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GENERAL METALLOGENIC FEATURES AND COMPARISON OF THE METALLIFERI MOUNTAINS AND THE LECE – CHALKIDIKI METALLOGENIC ZONE

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A b s t r a c t: In this paper has been presented comparative metallogenic analysis between two metallogenic units of lower level that belongs to different geotectonic units, but in their composition has very similar metallogenic features. Those are Metalliferi Mountains district that belongs to the Carpatho-Balkan metallogenic province and Lece-Chalkidiki metallogenic zone that belongs to the Serbo-Macedonian metallogenic province. As basis for the performed metallogenic analysis were taken post-collision processes and geological phenomenon connected with them. In the frame of common features are enclosed volcano-intrusive complexes of Neogene age, structures of volcanic apparatuses and polymetallic mineralizations. As the most representative volcanic complexes, in the areas of consideration, were taken Brad-Sacarmb locality in the Romania and Kratovo–Zletovo in the Republic of Macedonia. Along the compared porphyry copper and gold mineralizations, of special interest were epithermal gold mineralizations connected with silicification zones in Rosia Montana, Lece and Plavica. Gold content is from few g/t up to 30 g/t Au.

Key words: Metalliferi Mountains; Lece-Chalkidiki zone; metallogenic analysis; comparison

INTRODUCTION

According to the basic goals of the paper it is necessary to make correlation between similar areas at the territory of Western Romania and the Republic of Macedonia. Geological and metallogenic features are most appropriate for correlation between Matalliferous Mountains and Kratovo-Zletovo volcanic area. Because the Kratovo-Zletovo volcanic area belongs to the Lece-Chalkidiki metallogenic zone, we consider that it is better, the correlation of the area of the consideration to start between the larger metallogenic units. In that context in the text that follows are given the main metallogenic features of the Metalliferous Mts. sub province and Lece-Chalkidiki metallogenic zone. These two regional metallogenic units occur in two metallogenic provinces. The Lece-Chalkidiki metallogenic zone (LChMZ) is a part of the Serbo-Macedonian metallogenic province, while the Metalliferi Mountains metallogenic district (MMMD) is situated in the Apuseni Mts. Sub-province of the Western Carpathian metallogenic province. Fig. 1 presents the position and outlines of these two regional metallogenic units and meridial geological structures, that additionally make structural relationship between these two localities. This is especially important because lately more and more are emphasized the facts that meridial structures have important significance in the spatial distribution of the ore mineralizations.

Though the LChMZ and the MMMD are the sectors of already defined metallogenic provinces, they exhibit many specific features with regard to surrounding metallogenic environments, but on the other hand the LChMZ and the MMMD have many common metallogenic characteristics.

This study aims to analyze the LChMZ and the MMMD in order to recognize and define their common metallogenic features which can be used as the principal criteria for the correlation of these two regional metallogenic units.

The metallogenic analysis embrassed not only available data (Serafimovski, 1990, 1993, 1999; Ianovici and Borcos, 1982; Ianovici et al., 1976; Borcos et al., 1998; Borcos, 2000), but some of the new field observations, particularly in the LChMZ are included as well.

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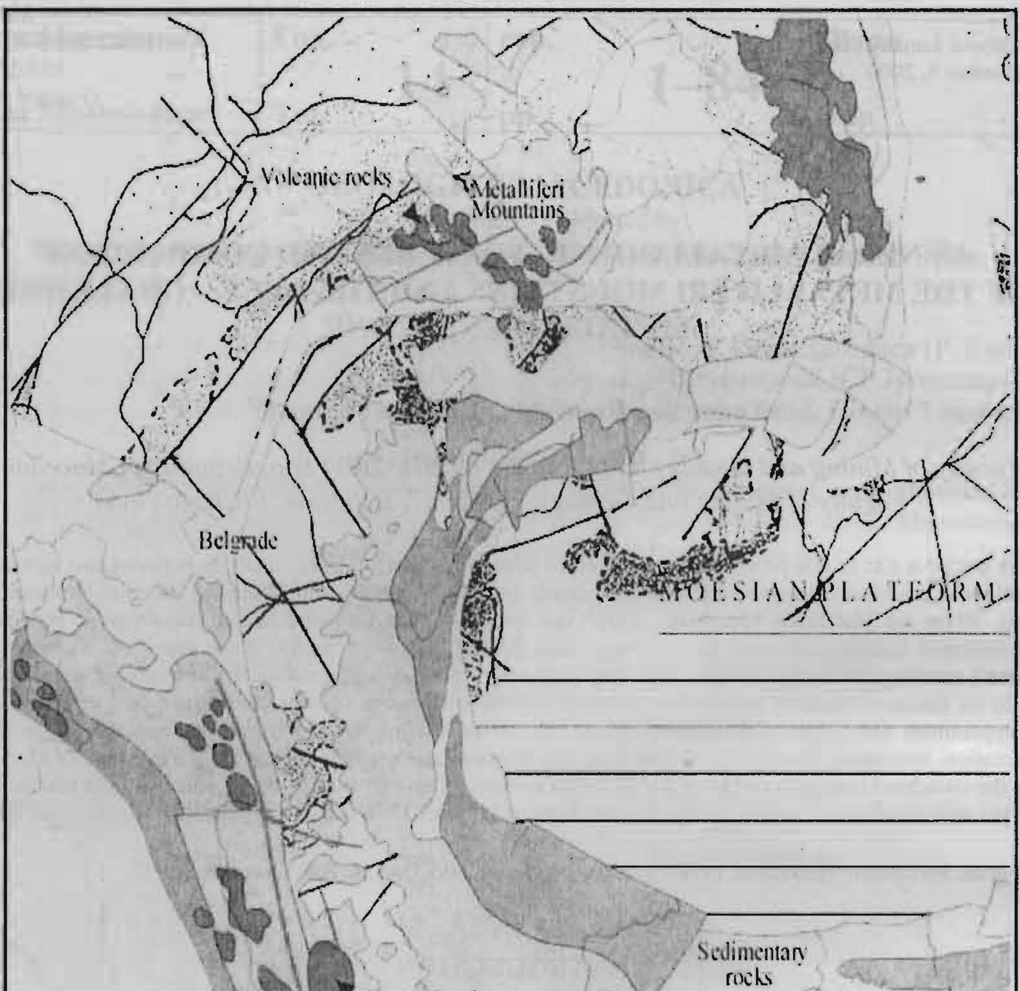

Fig. 1. Regional geotectonic scheme of the SW-flank of the Carpatho-Balkanides

SPECIFIC FEATURES OF THE LChMZ AND THE MMMD AS THE CRITERIA FOR THEIR MUTUAL COMPARISON

The metallogenic analysis of these two regional metallogenic units, and recognition of their specific features as the basis, for their mutual comparison, include following parameters:

1. *Regional geotectonic setting.* – Both regional metallogenic units formed in a post-closure oceanic environments. Mineralization is associated to postcollisional volcanic activity and shallow, mostly, subvolcanic intrusions. The magmatism took place in the Tertiary intramontane basin superposed on regional fault systems. The present orientation of faults differ in these two regional metallogenic units.

The MMMD is surrounded by the Jurassic Drocea ophiolites in the south, and the Techereu ophiolitic complex in the north (Fig. 2), while the LChMZ is developed nearby of the suture zone of the Jurassic Vardar ocean. There seems that both the LChMZ and the MMMD are situated along the same suture zone. This suture zone is covered by the Neogene sediments between the area of Crni Vrv (north of Jagodina) and the western outcrops of ophiolites of Metalliferi Mountains, but its existence in that sector has been indicated by aeromagnetic survey (Vukašinović, 1975).

2. *Volcanic activity.* – Both regional metallogenic units are characterized by extension, multistage activity of calc-alkaline affinity.

Metalliferi Mts. District: The volcanic activity and mineralization took place within three main phases. The composition of volcanics ranges from rhyolite to andesite and quartz andesite; the latter volcanics prevails. The distribution pattern of volcanics formed in the Badenian and the Sarmatian shown in Fig. 3.

3. *Associations of elements.* – The dominant, major elements of ore mineralization in both regional metallogenic units under consideration are base-metals (Pb, Zn), gold, silver and copper. Unlike the LChMZ, the MMMD is also characterized by high Te concentrations. Fe as sulphides is also abundant and widespread, but not specific element of the LChMZ and the MMMD.

Vertical zoning of distribution pattern of major metals is a common characteristic of these two regional metallogenic unit. In a general case, this vertical zonal arragement of major metals is mostly expressed as:

Top of mineralization system: The prevailance of Au-Ag, and Pb-Zn accompanied by variable concentrations of gold and silver. In the MMMD the abundance of Te in this level of mineralized system is a specific geochemical feature.

Middle zone of mineralization: The dominance of Pb-Zn accompanied by Au-Ag, minor copper.

Bottom of mineralization system: Copper is the dominant metal accompanied by variable concentrations of Au-Ag and minor base metals.

The contents of trace elements in the volcanics are rather variable, displaying some correlation to the mineral composition of volcanics (Table 1, 2).

Table 1

Variations of trace elements in the volcanics of Metalliferous Mountains

No.	1	2	3	4	5	6	7	8	9	10
SiO_2	71.8	60.135	54.39	57.73	57.325	59.855	57.355	56.94	57.355	65.12
Al_2O_3	14.31	19.9	21.35	18.47	20.91	17.905	18.47	10.075	18.47	18.47
Fe_2O_3	1.08	3.61	2.905	4.64	4.41	5.265	4.64	3.47	4.64	4.64
FeO	0.89	2.28	1.625	5.26	2.615	3.87	5.26	2.87	5.26	5.26
MnO	0.03	0.13	0.105	0.5	0.45	0.14	0.5	0.14	0.5	0.5
MgO	0.78	1.51	2.43	3.005	3.025	3.315	3.005	3.675	3.655	3.655
CaO	2.19	5.835	9.395	5.355	7.11	6.235	6.555	8.085	6.545	6.545
Na_2O	3.245	4.135	3.195	2.525	2.575	2.34	3.51	2.96	3.51	3.51
K_2O	3.825	1.49	1.235	2.12	0.95	2.03	2.12	1.16	2.045	2.51
TiO_2	0.315	0.675	0.425	1.93	1.605	0.66	1.93	0.87	1.93	1.93
P_2O_5	0.055	0.15	0.085	0.335	0.115	0.225	0.335	0.25	0.335	0.335
CO_2	0.96	1.255	0.475	1.1	0.78	1.16	1.16	0.635	1.16	1.16
S	0.18	0.075	0	0.39	0.045	0.17	0.39	0.13	0.39	0.39
H_2O	5.255	0.9	2.11	2.93	1.505	1.365	2.93	1.59	2.93	5.015

1. Produce, phase, cycle, 2. Produce acid cycle I, 3. Produce andesitic cycle II, 4. Produce andesite ~ phase de Clinel, 5. Produce andesite ~ phase de Brad-Sacarmb, 6. Produce andesite Zarand&Beus, 7. Produce andesite ~ phase de Cetras, 8. Produce andesite cycle II, 9. Produce andesite cycle III, Variable production of andesite cycle I, II, III, 10. Global volcanism Apuseni Mountains

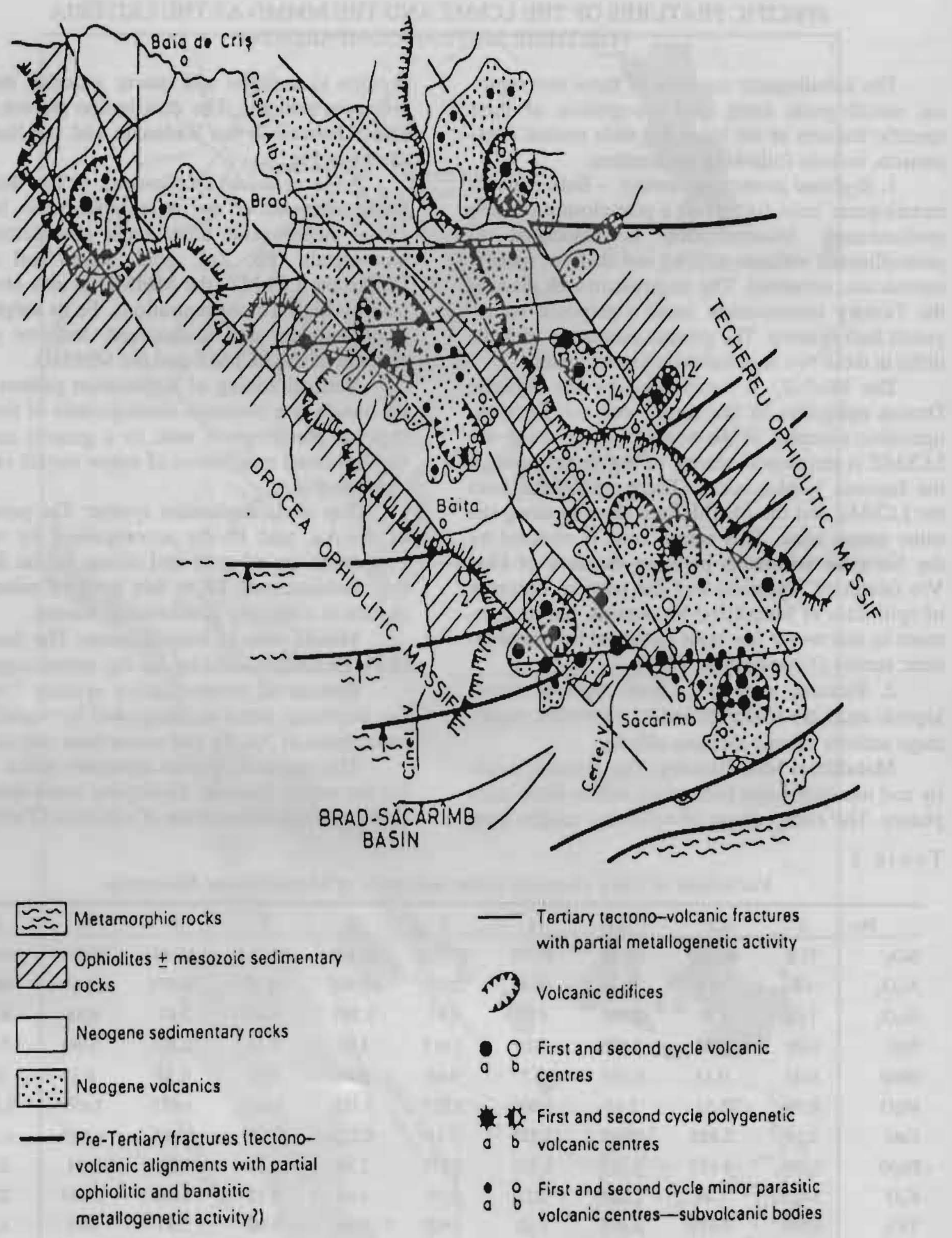

Fig 2. Tectono-volcanic scheme of the Brad-Sacarınb volcanic area (after Borcos from Ianovici et al., 1976). Main edifices and volcanic centres: 1. Ciinel, 2. Baita, 3. Draica, 4. Barza, 5. Caraci, 6. Bucutesci-Rovina, 7. Tresita-Magura, 8. Hondol, 9. Sacarmb, 10. Macris, 11. Cetras, 12. Valisoara, 13. Cordurea-Cerburea, 14. Duba

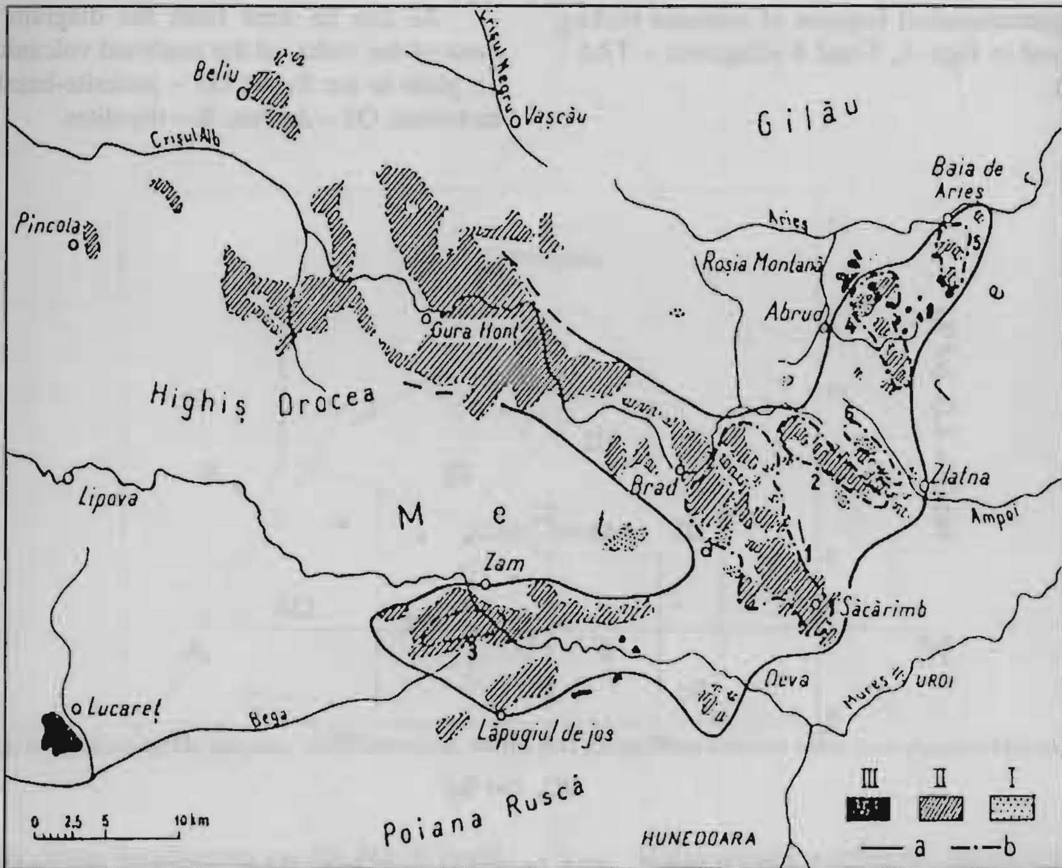

Fig. 3. Definition of the neogene volcanites in the Apuseni Mountains and associated metallogenic units.
I. First phase of the eruption. II. Second phase of the eruption. III. Third cycle of the eruption: a) Subprovince of the neoge volcanism associated concentrations, Apuseni Mountains; b) metallogenic district (1. Brad-Sacarmb, 2. Almas-Stania, 3. Bu 4. Rosia Montana – Bucium. 5. Isvorul Ampoiului)

Table 2

Variations of micro elements in the volcanics of Metalliferous Mountains

No	1	2	3	4	5	6	7	8	9	10
Cu	31.00	23.00	21.50	52.50	53.00	56.50	52.50	54.00	52.50	52.50
Pb	30.00	26.00	9.50	19.50	10.50	26.00	25.50	19.50	25.50	27.50
Zn	30.00	50.50	40.50	61.50	48.00	47.50	61.50	49.00	61.50	61.50
Ga	13.50	21.00	20.00	18.00	15.00	16.50	18.00	16.00	18.00	17.00
Ni	6.00	12.00	3.00	12.50	7.25	11.00	12.50	39.25	37.50	37.50
Co	6.25	17.00	8.50	17.50	11.00	12.50	17.50	17.50	17.50	22.00
Cr	4.50	15.00	3.00	13.00	5.50	4.50	28.50	151.00	149.50	149.50
V	11.75	70.00	64.00	104.00	109.00	101.00	104.00	150.00	122.50	118.2
Be	2.90	2.35	1.75	2.70	1.40	2.70	2.70	1.75	2.70	2.50
Sr	283.00	315.00	375.00	577.50	260.00	660.00	577.50	750.00	577.50	544.0
Ba	929.00	640.00	337.50	1032.50	369.00	790.00	1032.50	782.50	1032.50	986.50
Li	29.50	34.00	41.00	62.75	7.50	37.50	62.50	23.50	62.50	62.00
Ni/Co	1.33	1.00	0.50	1.00	0.80	1.00	1.00	2.77	1.64	1.64

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The petrochemical features of volcanic rocks are displayed in Figs. 4, 5 and 6 (diagrams – TAS and AFM).

As can be seen from the diagram (Fig. 5) most of the rocks, of the analyzed volcanics (Table 1), plots in the fields: O1 – andesite-basalts; O2 – andesites; O3 – dacites; R – rhyolites.

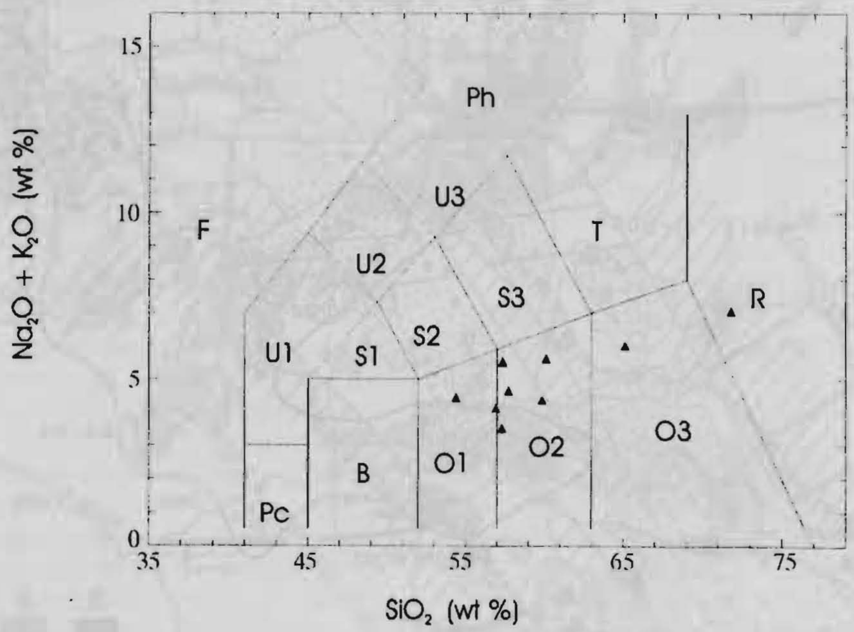

Fig. 4. Total alkali/silica diagram ($Na_2O + K_2O$)/SiO_2 – TAS, for the data gained from volcanic rocks from Apuseni Mountains F – foitide; Pc – pikrobasalts; U1 – tefrites (Ol < 10%), basanites (Ol < 10%); U2 – fono-tefrites; U3 – tefrite-fonolite; Ph – fonolite; B – basalts; S1 – trahi-basalts; S2 – basalt-trahiandezites; S3 – trahi-andezites; T – trahites (q < 20%), trahi-dacites (q > 20%); O1 – andesite-basalts; O2 – andesites; O3 – dacites; R – rhyolites

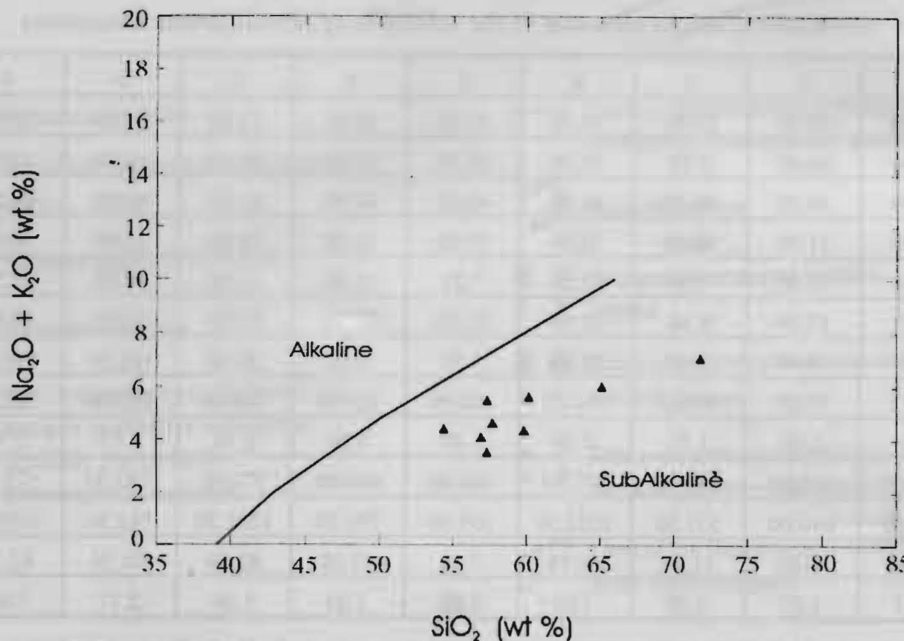

Fig. 5. Total alkali/silica diagram, for the data gained from volcanic rocks from Apuseni Mountains (diagram according Irvine and Baragar, 1971)

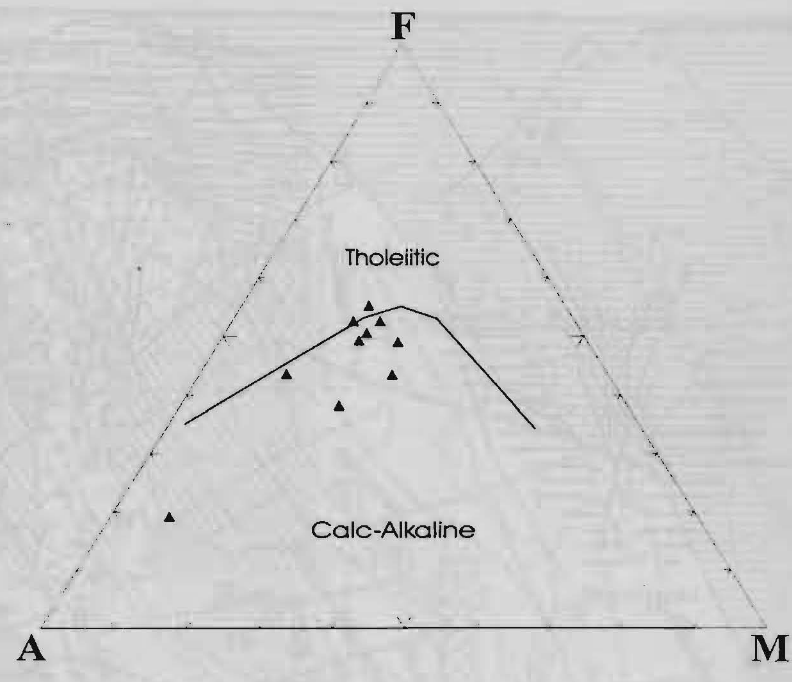

Fig. 6. AFM triangular diagram, alkali ferro ratio, for the data gained from volcanic rocks from Apuseni Mountains

While, from the diagram on the Fig. 5 (total alkali/silica ratio) can be seen that most of the rocks of the analyzed volcanics (Table 1), plots in the field of subalkaline series that suggests deeper origin of magma that caused their formation.

From the AFM diagram (alkali-ferro-magnesia) can be seen that most of the rocks from the analysed area plots in the frame of calk-alkaline series.

Mineralization is commonly associated to the roots of the volcanic structures (Fig. 7). The contents of Cr, V, Ba and Li display particularly very wide ranges of concentration. There seems that increased concentrations of gold related to the ore mineralization of both the LChMZ and the MMMD derived from the ophiolites as the ultimate source from the same ultimate source originated local enrichment of Cr. The trace elements in the volcanics of the LChMZ shows similar concentration rates.

4. *Morphogenetic types of mineralization* – The dominant morphogenetic types of mineralization in both the LChMZ and the MMMD include the following:

4.1. Epithermal volcanogenic mineralization of native gold and tellurides (the latter particularly developed in the MMMD). This type of mineralization includes phreato-magmatic breccia, breccia pipe and vein-types.

Volcanogenic epithermal mineralization consists of several associations of elements such as:

Au-Ag (±Cs, Pb-Zn, Cu),

Cu-As (±Ga) or Cu-As, Py, Au, Ag.

4.2. Volcanogenic mesothermal mineralization of vein-type is very frequent in both regional metallogenic units. They have mostly rather simple mineralogical composition encompassing apart Fe-Pb-Zn-Cu sulphides, sporadically tellurides, and various sulphosalts as well.

The most frequent associations of metals are:

Au-Ag-Pb-Zn (Te in the MMMD),

Pb-Zn ± Au-Ag,

Pb-Zn-Cu.

There are some possibilities that sporadically porphyry copper mineralization was formed beneath Pb-Zn vein-type mineralization.

4.3. Porphyry copper mineralization occurs sporadically in both the LChMZ and the MMMD. The Sarmatian igneous events yielded porphyry copper system in the MMMD, centered on shallow subvolcanic bodies of andesite and quartz-andesite, while in the the LChMZ porphyry copper mineralization is associated with subvolcanic intrusions of andesitic/dioritic composition.

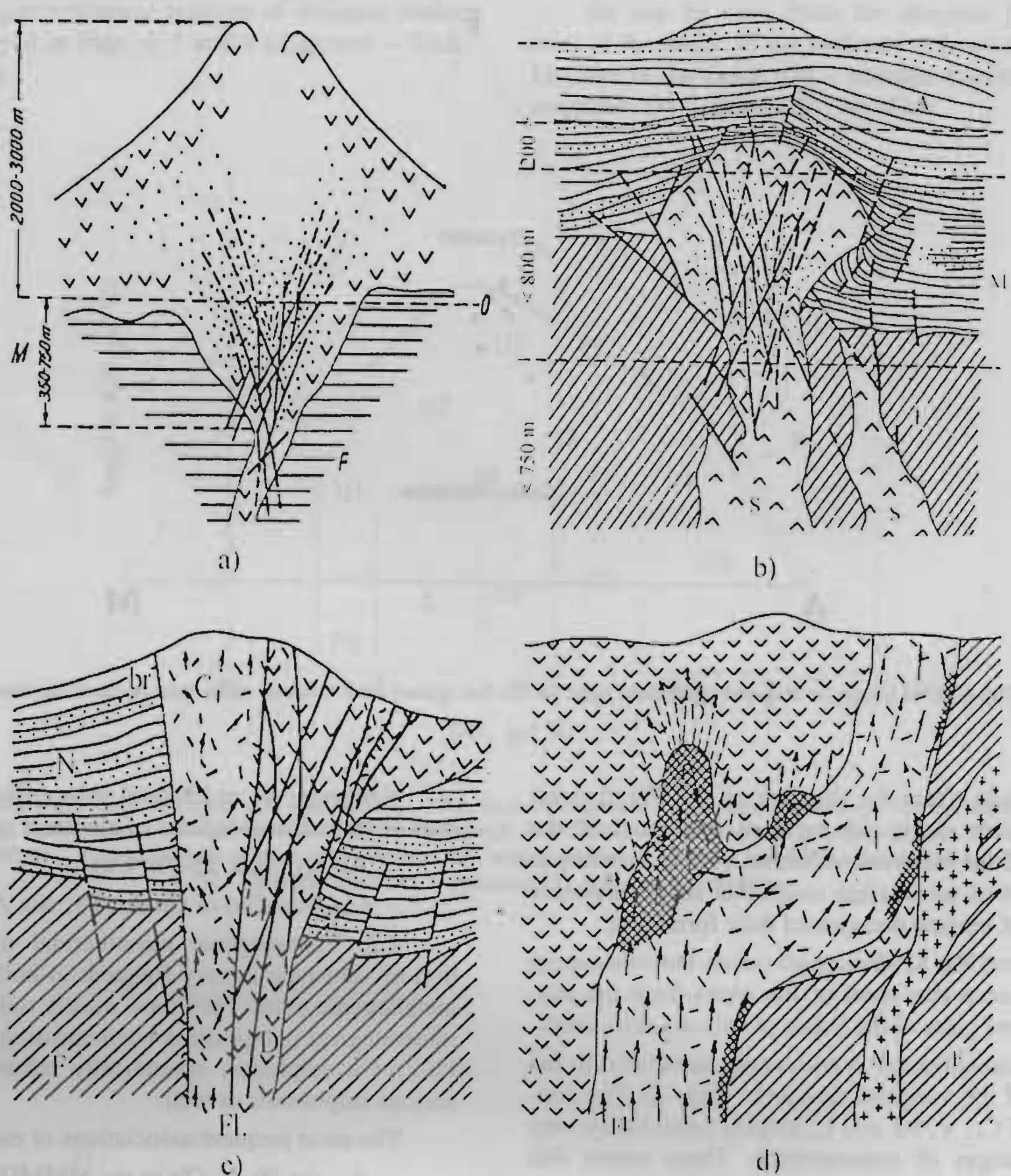

Fig. 7. Position of the ore veins in the volcanites

A part of the porphyry copper systems in the MMMD shows outward radiating veins. In the same regional metallogenic units, two models of porphyry copper mineralization is distingiushed (Borcos, 2000): (a) porphyry-epithermal model (i.e. the Valea Morii), and (b) porphyry model with pyrite halo model (i.e. the Rosia Poeni model). The mineralization of the latter model includes disseminated gold in pyrite hosted in porphyry epithermal system.

The Lece-Chalkidiki metallogenic zone: This zone is situated in the marginal parts between the Vardar zone in the west and the SMM in the east. It represents an elongated metallogenetic unit starting with the Lece ore district in the N–NW, extending through the Kratovo–Zletovo, Bučim and Kilkis to the Eastern Chalkidiki ore districts in the S–SE. After this ore district, the zone under consideration, along with the Vardar zone, buries into the Aegean Sea and bends to Izmir in the east. It can be traced for over 700 km along strike with average width of 30 km (Fig. 8).

Lead and zinc are the dominant metals, followed by copper, gold, silver, antimony, arsenic and locally molybdenum. Uranium, PGE, bismuth, mercury also occur locally, but are less abundant.

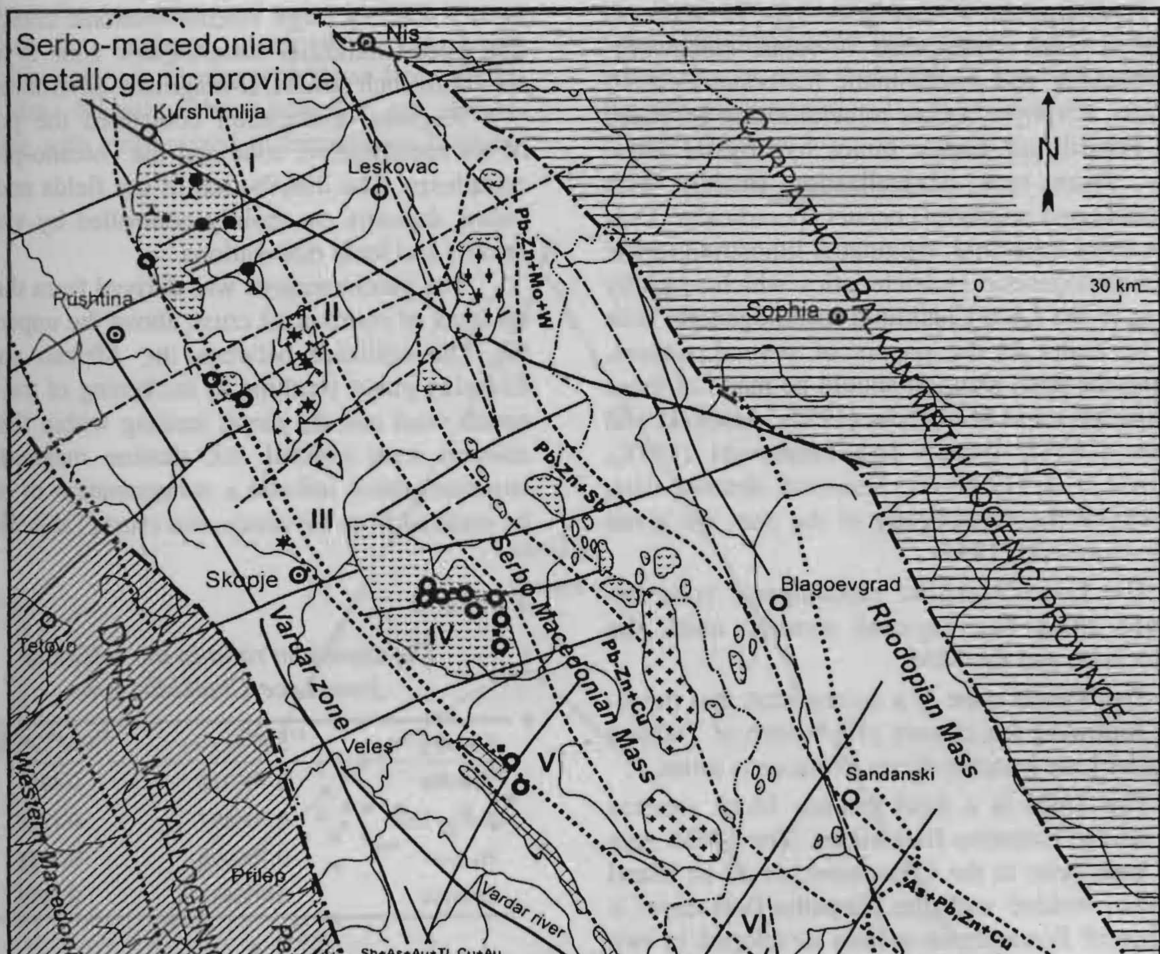

Fig. 8. Geotectonic and matallogenic position of the Lece-Chalkidiki zone.
1. Neogene volcanics; 2. Tertiary intrusives; 3. Neogene granitoids; 4. Jurassic grano-diorites; 5. Hercynian granites; 6. Boundary of metallogenic provinces; 7. Boundary of metallogenic zones; 8. Lineaments

Hydrothermal volcanogenic type of mineralization is most widespread – veins, stockwork-disseminated, and metasomatic (carbonate-hosted) deposits. Porphyry copper mineralization is related with subvolcanic and/or minor hypabyssal intrusions. Skarn type mineralization (mainly with magnetite and sulphides) occurs sporadically. Data about latest structural, magmatic, lithostratigraphic and metallogenetic characteristics which spatially belong to the Lece-Chalkidiki metallogenetic zone can be found in the papers of several authors. Among the first, mention should be made of those of Papadakis and Michalidis (1976), Arsovski and Ivanov (1977), Ivanov and Denkovski (1978), Janković et al. (1980) etc. However, detailed data, in terms of the metallogeny of the unit, are given by Serafimovski (1993).

The Lece-Chalkidiki metállogenic zone developed along two regional tectonic units, the Vardar zone and the SSM.

The Vardar zone is a suture zone that developed following the closure of a branch of Tethyan ocean by Late Jurassic–Early Cretaceous times.

The SMM is a rigid tectonic block situated west of the Carpatho-Balkanides. The SMM may have been prior to the Cretaceous period an island arc, then welded with the Carpatho-Balkanide. It consists of Precambrian schists developed in two units – the Lower and Upper Complex. Such a tectonic environment was cut, during the Tertiary period, by several deep-fractured zones, striking mainly NNW–SSE. Calc-alkaline magmas penetrated along these regional dislocations at intervals, locally forming large volcano-plutonic complexes. The Lece-Chalkidiki metallogenic zone is associated with such structural-magmatic environment.

Regional dislocation controlled the position of the metallogenic zone and the volcano-plutonic complexes. The distribution of ore fields and individual deposits are mainly controlled by volcanic centers and local dislocations.

The parent magma was derived from the lowest level of continental crust, above the upper mantle. The collision between the African and the Eurasian plates resulting in thickening of the continental crust and its partial melting within the post-colision zone yielded calc-alkaline magmas. The strontium ratios indicate a contamination of magma by material from the continental crust (Table 3).

Table 3

The strontium ratio in the volcanics from Lece-Chalkidiki zone

Locality	$^{87}Sr/^{86}Sr$ (%)	$^{87}Rb/^{86}Sr$ (%)
Zletovo	0.706318	0.4087
Borov Dol	0.706897	0.1246
Bučim	0.706928	0.2908
Damjan	0.706633	0.1459

The REE data may indicate similarities of igneous rocks in the Lece-Chalkidiki zone with those related with active continental margin (Table 4). The absolutely age of this magmatism is in the range between 37.5 and 16 million years.

Table 4

The contents of rare earth elements in volcanic rocks in the Lece-Chalkidiki zone, ppm (Serafimovski, 1993)

No	1	2	3	4	5	6	7	8	9	10
La	38	50	26	35	28	41	40	56	55	21
Ce	65	90	42	58	50	80	76	93	102	35
Nd	–	–	–	–	–	–	–	–	–	–
Sm	4.5	5.3	3	4.9	5.9	6.3	4.7	7.6	7.9	4.4
Eu	1.4	1.7	0.9	1.2	0.7	1.7	1.1	1.8	1.8	1.1
Tb	–	1.1	–	–	–	3.6	1.9	1.9	1.3	0.4
Yb	0.9	3.0	1.1	1.3	2.1	2.7	2.9	1.3	2.4	4.0
Lu	0.13	0.27	0.15	0.24	0.30	0.41	0.54	0.41	0.26	0.96
Σ	109	151.37	73.15	100.64	87	135	127.14	162	170	66.86
La/Yb	38.9	16.6	23.6	26	13.3	15.18	13.7	43	23	5.25
La/Sm	8.4	9.4	8.6	7.14	4.7	6.5	8.5	7.36	6.9	4.7

1. Andesite, Tulare; 2. Hydrothermally altered andesite, Tulare; 3. Fresh andesite, Tulare; 4. Andesite, Bakrenjaca; 5. Rhyolite, Lojane; 6, 7. Hydrothermally altered andesite, Plavica; 8. Andesite, Borov Dol; 9. Rhyolite, Vathi; 10. Rhyolite, Gerikaria. Neutrono-activation analysis, Lab. Geol. Committee, Sofia

From the petrochemical point of view we can say that the volcanic rocks from the Lece-Chalkidiki zone are similar with those from Metalliferi Mts. Namely, they basicaly are dacito-andesites with emphasized differentiation continuity. From the data of the analysis of rocks in the Lece-Chalkidiki zone was created AFM diagram, where can be seen that most of the rocks plots in the calk-alkaline series. It can be noticed continuity of differentiation from andesites to [illegible] (Fig. 9).

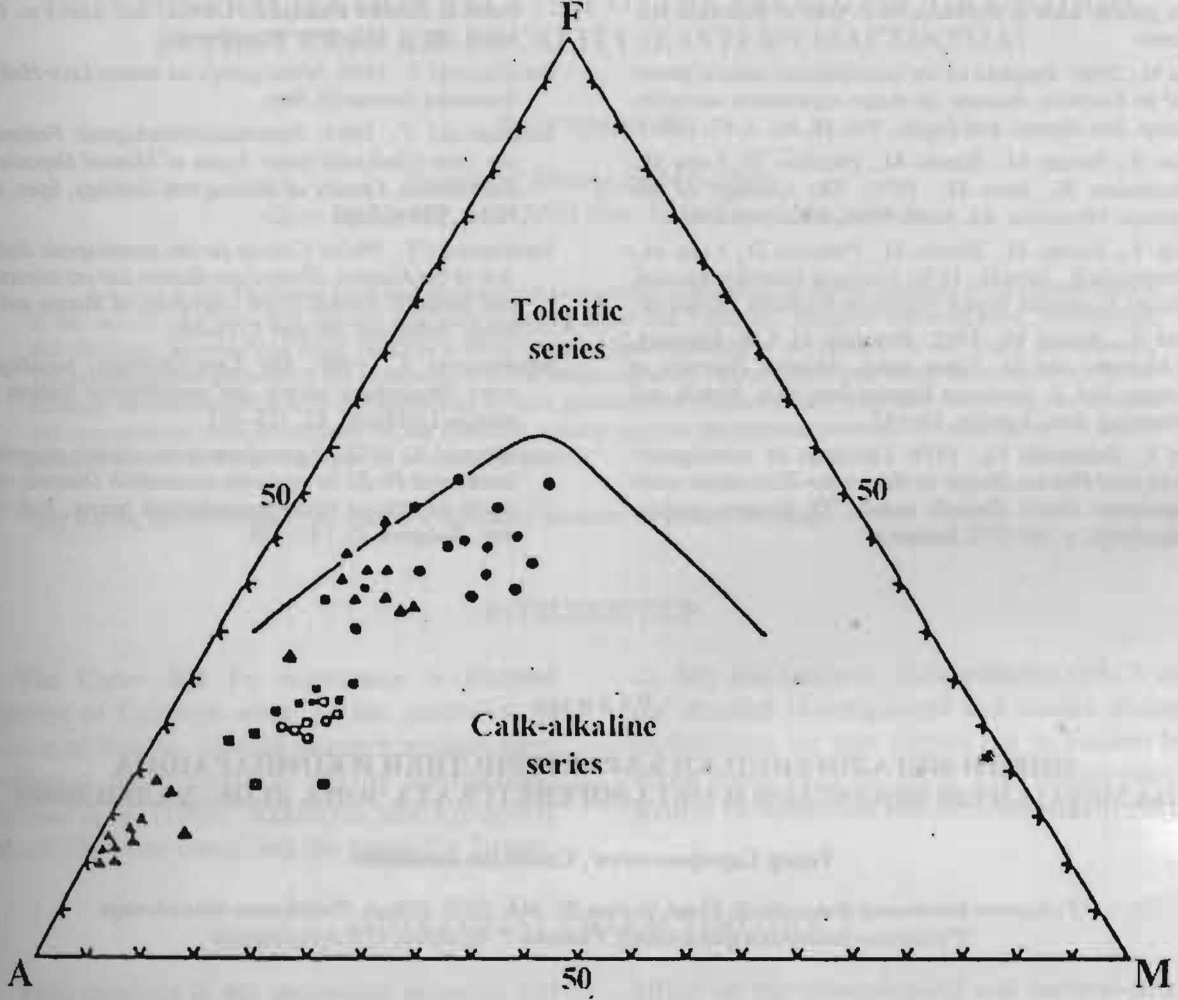

Fig. 9. AFM diagram of the volcanic rocks from the Lece-Chalkidiki zone.

The Lece-Chalkidiki zone is part of the Serbo-Macedonian metallogenic province as a larger metallogenic unit (Fig. 8). Polymetallic deposits are the basic metallogenic feature of the zone. Examinations performed defined various morphogenetic types among which hydrothermal lead-zinc and porphyry copper deposits are dominant. Antimony vein and metasomatic lead and zinc (Olympias type) deposits are also dominant. In order to get a more complete view of the metallogentic features of individual deposits in the Lece-Chalkidiki zone the paper will give a detailed account of individual features of lead-zinc and porphyry copper deposits.

Minerals contents are of interest in some deposits such as the gold contents in the Lece and Olympias deposits. The Zletovo is a typical vein type deposit, whereas Olympias is of hydrothermal metasomatic type. The ore mineralization in the Lece deposit is located within the silicified fracture zones. In addition to hydrothermal lead-zinc deposits, porphyry copper deposits discovered are also of interest. Also, gold mineralization is very extended in the Lece district and especially in the Kratovo–Zletovo ore district.

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Резиме

ОПШТИ МЕТАЛОГЕНЕТСКИ КАРАКТЕРИСТИКИ И КОМПАРАЦИЈА НА METALLIFERI MOUINTAINS И МЕТАЛОГЕНЕТСКАТА ЗОНА ЛЕЦЕ–ХАЛКИДИКИ

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Клучни зборови: Metalliferi Mountains; зона Леце-Халкидики; металогенетска анализа; компарација

Во трудот е презентирана една компаративна металогенетска анализа помеѓу две металогенетски единици од понизок ранг, кои припаѓаат на две различни геотектонски единици, но во својот состав имаат и заеднички металогенетски обележја. Тоа се Metalliferi Mountains, кои ѝ припаѓаат на карпато-балканската металогенетска провинција, и зоната Леце–Халкидики, која ѝ припаѓа на српско-македонската металогенетска провинција. Како основа за извршената металогенетска анализа се земени постколизионите процеси и геолошките феномени поврзани со нив. Во заедничките односи се вбројуваат главно вулкано-интрузивните комплекси од неогена старост, структурите на вулканските апарати и полиметалната минерализација. Како маркантни вулкански комплекси во терцијарните металогенетски единици се земени локалитетите Брад–Сакармб во Романија и Кратово–Злетово во Македонија. Покрај компарираните порфирски минерализации на бакар и злато, посебно забележителни се и епитермалните минерализации на злато поврзани со зоните на силификација во Росија Монтана, Леце и Плавица. Содржината на златото се движи од неколку грама до преку 30 g/t.