its metallogenic specialization and previous metallogenic models of this belt (Tomson et al. 1998). To study this phenomenon, we carried out complex studies, which involved structural–geomorphological analysis of the ore district (Volkov et al., 2006a) and thermobarogeochemical study of the ore forming conditions.

4. Tectonic setting of the Carlin type Alshar deposit

The Pliocene volcanic-plutonic complex of calc-alkaline rocks of the Kozuf-Arid Zone was formed on a basement of Precambrian gneisses, Triassic sedimentary rocks (dominant), Jurassic ophiolites (gabbro-peridotite), and Cretaceous sedimentary sequences. The Precambrian albite gneiss with sporadic lenses of amphibolites forms the oldest rocks of the Kozuf-Arid Zone. Marble blocks are sporadically incorporated in gneiss. Paleozoic schist, phyllite, metasandstone, shale, and quartzite occur locally. The Triassic sequence occupies most of the area and is composed of two main facies: (1) limestone and dolomite and (2) mudstone and sandstone with sporadic dolerite and greenschist. The Jurassic sequence consists of limestone, sandstone, shale, quartzite, cherty shale, and a severely serpentinized dunite-harzburgite complex that hosts small podiform chromite bodies. Serpentinite is exposed as narrow tracts that have tectonic boundaries with the adjacent rocks. Their emplacement is related to diapiric processes. The Cretaceous sedimentary rocks are include Barremian-Albian conglomerate and Turonian limestone. The Upper Eocene sequence is composed of basal conglomerate overlain by flysch (siltstone, clay, and sandstone with limestone interbeds). Pliocene sedimentary and pyroclastic rocks are widespread around the Alshar deposit. They are composed of conglomerate and clayey sandstone with calca-

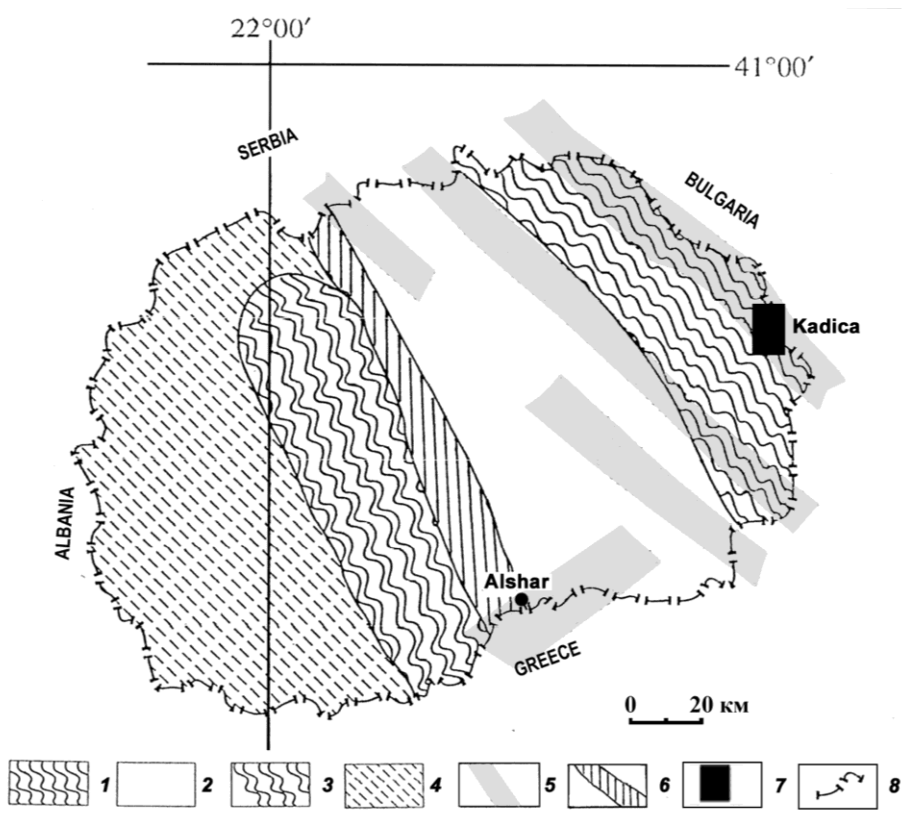

Fig. 4. Geotectonic units of F.Y.R. Macedonia. 1 - Serbo-Macedonian Massif; 2 - riftogenic Vardar Zone; 3 - Pelagonian Zone; 4 - West F.Y.R. of Macedonian region; 5 - Cenozoic metallogenic zones; 6 - Vardar metallogenic zone; 7 – Kadica–Bukovik area; 8 - F.Y.R. of Macedonian border.

reous clay interbeds. Volcano-sedimentary and pyroclastic rocks and clayey sandstone occur in some Pliocene basins north of the Alshar deposit. Quaternary sedimentary rocks form river terraces.

The Alshar deposit is located at the intersection of the Vardar and Kozuf-Arid metallogenic zones (Fig. 4) at the western flank of the Vardar Graben and the Pelagonian crystalline massif, approximately 50 km southwest of the town of Kavadarsi and 3 km from the Greek-F.Y.R. of Macedonian border. The ore field occupies an area of around 21 km^2. The tectonic setting of the ore district and the Alshar deposit itself was deduced from the results of morphostructural analyses and the interpretation of satellite images. First, the present-day structural grain of southern F.Y.R. of Macedonia was outlined. For this purpose, the traditional method of morphotectonic contour lines was used to generalize the topographic contour lines and drainage pattern. Structural features of different ranks were contoured from the analysis of present-day landforms of several orders.

The Alshar deposit is located in the upper flow of the Rozdenska River (the right tributary of the Crna River). The streams in the Rozdenska River basin form a radial-centripetal pattern (Fig. 5). The branched radial rivers and creeks are surrounded by arcuate ridges up to 1500-1800 m in height with arcuate valleys along their outer framework. Such an orographic pattern fits an endogenic ring structure 18 x 15 km in size with a relatively subsided inner part and an elevated outer belt. This ring structure is located at the intersection of two extended diagonal through fault zones: the northwestern zone, which is an element of the Vardar Zone and the northeastern zone deduced from linear shade anomalies in satellite images. This fault zone is emphasized by the rectilinear valley of the Bosavica River, by the present-day slope elements, and by a chain of dome-shaped structural features up to 10 km across. In addition, a system of very NE-trending young faults controls the Pliocene lava flows here. The Alshar ring structure is surrounded by a belt of daughter domes up to 5 km across. Each of these domes is comparable with associated ore-bearing central-type structures (Fig. 5). The three second-order domes located in Greece, south of the Alshar ring structure, are characterized by most complex structure and are contrastingly expressed in the present-day topography. By analogy with other regions studied previously (Figs 2 and 3), such structures control large ore districts and deposits (Volkov and Sidorov, 2001). The tectonic position of the Alshar deposit is emphasized by the configuration of geochemical ha-

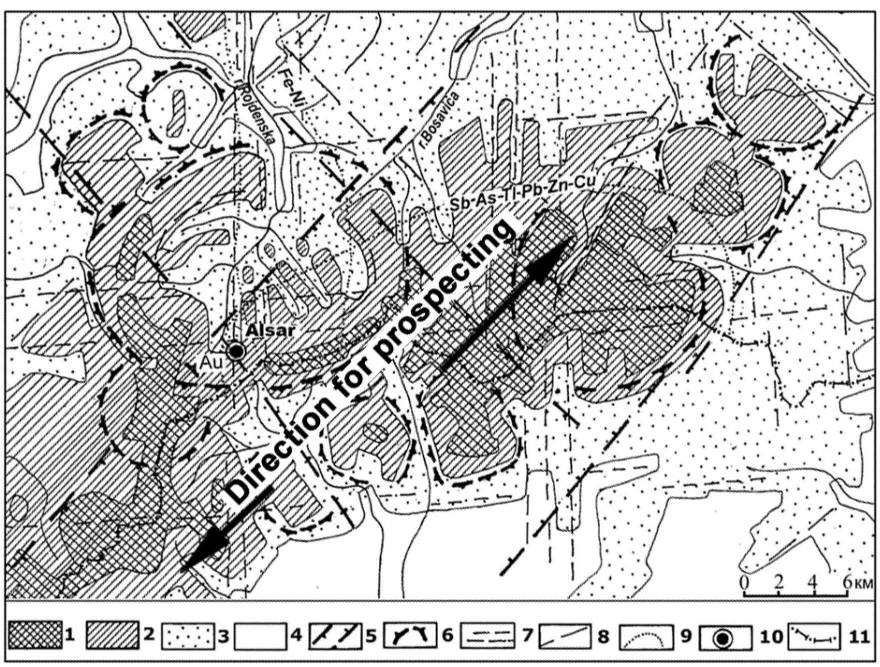

Fig.5. Structural-metallogenic map of the Kozuf-Aridea area and Alsar Carlin type deposit. Hypsometric levels: 1 - 1500-2000 m; 2 - 1000-1500 m; 3 - 500 -1000 m; 4 - lower than 500 m; 5 - zones of diagonal dispositions; 6 - borders of ring structures; 7 - deep orthogonal breaks; 8 - other breaks; 9 - geochemical anomalie; 10 – Alsar deposit; 11 - F.Y.R.O. Macedonian border.

los. A Fe-Ni halo extends along the Vardar Zone and an Sb-As-Tl-Pb-Zn-Cu halo corresponds to the young NE-trending fault system that crosses the Oligocene and Miocene metallogenic zones (Fig. 5). According to Jankovic (1993), the extensive and wide meridional fracture zone, which spreads radially relative to the center of the ring-structure, serves as a main ore-controlling tectonic line. We also traced a latitudinal fault zone, which is the fragment of an extended system interpreted in a satellite image.

The data obtained (Percival et al., 1990; Volkov et al., 2006b) show that the gold mineralization at the Alshar deposit is similar to that observed at the Carlin-type deposits in the western United States. Similar characteristics include: 1) the Au-As-Sb-Tl-Hg geochemical assemblage, 2) low Pb, Zn, Cu, and Ag contents in the ore, 3) widespread jasperoid and argillic metasomatic alterations of host siliciclastic-carbonate sedimentary rocks, and 4) the spatial relationship with fault zones. However the Alshar deposit differs from the Carlin-type deposits by the following features: 1) the Pliocene age of the mineralization, 2) extension of mineralization over younger volcanic rocks, 3) a high Tl grade in the ore, and 4) location of the ore field in a long-lived central-type magmatic structure (Fig. 5).

5. Tectonic setting of the Kadica Cu-porphyry ore field

Copper mineralization near the town of Pehchevo was recently discovered and preliminarily estimated. The Kadica deposit is found at the contact between Neogene quartz latites and the volcano-sedimentary rocks of the Vlasina Group. Based on its characteristics, it is classified as a porphyry-Cu type, although some of the ore minerals and the wall-rock alteration are also typical for epithermal deposits (Volkov et al., 2006c). The Kadica–Bukovik ore district is located at the upper reaches of the Bregalnica, Pechevska, and Celevich rivers. The waterways form two systems: a centrifugal system in the upper flow of the Bregalnica River and a centripetal system in the Kadica plain. The northern part of the area represents moderate mountains (altitude up to 1700–1900 m). The relatively lower, southern part (up to 1000–1300 m) is crosscut by a wide sublatitudinal valley and numerous small water flows flowing into the main riverbed. From the north and east, the relatively lowered part of the area is surrounded by an arcuate ridge with an altitude ranging from 1600 to 1700 m. Radial-centripetal and radial-centrifugal patterns of waterflows in both the uplifted and lowered parts, make it possible to distinguish the intersecting oval southern (11 x 8 km) and northern (7.5 x 6 km) structures (Fig. 6). Altitude marks, erosion reworking, and alluvium accumulation, which are typical of the morphology of valleys and slopes, indicate a descending evolution of the southern oval and an ascending of the northern oval. Intersection of distinguished ovals is complicated, forming a ring structure with a diameter of 3.5 km. The central part of this structure coincides with the autonomous Bukovik Uplift elevated up to 1700 m. The most uplifted part of the Bukovik structure contains large occurrences of Pliocene volcanic rocks. The uplift is bounded by a ring depression belt, which is emphasized by arcuate valleys of the upper flows of the Celevich, Pechevska, and Rakovec rivers (Fig. 2). In the east, the structure is rimmed by an arcuate uplift 1700–1900 m high. It was found that the distinguished group of ring structures is localized at the intersection of two metallogenic zones: the base metal Surdulica–Osogovo–Pasos zone and the auriferous Kuzuf–Arid zone. The latter zone extends from the Alshar gold deposit (Percival and Radtke 1994) and contains Pliocene mineralization along the entire zone (Fig. 6). The Kuzuf–Arid metallogenic zone occupies a specific position at the southern end of F.Y.R. of Macedonia (Fig. 4). In addition to the Alshar deposit, this zone contains several Sb–As–Au-bearing mineralizations, porphyry copper deposits, and native sulfur occurrences. The intersection of the two aforementioned zones has a complex structure. For example, the Bukovik ring structure is located exactly at the junction of orthogonal fault systems revealed by linear tectonic elements of the modern relief. Meridional dislocations are traced as highly fissured belts, deciphered on the satellite images and expressed as accumulations of small linear elements of relief in the topographic map. Numerous latitudinal systems are emphasized by tectonic scarps, bends of large rivers, and modern graben-like depressions.

6. Conclusions

Our studies show that the Alshar deposit is confined to the central part of a ring structure, located at the intersection of two large diagonal fault zones, which host ore mineralizations of different ages. The deposit occupies a special structural position within southern F.Y.R. of Macedonia. Geological and morphostructural investigations indicate that this structure represents a center of long-

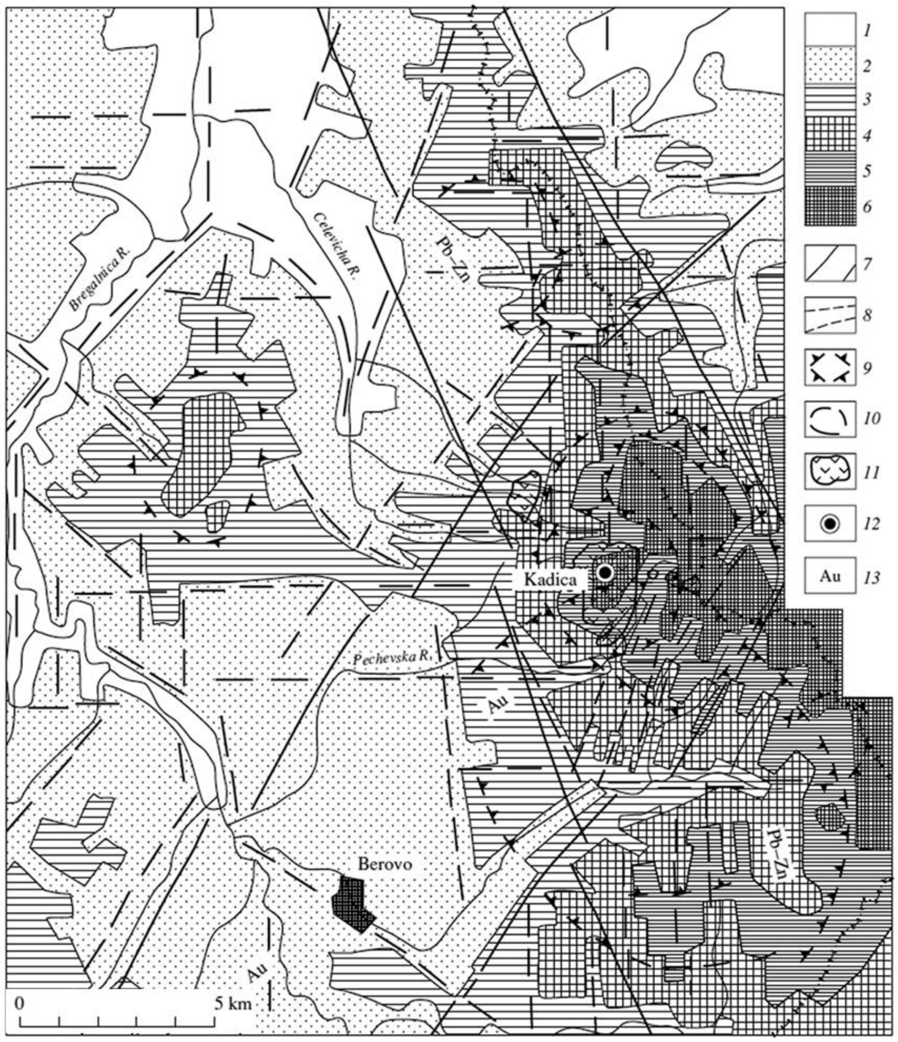

Fig. 6. Morphostructural scheme of the Kadica–Bukovik area. 1–6 - Hypsometric levels (m): 1 - below 800; 2 - 800–1000; 3 - 1000–1200; 4 - 1200–1500; 5 - 1500–1700; 6 - above 1700; 7 - metallogenic zones; 8–10 - structures deciphered from topographic maps and satellite images; 8 - linear dislocations, 9 - boundaries of ring structures, 10 - ring dislocations; 11 - outcrops of Pliocene volcanic rocks, 12 - Kadica deposit, 13 - specialization of metallogenic zones.

term endogenous activity, which started in the Jurassic–Cretaceous and evolved during subsequent periods. The Kadica ore field also occupies a specific structure position within Eastern F.Y.R. of Macedonia. It is confined to the central part of the ring structure, situated at the junction of two large orthogonal fault zones and corresponding to metallogenic zones of different ages (the base metal Surdulica–Osogovo–Pasos and the auriferous Kuzuf–Arid). The Kadica ore field is a promising area for the discovery of gold mineralization.

Acknowledgments

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