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Dacitic — rhyolitic volcanic products at Bukovik — Kadijca (Pehčevo District) and the related porphyry-copper mineralization

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Р. Стојанов, Б. Хаджипетрушев, М. Александров — Дацито-риолитовые вулканические продукты в районе Буковик — Кадийца (округ Пехчево) и связанные с ними меднопорфировые оруденения. — Вулканические породы дацитового до риолитового состава и сильно гидротермально измененные дацитоподобные породы обнажаются среди метаморфических и гранитовых пород вблизи вершин Буковик и Кадийца во восточном борту Пехчевско-Делчевского грабена третического возраста. Полученные данные в результате иследований на площади около четырех квадратных километров показали что вулканическое тело Буковик является вулканическим аппаратом который был подвержен интесивной аргиллизации, силлификации и карбонатизации, и вмещает меднопорфировую минерализацию с минералами полиметаллов и благородных металлов. Будущие иследования должны выяснить экономическое значение минерализации.

Abstract. — Volcanic rocks of dacitic to rhyolitic composition and strongly hydrothermally altered dacitoids crop out within the metamorphic and granitic terrains near the peaks of Kadijca and Bukovik in the eastern edge of the Pehčevo- Delcevo Tertiary graben. Data obtained on a surface of about 4 square kilometers show that the Bukovik volcanic body represents a volcanic apparatus that underwent intense argillization, sillification and carbonatization, and hosted porphyry copper mineralization with base metal and noble metal minerals. Further studies have to evaluate the economic importance of the mineralizations.

Introduction

The present paper is a summary of results obtained during the geological explorations in the area of Bukovik — Kadijca. It is dedicated to J o r d a n R i z o v from Pehčevo who made all efforts to help the geological studies, and wrote in the newspaper of the Geological Institute (Skopje) in 1975: "It is my greatest desire to see a mine opened at the nearest future".

The geological explorations have been carried out by the Institute for Exploration of Mineral Raw Materials (Skopje) and the Lead-Zinc Mines "Sasa", and have

been summarized thanks to a project financed by the Ministry for Science of the Republic Macedonia, in the period 1991-1993.

Geological setting

The volcanic body of the peak Bukovik (1722 m) represents a volcanic centre. It is built up of volcanic rocks of dacitic to rhyolitic composition that underwent a strong hydrothermal alteration. Subvolcanic rocks of dacitic to rhyolitic composition occur also around the peaks Bukovik and Kadijca.

The volcanic rocks are located within a metamorphic terrain built up of greenschist-facies metamorphic rocks (metadiabases and schists) belonging to the Vlasina complex (Frološ and Kadijca Formations on the territory of Bulgaria).

The volcanic rocks of Bukovik are entirely hydrothermally altered. Argillization, sillification, carbonatization, and alunitization are the principal processes accompanying a porphyry-type mineralization of oxide and sulphide minerals. The mineralization is present both in the volcanic rocks and in their metamorphic host rocks as well as along fault structures in the metamorphic and igneous rocks.

The western parts of the volcanic body are covered by deluvial breccias built up of volcanic fragments and mineralized with limonite. They were explored by M. Stojanovič in the years 1969-1970 (Стојанович, unpublished report Skopje, 1967; Стојанович, 1970).

The mineralization is mainly represented by minerals of copper, base metals and noble metals typical for the porphyry-copper mineralizations.

Geological structure

The terrain Bukovik — Kadijca studied (Fig. 1) is built up mainly of Riphean — Cambrian and Palaeozoic metamorphic rocks represented by metadiabases, schists and diorites. Near Berovo they cover directly amphibolite-facies gneisses. North of Belo-brdo towards Kriva-buka and Pančarevo granitoids are dominating. They are represented by granites, granite porphyries and granodiorites. They all cross-cut the metamorphic complex and the diorites of the Struma diorite formation. West of Pančarevo and Negrevo, the terrain represents a Tertiary graben filled in by Eocene and Pliocene sediments covered by deluvial and alluvial sediments.

Formation of metadiabases and schists (diabase-phyllitoid complex, Vlasina complex)

This formation is represented by epimetamorphic (greenschist facies) basic igneous rocks and sedimentary rocks. They are described in detail by Загорчев (1987) as Kadijca Formation. Metadiabases and schists are cross-cut by dikes of younger gabbros and diabases. The age of this Kadijca Formation is according to Загорчев (1987) post-Vendian and pre-Permian, metadiabases and schists covering discordantly the older Frološ Formation (Vlasina complex) that is 530 — 550 Ma old (according to Bulgarian data). Metadiabases and schists build up on our territory a monocline, with foliation dipping West — Southwest.

Granites and granodiorites

These igneous rocks build up North of Belo-brdo a belt along the Macedonian — Bulgarian border. To the West, they subsided into the Pehčevo — Delčevo graben,

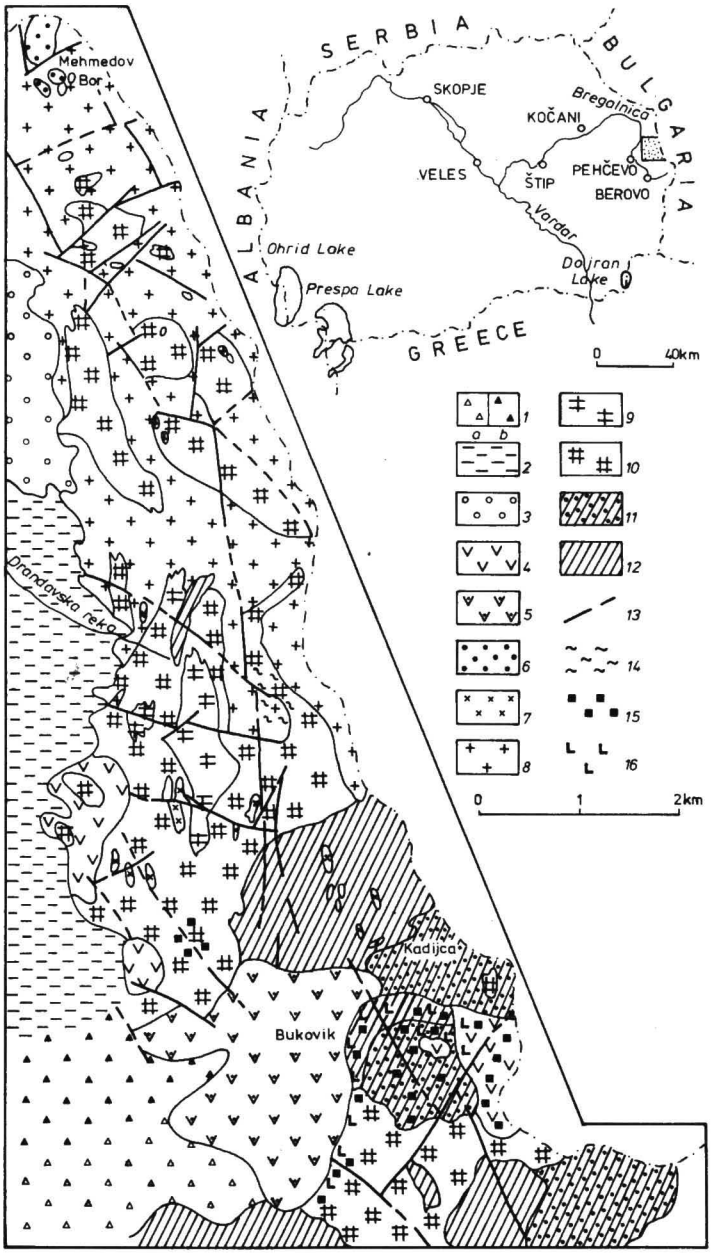

Fig. 1. Geological map of the area Pehčevo — Kadijca (location of the area studied in inset)

1a — breccia of dacite fragments; *1b* — limonite breccia; *2* — bog-limnic deposits; *3* — gravel and sand; *4* — dacite; *5* — altered dacite; *6* — gray argillaceous sandstone; *7* — granodiorite; *8* — granite; *9* — amphibolized gabbro; *10* — metagabbro-diabase; *11* — epidote-chlorite-amphibole schist; *12* — quartz-chlorite-sericite schist; *13* — fault; *14* — sillification; *15* — pyritization; *16* — limonitization

and are covered with Tertiary (Paleogene and Neogene) sedimentary formations. The oldest rocks present are diorites, and they are cross-cut by granite-porphyries and granodiorites. All they are referred to the Paleozoic. The granite-porphyries are a margin facies of the Hercynian Delčevo granites. The age is proven by the presence of granite fragments within the Permian and Triassic conglomerates. The granitoids are cross-cut by diabase dikes near Pančarevo.

The granitoid complex is affected by considerable cataclasis. The K-feldspars are albitized. Along an orthogonal fault system, the granitoids are hydrothermally altered, manganese-limonitized, sericitized and kaolinized. The mafic minerals are chloritized. Barytine has been found near Nov Istevnik and Pančarevo. It is most probable that the hydrothermal alterations in the granitoids were related to the postmagmatic hydrothermal processes of the Tertiary volcanic rocks.

Tertiary volcanic activity

The Tertiary volcanism in the Bukovik — Kadijca area is represented by the volcanic dome Bukovik (1722 m) and small subvolcanic bodies of dacites and rhyodacites at Belo brdo and Kadijca (1932 m) at a surface of about 4 km^2. Small dacite bodies and dikes have been found also on Bulgarian territory within a zone of NW-SE direction as well as an extrusive dome with subvolcanic breccias at the intersection of faults with North-South and NE-SW strike (K h a r k o v s k a, 1984). Hydrothermal alterations (silification, kaolinization, and carbonatization of the volcanic rocks, and lead-zinc mineralization with pyrite and iron-rich minerals and barite) have been recorded. Mankov (М ъ н к о в, 1984) reported also pyrite with a high arsen content at the Kozhukh heights near Sandanski.

The volcanic body of Bukovik represents an extrusive dome with NE-SW elongation within the formation of metagabbrodiabases and schists. The body is built up of dacitic lavas and breccias that are entirely hydrothermally altered. The alterations consist of argillization, sericitization, kaolinization, pyrophyllitization, alunitization, carbonatization (siderite), and total silification of the dacites situated in the highest parts of Bukovik. Pyritization is typical of the northern parts of the volcanic body as well as in the contact parts with the metamorphic rocks. In the western and south-western parts of the body, beneath limonitized volcanic breccias, intensely altered volcanic rocks (kaolinization, sericitization and pyritization) have been found into the boreholes. The western and south-western periphery is covered by deluvial sedimentary breccia mineralized with limonite ore. Along the valley of the Pehčevska river, sulphide mineralization has been found along the contact of the volcanic rocks with the metamorphic complex, and the volcanic rocks are represented by hydrothermally altered dacites. In the upper parts of the volcanic dome, hydrothermally altered volcanic breccia and silicified dacite with alunite and siderite occur.

The smaller subvolcanic bodies (Kadijca, Belo brdo) are less affected by the hydrothermal alterations, being only slightly propylized. Porphyry ore mineralizations are observed in the contact parts. According to the petrographic studies, they are represented mainly by dacites, and according to chemical analyses, they are dacites in transition to subalkaline rhyolites of a slightly sodium type. The rhyodacites North of Zvegor are of a potassium type similarly to most of the rocks in the Osogovo Mountain (С т о j а н о в, А л е к с а н д р о в, 1990). They are mostly of subvolcanic character thus differing from the volcanic rocks in Pijanec (on the Bulgarian territory; Kharkovska, 1984) that are volcanic lava sheets within the sedimentary filling of the Pijanec basin. Similar is the character of the volcanic rocks in the northern part of the Delčevo valley.

Table 1
Chemical composition of the volcanic rocks

oxides	1	2	3	4	5	6	7
Si_2O	64.20	68.14	70.04	65.93	66.12	72.76	69.83
TiO_2	0.46	0.48	0.44	0.48	0.53	0.17	0.40
Al_2O_3	15.43	14.00	13.20	14.80	15.56	13.77	14.02
FeO	1.68	0.21	0.36	0.29	1.35	0.30	0.65
Fe_2O_3	2.11	3.19	3.32	3.16	2.60	4.79	1.18
MnO	0.21	tr.	tr.	0.04	0.16	tr.	0.04
MgO	1.70	0.68	0.51	1.56	1.20	0.58	1.77
CaO	2.94	2.80	2.88	3.45	2.55	tr.	3.00
Na_2O	3.10	3.00	3.10	4.18	5.00	tr.	2.77
K_2O	3.50	2.70	2.70	3.25	3.10	4.10	2.90
P_2O_5	0.32	0.13	0.15	0.15	0.11	0.09	0.12
H_2O+	3.38	3.13	2.37	1.58	0.24	0.12	0.22
H_2O-	0.04	1.32	0.81	0.95	2.04	3.26	2.28
CO_2	0.94						
sum	100.01	99.78	99.88	99.32	100.56	99.94	99.82

The chemical analyses are made by Gordana Musović, chemist, Geological Institute — Skopje. The samples come from the following localities: 1 — quartz-latite, Zvegor; 2 — rhyodacite, Kadijca; 3 — rhyodacite, Kadijca; 4 — dacite, Belo brdo; 5 — rhyodacite, Kadijca (С т о ј а н о в и ч, 1970); 6 — dacite?, strongly altered — Bukovik; 7 — rhyodacite — Kadijca

According to radiogeochronological studies in Bulgaria, the age of the volcanic activity is within the time span 35 — 27 Ma. It is possible that the activity lasted longer on our territory but ended before the deposition of the Neogene (mostly Pliocene) sediments that are not affected by the volcanic postmagmatic processes.

The volcanic rocks of Kadijca and Belo brdo are rhyodacites with grayish-greenish colour, massive structure and phenocrysts (usually plagioclases) up to 5-6 mm large and situated within the predominant groundmass. They possess a porphyric holocrystalline texture. Plagioclases dominate among the phenocrysts. Sanidine is rare. Quartz is present in corroded crystals. Biotite is rarely found in fresh crystals, and usually is transformed into chlorite with opacitic margins. Hornblende and pyroxen are entirely propylitized. Plagioclases, both in the groundmass and phenocrysts, are argillized to a different degree. The secondary minerals are represented by chlorite, epidote, and carbonate minerals.

The content of SiO_2 in the less altered volcanic rocks (Table 1) varies between 66 and 70%, of the alkalies, between 5 and 8%, and of CaO, between 2.55 and 3.45%. The normative albite amount is approximately twice as much as the orthoclase thus pointing at a sodic character. The chemical composition points (Tables 1, 2, 3) at a rhyodacitic character for the subvolcanic rocks of Kadijca and Belo brdo. On the diagram of P. G e o f f r e y-F e i s s (1980), these rhyodacites are close to the trachyandesites from the Bučim ore field, and similar to volcanic rocks from America and the Far East, all bearing porphyry-copper deposits.

Ore mineralizations

The ore mineralizations of the terrain Bukovik — Kadijca have been studied extensively during the last fourty years. Our studies aimed to sum up these results, and to find out the genetic and paragenetic relations of the mineralizations with the volcanic rocks together with an evaluation of the prospects of this terrain for larger mineral deposits.

Table 2
CIPW and Niggli parameters, samples 4 and 5

CIPW-parameters:	4. dacite, Belo brdo	5. rhyodacite, Kadijca
Q	20.24	18.49
or	19.48	18.37
ab	36.65	42.47
an	11.96	10.57
wo	1.86	0.35
en	4.02	3.01
il	0.61	
hm	3.19	
mt		3.70
ti		0.76
ap	0.34	0.20
ru	0.03	0.34
salic	87.33	89.81
femic	10.05	8.36
Niggli parameters		
si	287.92	279.44
al	37.95	38.32
fm	18.89	21.06
c	16.27	11.42
alk	26.27	29.03
k	0.33	0.29
mg	0.55	0.36
magma	Ca-alkaline, granodiorite group, farsundite type	Ca-alkaline, leucoquartzdiorite group, trondhjemite type

The mineralized area that contains also numerous dacitic and rhyodacitic bodies and dikes, has an area of ca. 4 square kilometers. Intensely hydrothermally altered volcanic and subvolcanic rocks crop out, and the alterations and sulphide mineralizations are found both in the volcanic rocks and in their host metamorphic rocks.

Богојевски (unpublished report, Skopje, 1964) determined the presence of several ore minerals in the Bukovik area, and namely: pyrite (1st and 2nd generation), pyrite-melnikovite, chalcopyrite, bornite, tetrahedrite, galena, sphalerite, enargite, lusonite, covelin and famatinite.

During the prospection for iron at the western slopes of Bukovik, Stojanovič (Стојановић, unpublished reports, Skopje, 1960, 1967; 1970) proved considerable reserves of limonite ore into deluvial breccias. In a deeper borehole, intensely kaolinized volcanic rocks have been crossed through, followed by pyrite-impregnated dacites, and beneath them (from 52 to 96 m), metamorphic rocks intensely impregnated with pyrite and other sulphides. Two other boreholes (A-7 and A-2) situated between Bukovik and Kadijca yielded porphyry sulphide mineralization to a depth of 100 m but remained unprospected (П. Стојановић, unpublished report, Skopje, 1967). The borehole A-7 (at an altitude of 1597.40 m near the peak Kadijca) found 7 — 18% magnetite in the depth interval 24 — 48 m, and 3 — 6% magnetite along the other intervals. The core was not analysed for any other components. The borehole A-2 was located in the contact parts of the volcanic body of Bukovik (in its eastern parts) with the metamorphic rocks, at an altitude of 1545 m. The core has been entirely analysed for copper, the content varying between 0.02 and 0.12%. No analyses for gold, silver and other noble metals have been made although the microscopic studies found native gold and gold tellurides, together with magnetite, haematite, rutile, sphene, pentlandite, pyrite, chalcopyrite, pyrrhotite,, mushketovite, bravoite, anatase, galena, calaverite, molybdenite, chalcocite, coveline and sphalerite. Deeper (down to 300 m) drilling has been recommended.

Data obtained through detailed prospection by H a d ž i-P e t r u š e v and collaborators (unpublished report, Skopje, 1986) evaluate the terrains of Bukovik and Kadijca as prospective for ore, and namely, the terrains Belo brdo, Zjelovica, Treshten kamen, Kadan bunar, Gushterica and Skalite as well as terrains along fault structures: Obojata, Okno, Ostri Rid, Zanoga, Karadzhov Volk, etc. Considerable mineralizations are found also in the contact parts of the volcanics with the metamorphic rocks along the valley of Pehčevska reka..

The contact parts of Bukovik yielded (microscopic studies) the minerals chalcopyrite, pyrrhotite, arsenopyrite, and sphalerite as well as coveline, galena, malachite, azurite and native copper. Polished sections from the mineralizations along faults and fractures in metamorphic rocks and granites yielded also enargite, bornite, chalcocite, neodigenite, coveline, malachite, azurite, manganese oxides and iron hydroxides together with the mineralization, and B o g o j e v s k i (unpublished report, Skopje, 1964) found also barite and brawnite at "Centrala". Stockwork impregnations have been found by the present authors in the Pehčevska reka, with presence of enargite, tenantite, tetrahedrite, kosalite, sphalerite, freybergite and pierceite, and the presence (chemical analysis) of gold, silver, antimone, bismute, indium, etc.

All these data show that only the surface parts of the mineralization has been prospected sofar, and the minerals found point at the presence of oxidation zone, cementation zone, and zone of the primary mineralization.

Geophysical results

According to induced polarization data of the Skopje geophysicist Novica Stolik, two profiles of dipole sounding have been done in 1985, and in 1986, following own data, and geoelectric survey, a wide anomalous field has been located in the source areas of the river Pehčevska reka. The high values of induced polarization (more than 100 mV/V) and low values of electric resistivity (less than 10 Ohm) point at the presence of a rich sulphide mineralization. The anomalies are not close in depth that shows a continuation of the mineralization downwards.

The magnetic survey in 1965 (consistent also with the results of the aeromagnetic measurements by Vukašinovič (В у к а ш и н о в и ч, unpublished report, Skopje, 1962) indicated a most prospective area in the north-western periphery of the Bukovik effusive body. The anomaly is most probably due to an intense magnetite concentration related to the sulphide mineralization. Therefore, a geophysical survey with induced polarization is recommended for the whole Bukovik area.

Conclusions

The studies made confirm a genetic-paragenetic relationship of the porphyry ores of Bukovik and its area with the rhyodacites of Bukovik-Kadijca.

The volcanic rocks have been determined as rhyodacites of a quartz-diorite-granodiorite magma type with a sodic character (Kadijca and Belo brdo). The volcanic rocks at Bukovik are intensely altered. They are argillized, silicified and carbonatized. They host an impregnation-stockwork type of mineralization with copper, base metals, noble and rare metals, barite, barite-fluorite, all displaying a zonal arrangement both in the volcanic rocks and in the host magmatic and metamorphic rocks.

All mineral parageneses found and their distribution in the area point at the presence of a copper porphyry-type mineralization with a very strong silification

related to the volcanic centre Bukovik. The latter is a slightly eroded volcanic apparatus around that oxide and sulphide ore mineralizations are both vertically and laterally arranged in oxidation, cementation and primary zones.

The presence of a copper porphyry mineralization is confirmed also by the position of the volcanic rocks of Kadijca-Belo brdo within the field of porphyry-bearing volcanic rocks of the world on the diagram of G e o f f r e y-F e i s s (1980).

The available data point at the presence of an important complex (copper, base metals, noble metals) porphyry deposit that should be further studied for the elucidation of all economic parameters.

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