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PREFACE (FOREWORD)

This volume/special issue represents the proceedings of the annual of the IGCP Project No 356, held in Romania from 7-19 June, 1994, meeting. The meeting was organized by the Geological Institute of Romania, București and "Quartz" S.A., Baia Mare, including a Symposium in Baia Mare (13-14 June, 1996, and metallogenic field trips București-Gurghiu-Harghita Mts (East Carpathian Tertiary volcanic arc)-Baia Mare (7-12 June, 1994) and Baia Mare-Gutâi Mts (East Carpathian Tertiary volcanic arc)- Apuseni Mts (Banatites and Tertiary volcanics)-Deva (15-19 June 1996).

The Romanian Carpathians possess a great variety of genetic types and a large amount of ore deposits related to Upper Cretaceous-Tertiary magmatism than any other region through Europe. Baia Mare region and Apuseni Mts once very important gold, copper, lead and zinc producing regions contain still numerous active mining sites of this kind.

The aim of the meeting was to discuss Upper Cretaceous-Tertiary mineralization in this regional metallogenic units and adjacent Carpathian-Balkan areas in terms of plate tectonics, as a continuation of the IGCP Project No 169. The various approach to this topic provided a platform for discussion and opportunities for better understanding and future cooperation across national boundaries too.

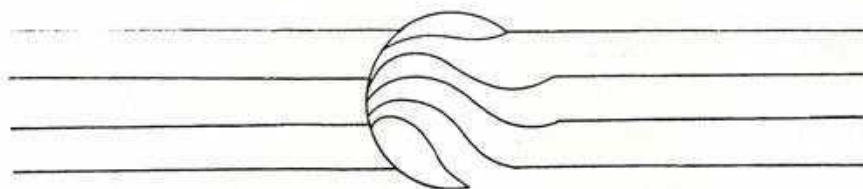
The contributions presented during the symposium of whom 13 were submitted for publication spanned major metallogenic units involving their main ore types. Any way, some papers included rather restrictive topics or general overviews that represent variation on older themes. Since authors' contributions were so diverse, no attempt has been made to standardize the papers. However, the editorial board of the Geological Institute of Romania and the editors of the present volume agreed to publish the papers without alterations, according to the original manuscript. In addition, they decided to publish as subsequent discussions critical comments by the referees selected by the editorial board and replies by the authors. This was considered as a constructive polemic, following examples given by prestigious publications as *Economic Geology*.

Eventually it is felt that this volume presents an important contribution to the Carpathian metallogeny and an endeavour for further metallogenic correlation in terms of plate tectonics throughout the whole Carpathian-Balkan realm.

Thanks are due to the Geological Institute of Romania for supporting the publication of this volume and the editorial board of the Institute for assistance with volume preparation.

Ș. Vlad

M. Borcoș



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ALPINE METALLOGENESIS OF THE ROMANIAN CARPATHIANS

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Key words: Alpine metallogenesis. Plate tectonics. Romanian Carpathians. Metallogenetic models.

Abstract: From both metallogenetic and structural points of view the Romanian Carpathians belong to the Alpine realm and represent a part of the subglobal Mediterranean (Tethyan)-Himalayan belt. The Alpine cycle is represented by a complete sequence of spreading-contraction events. Both short-lived and more evolved rifts are characteristic of this setting and yielded various types of magmatic and metallogenetic products. The Alpine ores are the most important quantitatively and represent 33% of the national resource estimates (mined out and present reserves/resources). The main stages are connected with the Laramian (Banatitic) and Neogene magmatic products. The metallogenesis is related to Senonian-Paleocene and Late Tertiary subduction events that in turn yielded ore deposits of island arc of Andean types. Regional occurrences, tectonic characteristics, alteration and zoning, ore mineralogy and other elements form the outline of the metallogenetic models in porphyry and non-porphyry environments. Laramian (Banatitic) metallogenetic models in porphyry environments are represented in Banat by the Suvorov model with skarn halo and the Bozovici model with pyrite halo. Laramian (Banatitic) metallogenetic models in non-porphyry environment are defined as Ocna de Fier model and Dognecea model in Banat of commonly calcareous host rock with proximal and distal Fe-Cu/Pb-Zn skarn formation and Băița Bihorului model in the Apuseni Mts. with extended skarn formation and Mo-Bi-W-Cu mineralisation through the whole contact aureole of the pluton. Neogene metallogenetic models in porphyry environment are outlined in the South Apuseni Mts., i.e. Valea Morii model with epithermal veins halo and Roșia Poieni model with pyrite halo. The Gurghiu-Harghita-Călimani portion of the East Carpathian volcanic arc exhibits aborted porphyry copper systems. Neogene metallogenetic models in non-porphyry environment are represented by epithermal systems in Baia Mare region and South Apuseni Mts as follows: Baia Sprie model with breccia pipe and veins carrying Au-Ag-Pb-Zn, Căvnic model with Au-Ag-Pb-Zn veins, Săcărâmb model with Au-Ag-Te veins and Roșia Montană Au-Ag composite system (breccia pipe and veins).

I. Introduction

The main geotectonic units of the Romanian territory are represented by two mobile regions, the Carpathians and North Dobrogea, and adjacent cratons. The Carpathian mountain range (that is the East and South Carpathians and Apuseni Mts) with intramontane Transylvanian and Pannonian Basins is surrounded by the foreland of mainly planes.

From both metallogenetic and structural points of view the Romanian Carpathians belong to the Alpine realm and represent a part of the subglobal Mediterranean (Tethyan)-Himalayan belt. They are bound

westward by the West Carpathians and southeastward by the Balkans.

II. Geodynamic evolution

The geodynamic evolution of the Romanian territory is interpreted in connection with successive cycles of ocean opening and closing (Wilson orogenic cycles). Geologic-structural and metallogenetic data provide evidence for reconstitution of recent and prior (that is Alpine as well as Upper Paleozoic, Lower Paleozoic

and Precambrian) tectonic settings. The Alpine cycle is represented by a complete sequence of spreading-contraction events whereas the pre-Mesozoic cycles are represented by remnants of sequences incorporated into Alpine structures.

The present-day architecture of the Romanian Carpathians is confined to the evolution of the Tethyan trench system. Both short-lived and more evolved rifts are characteristic of this setting and yielded various types of magmatic and metallogenetic products. The ultimate result is the Tethyside collage that formed by interaction of the African plate and related microplates with the European plate and related microplates (Plate). Interpretation of ocean floor spreading, subduction, collision and post-collision events is sometimes difficult due to contradictory assessments when using terms such as plate-microplate-sialic block, related subduction or subfluence (intracrustal movement), ophiolite meaning and significance (island arc- or ocean floor spreading-products), calc-alkaline volcanicity (subduction-related or rift-related products), position to and correlation with the major Tethyan suture, acceptance or denial of back-arc settings in the Carpathians and so on.

Pre-Alpine geodynamic or paleotectonic models of the Carpathians are difficult to reconstruct. The Alpine evolution, according to recent interpretations (e.g. Săndulescu, 1994; Rădulescu et al, 1993; Balintoni et al, 1996; M. Lupu, 1996), is related to the main Tethyan suture, that is the Vardar zone. The Transylvanian Tethys area and the rift of the East and South Carpathians occurred during the spreading period. Contractions gave rise to the present curved Carpathian configuration and the complex nappe structure. Anyway, the problem of bending and torsion referred to the orocline versus spurious orocline theme of the Alpine belt in general and the Carpathian-Balkan branch in particular still represents a topic of discussions.

Three major petrogenetic associations penetrated the groups of nappes or post-nappes basins of the Romanian Carpathians (Plate): the Jurassic-Early Cretaceous magmatic products of tholeiitic to calc-alkaline character in the South Apuseni Mountains, the Laramian magmatic belt (Banatites) of calc-alkaline character in the Apuseni Mountains and South Carpathians and the Late Tertiary magmatic products of calc-alkaline to shoshonitic character in the East Carpathians and South Apuseni Mountains.

III. Metallogenesis

The Romanian territory contains numerous ore deposits known and mined since pre-Roman times. The

metallic resources (Au, Ag, Pb, Zn, Cu, Mn, Fe, etc) have been almost continuously extracted, especially the high-grade ores. Numerous ore minerals have type localities in occurrences in famous ore regions such as Baia Mare, the Gold Quadrilateral in the South Apuseni Mts., and Banat. Baia Mare vein sets and the Gold Quadrilateral are known in the geological literature for their gold-silver deposits whereas skarn deposits in Banat are type deposits of their kind.

An attempt is made below to outline the Alpine metallogenetic evolution of the Romanian Carpathians. Metallogenesis related to all stages of a Wilson orogenic cycle has been recognized (from intracontinental rifting to spreading-, subduction-, collision- and post-collision-related settings). The geological features that controlled the episodic ore deposition during this cycle are correlated with the geochemical behaviour of the major metals (Plate).

The Alpine ores are the most important quantitatively and represent 80% of the national resource estimates (mined out and present reserves/resources) of the national resource estimates. The main stages are connected with the Laramian (Banatitic) magmatic products (especially skarn deposits and porphyry deposits) and Late Tertiary volcanic products (especially vein deposits and porphyry deposits).

Metallogenesis related to intracontinental rifting

The Danubian units of the South Carpathians contain Mo-W mineralization in the Mraconia region. The environment consists of bimodal magmatic products represented by north-south striking monzogranite-granodiorite dikes and lamprophyre dikes that penetrated mylonitised metamorphic rocks of the Neamtu Series (Metallogenetic unit 1A in Plate). A major monzogranite dike underwent potassic and phyllic alteration; molybdenite and common sulfides veinlets and impregnations occur in the phyllic zone. Carbonate intercalations of the surrounding crystalline schists were converted into grandite garnet skarns with scheelite, pyrite, chalcopyrite, magnetite, and hematite. Absolute age data (209-145 m.y., K-Ar) and bimodal magmatic products with associated porphyry Mo mineralization are characteristic of an aborted ensialic rift. It is, however, difficult to ascertain if this rifting represents back-arc extension of Late Paleozoic collisional Ogradena granitoids or incipient intracontinental rupturing during the Early Mesozoic (Vlad et al, 1984).

The basement nappes of the South and East Carpathians contain small Pb-Zn-Ba ore deposits. The Făgăraș Group (South Carpathians) is cut by Jurassic bimodal (alkali-rhyolite and lamprophyre) dikes and Pb-Zn ore veins controlled by regional ENE-WSW lineation. Common sulphides occur in carbonate, quartz

or barite gangue (Barsa and Șinca- Holbav metallogenetic districts). Aborted rifts found in the Bucovinian Nappe (East Carpathians) contain Ba-Pb-Zn, Fe and Mo occurrences related to Mesozoic sedimentary and igneous rocks, as explained below (Ianovici and Borcoș, 1982).

Triassic dolomitic limestones at Delnita contain stratabound Fe ores associated with minor barite and Pb-Zn ores. The lens-like bodies are mainly sideritic-ankeritic in the east and hematitic in the west.

Along the Ostra-Gemenea-Slătioara alignment barite and witherite accumulations are associated with base-metal ores. At Ostra north-south striking veins cut the metamorphic basement and the Mesozoic sedimentary cover. At least two barite generations as well as witherite, pyrite, sphalerite, galena, tetrahedrite have been recognized; at depth the penetrated gneisses are impregnated with barite. It seems likely that early barite occurrences were remobilised during post-Jurassic rifting, before major Middle Cretaceous deformation. The mineralization is found discontinuously as far south as Gemenea and Slătioara where base-metal and barite veins cut the crystalline schists (Metallogenetic Unit 1B in Plate).

The Jurassic-Lower Cretaceous (196-121 m.y.) ring-like alkaline intrusion that occurs at Ditrău exhibits a conspicuous zonal structure; inner foidites are surrounded by syenite and monzonite. Hornblende, diorite, granite and alkali-granite occurrences are peripheral. Numerous lamprophyre, microsyenite, alkali-granite and aplite dikes cut the massif. Albitite segregations and carbonatite veins occur locally. Porphyry Mo-like mineralization occurs along east-west alignments, especially in the north at Jolotca (Vlad and Borcoș, 1994). The ores are hosted by diorite and hornblende and contain subordinate ilmeno-rutile, ilmenite, monazite, tapiolite, columbite and common sulfide; veins that cut the syenite contain xenotime, common sulphides and niobo-tantalates (Constantinescu et al., 1981) (Metallogenetic Unit 1C in Plate).

Metallogenesis related to ocean floor spreading

The Severin Nappe of the South Carpathians contains ophiolites and related pyritic Cu ores. During Mesozoic times an elongated basin with oceanic crust formed between the Getic and the Danubian realms (first named "Eastern basin" by Rădulescu and Săndulescu, 1973); it corresponds to the above mentioned rift of the East and South Carpathians. The resulting basaltic flows and pyroclastic rocks associated with Lower Cretaceous flysch sediments of the Severin Nappe were obducted eastward during Laramian compression when the Getic and the Danubian realms collided. Cioflica et al (1981) provided geological and

geochemical evidence that the ophiolite association formed as tholeiitic ocean-floor basalts in a small ocean basin; the related ore deposits were ascribed to the Joma type *sensu* Pearce and Gale (1977). They occur in basalts as small stratiform pods of massive chalcopyrite, with subordinate pyrite and sphalerite in quartz gangue. The massive ore is commonly underlain by pyrite + chalcopyrite + sphalerite stockworks (Metallogenetic Unit 2 in Plate).

Metallogenesis in subduction-related settings

Three successive Alpine subduction events in the Romanian Carpathians formed the vast majority of metallic ore deposits in Romania.

Jurassic-Lower Cretaceous, Upper Cretaceous-Paleocene and Late Tertiary events in turn yielded ore deposits of island arc or Andean types (Plate, Fig.1).

The Jurassic-Lower Cretaceous event yielded three stages of magmatism in the South Apuseni Mts. These are a tholeiite series and subsequent calc-alkaline series, both of island arc type, and a final spilitic complex associated with an active marginal basin (Nicolae et al., 1992).

The metallogenesis related to the tholeiitic series consists of Fe-Ti-V and Ni late-magmatic segregations in gabbroic intrusions and pyritic Cu veins and stockworks in basaltic lavas (Cioflica and Vlad, 1984). The Fe-Ti-V segregations are found as titanomagnetite-ilmenite nests, lenses and grains within layered gabbroic bodies at Căzănești-Ciungani. The Ni ores are confined to the Ciungani gabbroic body wherein pyrrhotite and pentlandite with associated chalcopyrite and magnetite occur as a small pod. The pyritic Cu volcanogenic ores are considered of Gjersvik type *sensu* Pearce and Gale (1977). Various veins and stockworks are controlled by brecciated basalts at Căzănești-Ciungani, Almășel, and Roșia Noua. The mineralization at Patars is located in the upper part of a basaltic unit and contains an inner zone with pyrite+chalcopyrite veinlets and a massive pod, surrounded by a disseminated pyrite aureole.

The calc-alkaline series contain base-metal ores at Vorța. The dacitic-andesitic rocks and related pyroclastics underwent silicification and argillization along an E-W lineation. The altered volcanics contain E-W striking lenses and impregnations of pyrite, sphalerite, galena and chalcopyrite (Cioflica et al 1984). Vlad (1983, 1984) postulated that such an island arc suite of rocks may incorporate Kuroko-porphyry copper systems.

Minor volcano-sedimentary Mn ores associated with jaspers occur in Lower Cretaceous sediments at Șoimuș-Buceava, Pârnești and Godinesti.

This island arc-related metallogenesis is represented in Plate, Metallogenetic Unit 3.

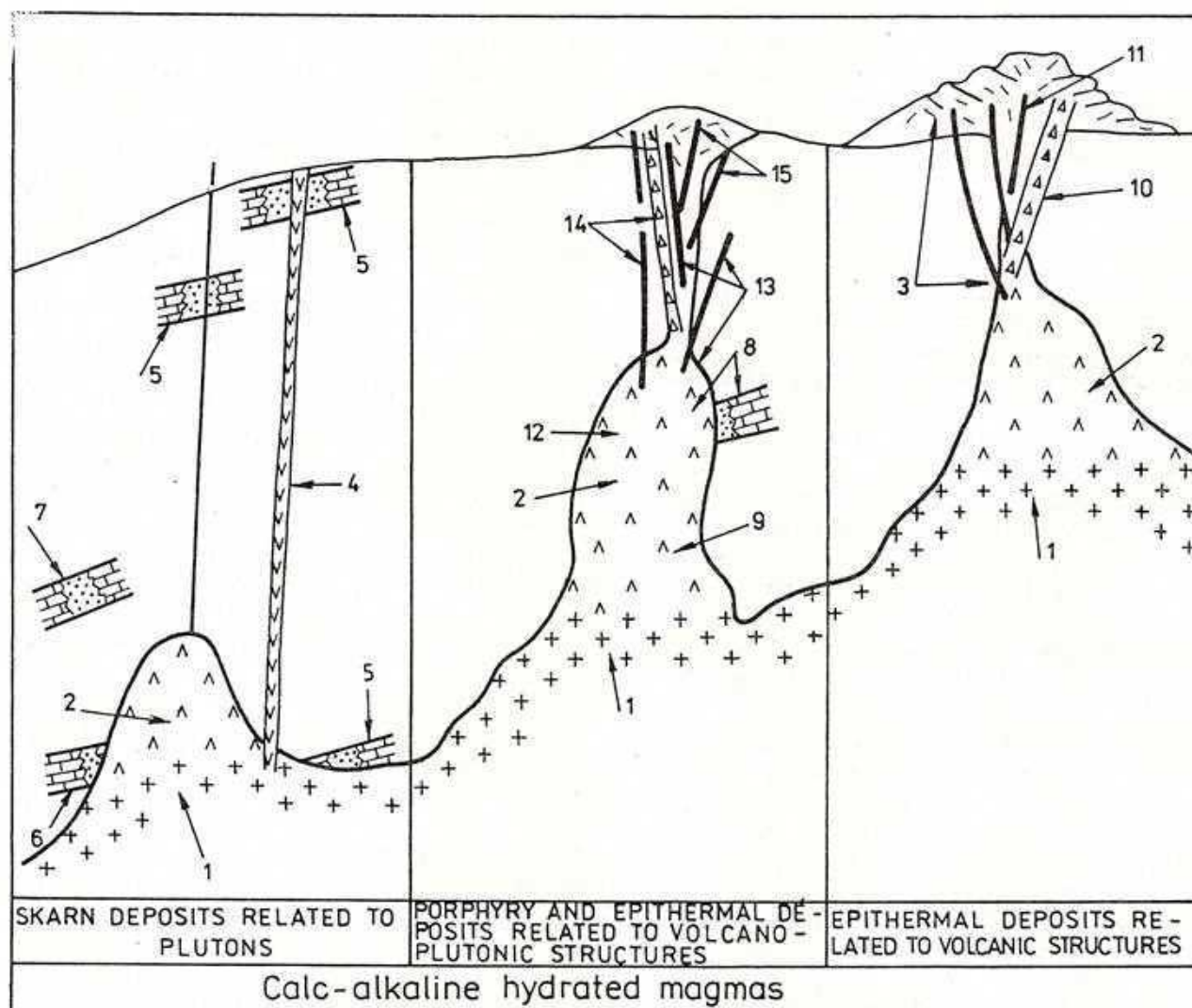


Fig. 1 – Metallogenesis in Upper Cretaceous-Paleocene and Late Tertiary subduction - related settings:

- 1, Pluton;
- 2, Apophyses of pluton;
- 3, Volcanic structure;
- 4, Dike;
- 5, Skarn deposits, model M I Băița Bihorului;
- 6, Proximal skarn deposits, model M II Ocna de Fier;
- 7, Distal skarn deposits, model M III Dognecea;
- 8, Skarn-porphyry deposits, model M IV Suvorov;
- 9, Porphyry deposits, model M V Bozovici;
- 10, Epithermal breccia deposits, model M VI Baia Sprie;
- 11, Epithermal vein deposits, model M VII Cavnic;
- 12, Porphyry deposits, model M VIII Roșia Poieni;
- 13, Porphyry-epithermal deposits, model M IX Valea Morii;
- 14, Epithermal breccia and vein deposits, model M X Roșia Montană;
- 15, Epithermal vein deposits, model M XI Săcărâmb.

Widespread westward subduction during the Upper Cretaceous-Paleocene gave rise to polyphase calc-alkaline magmatism (Laramian magmatism, also known as Banatitic). This magmatic belt is 280 km long in Romania, and runs from the Apuseni Mts. in the north to the South Carpathians. It extends further south into Eastern Serbia (Yugoslavia) and still further to Srednagora (Bulgaria) (Cioflica and Vlad, 1980). The major intrusive event commonly with a monzodiorite or diorite - granodiorite evolutionary trend or a granodiorite - granite evolutionary trend, or both is metallogenetically the most important. The magmatism of the monzodiorite or diorite - granodiorite type was generally related to copper mineralization in porphyry environment. The magmatism of granodiorite - granite type generally yielded base-metal ores in non-porphyry environment: skarn deposits predominate, whereas vein deposits are rare.

In Romania, the Laramian or Banatitic belt is comprised between the North Apuseni, South Apuseni and South Carpathian subbelts. These subdivisions result from different subduction-related settings; they are at present distributed along a major N-S lineation. The North Apuseni subbelt is characterized by granodiorite-granite magmatism and widespread base-metal metallogenesis (Metallogenetic Unit 4a in Plate). Two metallogenetic zones have been recognized (Cioflica and Vlad, 1984):

- 1) the inner zone corresponding to a northwestward direction of subduction exhibits a complex metallogenesis in the Bihor-Gilău Mts. It contains Fe, Mo, Bi, W, Cu, U, Co, Ni, Pb, Zn, B, Au and Ag ores in skarns, stratiform-impregnation bodies, and veins in the Băișoara, Băița Bihorului and Luncoșoara-Brusturi-Poiana districts. Băița Bihorului is the most important deposit. The ore zoning around the pluton is Mo - Bi - W - Cu - U - Pb - Zn / Mo - Bi - W - Cu - U - Pb - Zn - B and is expressed in a vertical column extending up to 1.5 km away from the granite pluton. Calcic and magnesian skarns contain molybdenite, bismuthinite, Bi sulfosalts and tellurides, scheelite (three generations), Cu minerals, galena, sphalerite, szabibelyite, ludwigite, fluorite and kotoite. Metasomatized detrital hornfels (epidote + chlorite + actinolite, albite + quartz and sericite + quartz associations) contain U and Cu in stratabound lenses and molybdenite in impregnations and veinlets, whereas Paleozoic detrital rocks and crystalline schists situated far from the pluton enclose bands and veins of common sulfides ores. The same granitic intrusion yielded "pentametalliferous" (U, Ag, Ni, Co, Bi) ores in veins and Cu-U ores as stratiform impregnations at Avram Iancu and replacement base-metal ores at Brusturi and Luncoșoara;

- 2) the outer zone (for the same subduction sense) is noted for base metals and is located in the Vlădeasa

Massif. Hydrothermal Pb-Zn ores occur in the Scind-Rachitea and Bucea-Cornil districts.

The South Apuseni subbelt is represented by monzodiorite or diorite - granodiorite magmatism with calcic Fe-skarn deposits (Vața) and granodiorite - granite magmatism Mo-Cu-pyrite vein deposits (Săvârșin, Cerbia). Recent absolute age data suggest that this magmatism may be of Cretaceous age (Ștefan, 1980). The plutonism would represent the completion of the above-mentioned island-arc subduction event.

The South Carpathian (Banat-Poiana Rusca Mts.) subbelt consists of two zones that are parallel to a suture-like contact between two crustal blocks that collided during the Laramian deformation (Vlad, 1979). The suture is the remnant of the above mentioned rift of the East and South Carpathians (Metallogenetic Unit 4b in Plate):

- 1) the inner zone (for a westward direction of subduction) in the South Banat Mts. exhibits a monzodiorite or diorite - granodiorite magmatism and related Cu-Mo porphyries that occur at Moldova Noua (e.g. Suvorov orebody) and Sasca;

- 2) the outer zone in the North Banat-Poiana Rusca Mts. exposes granodiorite - granite magmatism with Fe, Cu, Pb-Zn skarn deposits (Dognecea and Ocna de Fier) and Mo-W-Cu skarn deposits (Oravița).

Regional occurrences, tectonic characteristics, alteration and zoning, ore mineralogy and other related elements form the outline of the metallogenetic models in porphyry and non-porphyry environments (Plate, Fig. 1).

Metallogenetic models in porphyry environment. The South Carpathian subbelt contains porphyry deposits and prospects that have in common the occurrence of porphyritic tongue-like apophyses of deeply buried plutons of monzodiorite or diorite to granodiorite composition. Such apical setting represents centres of zoned hydrothermally developed sulphide mineralization and rock alteration controlled by intensively fractured host rocks. Two models are outlined, that is the Suvorov model with skarn halo and the Bozovici model (Vlad and Borcoș, 1996). Their relevant characteristics are presented in Table 1 and Figure 2.

Metallogenetic models in non-porphyry environment. The Apuseni Mts. and South Carpathian subbelts contain skarn deposits and prospects related to granodiorite - granite plutons. When wall-rocks are mainly calcareous, Fe-Cu skarn deposits occur near the contact and Pb-Zn skarn deposits occur far from the contact. When wall-rocks are various sedimentary rocks and coeval or older igneous rocks, magnesian and calcic skarns with Mo, W, Bi, Cu, Pb, Zn and B mineralization are found near and away from the pluton.

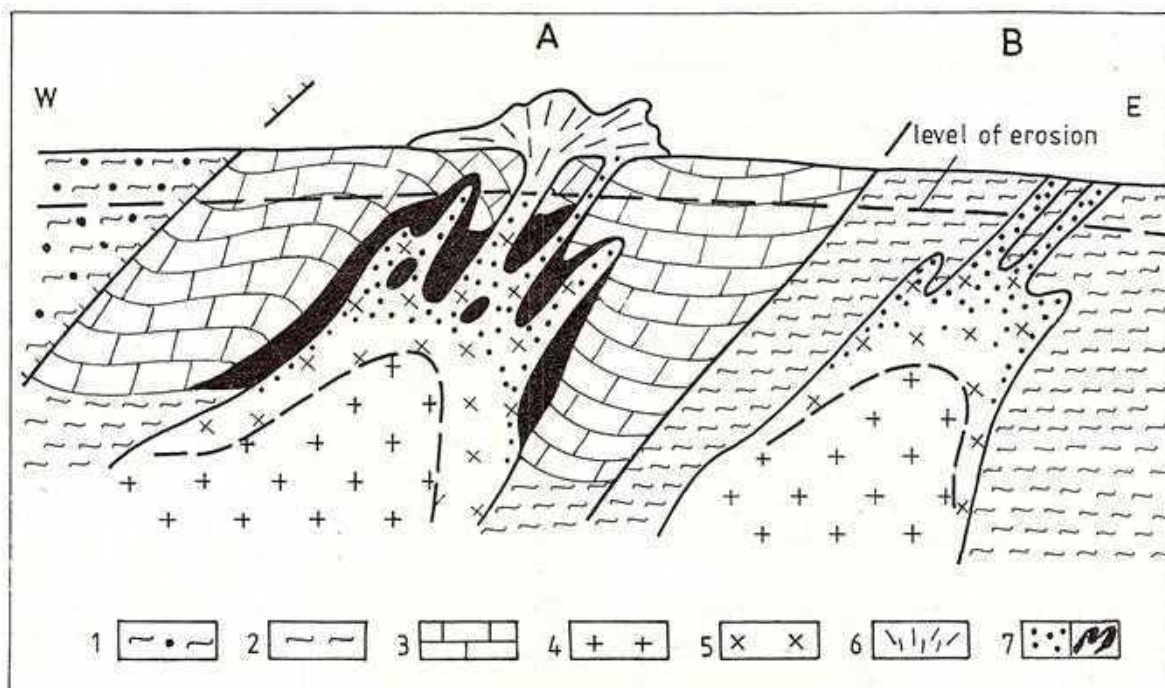


Fig. 2 - Banatitic porphyry copper models (according to Vlad and Borcoș, 1995): A. Model Suvorov; B. Model Bozovici. 1, Supragetic crystalline schists; 2, Getic crystalline schists; 3, Carbonate rocks; 4, Monzodiorite and diorite to granodiorite plutons; 5, Subvolcanic and hypabissal apophyses of dioritic to granodioritic composition; 6, Volcanic edifices of andesitic composition; 7, Mineralization: a) porphyry Cu; b) skarn Cu.

Three models are defined, that is the Ocna de Fier model and the Dognecea model of commonly calcareous host rock with proximal and distal skarn formation, respectively, and the Băița Bihorului model with extended skarn formation through the whole contact aureole of the pluton. These contrasts are the result of processes that proceed to different extent in response to similar felsic magmatism and wall-rocks of various origin. Table 2 and Figure 3 show their main characteristics.

These ore deposits have been mined since pre-Roman times and were described in the last century by such well-known geologists (from the Freiberg school) as von Cotta and Posepny. Accordingly, the deposits Dognecea, Ocna de Fier, Băița Bihorului became famous all over the world. They have a rich and complex paragenesis, with up to 200 ore and gangue minerals. Several minerals were described from these deposits for the first time: ludwigite, szaibelyite, rezbanyite, csiclovaitite, veszelyite, and dognacskaitite, cf. Udubasa et al. (1992).

Late Tertiary subduction gave rise especially to volcanic rocks, mainly andesitic, from Lower Miocene to Pliocene times.

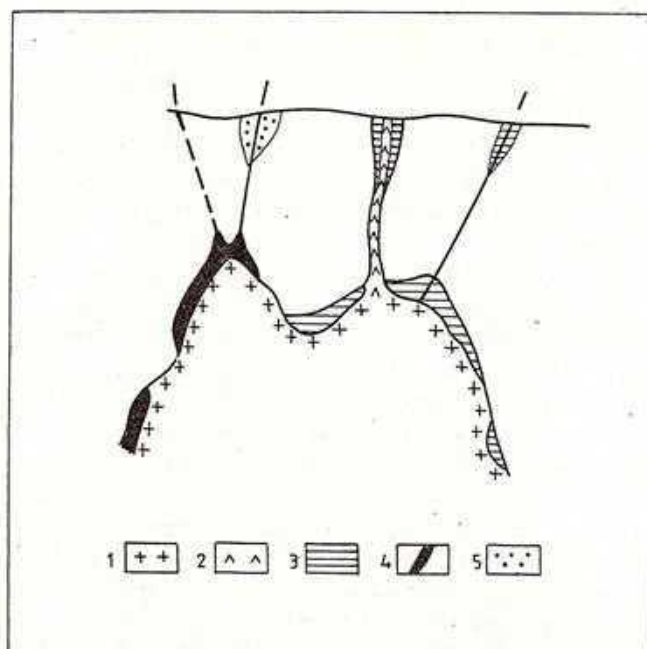


Fig. 3 - Banatitic skarn models (adapted from Vlad, 1990): 1, Granitoid pluton; 2, Dike; 3, Model Băița Bihorului; 4, Model Ocna de Fier; 5, Model Dognecea.

The petrogenetic and metallogenetic characteristics of these Tertiary volcanic rocks have been described by numerous authors, beginning in the last century. Comprehensive reference works of more recent decades include those by Ghițulescu and Socolescu (1941), Giuscă et al. (1968, 1973), Rădulescu et al (1981), Ianovici and Borcoș (1982), Borcoș, (1994a,b).

The 300 km long East Carpathian volcanic arc occurs in the Oaș, Gutâi, Țibleș, Bărgău, Rodna, Căliman, Gurghiu and Harghita Mts. and formed as a result of westward subduction related to the closure of the East Carpathian rift. For a long time the metallogenesis was considered to consist of three stages all related to Miocene volcanics. Recent investigations assign the ore formation during the Sarmatian, Pannonian and Pontian to shallow intrusions (Borcoș, 1994a). The epithermal deposits in non-porphyry environment contain base-metal and Au-Ag mineralization. The Oaș Mts. metallogenetic zone contains base-metal veins between Tarna and Bicsad. The metalliferous systems in the very well-known Baia Mare metallogenetic zone are related to a large crustal fault system trending E-W, i.e. Dragoș Vodă fault in association with a major quartz diorite pluton (Borcoș, 1994a). This regional fracture controls the spatial disposition of ore districts, i.e. Ilba-Nistru, Săsar-Valea Roșie, Dealu Crucii-Băiuț (Metallogenetic Unit 5a in Plate).

The local variety of epithermal deposits is base metal

- precious metal quartz - adularia deposits. This is somehow similar with the descriptive model of Creede epithermal veins (Monsier et al., 1986).

A high temperature column of about 5 km occurs in the plutonic-volcanic center. The heat generated by the pluton and the important supply of fluids controlled by the regional fault drove the ore deposit-forming geothermal systems. Variations in metal concentration with depth are found in important deposits such as Ilba, Nistru, Herja, Baia Sprie and Căvnic. They show a conspicuous vertical zoning Au-Ag - Pb-Zn-Cu. Porphyry deposits have not yet been found in this setting. Two models are defined, that is the Baia Sprie breccia (phreatomagmatic explosion type) - vein breccia (phreatomagmatic explosion type)-vein deposit and Căvnic vein deposit. Table 3 and Figure 4 show their main characteristics.

The metallogenetic zone belonging to the sub-volcanic bodies of the Țibleș-Bărgău-Rodna Mts. contains especially base-metal veins in the Țibleș, Toroiața and Bărgău-Rodna districts (Metallogenetic Unit 5 b in Plate). The Căliman, Gurghiu and Harghita Mts. contain only a minor mineralization in siderite (Vlăhița), Hg (Sântimbru), base-metal (Dorņișoara-Colibița) and a large S deposit (Căliman). This portion of the East Carpathian volcanic arc exhibits aborted porphyry systems (Metallogenetic Unit 5c in Plate).

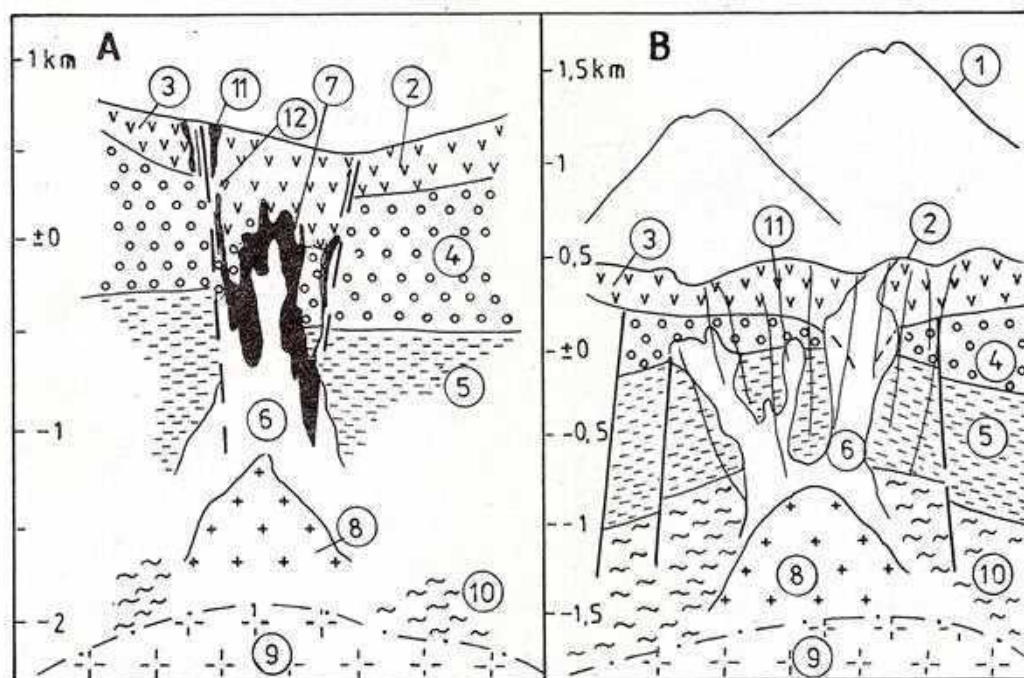


Fig. 4 - Tertiary epithermal models in the East Carpathians: A. Model Baia Sprie; B. Model Căvnic: 1, Syn-ore palaeosurface; 2, Level of erosion; 3, Volcanic products; 4, Siliciclastic rocks of the Tertiary molasse; 5, Hornfels in Paleogene sedimentary host rocks; 6, Subvolcanic body; 7, Phreatomagmatic explosion breccia; 8, Culmination of pluton; 9, Pluton; 10, Crystalline schists; 11, Vein; 12, Stockwork mineralization.

The South Apuseni Mts. volcanic suite cannot be explained satisfactorily by subduction, because the ocean basin to which they might be related closed at the end of the Cretaceous. Back-arc rifting involved reactivation of earlier Alpine island arc structures with ophiolites and banatites and yielded an intermediate volcanic-plutonic suite and associated porphyry and vein deposits (Vlad, 1980).

The metallogenesis consists of two stages related to Badenian and Sarmatian igneous events. Recent investigations suggest that shallow intrusions were responsible of ore formation in relation to a 2-4 km deep-seated pluton (Borcoș, 1994b). The magmatism took place in Tertiary intramontane basins superposed on NW-SE and E-W regional fractures. The Badenian igneous event yielded epithermal deposits of breccia pipe and vein type. The Sarmatian igneous events yielded porphyry copper systems centered on shallow subvolcanic bodies of andesite to quartz diorite composition. The subvolcanic bodies are located on protuberances of deeper-seated diorite plutons and represent the transition to volcanic edifices formed in uppermost portion of large volcano-plutonic complexes. Furthermore, part of these porphyry systems exhibits outwards radiating veins. In places epithermal systems that consist only of sets of veins are associated with the Sarmatian

volcanic-subvolcanic suite.

The spatial distribution of ore deposits in the South Apuseni Mts. is listed below Metallogenetic Unit 5d in Plate.

The Brad-Săcărâmb district contains Pb-Zn and Au-Ag-Te veins and stockworks at Săcărâmb and Hîndol with peripheral distal metasomatic disseminated mineralization at Coranda as well as porphyry Cu-Au deposits at Bolcană, Voia, Musariu, Valea Morii, Rovina and major Au-Ag veins at Barza. In extension the Zarand basin contains Cu-Au porphyry and veins at Talagiu. The Almaș-Stănița district is similar, with Au-Ag-Te-Pb-Zn veins at Stănița, Breaza, Baba and Almaș and Cu-Au porphyry at Muncaceasca Haneș-Larga. The Bucium-Roșia district contains Au-Ag veins at Botes, Valcoi, Corabia and breccia (phreatomagmatic explosion type) pipes at Roșia Montană, Cu-Au porphyry at Tarnița and Cu-Mo porphyry at Roșia Poieni. The Deva district has the Deva Cu-Mo porphyry. The Baia de Arieș district contains Au-Ag in veins and breccia (collapse type) and Pb-Zn in replacement ores in marbles.

In terms of tectono-magmatic features, porphyry-epithermal relation, composition and intensity of mineralization and alteration the following models are presented below:

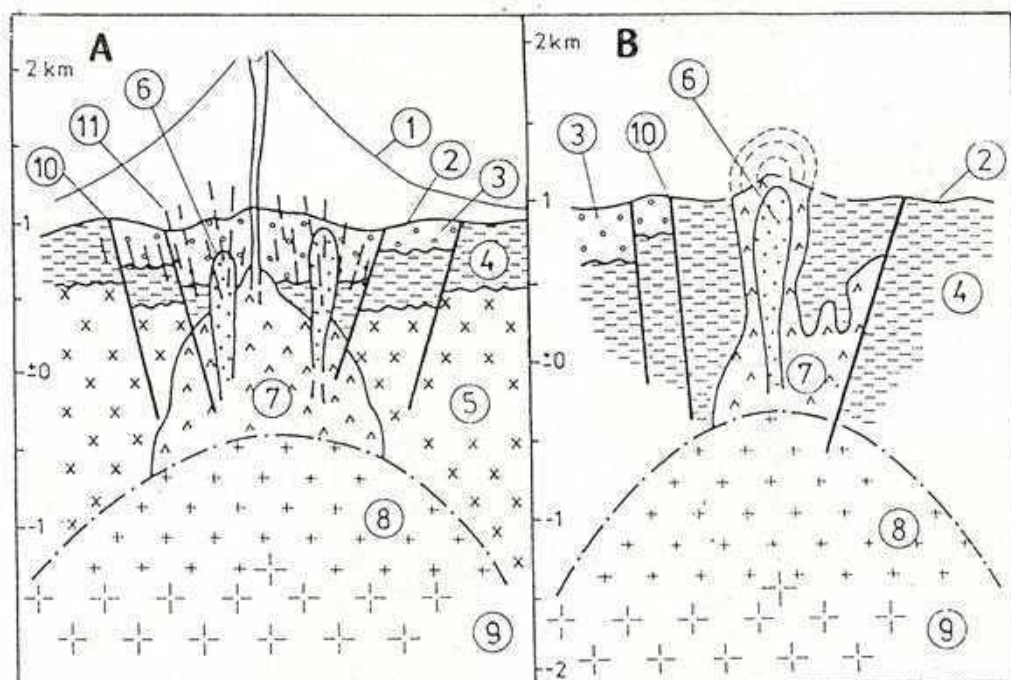


Fig. 5 - Tertiary porphyry models in the South Apuseni Mts (according to Vlad and Borcoș, 1996): A. Model Valea Morii; B. Model Roșia Poieni: 1, Syn-ore palaeosurface; 2, Level of erosion; 3, Siliciclastic rocks of the Tertiary molasse; 4, Mesozoic sedimentary rocks; 5, Ophiolites; 6, Porphyry copper intrusion; 7, Composite subvolcanic structure; 8, Culmination of pluton; 9, Pluton; 10, Fracture; 11, Au-Ag and Au-Ag-Pb-Zn sets of veins.

– two models of porphyry copper systems, that is Valea Morii porphyry-epithermal model and Roşia Poieni porphyry with pyrite halo model. Table 4 and Figure 5 show their main characteristics;

– the non-porphyry environment is also represented by two models, i.e. Roşia Montană composite system of breccia pipe and veins and Săcărâmb vein set. Their relevant information is presented in Table 5 and Figure 6.

The Baia Mare and South Apuseni Mts. regions have been mined for their valuable metallic deposits since pre-Roman times. Numerous rare minerals such as tellurides and sulfosalts occur in these areas. Various species e.y. nagyagite, semseyite, tellurium, tellurite felsobanyites, fizelyite, krennerite, petzite, sylvanite and monsmelite were described from these regions for the first time, cf. Udubaşa et al (1992).

the major Alpine deformation (Dobsina type of the West Carpathians). The Barsa and Sinca-Holbav districts contain small but numerous boudined and laminated vein-like occurrences along ENE-WSW fractures (e.g., at Nimaia). Sphalerite and galena with subordinate chalcopyrite, pyrite and gold are highly deformed. The mineralization seems to represent remobilization of preexisting ores that occurred during the Alpine compression owing to regional temperature increase. The central portion of the South Carpathians contains gold and common sulphides in aligned quartz lenses; these presumably formed during remobilization connected with similar deformations according to a shear zone genetic model. The type locality is Valea lui Stan (Sebes-Lotru Group of the Getic Nappe) (Udubaşa and Hann, 1980). The metallogenic model of the shear zone related mineralization in the South Carpathians:

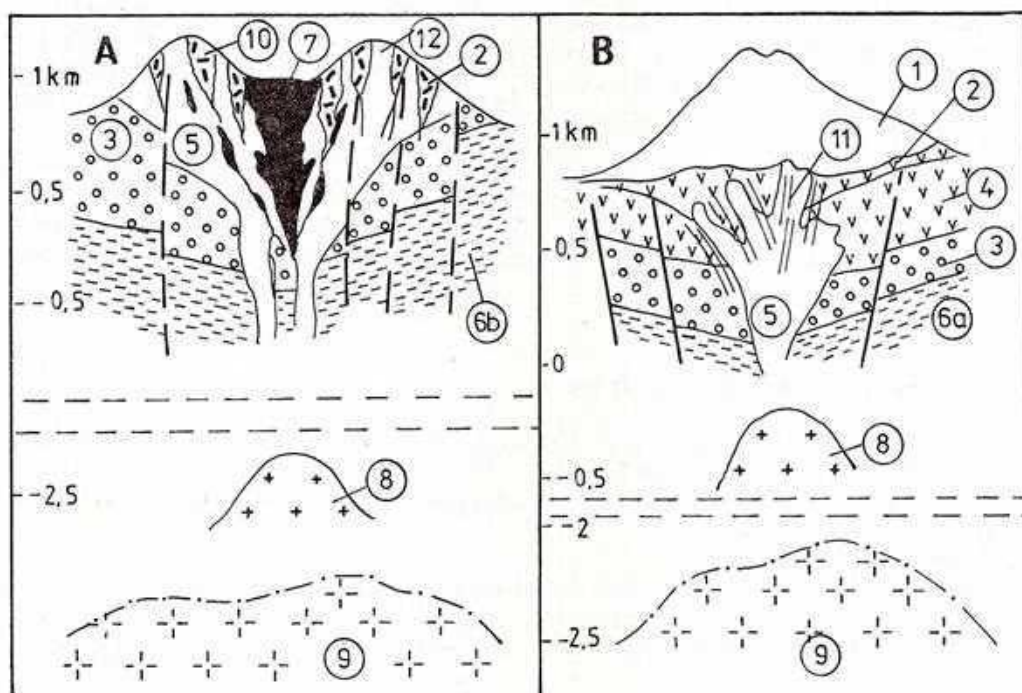


Fig. 6 – Tertiary epithermal models in the South Apuseni Mts: A. Model Roşia Montană; B. Model Săcărâmb: 1, Syn-ore palaeosurface; 2, Level of erosion; 3, Siliciclastic rocks of the Tertiary molasse; 4, Volcanic products; 5, Subvolcanic body; 6, Underlying rocks (a. mesozoic ophiolitic and associated sedimentary rocks; b. crystalline schists and Mesozoic sedimentary rocks); 7, Phreatomagmatic explosion breccia; 8, Culmination of pluton; 9, Plutons; 10, Breccia pipe; 11, Vein. 12, Stockwork mineralization.

Metallogenesis in continental collision-related settings

Getic and Supragetic Nappes of the Leaota and Făgăraş Mts. (eastern part of the South Carpathians) expose minor vein sets with base-metal and "pentametallic" ores (Bi minerals, Co-Ni sulphides and arsenides, pitchblende, chalcopyrite, galena, sphalerite, pyrite, pyrrhotite, silver and gold). According to Vlad and Dinica (1984) the ore deposition might take place during metal remobilization from metabasites during

was defined by Popescu and Lupulescu (1996). This metallogenesis is represented in Plate as Metallogenic Unit 6.

Metallogenesis in post-collisional-related settings

In Jitia (southern part of the East Carpathians), the Burdigalian sandstones of the Miocene molasse contain stratabound sedimentary base-metal ores of restricted extent. Sphalerite and galena with subordinate pyrite

and chalcopryrite occur as nests, veinlets and impregnations in siliciclastics that underwent slight diagenetic silicification (Cioflica and Vlad, 1984) (Metallogenetic Unit 7 in Plate).

Latest Tertiary-Quaternary rifting yielded basalts in the Carpathians, but these rocks lack metallogenetic importance.

IV. Conclusions

This interpretation of ore formation and distribution in the Romanian Carpathians, using the concept of Wilson orogenic cycles, suggests the following:

- The Alpine orogenic cycle is represented by an overall sequence of intracontinental rifting, ocean-floor spreading, subduction, collision and post-collision rifting in the Carpathians during Mesozoic-Tertiary times.

- The metallogenetic events related to the Alpine Wilson cycle represent approximately two-thirds of the total resource estimates of Romania. This present-day situation is due to three factors:

- 1) the smaller amount of erosion that has affected the Alpine vs. the pre-Alpine structures;

- 2) significant metal remobilisation from preexisting sources during Alpine times;

- 3) the major role of Alpine tectono-magmatic events themselves in carying and concentrating metals from allochthonous sources.

- The main ore forming events were associated with Laramian (Banatitic) and Tertiary magmatism and resulted in deposition of ores mainly of Cu, base-metals, and Au-Ag. During subduction, Cu was carried upwards from deep-seated sources during the emplacement of Banatitic and Tertiary igneous rocks, whereas Mo and Pb-Zn may have been derived from crustal environments. These different processes locally led to regional zoning of Cu vs. Pb-Zn (e.g., in the Banat-Poiana Ruscă Banatitic subbelt).

- Superposition of Au-Ag, Pb-Zn and Cu ores during a single metallogenetic event with tendencies towards vertical zoning is common (e.g., in Tertiary metallogenetic units).

- Cu-Au and Cu-Mo spatial segregation in the Tertiary porphyry copper deposits seems to be explained by Au remobilization from Early Mesozoic island arc tholeiites and Mo remobilization from the crystalline basement.

- Superposition of three magmatic-metallogenetic events in the restricted domain of the South Apuseni Mts. (Alpine ophiolites, Banatites and Tertiary volcanics) is interpreted in terms of the inheritance-reactivation concept.

TABLE 1. BANATITIC PORPHYRY COPPERS

MODEL SUVOROV-GRANODIORITE TYPE, Cu-Mo MONOASCENDENT

EVOLUTION, SKARN HALO (M IV in Plate and Fig. 2)

DESCRIPTION. Chalcopryrite + pyrite in stockwork in hydrothermally altered hypabyssal-subvolcanic intrusives and in related skarn with retrograde alteration.

GEOLOGICAL ENVIRONMENT

Rock types. Monzodiorite and diorite to granodiorite plutons with hypabyssal-subvolcanic apophyses intruding carbonate rocks or calcareous siliciclastic sequences of Mesozoic age. The sedimentary rocks belong to the Getic Nappe and the igneous rocks to the Banatitic belt developed in the Apuseni Mts., Banat-Poiana Ruscă Mts., Eastern Serbia and Srednagora.

Age 72-67 m.y.

Structural type. The porphyry copper system is centered on subvolcanic apophyses of deep-seated plutons.

Depositional environment. Deep-seated intrusion of N-S striking and westward dipping tongue-like pluton in mainly carbonate milieu. Intense fracturing: first order strikes N-S and second order strikes E-W (orthogonal system). Permeable volcano-plutonic complex with volcanic part eroded and subvolcanic hypabyssal apophyses exposed.

Major tectonic setting. Andean-type magmatic arc.

Large scale zonality/associated deposit types. Cu-Mo stockwork in hydrothermally altered igneous host - skarn Cu ± Mo, W - replacement Pb-Zn - telethermal As-Sb - presumable Carlin gold.

DEPOSIT DESCRIPTION

Mineralogy. Magnetite ± chalcopryrite, pyrite impregnations in potassic zone, pyrite + chalcopryrite ± sphalerite, molybdenite, tetrahydrite veinlets and pyrite + chalcopryrite impregnations in phyllic zone (restricted areas of intensive silicification contain molybdenite ± pyrite, chalcopryrite veinlets and impregnations). Magnetite that replaced andraditic garnet and pyrite + chalcopryrite veinlets and impregnations in skarn with extensive fracturing and propylitization.

Alteration. Pervasive potassic alteration (biotite + K feldspar + anhydrite) in the lower part of the subvolcanic apophyses is associated with andraditic garnet in carbonate rocks. Phyllic alteration (sericite + quartz + chlorite) in the upper part of the subvolcanic apophyses is associated with argillic (montmorillonite ± kaolinite) and propylitic (epidote + chlorite + calcite) alteration in skarn. The alteration pattern is concentric of Lowell and Guilbert type.

Ore controls. Intense stockwork veining in igneous and skarn rocks contains most of the copper.

Weathering. Argillization and limonitization.

Geochemical signature. Cu, Mo, Pb, Zn, As (Sb, Au, W)

Deposits/Prospects. Moldova Nouă, (Varad, Garana, Valea Mare, Suvorov, Corcana-Baies, Greci-Apele Albe)
Sasca,
Șopot (Lilieci, Purcariu, Nasovăț).

MODEL BOZOVICI-GRANODIORITE TYPE, Cu-Mo MONOASCENDENT

EVOLUTION, PYRITE HALO (M.V. in Plate and Fig. 1)

DESCRIPTION. Stockwork veinlets of quartz, chalcopryrite, pyrite and molybdenite in porphyritic minor intrusion.

GEOLOGICAL ENVIRONMENT

Rock types. Minor quartz diorite to quartz monzodiorite apophyses of deep-seated plutons intruding crystalline schists of Pre-Mesozoic age. The metamorphic rocks belong to the Getic Nappe and the igneous rocks to the Banatitic belt developed in the Apuseni Mts., Banat - Poiana Ruscă Mts., Eastern Serbia and Srednagora

Age. "Laramian"

Structural type. High-level porphyry subvolcanic-hypabyssal apophyses and dikes. The porphyry copper system not well expressed.

Depositional environment. Deep-seated intrusion of N-S striking plutons in crystalline schists and shallow (subvolcanic-hypabyssal) apophyses.

Major tectonic setting. Andean-type magmatic arc.

Large scale zonality/ associated deposit types. Not expressed.

DEPOSIT DESCRIPTION

Mineralogy. Quartz veinlets with chalcopryrite, pyrite, magnetite and molybdenite in the upper part of the potassic zone and sporadic molybdenite, chalcopryrite and magnetite impregnation in the lower part of the potassic zone (Bozovici). Pyrite $\pm$ chalcopryrite, magnetite impregnations in phyllic and argillic zone (Teregova-Lăpușnicel). Disseminated pyrite halo.

Alteration. Pervasive potassic alteration (biotitization) at Bozovici, restricted potassic, phyllic and argillic alterations at Teregova-Lăpușnicel. The alteration pattern is not well expressed.

Ore controls. Veinlets and mineralized fissures in the upper part. The stockwork pattern is replaced at depth by impregnations (Bozovici).

Weathering. Not well expressed.

Geochemical signature. Cu, Mo, Pb, Zn.

Deposits/Prospects. Bozovici,
Teregova-Lăpușnicel.

TABLE 2. BANATITIC SKARN DEPOSITS

MODEL OCNA DE FIER: Fe-Cu SKARN DEPOSITS (MII in Plate and Fig. 1)

DESCRIPTION. Magnetite + hematite, chalcopryrite + pyrite in calcic dark skarns and in magnesian skarns.

GEOLOGICAL ENVIRONMENT

Rock types. Granodiorite pluton intruding carbonate rocks. The carbonate rocks belong to the Supragetic nappe and to the Transylvanide and Apusenide Groups of Nappes. The plutons belong to the Banatitic belt developed in the Apuseni Mts., Banat-Poiana Ruscă Mts., Eastern Serbia and Srednagora.

Age. "Laramian"

Structural type. The skarn association occurs near the igneous contact by diffusion/infiltration metasomatism (proximal skarns).

Depositional environment. Crystalline schists and sedimentary carbonate rocks intruded by felsic plutons.

Major tectonic setting. Andean-type or island arc subduction-related magmatism.

Large scale zonality/associated deposit types. Contact aureole around the pluton: Fe-Cu skarn - Pb/Zn skarn - polymetallic replacement or pyrite veins.

DEPOSIT DESCRIPTION

Mineralogy. Magnetite + hematite $\pm$ ludwigite, pyrite, chalcopryrite, sphalerite, galena. Bi minerals may be present.

Alteration. Dolomitic environment: grossularite + vesuvianite inner zone; diopside + phlogopite center; forsterite $\pm$ phlogopite, clinohumite outer zone; calciphyre peripheral zone. Retrograde alteration to tremolite, epidote, serpentine, talc. In places high temperature fassaite, spinel. Calcareous environment: andradite in zone; pyroxene restricted outer zone; marble peripheral zone. Epidote, chlorite, tremolite-actinolite as post-skarn minerals. In places high temperature spurrite and melilite (Măgurea Văței).

Igneous rocks may be altered to diopside + grossularite (endoskarn).

Ore controls. Irregular or tabular iron oxides bodies in andradite skarn or fractures zones in marble. Magnetite + ludwigite in magnesian skarns. Associated igneous rocks are barren.

Weathering. Fe-rich gossan.

Geochemical signature. Fe, Cu, Pb, Zn, Co, Bi. Strong magnetic anomalies.

Deposits: Ocna de Fier, Băișoara, Măgurea Văței, Tincova.

MODEL DOGNECEA: Pb-Zn SKARN DEPOSITS (MIII in Plate and Fig. 1)

DESCRIPTION. Sphalerite + galena in dark calcic skarns.

GEOLOGICAL ENVIRONMENT

Rock types. Granodiorite pluton intruding carbonate rocks. The carbonate rocks belong to the Supraetic Nappe and to the Transylvanide and North Apusenide Groups of Nappes. The plutons belong to the Banatitic belt developed in the Apuseni Mts., Banat-Poiana Ruscă Mts., Eastern Serbia and Srednagora.

Age: "Laramian".

Structural type. The skarn system occurs hundreds of meters from intrusive by infiltration metasomatism (distal skarns).

Depositional environment. Crystalline schists and sedimentary carbonate rocks intruded by felsic plutons.

Major tectonic setting. Andean-type or island arc subduction-related magmatism.

Large scale zonality/associated deposit types. Contact aureole around the pluton: Fe-Cu skarn - Pb/Zn skarn - polymetallic replacement or pyrite veins.

DEPOSIT DESCRIPTION

Mineralogy. Sphalerite + galena + pyrite ± magnetite, chalcopryrite, arsenopyrite, pyrrhotite.

Alteration. Andradite restricted inner zone; Mn-salite to Mn-ferrosalite (Fe-diopside) center; Mn-hedenbergite outer zone; marble peripheral zone. Retrograde alteration to tremolite-actinolite, chlorite, epidote, ilvaite.

Ore controls. Mn-hedenbergite ± ilvaite skarn contains pipe-like or tabular Pb-Zn orebodies.

Weathering. Gossan with strong Mn oxide stains.

Geochemical signature. Zn, Pb, Mn, Cu, Co, As.

Deposits: Dognecea, Rușchița, Tincova, Brusturi.

MODEL BĂIȚA BIHORULUI: Mo-Bi-W-Cu SKARN DEPOSITS (M in Plate and Fig. 1)

DESCRIPTION. Molybdenite, scheelite, chalcopryrite, Bi-minerals in calcic light skarns and magnesian skarns.

GEOLOGICAL ENVIRONMENT

Rock type. Granite (granodiorite) pluton (batholith) intruding carbonate rocks and carbonate-siliciclastic sequences. The carbonate rocks belong to the Getic Nappe and the Apusenide Group of Nappes. The plutons belong to the Banatitic belt developed in the Apuseni Mts., Banat-Poiana Ruscă Mts., Eastern Serbia and Srednagora.

Age: "Laramian".

Structural type. The skarn system occurs near igneous contacts by diffusion/infiltration metasomatism (proximal skarns at Oravița and Băița Bihorului) and hundreds of meters from the contact by infiltration metasomatism (distal skarns at Ciclova and Băița Bihorului).

Depositional environment. Contacts and roof pendants of pluton and thermal aureoles of pluton and apical zones of stock that intrude carbonate rocks and carbonate siliciclastic sequences.

Major tectonic setting. Andean-type or island arc subduction-related magmatism.

Large scale zonality/associated deposit types. Contact aureole around the pluton: Mo-W skarn - Bi-W-Cu skarn - Pb-Zn skarn - B marble. "Pentametallic" veins, U-Cu polygenetic, Pb-Zn replacement.

DEPOSIT DESCRIPTION

Mineralogy. Scheelite + molybdenite + chalcopryrite + bismuthinite + Bi minerals ± sphalerite, galena, arsenopyrite, lollingite, glaucodote, gold, bornite, tetrahedrite, cubanite. Fluorborite, ludwigite, szaybellite and kotoite may be present.

Alteration. Dolomitic environment: grossularite + vesuvianite inner zones; diopside ± phlogopite center; clinohumite + chondrodite ± phlogopite outer zone; calciphyre, kotoite marble and brucite marble peripheral zones. Retrograde alteration to talc, serpentine, chlorite, tremolite. In places high temperature fassaite, forsterite, spinel.

Calcareous and calcareous-siliciclastic environment: ribbon rock of wollastonite and grossularite + vesuvianite alternating layers, metasomatised (skarnified) hornfels is diopside + wollastonite + grandite. Retrograde alteration to epidote, actinolite, chlorite.

The pluton may be altered to periskarn and grossularite + vesuvianite endoskarn.

Igneous rocks found as dikes throughout the contact aureole are converted into grossularite + vesuvianite skarn.

Ore controls. Tabular Mo-W and pipe-like (Cu-Bi-W; Pb-Zn) ore bodies in magnesian skarns. Mo-W impregnations, pods and veins in ribbon rock. Associated igneous rocks occurring as dikes may be mineralized (Mo ± W stockwork in grossularite ± vesuvianite skarn).

Weathering. In places enrichment zone with secondary Cu-sulfides, native copper and cuprite

Geochemical signature. W, Mo, Zn, Cu, Bi, Au, Ag, B

Deposits: Băița Bihorului, Oravița, Ciclova.

TABLE 3. TERTIARY EPITHERMAL DEPOSITS IN BAIA MARE

MODEL BAIA SPRIE - POLYMETALLIC AND PRECIOUS METAL BRECCIA PIPE AND VEINS (M VI in Plate and Fig. 1)

DESCRIPTION. Epithermal gold and polymetallic veins and breccias.

GEOLOGICAL ENVIRONMENT

Rock types. Quartz andesite and andesite and associated sedimentary rocks. The igneous rocks belong to the Later Tertiary volcanic arc of the East Carpathians.

Age. Sarmatian-Pannonian, Pontian

Structural type. Epithermal system controlled by subjacent pluton situated in major crustal fault.

Depositional environment. Volcano-plutonic complexes. Deposits related to subvolcanic level undergoing phreatomagmatic explosion along reactivated NW-SE and SW-NE regional fracture sets. The Late Tertiary pluton of quartz diorite composition is situated at 2 to 4 km depth. The metalliferous systems extend 1.5 km away from the apical part of the plutonic culmination.

Major tectonic setting. Island-arc volcanic setting.

Large scale zonality/associated deposit types. Epithermal gold (quartz-adularia), polymetallic veins.

DEPOSIT DESCRIPTION

Mineralogy. Early stage with pyrite + chalcopyrite + hematite, scheelite, magnetite, wolframite in chlorite + quartz + ankerite + barite gangue. Subsequent stage with pyrrhotite + sphalerite + chalcopyrite + galena.

Alteration. Regional propylitization, chloritization, quartz + adularia, sericitization, argillic alteration.

Ore controls. Tectonic: fractures and anastomosing fissural systems. Vertical zoning: top to bottom Au-Ag - Pb-Zn-Au-Ag - Cu-Pb-Zn - Cu $\pm$ W. Selective association of gold with quartz-adularia alteration, polymetallic ores with sericite-argillization and copper with chloritization.

Weathering. Bleached country rock. Limonitization.

Geochemical signature. Cu, Pb, Zn, Au, Ag, As, Sb, Bi, Se, Cd, Ga, Te, Ti, W, Co, Ni.

Deposits: Baia Sprie, Șuitor, partly Băiut-Văratice, Vf.Țapului-Mihai-Nepomuc.

MODEL CAPNIC-BASE METAL AND PRECIOUS METAL VEINS (M VII in Plate and Fig. 1)

DESCRIPTION. Epithermal gold and polymetallic veins.

GEOLOGICAL ENVIRONMENT

Rock types. Quartz andesite and andesite and associated sedimentary rocks. The igneous rocks belong to the Late Tertiary volcanic arc of the East Carpathians.

Age. Sarmatian-Pannonian, Pontian.

Structural type. Epithermal system controlled by subjacent pluton situated in major crustal fault.

Depositional environment. Volcano-plutonic complexes. The mineralized system is commonly located within volcanic rocks. It is centered on subvolcanic apophyses corresponding to culmination of the quartz diorite pluton. The mineralized column is 1.5-2 km high. At depth the igneous rocks come in contact with Early Tertiary siliciclastic rocks converted into hornfels. The sedimentary rocks are displaced along distensional N-S fractures.

Major tectonic setting. Island-arc volcanic setting.

Large scale zonality associated deposit types. Epithermal gold (quartz-adularia), polymetallic veins.

DEPOSIT DESCRIPTION

Mineralogy. Early stage with pyrite + chalcopyrite + hematite + magnetite in quartz $\pm$ chlorite, epidote gangue. Stage 2 is pyrite + sphalerite + galena + chalcopyrite + arsenopyrite in quartz, adularia, carbonate, clay minerals and barite gangue. Stage 3 contains pyrite + galena + sphalerite + chalcopyrite + tetrahedrite in quartz and carbonate (especially rhodochrosite) gangue. Last stage with pyrite + tetrahedrite + bournonite + jamesonite + gold + realgar + orpiment in quartz, gypsum and carbonate gangue.

Alteration. Regional propylitization; chloritization, quartz + adularia, sericitization, argillic alteration.

Ore controls. Tectonic: major fracture and related fault systems. A tendency of vertical zoning from Cu-Pb-Zn bottom zone to Pb-Zn-Au-Ag toward top.

Weathering. Bleached country rock, "limonitization".

Geochemical signature. Pb, Zn, Cu, Au, Ag, As, Cd, Ga, In, Se, Te, Bi, Sb, Mn.

Deposits: Căvnic, Roata, Herja, Ilba, Nistru, Dealul Crucii.

TABLE 4. TERTIARY PORPHYRY COPPERS IN THE SOUTH APUSENI MTS.

MODEL ROȘIA POIENI-DIORITE TYPE, Cu-Mo POLYASCENDENT EVOLUTION PYRITE HALO (M VIII in Plate and Fig. 1)

DESCRIPTION. Chalcopyrite + pyrite $\pm$ molybdenite in stockwork in hydrothermally altered porphyritic intrusion.

GEOLOGICAL ENVIRONMENT

Rock types. Quartz andesite to quartz diorite porphyry stocks and related breccia intruding crystalline basement, Cretaceous and Tertiary sedimentary rocks.

Age. Sarmatian.

Structural type. High-level intrusive porphyry contemporaneous with faults and breccia pipes.

Depositional environment. Plutonic cupola and related subvolcanic intrusion along tectonic alignments striking E-W or NW-SE in the Tertiary molasse basin. The igneous assemblage penetrated in the crystalline pre-Mesozoic basement and Cretaceous flysch and Badenian-Sarmatian molasse.

Major tectonic setting. Back arc reactivation along extensional fault systems.

Large scale zonality associated deposit types. Not expressed.

DEPOSIT DESCRIPTION

Mineralogy. Pyrite + chalcopyrite + molybdenite $\pm$ magnetite, hematite veinlets with subordinate pyrrhotite, bornite, sphalerite, galena, digenite, enargite-famatinite, lusonite-stibiolumonite, tetrahedrite-tennantite in potassic zone.

Alteration. Potassic alteration (biotite + quartz $\pm$ Q-feldspar and anhydrite) in the porphyritic intrusion, partly replaced by albite $\pm$ actinolite. Argillic alteration (kaolinite + illite + montmorillonite $\pm$ alunite) at the margin of the subvolcanic body. Early propylitization (calcite + chlorite + rutile + albite) in surrounding volcanic rocks. The alteration pattern is similar to the diorite type.

Weathering. Restricted chalcocite blanket and gossan.

Geochemical signature. Cu, As, Mo, Ti, Mn, Au, Pb, Zn, Ag, Bi, Se, Ta.

Deposits Prospects: Roșia Poieni, Bucuresci-Rovina, Deva, Măgura.

MODEL VALEA MORII-DIORITE TYPE, Cu-Au POLYASCENDENT EVOLUTION EPITHERMAL VEINS HALO (M IX in Plate and Fig. 1)

DESCRIPTION. Stockwork veinlets of chalcopyrite $\pm$ magnetite, bornite in porphyritic intrusions of subvolcanic type and volcanic rocks.

GEOLOGICAL ENVIRONMENT

Rock types. Quartz andesite to quartz diorite and andesite flows.

Age: Sarmatian.

Structural type. The porphyry copper system is centered on subvolcanic apophyses corresponding to culminations of deep-seated plutons.

Depositional environment. Volcano-plutonic complexes situated at the intersection of the main ophiolitic, Laramian and Tertiary tectono-magmatic lineaments trending E-W, NE-SW and NW-SE, respectively. The apical part of the mineralized system is commonly located within Tertiary volcanic rocks, sandstones, conglomerates and pyroclastics. At depth the igneous rocks come in contact with Mesozoic sedimentary and ophiolitic rocks and pre-Mesozoic metamorphic rocks. The Tertiary igneous assemblages occur in molasse basins controlled by reactivation of early fracture systems.

Major tectonic setting. Back arc reactivation along extensional fault systems.

Large scale zonality- associated deposit types. Cu-Au stockwork in hydrothermally altered subvolcanic body - Au-Ag $\pm$ Te and Pb-Zn $\pm$ Cu veins in hydrothermally altered volcanic rocks - pyrite halo in some intruded rocks (e.g. Mesozoic ophiolites).

DEPOSIT DESCRIPTION

Mineralogy. Chalcopyrite $\pm$ magnetite with ilmenite or rutile inclusions + pyrite with rutile inclusions $\pm$ bornite, sphalerite, tetrahedrite, galena, gold, molybdenite veinlets and chalcopyrite + magnetite + pyrite impregnations in potassic zone.

Alteration. Potassic alteration (K feldspar + biotite with superposed anhydrite, adularia, albite, sericite, chlorite, actinolite, calcite) in subvolcanic bodies. Peripheral early and pervasive propylitic alteration (chlorite + actinolite + epidote + calcite).

The alteration pattern is similar to the diorite type.

Ore controls. Veinlets and fractures of quartz, chlorite, epidote and sulphide are closely spaced.

Weathering. Bleached country rock, "limonitization"

Geochemical signature: Cu, Au, As, Ti, Mn, Pb, Zn, Ag, Mo, Sb, Bi, Co, Ni

Deposits/Prospects: Valea Morii, Musariu, Bolcana, Voia, Colnic, Tălagiu, Haneș-Larga, Trampoiele, Muncăceasca W, Valea Tisei, Târnița.

TABLE 5. TERTIARY EPITHERMAL DEPOSITS IN THE SOUTH APUSENI MTS.

MODEL ROȘIA MONTANĂ-PRECIOUS METAL BRECCIA PIPE AND VEINS (M X in Plate and Fig. 1)

DESCRIPTION. Epithermal gold in volcanic rocks and associated sedimentary rocks.

GEOLOGICAL ENVIRONMENT.

Rock type. Dacite to rhyodacite and quartz andesite and associated volcano-sedimentary and sedimentary siliciclastic rocks.*Age.* Badenian*Structural type.* Fracture and breccia mineralization in dacite flow above subvolcanic plugs.*Depositional environment.* Volcano-plutonic complexes situated at the intersection of the main ophiolitic, Laramian and Tertiary tectonomagmatic alignments in molasse basins. The regional lineation is NW-SE and exhibits local phreatomagmatic explosions with associated ore formation. Breccia pipes as apex of the mineralized system occur in the volcanic edifices or toward their margins. At depth the igneous rocks come in contact with Mesozoic siliciclastic and ophiolitic rocks and pre-Mesozoic crystalline schists.*Major tectonic setting.* Back arc reactivation along extensional fracture systems.*Large scale zonality - associated deposit types.* Epithermal gold (quartz-adularia), polymetallic veins and replacement.

DEPOSIT DESCRIPTION

Mineralogy. Pyrite + arsenopyrite + gold, subordinate sphalerite, chalcopryrite, galena, alabandite, tetrahedrite. Peculiar proustite, pearceite, polybasite, argentite.*Alteration.* Regional propylitization, quartz + sericite + adularia, argillic alteration.*Ore controls.* Intimate association of quartz-adularia alteration with gold shoots.*Weathering.* Bleached country rock, "limonitization".*Geochemical signature:* Au, Ag, As, Sb, Bi, Ti, Se, Tl.*Deposits:* Roșia Montană, Radu-Frasin, Căinel, Draica, partly Baia de Arieș.

MODEL SĂCĂRĂMB-PRECIOUS METAL VEINS (M XI in Plate and Fig. 1)

DESCRIPTION. Epithermal Au-Ag-Te in volcanic rocks and associated siliciclastic sequences, local polymetallic veins.

GEOLOGICAL ENVIRONMENT

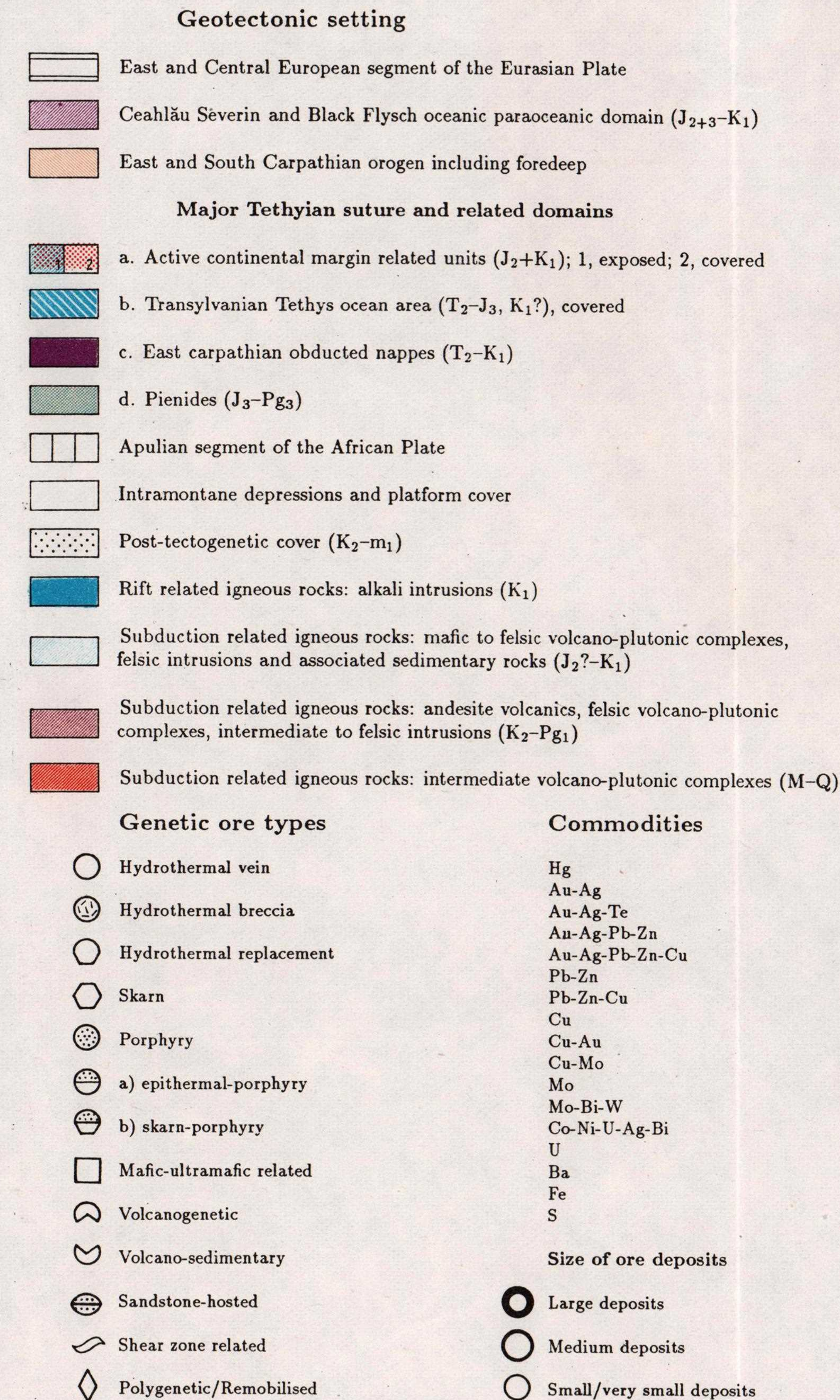
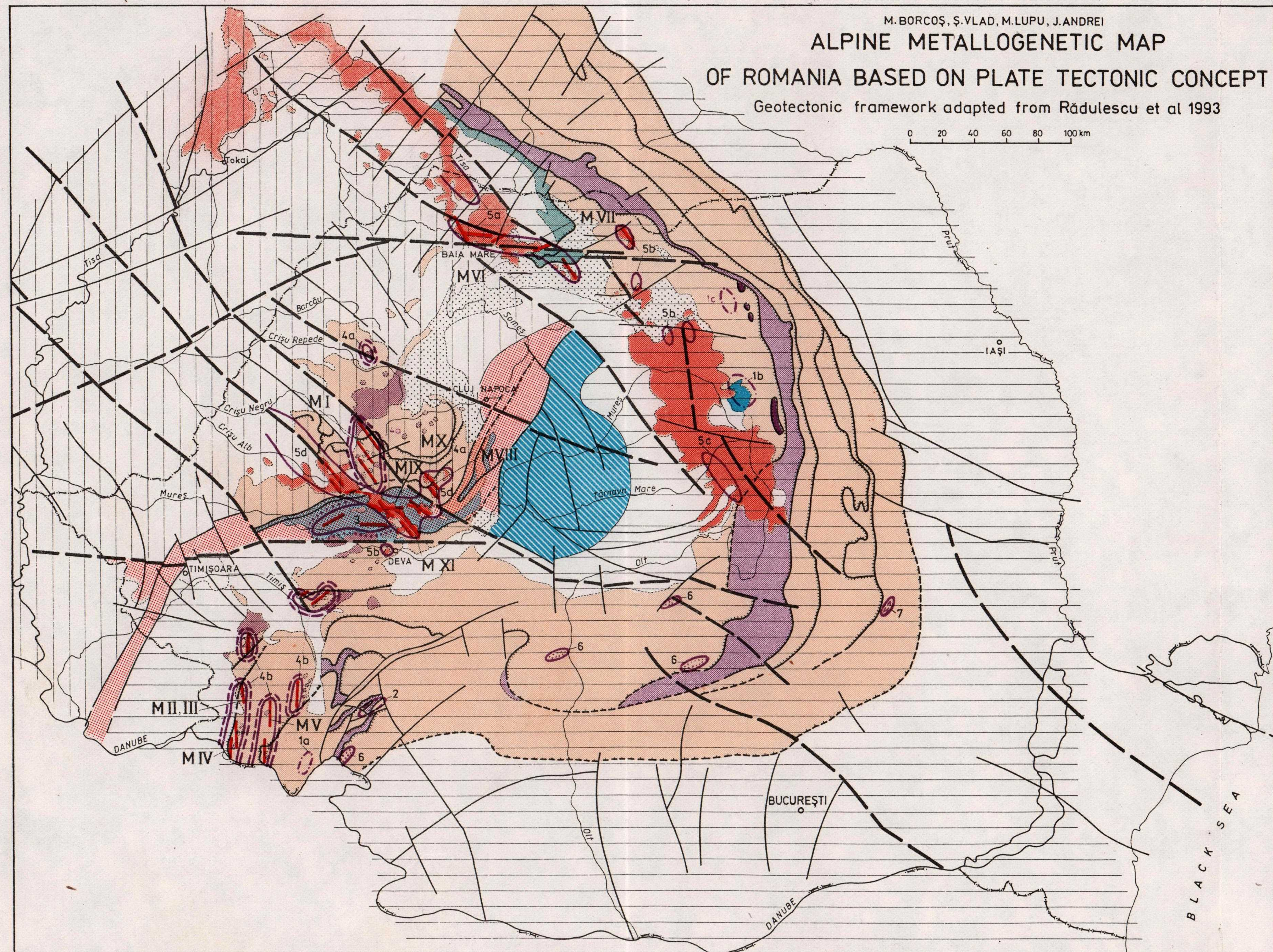
Rock types. Quartz andesite and andesite and associated siliciclastic sedimentary and volcano-sedimentary rocks.*Age.* Sarmatian.*Structural type.* Vein and stockwork sets in apical part of subvolcanic plugs.*Depositional environment.* Volcano-plutonic complexes situated at the intersection of the main ophiolitic, Laramian and Tertiary tectonomagmatic alignments in molasse basins. The apex of the mineralized system is commonly located within Tertiary volcanic and subvolcanic rocks and siliciclastic rocks. The basement consists of Mesozoic siliciclastic rocks and ophiolites.*Major tectonic setting.* Back arc reactivation along extensional fracture systems.*Large scale zonality - associated deposit types.* Polymetallic veins or stockworks and replacement, distal gold metasomatic disseminated.

DEPOSIT DESCRIPTION

Mineralogy. Stage 1 is pyrite + pyrrhotite + arsenopyrite + sphalerite + galena + chalcopryrite + alabandite. Stage 2 is represented by common sulphides and nagyagite, krennerite, silvanite, altaite, hessite, petzite, tellurium, tetrahedrite, boulangerite, jamesonite, antimonite, arsen, gold in quartz + carbonate (mainly rhodocrosite) + clay minerals gangue.*Alteration.* Regional propylitization; chloritization, quartz + adularia, sericitization, argillic alteration.*Ore controls.* Tendency of horizontal and vertical zonality. Quartz + adularia alteration is intimately associated with Te-Au-Ag mineralization, sericite and argillic alteration is associated with Pb-Zn-Au-Ag mineralization and chloritization with pyrite-Pb-Zn mineralization.*Weathering.* Bleached country rock, "limonitization".*Deposits:* Săcăramb, Stăniș, Fața Băii, partly Baia de Arieș.

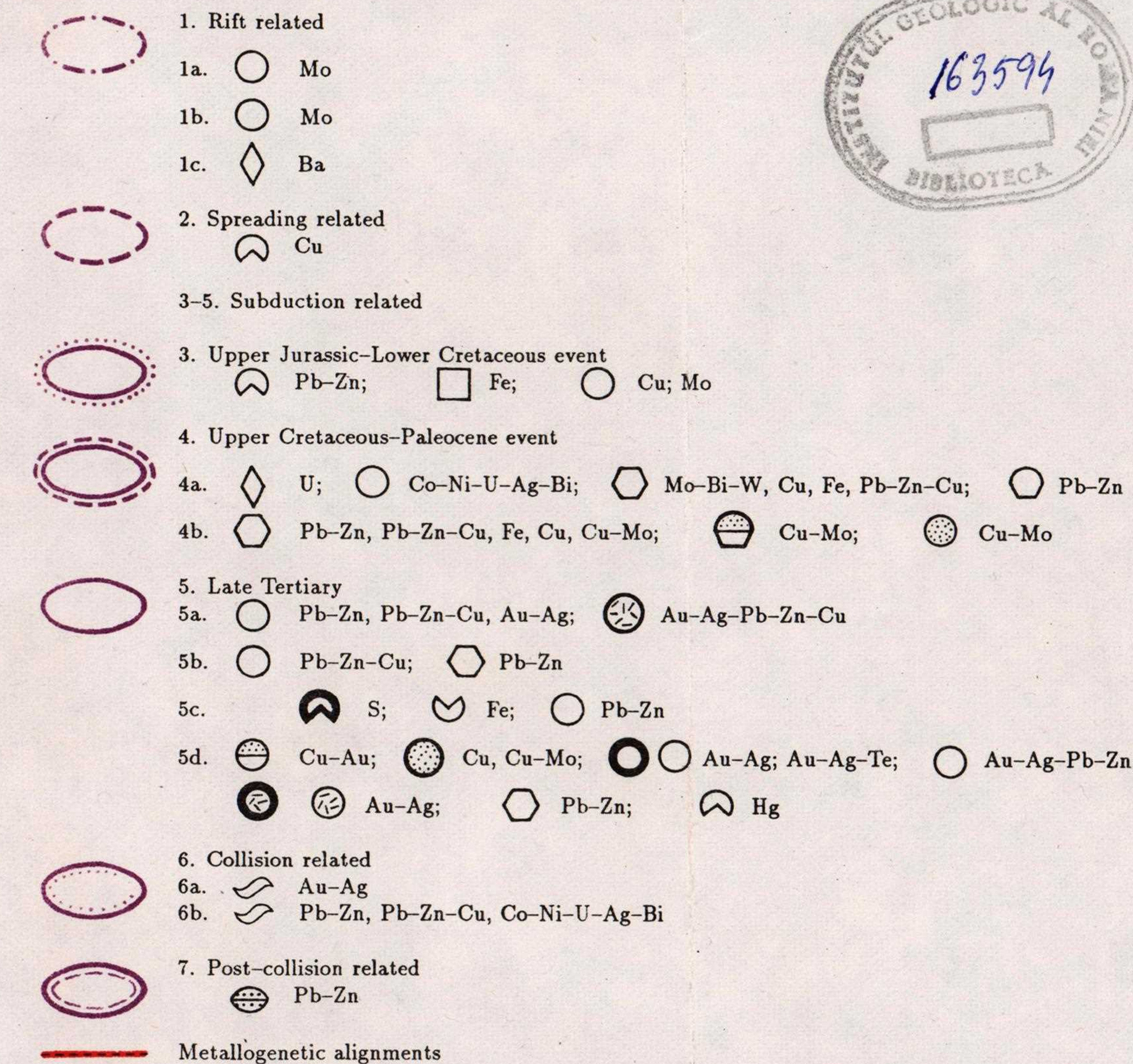
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LEGEND

Metallogenic units in terms of plate tectonics



Metallogenic models related to Upper Cretaceous-Paleocene (A) and Late Tertiary (B) subduction events

- | | |
|-------------------------|----------------------|
| A. MI - Băița Bihorului | B. MVI - Baia Sprie |
| MII - Ocna de Fier | MVII - Cavnic |
| MIII - Dognecea | MVIII - Roșia Poieni |
| MIV - Suvorov | MIX - Valea Morii |
| MV - Bozovici | MX - Roșia Montană |
| | MXI - Săcărâmb |

The following maps were used for completion of the geotectonic framework:

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IRON SKARN DEPOSIT MODEL FROM THE CENTRAL ZONE OF THE BANSKA STIAVNICA STRATOVOLCANO (Western Carpathians, Slovakia)

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Key words: Skarn. Iron skarn. Magnetite deposit. Skarn mineralization. Alteration zoning. Mineralogy

Abstract: Magnetite skarn deposits and occurrences in the central zone of the Banská Stiaavnica stratovolcano originated on the contact of the Neogene granodiorite body with the Mesozoic carbonate rocks (Velký Bok group). Two types of skarns (Ca and Mg) are present as a result of different carbonate host rocks and different contact temperature. The largest occurrence is the Vyhne Klokoč deposit, classified as Ca-exoskarn. Based on detailed geological and mineralogical data it was possible to distinguish three basic evolution stages: isochemical magmatic, metasomatic magmatic and retrograde meteoric stage.

1. Introduction

General description

The iron skarn mineralization in the Banská Stiaavnica stratovolcano has been known and extracted for centuries. Although these localities were not so famous, they were very important for the whole district. The ironworks were built here, that supported the precious-metal mining. In this time, only one iron (magnetite) skarn locality is of economic value - the Vyhne-Klokoč deposit.

The iron skarn localities are situated mostly in the western part of the central zone of the Stiaavnica stratovolcano, where the deep erosion level had exposed the granodiorite intrusion and the basement rocks (Fig.1). A few occurrences were also found in other parts of the horst - both underground and in bore holes (Zábranský, 1969; Káčer et al, 1993).

Skarns were formed by replacement of the carbonate rocks of the basement by contact metasomatic processes related to granodiorite intrusion (it belongs to the 3rd evolution stage of the stratovolcano, according to Konečný et al, in Štöhl et al, 1990).

Two different types of iron skarn mineralization had been recognised in the Banská Stiaavnica stratovolcano district: the magnesian type and the calcic type (Zábranský, 1969).

The magnesian type originated at the contact with dolomite and dolomitic limestone, if the contact temperature was high enough. The calcic type was

developed at the contact with limestone and also with dolomitic limestone, if the temperature was not sufficient for creating magnesian type.

The lower temperatures might be caused by indirect contact of the intrusion with carbonate rocks, when non-carbonate rocks (for instance crystalline schist) create an obstacle between both environments. Overprinting of calcic skarns on the older magnesian ones has been observed. If both skarn types are present at one locality, the magnesian skarn assemblages originated earlier than the calcic ones. Most of the magnetite ores are set in the calcic type of skarns (Káčer et al, 1993).

Description of Vyhne-Klokoč iron skarn deposit

The Vyhne-Klokoč skarn deposit is the largest and the best known skarn locality in the Western Carpathians with economically interesting accumulation of magnetite ore. This deposit belongs to the iron rich Ca-exoskarn deposits and has also accessory amounts of base metal mineralization.

Two larger lenses of magnetite ore were recognised within the Vyhne-Klokoč deposit. The biggest one reaches about 500 m in diameter, with varying thickness 1 to 35 m. The average iron concentrations range here from 20 to 40%. The proved magnetite ore stock is of 2.6 mil tones, and 7 mil tones were estimated in the larger surroundings of the locality (Gavora and Lukaj, 1968).

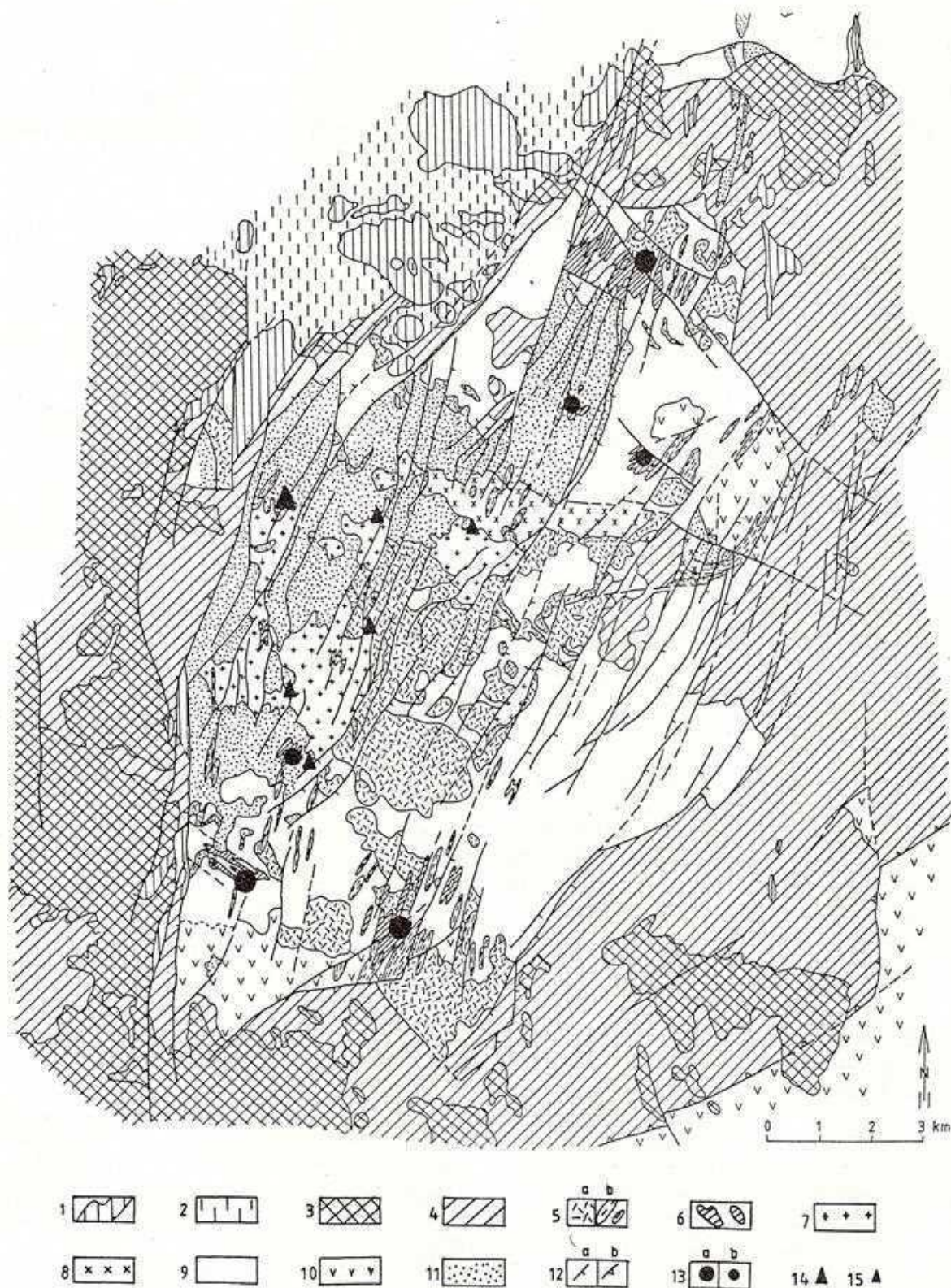


Fig. 1 – Structural scheme of the resurgent horst in the central zone of the Štiavnica stratovolcano.

After Konečný and Lexa in Štol, 1990). 1, rhyolite dykes and extrusive domes; 2, rhyolite volcanoclastic rocks; 3, postcaldera andesites and volcanoclastic rocks; 5, quartz diorite porphyries: a - sills, b - dykes; 6, clusters of dikes and stocks; 11, prevolcanic basement; 12, a - faults of resurgent horst, b - caldera marginal faults; 13, skarn related porphyry copper prospects (a - medium sized; b - small sized); 14, Vyhne-Klokoč iron skarn deposit; 15, iron skarn occurrences.

During the exploration in the 50-ties, the deposit was open with two mining floors. These mine work may illustrate the position of the magnetite bodies in the underground. The deposit is economically suitable for extraction and partly prepared, but till now it was not extracted, certainly, besides the older mining centuries.

1. Geological setting

The locality is set in the NW part of the central zone of the Banská Štiavnica stratovolcano (Fig.1). The basement rocks of the stratovolcano are the most widespread here. They consist of a crystalline basement (Hercynian granite) and two different Mesozoic groups. The first (Velký Bok group) contains mostly Middle to Upper Triassic carbonate rocks (limestone, dolomitic limestone), the second (Choč nappe) contains mostly Lower Triassic sandstone and shales (Fig.2).

The ore-bearing granodiorite intrusion (dated 17.2-17.5 m.y. by the fission-track method, Repcok, 1981) caused large-scale metasomatic changes at the indirect contact with carbonate rocks, where crystalline schists made a particular barrier. The latest are the quartz-diorite dikes, crossing all the mentioned rocks.

According to the older bore holes, a schematic cross section across this area was drawn (Fig.3). The carbonate rocks of the Velký Bok group with the skarn mineralization are located in the footwall of the Choč nappe, both dipping at the angle of 40° (Gavora and Lukaj, 1968). In the upper part of the skarn massive magnetite bodies are present, whereas in the hanging wall of the magnetite bodies (in the garnet skarn) the accessory retrograde base metal sulphidic mineralization is disseminated.

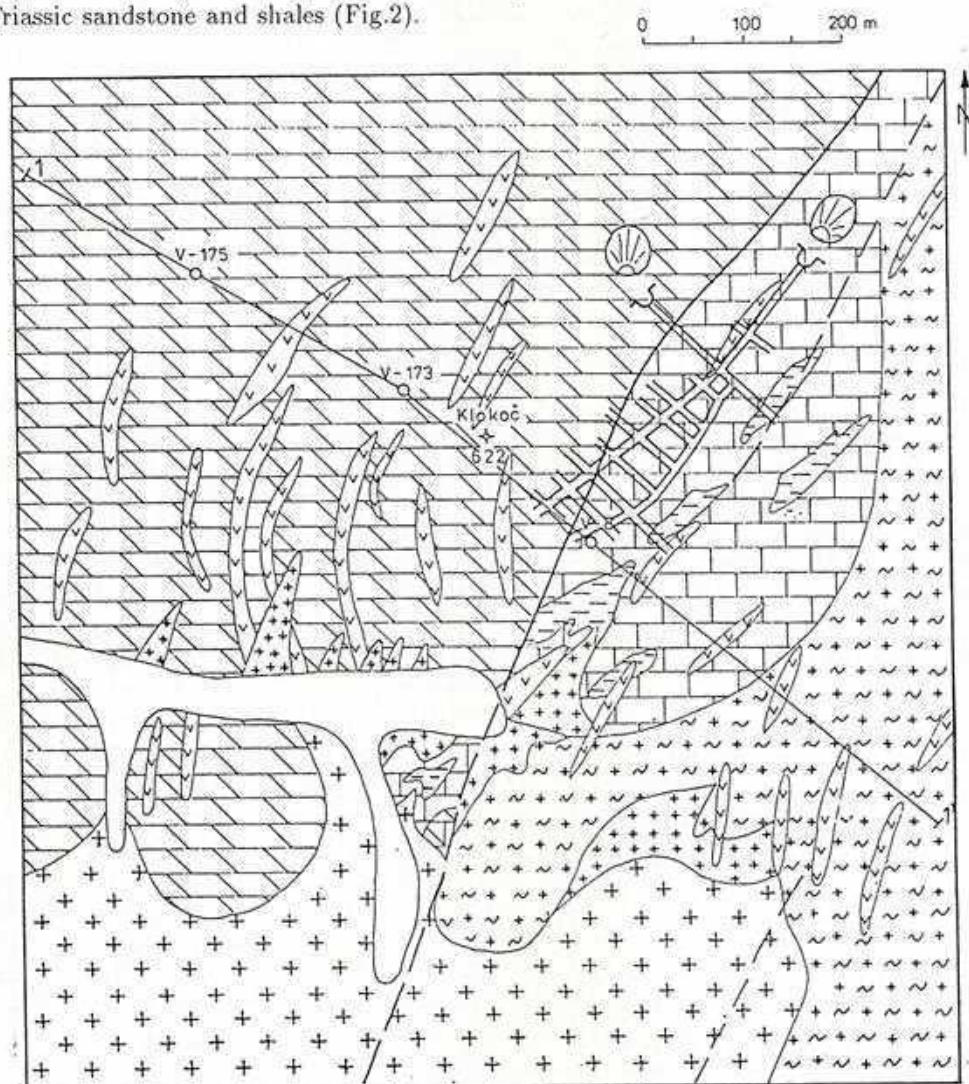


Fig. 2 - Geological map of the Vyhne - Klokoč iron skarn deposit according to Konecny and Lexa, 1993. (The same legend for Fig. 3)

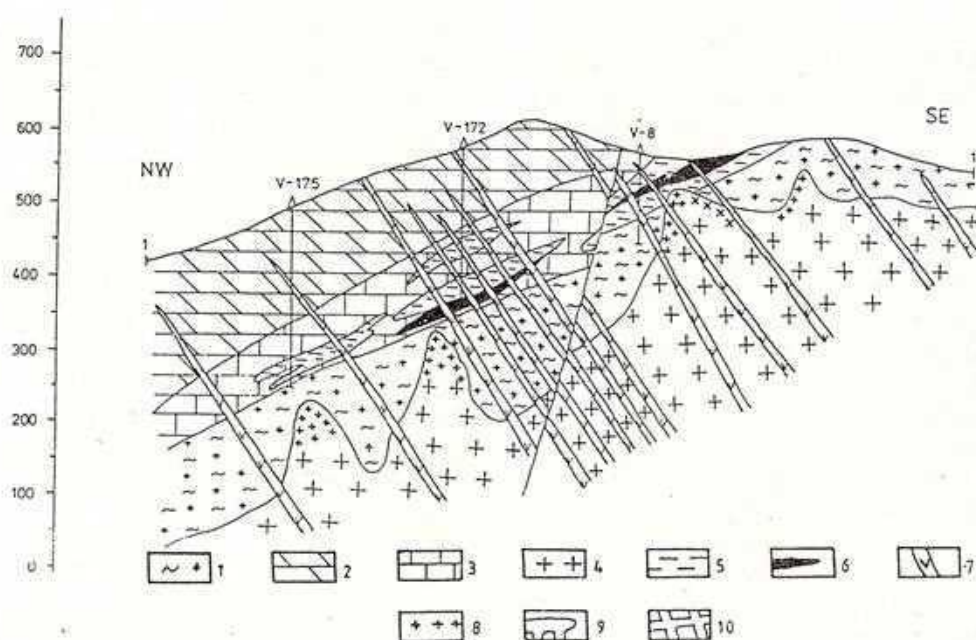


Fig. 3 – Cross section 1 – 1 through Vyhne – Klokoč iron skarn deposit (Lexa, Kacer, 1993). 1, Hercynian granite; 2, Middle-Upper Triassic limestones, dolomitic limestones (Vel'ký Bok group); 3, Lower Triassic shales, sandstones (Choč nappe); 4, granodiorite; 5, skarns; 6, magnetite lenses; 7, dykes of quartz-diorite porphyry; 8, marginal facies and apophysis of granodiorite; 9, fluvial sediments; 10, mining floors.

2. Alterations

In the granodiorite intrusion apophyses the decrement of iron rich mafic minerals has been observed. The rock-forming minerals are altered to sericite, albite and chlorite (rarely the accessory barren endoskarn mineralization occurs here).

Although the carbonate rocks are dolomitic limestone, only the closest to the contact skarn alteration assemblages are a little more magnesian rich (talk and serpentine minerals are present). It is a consequence of the indirect contact with the intrusion, that caused relatively low contact temperatures.

The intermediate crystalline schist (Hercynian granite) had been affected by fracturing. The ruptures were filled or sealed by tourmaline - quartz mineral assemblage. The Mesozoic shales and sandstones are affected by the quartz-sericite alterations, but only very near to the contact (Káčer et al, 1993).

3. Mineralogy

The succession scheme (Fig.4) of the deposit suggests that the entire mineralization was formed during three basic stages - isochemical, metasomatic and retrograde. The last retrograde stage finally changes into a hydrothermal meteoric system (Kodera and Chovan, 1994). The mineral assemblage of each stage generally overprints the assemblages of the older stages.

The skarn forming process during the isochemical stage had mostly the character of thermal contact metamorphism. Recrystallisation had caused origination of non-hydrous silicates - especially zoned garnets (grossularite-andradite series), more seldom pyroxene (diopside-hedenbergite series) and wollastonite, as well as marbles and contact hornfelses. Later, the assemblage with epidote and tremolite originated, while clinochlore occurs in the marginal zones.

Metasomatic stage began by gradual increase of tectonic activity and penetrating of metasomatic fluids, rich in Fe. Still characteristic is the occurrence of epidote, tremolite and also the development of several garnet generations, especially andradite. Important is the origin of magnetite, that beside the carbonate rocks also replaces the older skarn assemblages. Pennine was formed in the marginal zones.

Retrograde stage is generated by the gradual temperature decrease. Characteristic is non-equilibrium crystallization under varying redox conditions. Zoned garnet, major hematite and minor magnetite (both accompanied by extensive processes of mutual overprinting) were formed here; with lesser amounts of epidote, amphibole and chlorite.

Epidote-calcite stage, present in thin veinlets, represents the transition between the skarn and hydrothermal meteoric system.

STAGES MINERALS	SKARN MINERALIZATION				HYDROTHERMAL SULPHIDIC MINERALIZATION				
	IZOCHEMICAL [NONMETALLIC]	METASOMATIC [MAGNETITE]	RETROGRADE [HEMATITE]	EPIDOTE - CALCITE	PYRITE - CHALCOPYRITE	POLYMETALLIC	CALCITE - HEMATITE	QUARTZ - CARB.	CHALC. - OPAL
garnets									
pyroxenes									
wollastonite									
epidote									
zoisite									
amphiboles									
phlogopite									
titanite									
chlorites									
carbonates									
magnetite									
hematite									
quartz									
pyrite									
chalcopryite									
serpentine									
talc									
scheelite									
rutile									
galenite									
sphalerite									
marcasite									
chalcedony									
opal									
goethite									
weath. Cu min.									

Fig. 4 - Succession scheme of minerals of the Vyhne - Klococ deposit.

Hydrothermal mineralization was formed during five substages. The substages correspond to tectonic processes connected, as a rule, to the final cooling of the intrusion. The substages show the signs of decreasing temperature of the circulating meteoric fluids. Also, the amount of the minerals, crystallizing during these substages, is decreasing.

More abundant is only the first, pyrite-chalcopryite substage, responsible for the formation of the main pyrite mass in the deposit. Base metal stage (with galena, sphalerite, chalcopryite, hematite and pyrite) has a special spatial position in the deposit, where during the magmatic stages garnets originated. The last three stages (calcite-hematite, quartz-carbonate,

chalcedony-opal) occur mostly in form of crack fillings and are thus relatively less important (Koděra, 1992; Koděra and Chovan, 1994).

Conclusion

Two types of skarn mineralization (Ca and Mg) are present in the central zone of the Banská Štiavnica stratovolcano as a result of different character of carbonate host rocks and different contact temperature. Based on geological, mineralogical information and using published skarn models (Žarikov, 1968; Sabynin, 1974; Einaudi, Meinert and Newberry, 1981; Einaudi and Burt, 1982; Pirajno, 1992) it is possible to envis-

age a general scheme of their evolution.

Generally, the skarn mineralization originated during three basic stages: isochemical, metasomatic and retrograde.

Isochemical magmatic stage

The first stage is closely connected to the emplacement of the granodiorite intrusion. The timing of this stage corresponds with the crystallisation of the pluton margins. Thermal contact metamorphism on the carbonate wall rocks (Velký Bok group) results in early reaction skarn assemblages. Decarbonation, dehydration and recrystallization causes origination of non-hydrous silicates, marbles and hornfels. If the carbonate rocks are rich in magnesium, magnesium rich silicates may occur.

Metasomatic magmatic stage

The slowly cooling of the intrusion causes the rupturing of the crystallized margins of the intrusion and of the wall rocks. The metasomatic fluids penetrate along the fractures, contacts and permeable horizons forming the iron rich mineralization (with andradite and magnetite), by replacing the early reaction skarn and marbles. In the endocontact, the rock-forming minerals are altered (to sericite, albite, chlorite) and may also be replaced by minor skarn mineralization. In the mostly non-carbonate wall rocks (Choč nappe) quartz-sericite alterations occur. If the magnesian reaction skarns are present, they are affected by serpentinisation and may be overprinted by the calcic skarn assemblages.

Retrograde meteoric stage

The continual cooling causes the gradual collapse of the meteoric waters into the older skarn assemblages. The hydrous minerals replace the older non-hydrous ones, sulphides and clay minerals occur. The retrograde stage finally changes into a hydrothermal meteoric system and tends to create the insignificant vein mineralization.

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SKARN RELATED PORPHYRY COPPER DEPOSIT MODEL FROM THE CENTRAL ZONE OF THE BANSKÁ ŠTIAVNICA STRATOVOLCANO (WESTERN CARPATHIANS, SLOVAKIA)

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Key words: Skarn related porphyry coppers. Ore bearing intrusions. Mineralized exoskarns. Lithogeochemistry. Alteration zoning. Element distribution model.

Abstract: Distribution model of Cu, Mo, Pb, Zn, Ag, Au, Sn, S_T , K, Na, Mg, Ca, Si and Fe in the skarn related porphyry copper environment and its nearest surroundings from the central zone of Banská Štiavnica based on the quantitative chemical analyses of 600 surficial lithogeochemical samples and 500 drill core samples (13 boreholes) from the medium-sized and three small skarn related porphyry coppers is presented here. The results of other research methods e.g. local scale geological mapping, petrography, alteration and ore mineralogy etc. were used. At the contact of the intrusive (granodiorite porphyry) and carbonate complexes (dolomitic limestones and dolomites) the dominant mineralization type with up to 1 % Cu and about 0.5 ppm Au in the Ca-Mg and Mg exoskarns was evolved. Poor porphyry copper mineralization (up to 0.3 % Cu) in the granodiorite porphyry intrusion represents the second, less significant mineralization type here. Alteration zoning is represented by dominating centrally situated phyllic zone (quartz-sericite-pyrite $\pm$ kaolinite). More peripherally there is the argillic zone (illite, kaolinite, pyrite $\pm$ pyrophyllite) and the external prophyllitic zone (chlorite, carbonate, minor pyrite, albite and epidote). At the contact of porphyry intrusion with carbonates the skarn assemblage - forsterite, fassaite, diopside, pleonaste, garnet, salite, wollastonite - is present.

General description

Metallogenically the very active central zone of the Banská Štiavnica stratovolcano mostly represents an uplifted area, where the deep erosion level had exposed the subvolcanic intrusive complex and basement rocks (Fig. 1). The Neogene intrusive complex consists of diorite and granodiorite intrusions, clusters of dykes and stocks of granodiorite porphyries and sills and dykes of quartz diorite porphyries. The basement rocks comprise from the deeper to the upper levels crystalline schists, Mesozoic rocks of the Velký Bok group, sandstones and shales of the Upper Paleozoic, shales and quartzites of the Lower Triassic, dolomites of the Middle Triassic (the last three units belonging to the Choč nappe) and Paleogene conglomerates (Konečný, Lexa et al. in Štol et al., 1990).

The central zone has been very well known by the exploitation of precious and base metal veins since Middle Ages. After discovering the first medium-sized skarn related porphyry copper prospect Zlatno in the seventies, a large exploration project started in the

eighties. Its aim was to find other prospects with disseminated mineralization of possible economic value. Considering the age relations, the skarn related porphyry copper mineralization is older, belonging to the precaldra stages (16.2-16 mil. years) while the base metal (14.5-14 mil. years) and precious metal (12.5-10.5 mil. years) vein mineralization is younger, belonging to the postcaldra stages of the multistage development of the central zone of the Banská Štiavnica stratovolcano (Konečný et al., 1990).

Other two medium-sized and three small skarn related porphyry copper prospects have been discovered by the exploration project mentioned above, comprising geological mapping (scale 1:10,000), lithogeochemical prospecting, geophysics and other special methods including alteration and ore mineralogy and limited drilling.

None of them has been exploited because of low-grade ore situated at a depth of 20 to 1000 m. According to the mineral exploration data (Burian et al., 1980), at the Zlatno locality there is 66 million tons of copper ore with an average content of 0.34 % Cu

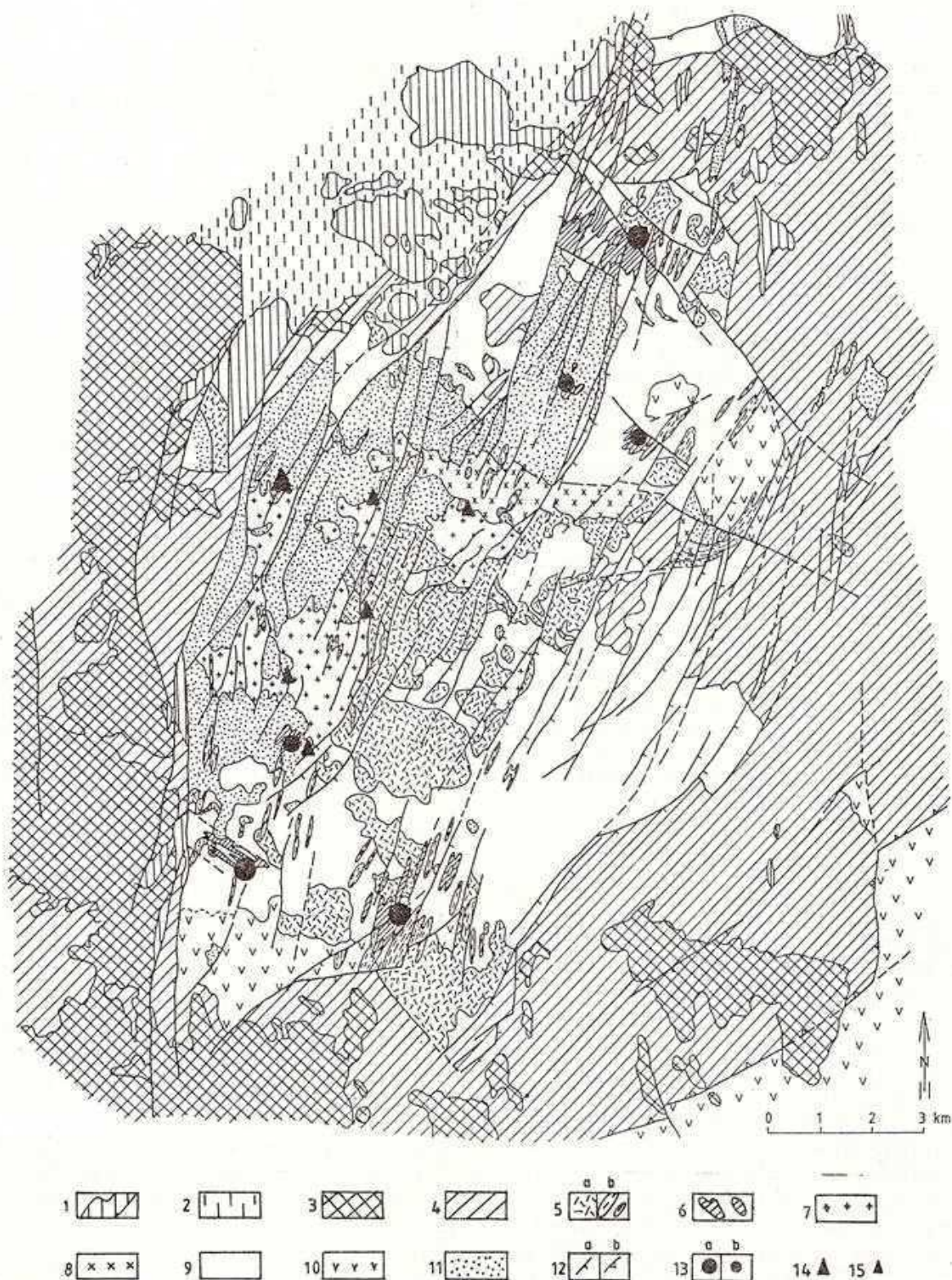


Fig. 1 – Structural scheme of the resurgent horst in the central zone of the Stiavnica stratovolcano (after Konecny and Lexa in Stohl, 1990). 1, rhyolite dykes and extrusive domes; 2, rhyolite volcanoclastic rocks; 3, postcaldera andesites and volcanoclastic rocks; 5, quartz diorite porphyries: a - sills; b - dykes; 6, clusters of dykes and stocks of granodiorite porphyry; 7, granodiorite; 8, diorite; 9, precaldern prophyllitized andesites; 10, precaldern andesites and volcanoclastic rocks; 11, prevolcanic basement; 12, a - faults of resurgent horst; b - caldera marginal faults; 13, skarn related porphyry copper prospects (a - medium sized; b - small sized); 14, Vyhne-Klokoč iron skarn deposit; 15, iron skarn occurrences

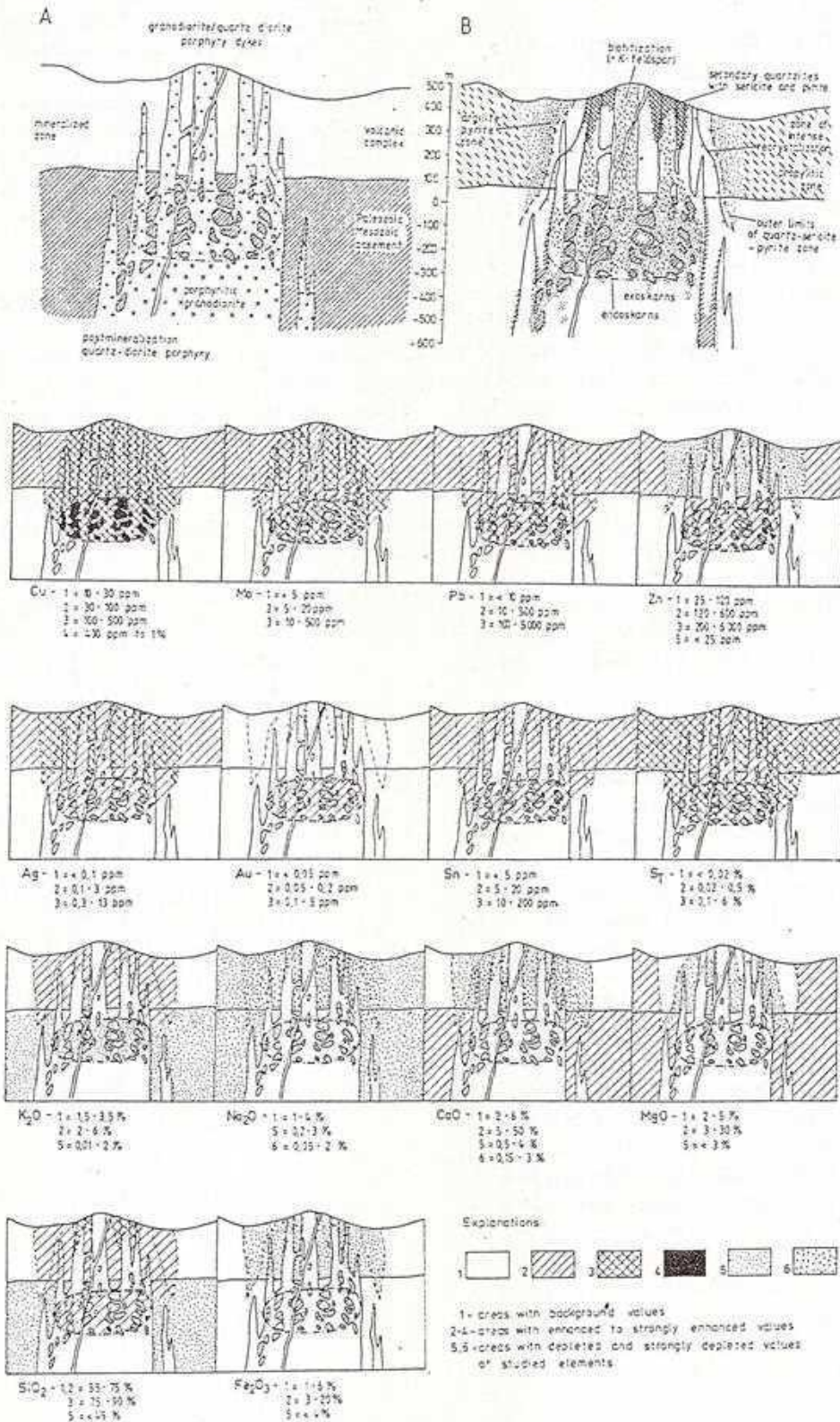


Fig. 2 - Distribution model of some major and minor elements in the host rocks (A) and alteration and mineralization zones (B) of the skarn related porphyry copper deposit. 1, areas with background values; 2, 3, 4, areas with enhanced to strongly enhanced values; 5, 6, areas with depleted and strongly depleted values of studied elements.

(from this ore 18 million tons contain 0.6 % Cu).

Description of the skarn related porphyry copper prospects

The intrusive complex of granodiorite porphyry (locally quartz diorite porphyry) is the main rock type responsible for the ore forming processes. It forms dyke clusters at the surface level. At the depth near the volcanites/basement boundary they are united to the stocks with many enclosed blocks of basement rocks.

The main basement rock type important for the mineralization processes is the carbonatic complex (Middle Triassic dolomitic limestones and dolomites). The mineralized Ca-Mg and Mg exoskarns originated at the contact of the intrusive and carbonate complexes. This mineralization type is dominant and contains up to 1 % Cu and about 0.5 ppm Au with maximum Au content up to 5 ppm. Poor porphyry copper mineralization in the granodiorite porphyry intrusion including endoskarns (up to 0.3 % Cu) represents the second, less significant mineralization type here.

The ore minerals are chalcopyrite, pyrite, valeriite, magnetite, pyrrhotite, bornite, galena, sphalerite, tennantite, argentite, arsenopyrite and some other minerals.

Mineral assemblages (from high temperature to lower temperature): magnetite-hematite, pyrrhotite-pyrite-chalcopyrite, quartz-carbonate-pyrite-chalcopyrite-galenite-sphalerite (Burian et al., 1985).

Regarding the host rocks, there are andesites and andesite porphyries of Neogene age in the upper part and shales, sandstones, quartzites, limestones and dolomites of Upper Paleozoic and Triassic age in the deeper part.

Alteration zoning with some general features characteristic of the majority of the described skarn-related porphyry copper prospects is apparent here. Potassic zone (biotitization) is evolved only rudimentarily. Phyllic alteration dominates the central zone (quartz-sericite-pyrite $\pm$ kaolinite assemblage is evolved either to the stage of quartz metasomite - the original texture is totally replaced by alteration assemblage or to the stage of recrystallization - the original texture is still recognizable). More peripheral is the argillic zone (illite, kaolinite, pyrite $\pm$ pyrophyllite), followed by the external propylitic zone (chlorite, carbonate, minor pyrite, albite and epidote). At the contact of porphyry intrusion with carbonates the skarn assemblage with forsterite, fassaite, diopside, pleonaste, garnet, salite, wollastonite is present.

The geometry of the alteration zones is irregular, showing signs of overprinting.

Distribution model of some major and minor elements in the host rocks and alteration and mineralization zones of the skarn related porphyry copper deposit

The presented lithogeochemical data are based on quantitative chemical analyses of approximately 500 drill core samples from 13 boreholes drilled at three medium-sized porphyry prospects mentioned above (Marsina et al., 1993) and on 600 surficial samples taken from all six porphyry prospects (Marsina, 1992, 1994) (Fig. 2).

All the available data from the studied prospects were at first evaluated separately for every prospect and afterwards generalized to the presented distribution model.

Figure 3 shows the generalized geological structure and Figure 4 shows the generalized alteration zoning of the skarn-related porphyry copper prospects.

Vertical distribution of the studied elements is shown in Figure 2 while the lateral zonality pattern is demonstrated by Figures 5, 6, 7.

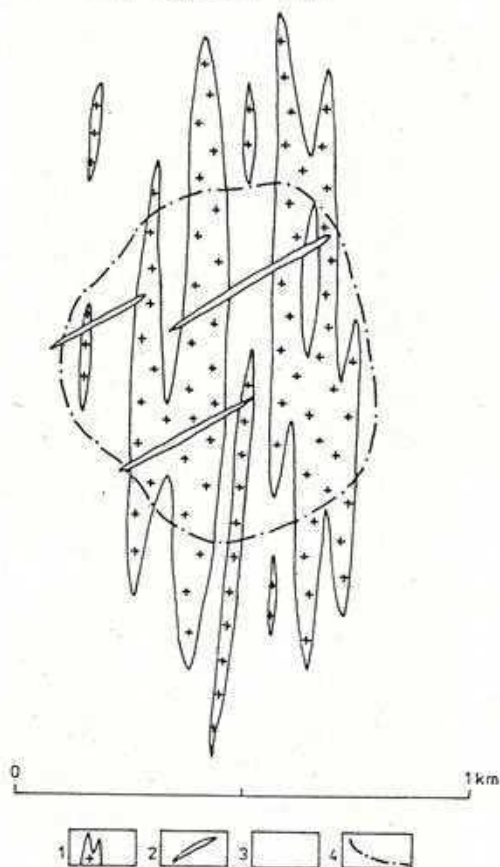


Fig. 3 – Geological structure. 1, granodiorite/quartzdiorite porphyry; 2, postmineralization quartzdiorite porphyry; 3, volcanic complex; 4, mineralized zone in depth

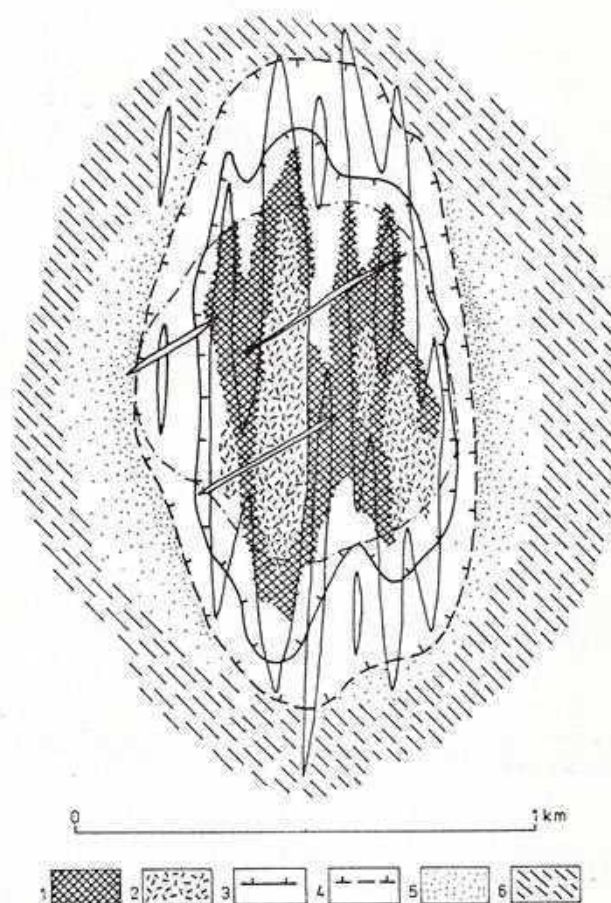


Fig. 4 - Alteration zoning. 1, secondary quartzites with sericite and pyrite; 2, biotitization ($\pm$ K-feldspar); 3, zone of intense recrystallization; 4, outer limit of the quartz-sericite-pyrite zone; 5, argillite-pyrite zone; 6, propylitic zone.

The ranges of element contents shown in fig. 2 are generalized. Their coincidence is caused partly by primary lithology and partly by extensive variation of element contents due to overprinting of alteration zones.

The principal metal in both poor porphyry copper and skarn mineralization is Cu with highest up to 0.3 % in the porphyry coppers (accompanied by Mo contents enhanced up to 500 ppm) and up to 1 % in the skarns (accompanied by Au contents enhanced up to 5 ppm, in average approximately 0.5 ppm). The highest silver contents are in the porphyritic intrusion (up to 13 ppm in the quartz metasomatites in the phyllic zone), while the most enhanced Ag contents in the skarns hardly reach 3 ppm.

Central Cu-zone is surrounded by irregularly shaped peripheral lower temperature Pb-Zn zone.

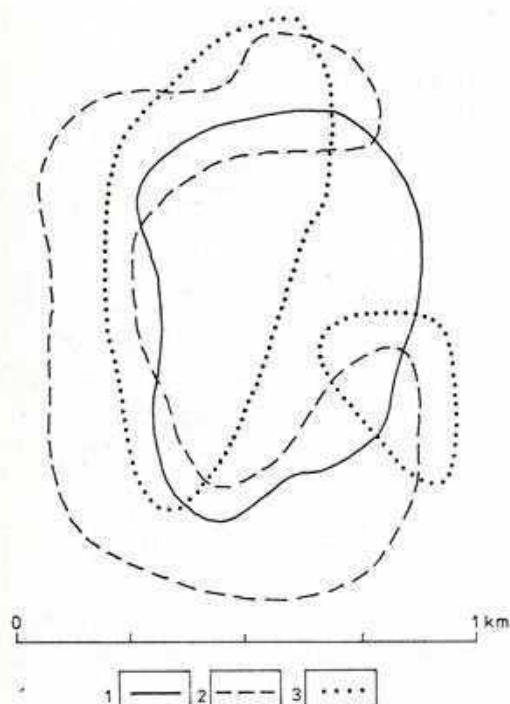


Fig. 5 - Mineralized zones - positive lithogeochemical anomalies. 1, central Cu-zone (100-2000 ppm Cu) $\pm$ Pb, Zn, Ag, Sn, Mo, Bi, B, S_T ; 2, peripheral Pb-Zn zone (30-200 ppm Pb, 120-500 ppm Zn) $\pm$ Cu, Ag, Sn, B, S_T ; 3, anomalous contents of K_2O (3.3-6 %).

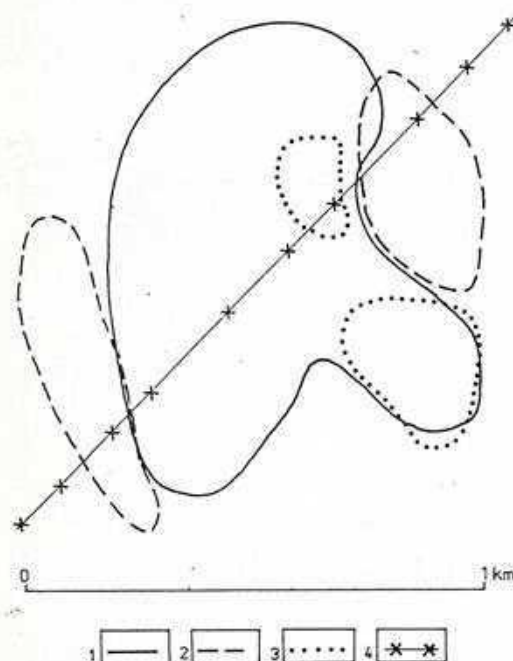


Fig. 6 - Negative lithogeochemical anomalies. 1, depletion of Na_2O (1.3-0.1 %), Mn (300-30 ppm) $\pm$ Fe_2O_3 (2.0-0.2 %); 2, depletion of Zn (25-5 ppm); 3, lithogeochemical profile through the zones of porphyry copper prospect.

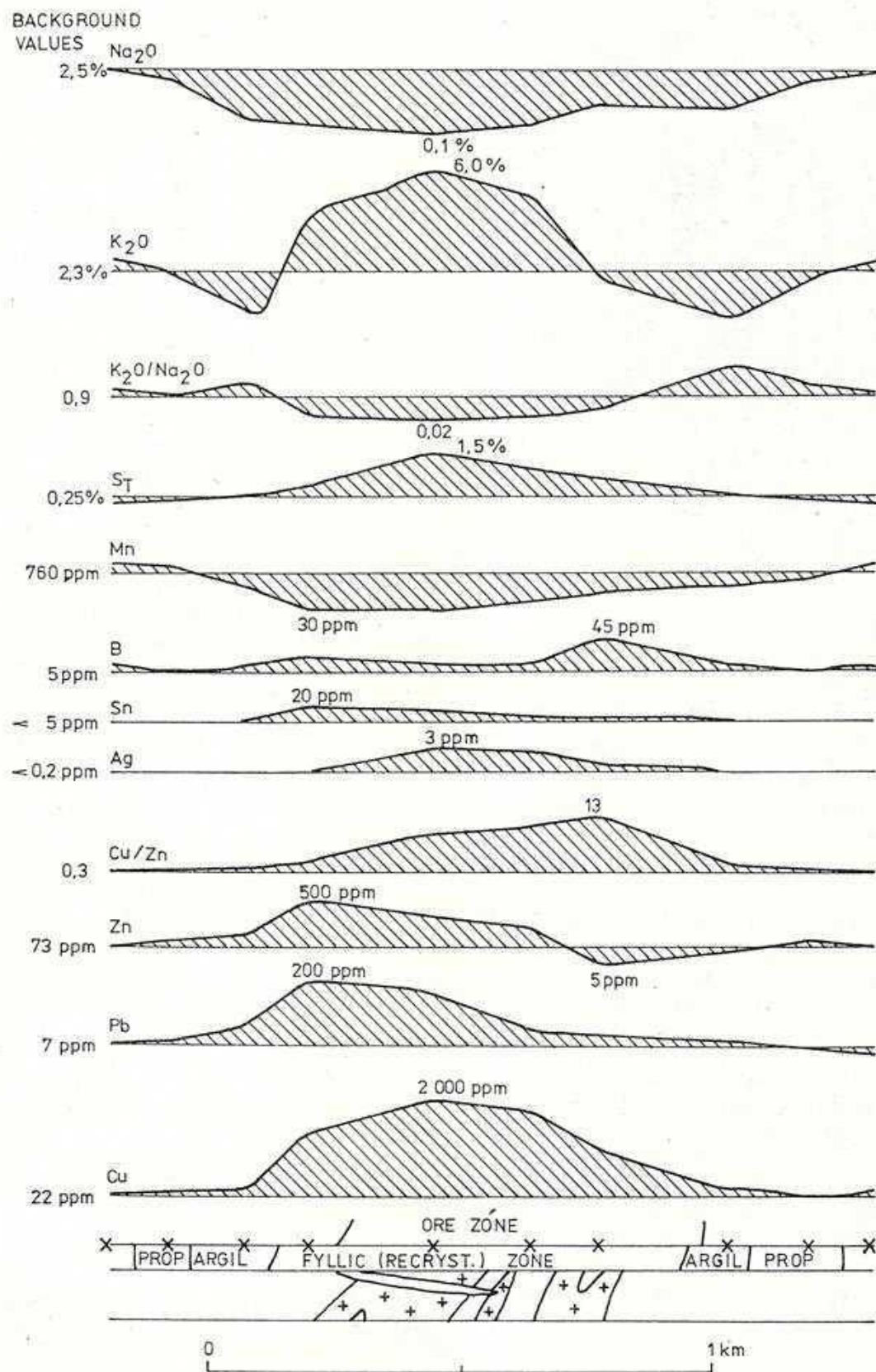


Fig. 7 - Lithogeochemical profile through alteration and mineralization zones

The negative geochemical anomalies of Na, Ca, Mg, Mn, Fe and Zn are caused mainly by the hydrothermal breakdown of plagioclases and Fe-Mg minerals (mainly biotite, less amphibole) in the process of sericitization. They are also due to silicification and argillization in some cases.

Conclusions

1. The main reason of the noneconomic grade porphyry copper mineralization in the studied area is the absence of the second boiling stage (therefore fracturing of the intrusions did not take place), what is due to the insufficient pT conditions and to the geometry of the intrusive bodies. That is why the dominant ore mineralization is connected with Mg and Mg-Ca skarn formation at the boundary of basement Mesozoic carbonates with granodiorite porphyry intrusions.

2. The presented alteration zoning model of the skarn related porphyry copper mineralization is transitional between the Lowell-Gilbert quartz monzonitic model (1970) and the Hollister dioritic model (1978). This fact corresponds to the granodiorite porphyritic composition of the related intrusions in the researched area.

3. The central copper zone with the most anomalous contents of Cu (up to 0.3 %), Mo (up to 500 ppm) and Ag (up to 13 ppm) is located in the phyllic alteration zone, while the highest contents of Pb (500 ppm) and Zn (600 ppm) are in the immediate surrounding of the peripheral polymetallic zone.

4. All the studied prospects are subeconomic with average contents of 0.1-0.35 % Cu (max. up to 1 % and 0.5 ppm), Au (max. up to 5 ppm) in the magnesian (partly Mg-Ca) exoskarns. According to the exploration data from the Zlatno prospect (66 mil. t of copper ore with the average content 0.34 % Cu) there might be about the same amount of copper ore on the other two medium-sized prospects, too. The ore is situated, with the exception of one prospect, in the depth range of 600 to 1000 m.

5. Oxidized cap and the cementation zone are not present here because of the deep erosion level.

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NEOGENE MAGMATISM AND METALLOGENY IN THE OȘ-GUTĂI-ȚIBLEȘ MTS.; A NEW APPROACH BASED ON RADIOMETRIC DATINGS

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Key words: Neogene volcanism. Epithermal ores. Andesites. K-Ar datings. Adularia. Illite. Pannonian. Oș-Gutâi-Țibleș Mts. East Carpathians.

Abstract: The Oș-Gutâi-Țibleș Mts are studied with numerous occurrences of fresh magmatic rocks and hydrothermally altered rocks with ages reaching Badenian to the youngest Upper Pannonian. K-Ar and Ar-Ar datings are the main tools for establishing their distribution in time. Radiometric determinations on whole rocks, adularia and illite were carried out at geochronological laboratories in Debrecen, Jerusalem and Grenoble. According to the available analytical data the magmatic activity started in Badenian ("acid phase") and continued with a complex intermediate volcanic activity ("intermediate phase") in Sarmatian and Pannonian. After a short period of quiescence (about 1 million years) the volcanic activity finished with basalts ("basic phase", 8.1-6.0 Ma) around the Pannonian/Pontian boundary. The dominant phase of magmatism belongs to the Pannonian. A continuation of the magmatism into the Pontian-Pliocene has been the subject of much debate. K-Ar determinations demonstrated that the Oș-Gutâi-Țibleș volcanism finished earlier than was expected. The hydrothermal activity and metallogenetic events have developed during the Pannonian (11.5-7.8 Ma). The previously considered Sarmatian and Pontian phases in the Gutâi Mts have not been proved. Based on radiometric data, the metallogenesis in the Gutâi Mts consists of two main phases: the first phase took place in the Lower Pannonian substage (11.5-10.0 Ma), including the metallogenetic events from Ilba-Nistru and Sasar-Dealul crucii districts and the second one was in the Upper Pannonian (9.4-7.0 Ma) including those of Herja-Băiuț district. The metallogenetic activity in the Oș and Țibleș Mts is contemporaneous with the second phase of the Gutâi Mts (9.6-7.8 Ma). The radiometric data give evidence of the presence of a gap (0.5-1.5 Ma) between the ages of the epithermal mineralizations (adularia-sericite type) and the host magmatic rocks (both volcanic and subvolcanic products). The results obtained in Baia Mare area are very similar those of other occurrences of the subduction zones.

Introduction

The Oș-Gutâi-Țibleș Mts belong to the Neogene/Quaternary volcanic chain of the Eastern Carpathians. They represent the northwestern segment of the chain from Romanian territory.

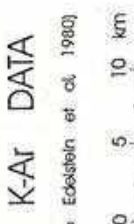
The volcanicity took place during the Neogene as a result of the magmatic processes related to the sub-

duction area located at the boundary of the East European Plate (Bleahu et al., 1973; Rădulescu & Săndulescu, 1973).

The Pre-Neogene basement consists of crystalline rocks belonging to Median Dacides and Paleogene formations of Transcarpathian Flysch forming the Botiza, Lăpuș and Petrova nappes (Săndulescu, 1984). The most important tectonic structure in the area is the W-E trending major transcrustal Dragoș Vodă fault situated on the southern border of the Gutâi Mts. Re-

SIMPLIFIED GEOLOGICAL MAP OF THE GUTĂI-OAȘ-TIBLEȘ MOUNTAINS

WITH K-AR DATA

(According to Edelstein *et al.* 1980)

Gutăi Mountains



Pannonian



Sarmatian



Badenian



Sedimentary deposits:

1. Quaternary;
2. Neogene;
3. Paleogene.

Igneous rocks:

1. Upper pyroxene andesites;
2. Quartz-diorites and quartz-diorites;
3. Lower pyroxene andesites;
4. Dacites and hyalodacites;
5. Rhyolites, perlites.

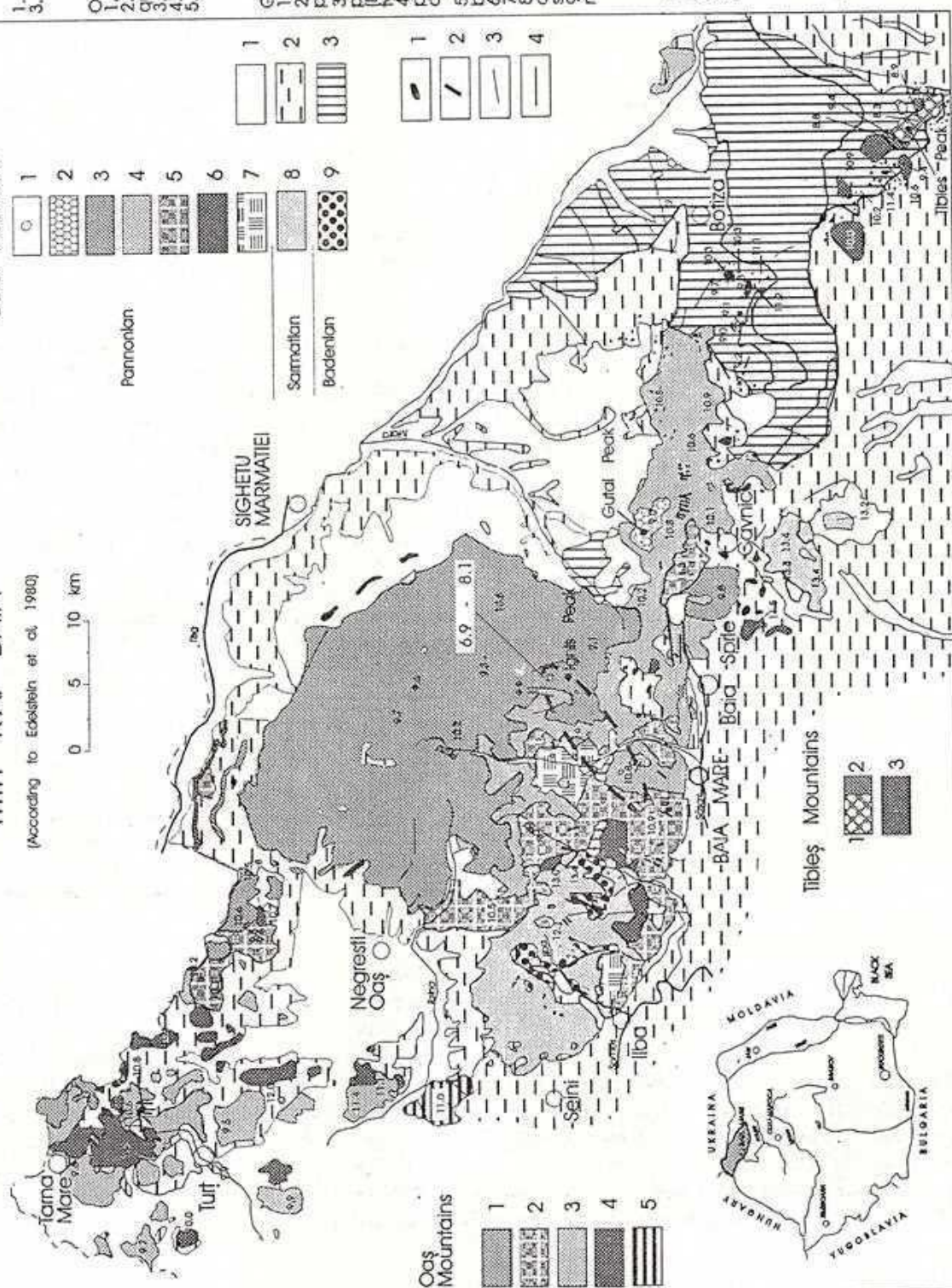
Gutăi Mountains:

1. Basalts;
2. Quartz, biotite, hornblende, pyroxene andesite (Gutăi type);
3. Pyroxene andesite and pyroxene basaltic andesite (Ighis-Mara, Sapina and Mogosa type);
4. Pyroxene basaltic andesites, pyroxene andesites and amphibole-pyroxene andesites;
5. Quartz andesites and quartz-basaltic andesites;
6. Dacites and hyalodacites;
7. Pyroxene andesite, andesite and pyroxene basaltic andesites, subordinated pyroxene dacites;
8. Volcaniclastic complex, mainly ignimbrites.

Tibleș Mountains:

1. Quartz-monzodiorites and diorites;
2. Andesites, microdiorites and dacites;
3. Microgranodiorites and dacites.

1. Intrusions;
2. Veins;
3. Faults;
4. Overthrusts.



lated to this area a deep-seated Neogene pluton was recently put in evidence by geophysical studies (Borcoş et al., 1991, 1993, unpubl. report).

The calc-alkaline character of the volcanism, their affinities with the island arc series, the presence of prevailing medium K rocks and the intense crustal contamination of the parental magmas were emphasized by Kovacs et al. (1987, 1992).

An important metallogenetical activity is related to the Neogene magmatism in the Oaş-Gutâi-Tibleş Mts. Well-known base metal and gold epithermal ore deposits occur especially in the southern part of the Gutâi Mts (Baia Mare area).

The sequence of eruption cannot generally be established by mere observations because of lacking stratigraphic relations and intercalations. Therefore a meaningful correlation in the complex magmatic activity and related metallogenesis can only be attained by radiometric dating.

The first K-Ar data on volcanics and adularia or sericite from different ore deposits in the Baia Mare mining district were determined at the Institute of Physics and Nuclear Engineering in Bucharest.

In the last years a large-scale radiometric investigations were performed in a scientific cooperation of Cuart S.A. Baia Mare with the Institute of Nuclear Research in Debrecen, Hungary, the Geological Survey of Israel in Jerusalem and the Dolomieu Institute of the Joseph Fourier University in Grenoble, France. At present more than 100 K-Ar data obtained on unaltered rocks (measured in Debrecen), 20 K-Ar and 3 Ar-Ar data determined on adularia (performed in Jerusalem) and 26 k-Ar ages obtained on adularia and illite mineral fractions (measured in Grenoble) are available for establishing the evolution of the Neogene magmatism and associated metallogenesis in the Oaş-Gutâi-Tibleş Mts.

Magmatism and metallogeny; geochronological data

The Oaş-Gutâi-Tibleş volcanic chain consists of three distinct units that show some peculiarities regarding the evolution of the magmatic activity and the structural features.

The Oaş Mts represent the northwestern part of the volcanic chain and consist of Neogene volcanic and sedimentary rocks. On the basis of biostratigraphical data, the volcanic products were generally considered Pannonian and Pontian-Pliocene in age (Borcoş et al., 1974, unpubl. report; Edelstein et al., 1980; Jude, 1986). However, according to the available radiometric data the volcanic activity of the Oaş Mts had a rapid evolution during a short time interval (12.0-9.5 Ma) which belongs to the Lower Pannonian and Upper Sarmatian (Fig. 1).

The Tibleş Mts represent a polystadial subvolcanic complex consisting of two magmatic phases (Edelstein et al., 1981, unpubl. report; Udubaşa et al., 1983): 1. an earlier acid phase including microgranodiorites and dacites and 2. an intermediate phase consisting of quartz monzodiorites (the main intrusion, Tibleş Măgura Neagră) and quartz diorites, microdiorites and andesites (the ring of the main intrusion and the small intrusions situated around the ring or in the northwestern part of the Tibleş Mts, Fig. 4).

K-Ar determinations on 15 magmatic rocks from the Tibleş Mts have yielded a range of ages 11.3-8.3 Ma. Thus, the magmatism in this area is contemporaneous with the dominant phase of the volcanism of the Oaş-Gutâi Mts. On the other hand the previously accepted stratigraphic succession of magmatic activity agrees with the relevant K-Ar ages. Contrary to expectations (Edelstein et al., 1981, unpubl.; Udubaşa et al., 1983), the small intrusions do not belong to the second phase of magmatism. In fact they are slightly older than the igneous rocks of the first phase (Hudieş Peak - 10.6 Ma and Stegioara Peak - 10.9 Ma, respectively).

The Gutâi Mts represent the unit with the most complex volcanism. According to Giuscă et al. (1973) and Borcoş et al. (1973) the volcanic activity developed in three cycles: the first cycle corresponds to the Badenian-Buglovian volcanism, the second cycle consists of four distinct phases between Sarmatian and Pontian and the third cycle includes the Pontian-Upper Pliocene volcanics.

The K-Ar datings on the volcanic rocks from the Gutâi Mts (Edelstein et al., 1993; Pecskey et al., 1994) do not confirm the presence of the Pontian and Pliocene volcanics (Fig. 1).

A sequence of events can be set up on the basis of field observations, petrographic considerations and geochronological data. The volcanism started with acid products, predominantly explosive, mainly ignimbritic character. Because of the strong alteration of these volcanic rocks they have not been radiometrically dated yet. However, the products of this volcanic phase have been determined biostratigraphically as Badenian-Lower Sarmatian. These are followed by an intermediate volcanic phase which consists of effusive and explosive features with associated intrusive counterparts. Andesites and basaltic andesites, mainly with pyroxenic character are predominant. The complex andesitic volcanic activity lasted about 4-5 Ma (13.4-9.0 Ma). A basic phase, consisting of small intrusions of basalts which occur only in the central part of the Gutâi Mts ceased the volcanic activity. The K-Ar data of the basalts fall in the age range 8.0-6.9 Ma (Edelstein et al., 1993).

The most important and complex activity took place

Table 1
The simplified succession of the volcanic rocks
in the Gutâi Mts according with the K-Ar ages

PONTIAN 7.0-8.5	Basic phase	Pyroxene basalts (Firiza zone)		6.9-8.1
PANNONIAN —11.5 ± 0.5—	Intermediate phase	IX	Quartz, biotite, hornblende, pyroxene andesites (Gutin type)	9.0-9.3
		VIII	Pyroxene andesites and basaltic andesites (Igniș-Mara, Săpința and Mogoșa type)	9.1-10.3
		VII	Amphibole andesites and dacites (Breze type)	10.0
		VI	Pyroxene andesites and basaltic andesites and pyroxene, hornblende andesites (Jereapăn type)	10.1-10.9
		V	Quartz bearing andesites (Piscuiatu - Șuitor type)	10.5-11.3
		IV	Biotite dacites (Dănești type)	11.6
		III	Pyroxene andesites (Ilba type)	11.9 (?)
		II	Pyroxene basaltic andesites and andesites (Seini and Răchițele - Căvnic type)	12.1-13.4
SARMATIAN —13.6 ± 0.2—	Acid phase	I	Pyroxene dacites (Șatra type)	13.2
BADENIAN		Volcaniclastic complex mainly ignimbrites		

during the intermediate phase (Tab. 1). The distribution of the radiometric ages determined on these rocks from the Gutâi Mts have led to the conclusion that the dominant phase of volcanism took place in the Pannonian (Fig. 2) consisting predominantly of medium K calc-alkaline rocks (Fig. 3).

It is worth mentioning that the subvolcanic activity in the Poiana Botizei-Botiza area (southeastern part of the Gutâi Mts) is contemporaneous with the paroxysm of the volcanic activity in Oaș and Gutâi Mts (Fig. 1).

The hydrothermal alterations consist predominantly of adularia-sericite type (typically low-sulphidation system, especially in the Gutâi Mts) and only in some areas advanced argillic type. An early propylitization, resulting from the activity of reducing $H_2O-CO_2-H_2S$ solutions in a partially closed system, was emphasized by Stanciu (1984) for the large majority of the alteration areas.

The mineralizations consist mainly of epithermal vein system having a base-metal and gold-silver char-

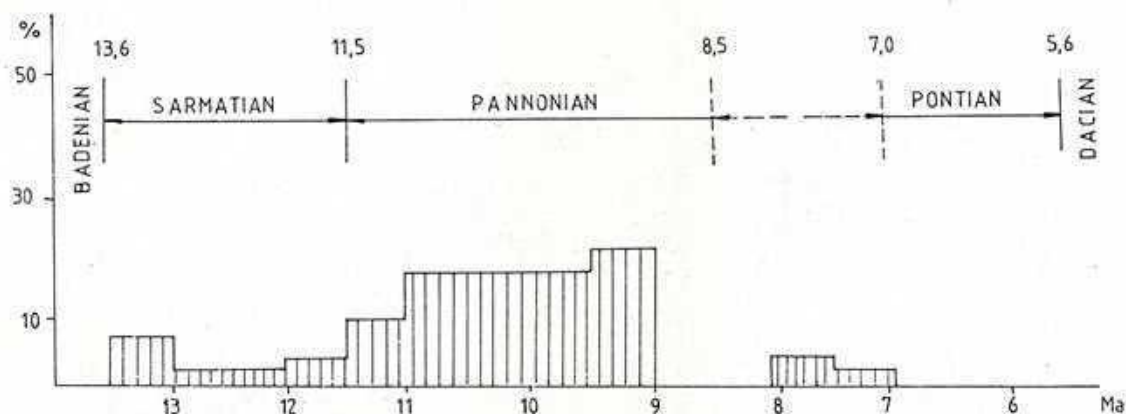


Fig. 2 - Distribution of the K-Ar ages on volcanic rocks in the Gutâi Mts (the histogram consists of a number of determinations reported at 0.5 Ma time interval)

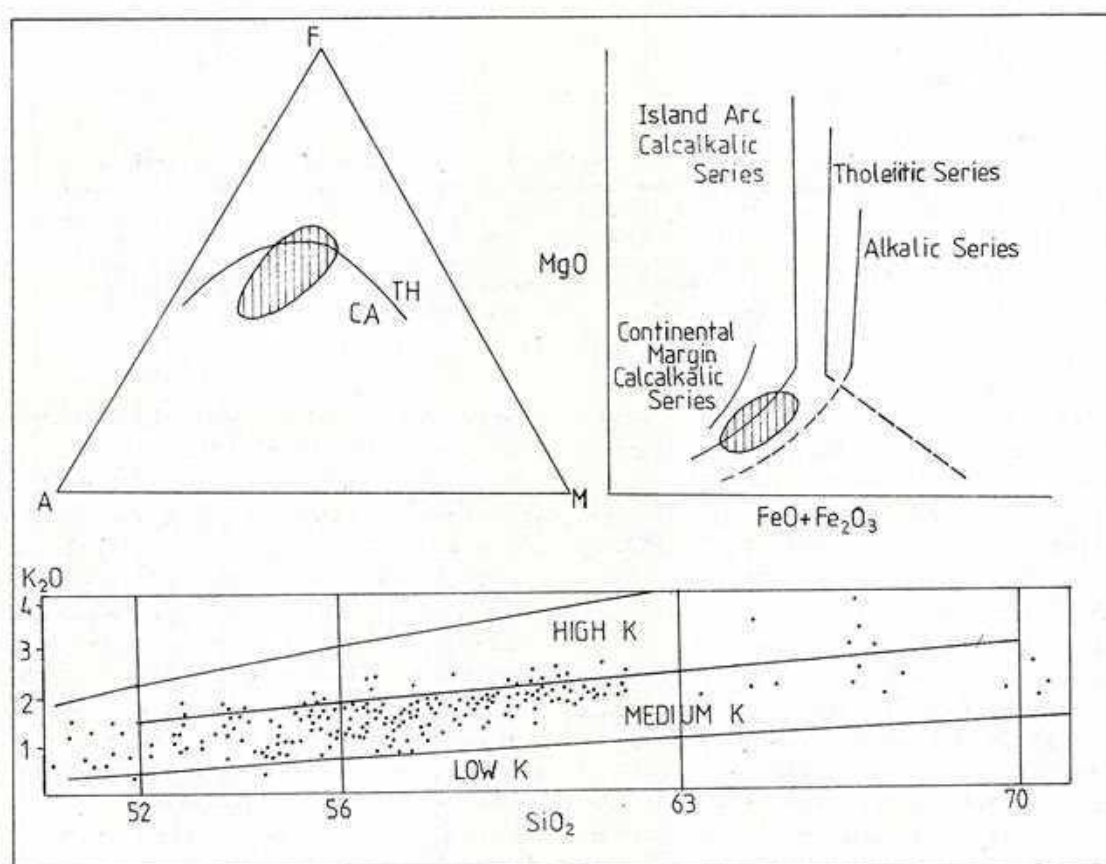


Fig. 3 - Distribution of the volcanic rocks belonging to the intermediate and basic phases in the Gutâi Mts in the AFM, MgO-FeO+Fe₂O₃ and K₂O-SiO₂ diagrams

acter. The stockworks and breccia pipes are subordinate. A hidden porphyry copper system was described in the southern part of the Tibleș Mts (Udubaș et al.,

1983, 1984).

In most of the cases the mineralizations developed almost entirely as vertical or subvertical veins of sev-

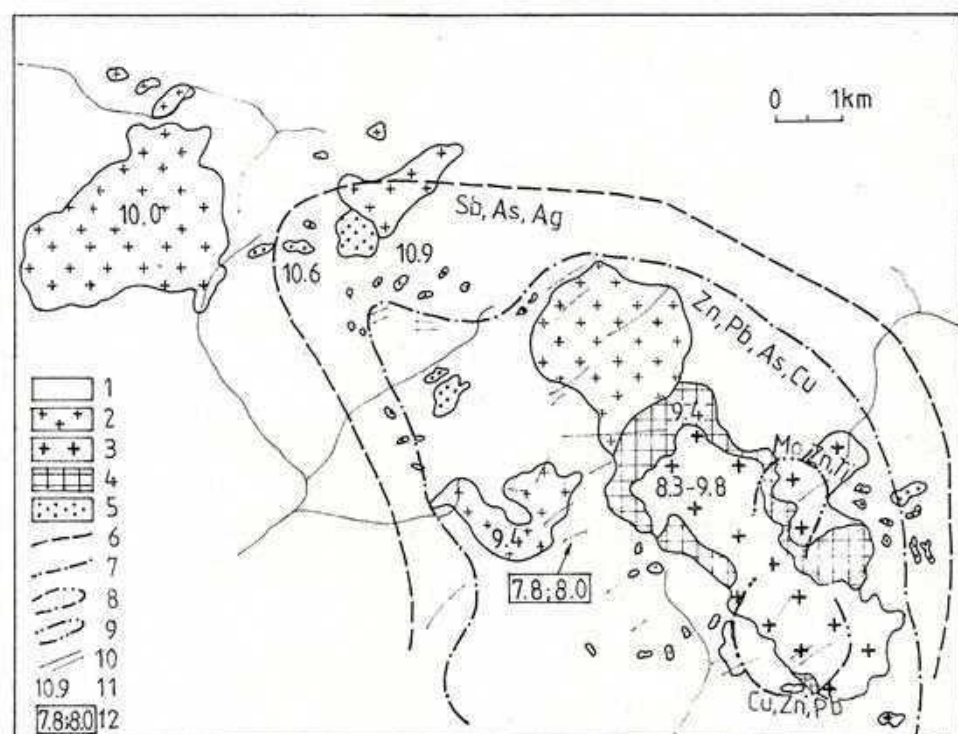


Fig. 4 – Metallogenetic map of the Tibleș Mts (according to Udubașă *et al.*, 1983) with radiometric data. 1. Oligo-Miocene sedimentary rocks; 2. microgranodiorites and dacites; 3. quartz monzodiorites; 4. quartz microdiorites and andesites (the ring of the main intrusion); 5. diorites, quartz diorites, microdiorites and andesites; 6. external belt of lower temperature vein assemblages; 7. inner zone of high temperature vein assemblages; 8. copper enriched ores and the hidden porphyry system; 9. Mo-Cu-Zn-Ti-B disseminations; 10. veins; 11. K-Ar ages of the igneous rocks; 12. K-Ar ages on sericite

eral hundred of meters up to 5 km in length and down to 800 m in depth. The majority of the ore deposits reveals a well developed vertical zonation: gold-silver in the upper part, lead-zinc in the middle part and copper in the deeper part (especially in the Gutâi Mts).

In the Oaș Mts, the main ore deposits, Socea-Tarna Mare, Ghezuri and Penigher-Turț, have a base metal character. Each of them represent a peculiar ore structure. The Socea ore deposit represents an andesitic stratovolcanic structure with associated intravolcanic intrusions. The mineralizations consist of a vein system located both in volcanics and in intrusions and of some breccia columns (like breccia pipes). The Ghezuri ore deposit represents an intrusive structure including dacites (microgranodiorites) with a vein system located at the western flank of the intrusion. The Penigher ore deposit is very similar with the Ghezuri structure but the veins are located only within the intrusion (microdiorites-monzodiorites).

The ages of the two adularia samples obtained in Grenoble laboratory (9.7 Ma from Socea) and in Jerusalem laboratory (9.2 Ma from Ghezuri) are in

good accordance and correspond to the presumed end of the volcanism in the Oaș Mts.

In the Tibleș Mts a complex metallogenetical activity took place. Two main mineralization types were described by Udubașă *et al.* (1983, 1984): 1. a vein system which forms some distinct metallogenetical belts (Fig. 4) and 2. impregnations and disseminated ores. The last one includes a hidden porphyry system with magnetite and chalcopyrite, developed in the southeastern part of the main monzodioritic intrusion, and a disseminated mineralization with sphalerite-rutile-molybdenite-tourmaline in Valea Mesteacănului area (northeastern part of the massif).

Until now, only two samples of sericite from the vein of Izvorul Rău II gallery (Bonhomme, 1993, unpubl.) were radiometrically dated (7.8 and 8.0 Ma respectively). These ages are younger than the radiometric ages determined on igneous rocks (see Fig. 4).

The best known ore deposits occur in the southern part of the Gutâi Mts (Baia Mare area). According to Giușcă *et al.* (1973) and Borcoș & Lang (1973), the metallogenetic events in the Gutâi Mts took place in

Table 2. Radiometric data for the main ore deposits
from the Gutâi Mts: Ad=adularia; Ill=illite

1. Base metal metallogenetical field Ilba - Nistru [Pb - Zn + Cu ± Au, Ag]				
Colbului Valley ore deposit	Purcăreț ore deposit	Mihai-Nepomuc ore deposit	Nistru ore deposit	
11.1 ± 0.2 (1)	10.8 ± 0.2 (4)	11.6 ± 0.6 (1)	11.5 ± 0.2 (2)	
(Ad)	(Ad)	(III)	(Ad)	
	10.7 ± 0.6 (2)			
	(III)			
	<u>10.6 ± 0.3</u>			
	(Ad)			
	Ar-Ar			
2. Gold epithermal system Săsar - Dealul Crucii metallogenetical field [Au - Ag ± Pb, Zn]				
Sofia ore deposit	Borzaș ore deposit	Valea Roșie ore deposit	Dealul Crucii ore deposit	Wilhelm ore deposit
10.0 ± 0.5 (6)	10.8 ± 0.3 (5)	10.2 ± 0.2 (2)	10.8 ± 0.2 (3)	11.0 ± 0.6 (3)
(Ad)	(Ad)	(Ad)	(Ad)	(Ad)
<u>10.1 ± 0.2</u>				
(Ad)				
Ar-Ar				
3. Base metal (± gold) metallogenetical field Herja - Băiuț [Pb - Zn ± Cu + Au, Ag]				
Herja ore deposit	Baia Sprie ore deposit	Șuitor ore deposit	Cavnic ore deposit	Băiuț (Văratec) ore deposit
8.8 ± 0.6 (1)	8.9 ± 0.4 (5)	9.3 ± 0.2 (1)	9.3 ± 0.5 (2)	9.0 ± 0.7 (2)
(III)	(Ad)	(Ad)	(III)	(III)
	8.2 ± 0.7 (3)			
	(III)			
	<u>7.9 ± 0.2</u>			
	(Ad)			
	Ar-Ar			

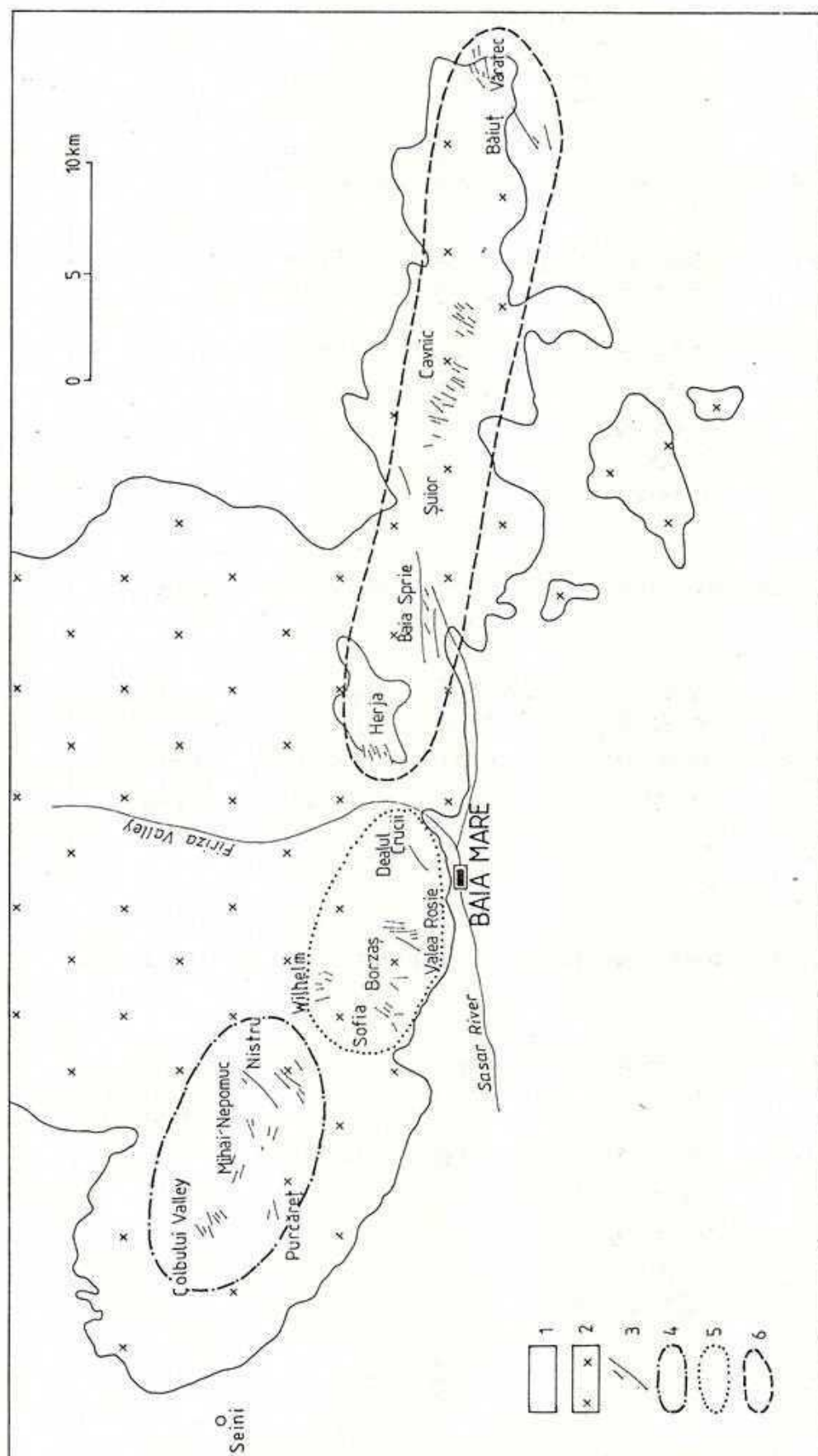


Fig. 5 – The main ore deposits from the Gutai Mts: 1, Quaternary, Neogene and Paleogene sedimentary deposits; 2, Neogene volcanic rocks; 3, Veins; 4, Base metal metallogenetic field Ilba-Nistru; 5, Gold epithermal system Săsar-Dealul Crucii metallogenetic field Herja-Băluț; 6, Base metal ($\pm$ gold) metallogenetic field Herja-Băluț.

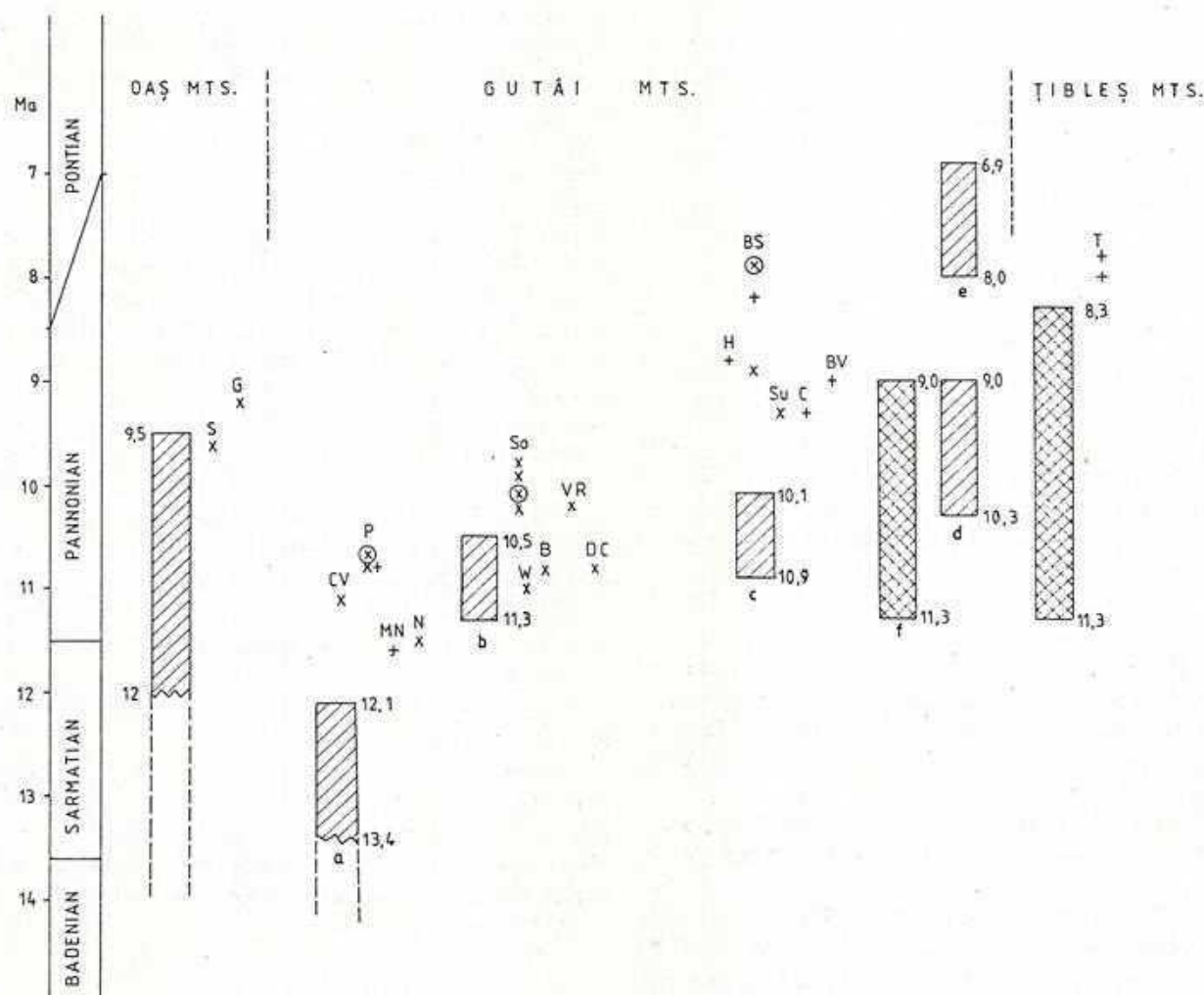


Fig. 6 - Geochronological data for the magmatic rocks and the hydrothermal K-bearing minerals from the main ore deposits in the Oaș-Gutâi-Țibleș Mts; vertical columns = time interval recorded by K-Ar dates in fresh magmatic rocks:

a = pyroxene basaltic andesites and andesites (Seini type);

b = quartz bearing andesites (Piscuiatu type);

c = pyroxene basaltic andesites and pyroxene, hornblende andesites (Jereapăn type);

d = pyroxene andesites and basaltic andesites (Igriș-Mara, Săpînța and Mogoșa type);

e = pyroxene basalts (Firiza zone);

f = subvolcanic intrusions from Poiana Botizei area;

x = K-Ar ages on adularia; = Ar-Ar ages on adularia (Lang et al, 1994);

+ = K-Ar ages on illite;

ore deposits: S = Socea; G = Ghezuri; CV = Colbul Valley (Ilba); P = Purcăret; MN = Mihai Nepomuc; N = Nistru; So = Săsar (Sofia); W = Wilhelm; B = Borzaș; VR = Valea Roșie; DC = Dealul Crucii; H = Herja; BS = Baia Sprie; Su = Șuor; C = Căvnic (Roata); BV = Băiuț (Văratec); T = Țibleș.

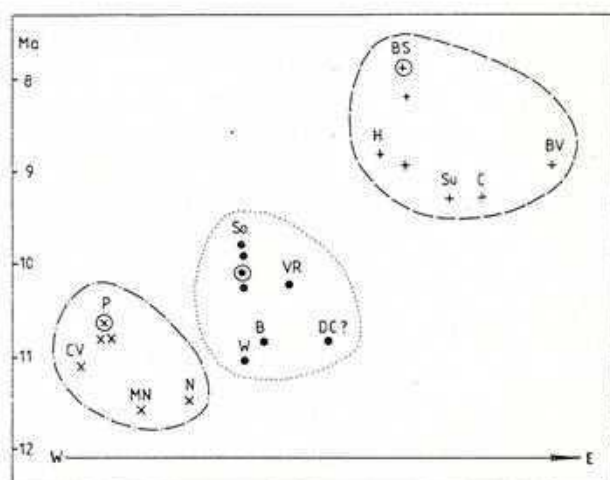


Fig. 7 - The relationships between the radiogenic ages on adularia and illite and the spatial distribution of the main ore deposits in the Gutâi Mts; x = radiogenic ages of the Ilba-Nistru district ore deposits; • = radiogenic ages of the Săsar-Dealul Crucii district; + = radiogenic ages of the Herja-Băiut district

three major phases:

- 1) The Sarmatian phase related to the Sarmatian andesitic volcanism developed in the Ilba-Băița district;
- 2) the Pannonian phase related to the Pannonian quartz andesites corresponding to the Băița-Valea Roșie district;
- 3) the Pontian phase associated to the Pontian andesites (Jereapăn type) developed in the Dealul Crucii-Băiut district.

The K-Ar and Ar-Ar datings on adularia from some ore deposits in Baia Mare area (Lang et al., 1994) do not confirm the previous considerations regarding the metallogenetical events. Based on these radiometric data the Sarmatian and the Pontian ages for the first and the third phases have not been proved; the hydrothermal activity took place only during the Pannonian.

Recent K-r datings on adularia and illite from the main ore deposits were performed at the Dolomieu Institute in Grenoble (Bonhomme, 1993, unpubl. data). All the available radiometric data for the ore deposits from the Gutâi Mts (Fig. 5) are presented in Table 2. In most cases the ages represent an average value of determinations performed in two or three laboratories (the number between brackets coincides with the number of K-Ar determinations).

Conclusions

The radiometric data obtained on fresh rocks and on hydrothermal K-bearing minerals from different ore deposits led to a new interpretation of the evolution of the magmatic activity and associated metallogeny in the Oaș-Gutâi-Tibleș Mts.

The magmatic activity took place in a shorter time interval as it was previously considered (Badenian-Upper Pannonian). The Pontian and Pliocene volcanic activity was not proved. On the other hand the radiometric ages of the hydrothermal products also confirm this assumption.

In the Gutâi Mts the volcanism ceased with a basic phase consisting of small intrusions of basalts.

The magmatic activity of Subvolcanic Unit Poiana Botizei-Tibleș was contemporaneous with the paroxysm of the volcanicity of the Oaș-Gutâi Mts.

The hydrothermal activity and metallogenetic events developed in a short time interval (11.5 - 7.8 Ma). They started after the beginning of the intermediate volcanic phase of the Gutâi Mts and took place only during the Pannonian.

In the Gutâi Mts the metallogenetical activity developed in two main phases (see Figs. 6 and 7): the first phase took place in the Lower Pannonian (11.5 - 10 Ma), including the metallogenetical events from Ilba-Nistru and Săsar-Dealul Crucii districts, and the second one is in the Upper Pannonian (9.4 - 7.9 Ma), including those from Herja-Băiut district.

The metallogenetic activity in the Oaș-Tibleș Mts is contemporaneous with the second phase of the Gutâi Mts (9.6 - 7.8 Ma).

The presence of a gap (0.5 - 1.5 Ma) between the ages of the epithermal mineralizations (adularia-sericite type) and the host magmatic rocks in Baia Mare area is very similar as compared to other occurrences from the subduction zones (Setterfield et al., 1992; McKee et al., 1992).

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CARACTÉRISTIQUES STRUCTURALES ET MÉTALLOGENÉTIQUES DES ROCHES MAGMATIQUES NEOGÈNES DU SECTEUR DE BAIA SPRIE-EST, À L'AIDE DE LA MODÉLISATION MAGNETIQUE EN 2 DIMENSIONS

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Key words: Igneous rocks. Neogene. Magnetic anomalies. Petrophysical data. Geophysical profiles. Metallogeny. Gutâi Mountains.

Abstract: The work shows the possibilities given by the simulation magnetical modelling in emphasising some major structural aspects, which are able to provide a better interpretation of the geological and metallogenetic processes, locally and regionally. The Baia Sprie area is located in the central-southern part of the Gutâi Mts and presents a special interest due its metallogenetic and geomorphologic particularities. The andesitic dike, mainly revealed through geophysical data, is one of the local structures responsible for creating the tectono-magmatic alignment, providing the longest vein ore. The magnetical modelling profile crossing the eastern side of the vein field, near Shaft 6, was designed for showing the morphological parameters of the Neogene plutonic body, defined by the aeromagnetical regional maximum in the southern Gutâi Mts and also for establishing the tectonic and structo-genetical relationship between the body and surface formations. In elaborating the modelling section, many types of geological data (surface-, underground-, drill-data), petrophysical data ("in situ" and laboratory determinations) and geophysical data have been used. The model, obtained through Talwani method for 2D structures, shows that the main anomalous source is a laccolithic quasi-horizontal structure, with a thickness of 2-4 kilometers and the average depth located at -1500 meters. It is obvious that the plutonic body has a symmetrical disposition referring to the faults that belong to the Dragoș Vodă field. The underground data, in the eastern zone, also showed a more complex structure, with a phreato-magmatical genesis. This profile is one of the six simulation magnetical sections, which were designed for establishing some major structural aspects of the whole area of the Gutâi Mts.

Introduction

L'objet de cette étude a été de faire l'analyse des possibilités offertes par la modélisation magnétique de mettre en évidence quelques aspects structuraux majeurs, pour une meilleure interprétation des éléments géologiques et métallogéniques en plan local et dans l'environnement géo-tectonique régional.

Le profil présenté est intégré dans un ensemble de six coupes de modélisation magnétique qui couvrent la région des Monts Guâi, de l'Ilba à l'ouest jusqu'à Băiuț à l'est (Crahmaliuc en Borcoș et al., 1994).

On a choisi le profil qui passe vers l'est du gisement de Baia Sprie pour plusieurs raisons:

- c'est une zone complexe, dont les particularités structurales et tectoniques la rendent tout à fait intéressante;

- l'extension réduite de la plaque des volcanites néogènes de ce secteur, qui a favorisé une meilleure interprétation des sources profondes;

- l'abondance des données géologiques et géophysiques dans cette région.

Cadre géologique et géophysique

Emplacé dans le secteur central des Monts Gutâi, le gisement de Baia Sprie est en directe liaison avec une structure magmatique complexe, de grade extension, développée entre deux fractures qui appartiennent à l'alignement transcrustal Câmpulung-Baia Mare-Carei. Ce système de fractures a été bien révélé par les données géophysiques, avec un développement de 260 km sur le territoire de la Roumanie (Andrei en Borcoș et al., 1994).

La structure composite de Baia Sprie a été interprétée soit comme un dyke, soit comme un graben rempli de coulées de laves en plusieurs étapes. L'activité volcanique et les processus métallogéniques ont été conditionnés par l'évolution des fractures majeures.

La carte gravimétrique Bourguer est caractérisée par une anomalie négative allongée dans le secteur dl. Minei - v. Limpedeia, continuée par un alignement des maxima jusqu'à Șuitor.

Les flancs des anomalies sont bordés par des gradients intenses qui marquent les tracés des fractures majeures (Andrei et al., 1970).

Les images magnétiques indiquent un alignement des maxima entre dl. Minei et Șuitor, qui peut représenter la zone très épaisse des produits andésitiques. L'amplitude des anomalies est caractérisée par une augmentation graduelle de l'ouest à l'est, en directe liaison avec l'intensité et la profondeur des transformations hydrothermales (Andrei et al., 1970).

Les déterminations mércurométriques, doublées par celles spectrométriques et pédo-géochimiques, ont mis en évidence les tracés des principales fractures filonienues leur continuation vers l'est, avec de petits décrochements, jusqu'à Șuitor (Ioane et al., 1988).

Données géologiques directes

Les andésites pyroxéniques de Jereapăn - couvrent la plus grande partie de cette région et sont représentées par des coulées disposées en alternance avec des séquences pyroclastiques et sédimentaires. Elles ont été interceptées dans tous les forages de cette zone, avec des épaisseurs et des altérations hydrothermales variables.

Les andésites pyroxéniques de Măgura et Mogoșa - sont développées vers le Nord et le Sud et sont en général plus basiques et plus fraîches.

Les andésites quartzifères de type Șuitor - affleurent au nord de la vallée du Săsar et dans un bloc tectonique élevé, entre Șuitor et la vallée du Cărnău.

Les structures intrusives - sont représentées par des dacites de Dănești, des andésites pyroxéniques et des andésites quartzifères, qui constituent le faciès intrusif des laves décrites auparavant.

Les formations sédimentaires - sont interceptées dans quelques forages profonds et montrent une succession normale, entre le Paléogène et le Pannonien (F. 508 Mohos, F. 490 Dănești, F. 519 Surdești).

Données pétrophysiques

La connaissance des propriétés pétrophysiques joue un rôle très important dans l'estimation des contrastes physiques entre les corps anomaux. Afin

de pouvoir établir des valeurs représentatives, on a exécuté de nombreuses déterminations de susceptibilité magnétique "in situ" et des déterminations pétromagnétiques et de densité, au laboratoire.

Dans cette région, les plus grandes valeurs pétromagnétiques sont enregistrées pour les andésites d'Igniș, de Șuitor et de Jereapăn (Tab. 1). Le coefficient Königsberger révèle des caractéristiques rémanentes plus fortes pour les andésites pyroxéniques de Jereapăn, affectées par des transformations hydrothermales.

Les valeurs de la densité sont: plus fortes - pour les andésites de Jereapăn (2.72-2.78 g/cm³), intermédiaires - pour les andésites de Mogoșa et Igniș et très faibles - pour les andésites quartzifères et les intrusions acides.

Modélisation magnétique

Les modélisations géophysiques sont représentées par l'ensemble des méthodes itératives, qui permettent une bonne corrélation entre les effets observés et calculés, obtenus à partir d'une structure aux paramètres morphologiques et physiques connus.

Pour la modélisation magnétique en 2D on a appliqué le procédé classique de Talwani, adapté aux microordinateurs. En bref, la méthode de Talwani est basée sur l'approximation des effets donnés par des corps au contour polygonal et extension latérale infinie (Talwani, 1965) (Fig. 1).

Dans notre situation, nous avons modélisé l'anomalie aéromagnétique, qui a été compensée pour un gradient anomal régional de 125 nT. Pour chaque corps sont utilisées les valeurs moyennes de susceptibilité magnétique effective (Tab. 1). Pour les andésites de Mogoșa et Igniș sont utilisées des valeurs réduites, parce qu'elles ne se rangent pas dans les conditions d'une modélisation 2D (Tab. 2). La valeur employée pour le corps plutonique est une approximation des données pétrophysiques obtenues sur quelques structures microdioritiques et granodioritiques (Andrei en Borcoș et al, 1993, 1994).

Les principales conclusions acquises après cette modélisation sont;

- la source majeure, responsable de l'anomalie magnétique (88 % de son amplitude) est représentée par le corps plutonique, alors que les effets donnés par la plaque des volcanites et les structures intrusives ne justifient que 12 % (Fig. 2);

- les zones apicales d'anomalie magnétique, doublées par des maxima gravimétriques, mettent en évidence les principales apophyses. Quoique pour ces élévations et pour le corps plutonique on ait utilisé des valeurs pétrophysiques semblables, elles peuvent avoir quand même des caractéristiques différentes en ce qui

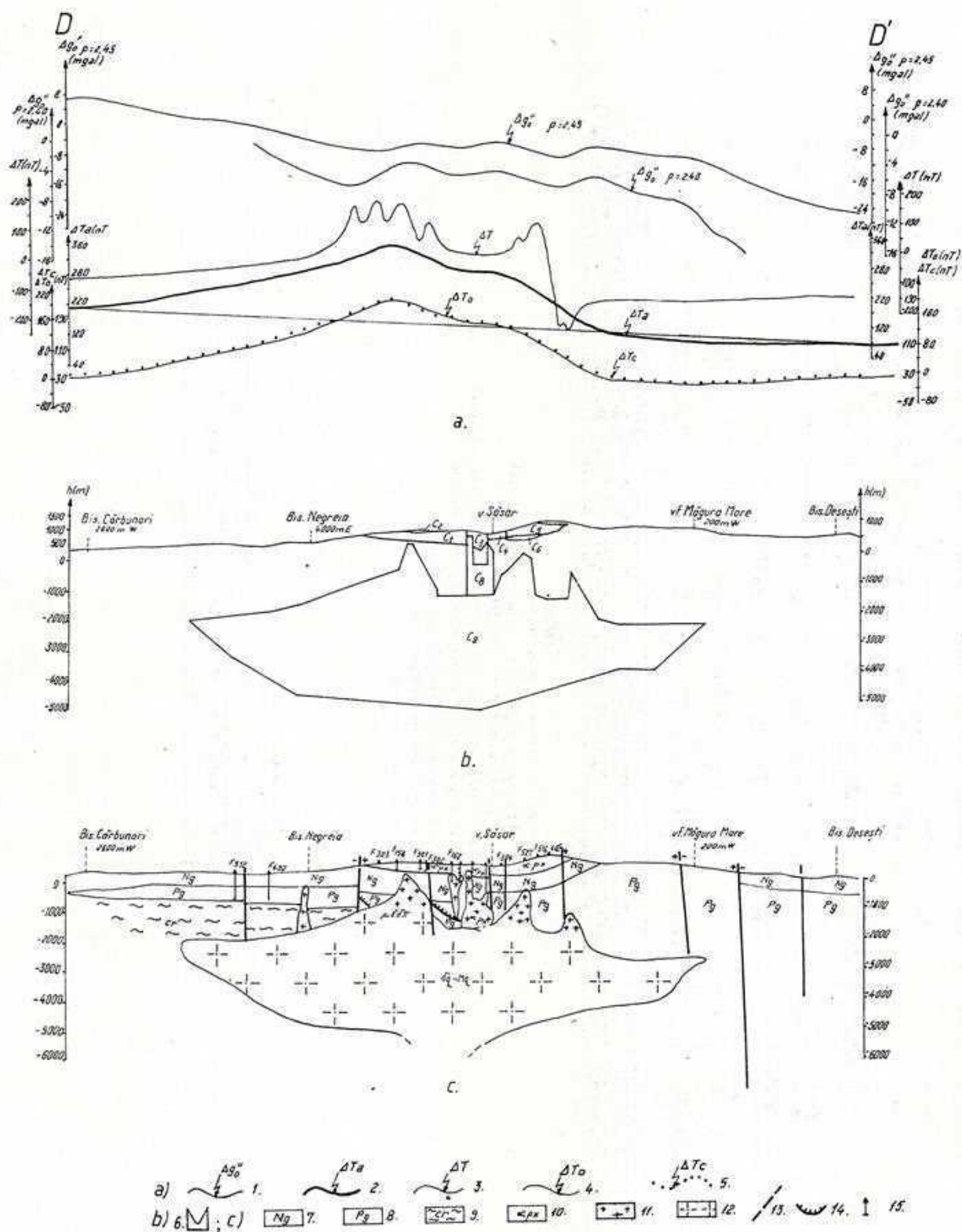


Fig. 1 - Modélisation magnétique en 2D : a, profils géophysiques; b, contours polygonaux modélisés; c, section géologique interprétative; 1, anomalie gravimétrique de Bouguer; 2, anomalie aéromagnétique régionale; 3, anomalie aéromagnétique locale; 4, anomalie magnétique observée; 5, anomalie magnétique calculée; 6, contours polygonaux des corps modélisés; 7, formations sédimentaires néogènes; 8, flysch paléogène; 9, formations métamorphiques du soubassement; 10, plaque des volcanites; 11, corps intrusifs; 12, corps plutonique; 13, fractures; 14 - nappes; 15, forages.

Tab. 1, 2

Table 1

Les valeurs moyennes des paramètres pétrophysiques des formations interceptées par le profil Cărbunari-Baia Sprie Est - Desești

formations	ages	X _{as} moyenne(min-max) μu CGS	X _v moyenne(min-max) μu CGS	Q moyenne(min-max)	dv moyenne(min-max) g/cm ³	observations
and. px. igniș	p-pl	2252 (1200-3600)	2600 (1270-3549)	0.93 (0.1-3.7)	2.63 (2.46-2.74)	lavas+intrusions
and. px.+ho. Mogoș	p-pl	991 (20-3900)	1618 (27-4247)	1.38 (0.2-4.5)	2.66 (2.30-2.84)	lavas+intrusions
and. px.+ho. Jereapăn	p	433 (12-3200)	2065 (364-3405)	0.95 (0.3-1.8)	2.72 (2.69-2.77)	lavas
and. px.+ho. Jereapăn	p	725 (16-5000)	1360 (13-3483)	1.88 (0.1-11.3)	2.78 (2.42-2.83)	intrusions
and. q.+ho., px. Șuier	pn	1475 (680-2300)	2314 (1626-4398)	0.47 (0.1-0.8)	2.55 (2.43-2.65)	
dac.+bi.ho.px. Dănești	pn	815 (410-1000)	1140 (834-1481)	0.47 (0.1-1)	2.44 (2.26-2.54)	
sédimentaire	sm	25 (8-80)	61 (17-191)	4.22 (0.1-17.2)	2.67 (2.61-2.71)	cornifications
sédimentaire	pg	35 (4-390)	38 (8-124)	1.27 (0.1-17)	2.66 (2.50-2.80)	souterrain+cornifications
sédimentaire	pg	68 (3-750)	997 (10-2844)	3.01 (0.1-36.5)	2.70 (2.46-2.82)	surface+cornifications

Légende

and.px. = andésites pyroxéniques
 and.px.+ho = andésites pyroxéniques à hornblende
 and.q.+ho = andésites quartzifères à hornblende
 dac.+ bi.ho.px. = dacites à biotite, hornblende et pyroxènes
 X_{as} = susceptibilité magnétique apparente in situ
 X_v = susceptibilité magnétique de volume
 Q = coefficient de Königsberger
 dv = densité de volume

Table 2

Les valeurs moyennes utilisées dans la modélisation en 2D

Numéro de corps	1	2	3	4	5	6	7	8	9
Susceptibilité μu CGS)	400	1100	200	1200	300	1200	1400	1200	2000

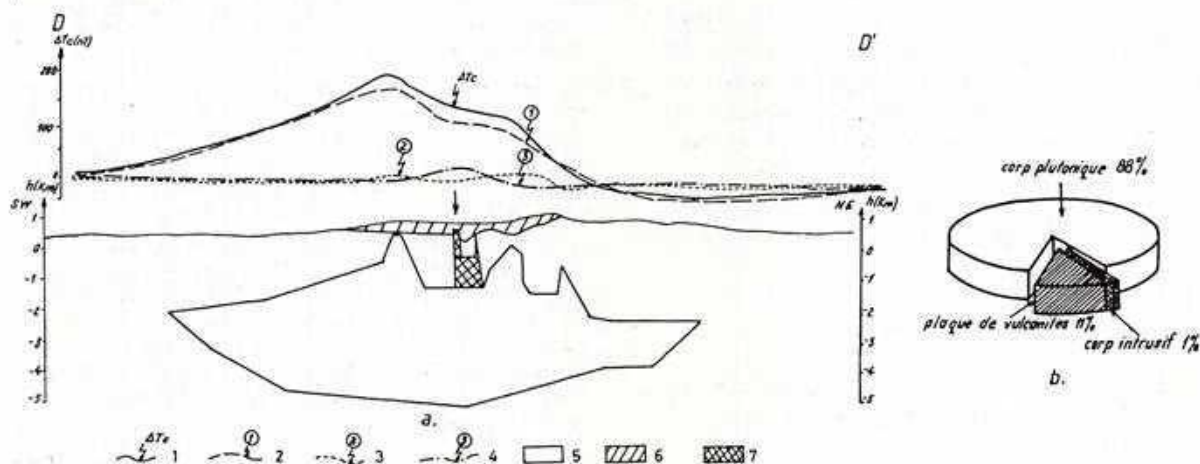


Fig. 2 - Représentation des contributions individuelles de chaque élément structural à l'engendrement de l'anomalie magnétique totale; a, effets magnétiques individuels de chaque élément structural; b, diagramme en 3D de la contribution de chaque élément structural; 1, anomalie magnétique totale; 2, effet du pluton; 3, effet de la plaque des volcanites; 4, effet des corps intrusifs; 5, corps plutonique; 6, plaque des volcanites; 7, corps intrusifs.

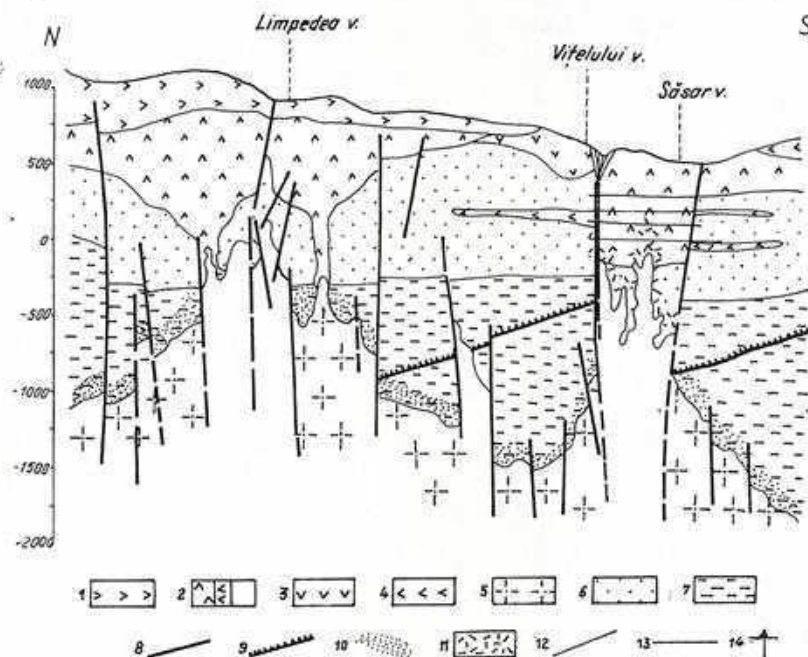


Fig. 3 - Profil géologique à travers le secteur de Baia Sprie Est (d'après Borcoş et al., 1994); 1, andésites pliocènes; 2, andésites pontiennes; 3, andésites quartzifères pannoniennes; 4, diorites; 5, diorites, culminations du pluton; 6, molasse néogène; 7, flysch paléogène; 8, fractures; 9, nappes; 10, cornifications; 11, bréchifications; 12, filons; 13, galeries; 14, forages.

concerne l'âge et la composition pétrochimique (Fig. 1);

- dans le secteur médian, le modèle est en accord avec les dernières interprétations de la zone Baia Sprie Est (Fig. 3). Ici, cette structure complexe est représentée par un graben rempli de plusieurs coulées de laves, en alternance avec de niveaux pyroclastiques et volcano-sédimentaires, qui ont été affectés par des transformations intenses, phréato-magmatiques. Les brèches et les andésites effusives sont percées par des intrusions d'andésites pyroxéniques et quartzifères (Borcoş et al., 1994) (Fig. 3).

Conclusions

Cette modélisation est un exemple qui montre les possibilités offertes par l'interprétation géophysique dans l'étude des structures profondes.

Dans notre situation, le corps plutonique des Monts Gutâi représente une structure bien contourée, qui a été interceptée par tous les 6 profils de modélisation magnétique (Crahmaliuc, en Borcoş et al., 1994). Cette modélisation a contribué, en corrélation avec les autres coupes, à la bonne connaissance de la morphologie de cette structure plutonique, en rapport avec les structures volcaniques de surfaces et les autres unités structurales de cette région.

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MODÉLISATION MAGNÉTIQUE EN 3 DIMENSIONS DE LA STRUCTURE PLUTONIQUE DE LIVADA

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Key words: Plutonic structure. Aeromagnetic anomalies. Geophysical profiles. Gutâi Mountains.

Abstract: In the western part of the Gutâi Mts, where the sedimentary formations grow thicker, the regional aeromagnetic map shows a maximum, with three local anomalous peaks. The only direct geological signs have been given in the Drăgușeni 1 Drill, which crossed some pyroxenic andesitic rocks at -941 meters. A 3D magnetical modelling was applied for obtaining the contour of the sources. This is based on approximating the structure with many horizontal slabs having constant thickness and polygonal contour. The final solution and the integrated interpretation of all available data prove the presence of a laccolithic structure, with a quartz-dioritic composition probably nature, placed at 2-4 kilometres depth. The shape of the body is almost elliptical, WNW-ESE mostly developed, suggesting a profound increase after a major fault with the same direction. The anomalous peaks from Agriș and Livada belong to some elevations of this structure, while the local maximum of Adrian is given by a superficial source. Through its physical and geological particularities, the Livada body has been an ideal structure for applying a 3D magnetical modelling, allowing a fine correlation with the results of other geophysical methods. All processing and interpretation methods point out the possibility of showing hidden structures, even when missing direct observation data, and can also be used for other similar structures of economic interest.

Introduction

L'anomalie de maximum aéromagnétique de Livada indique la présence d'une source magmatique profonde, avec des propriétés pétromagnétiques plus fortes que les formations sédimentaires et métamorphiques de cette zone.

Les particularités physiques et structurales et la forme pseudo-isométrique de l'anomalie ont encouragé la mise en pratique d'une modélisation magnétique en 3D.

L'absence des produits magmatiques superficiels a permis une meilleure détermination des éléments morpho-structuraux pour les sources anormales profondes.

Cadre géologique et géophysique

La zone anormale est localisée à presque 25 km de Satu Mare, dans les extrémité ouest des Monts Gutâi et sud des Monts Oaș.

Au point de vue structural, la zone est placée dans la région marginale de la Dépression Pannonique, en contact avec les structures caractéristiques des produits magmatiques néogènes.

Le soubassement tectonique par plusieurs systèmes de fractures est caractérisé par une succession normale, depuis le Paléogène jusqu'au Pannonien-Pontien.

L'anomalie aéromagnétique régionale indique la présence d'une structure magmatique profonde, capable de réaliser, en rapport avec le soubassement et les dépôts sédimentaires, un contraste pétromagnétique positif (Cristescu et al., 1967; Andrei et al, 1970; Crahmaliuc en Borcoș et al., 1994).

Les données gravimétriques et sismiques révèlent les accidents tectoniques du soubassement, qui est compartimenté dans un mosaïque de blocs aux différentes elevations.

Dans le secteur Livada, le forage 1 de Drăgușeni est le seul qui à intercepter (à 941 m de profondeur) des roches magmatiques, représentées par des andésites pyroxéniques.

Les données pétrophysiques ont été obtenues seulement sur quelques échantillons prélevés dans les for-

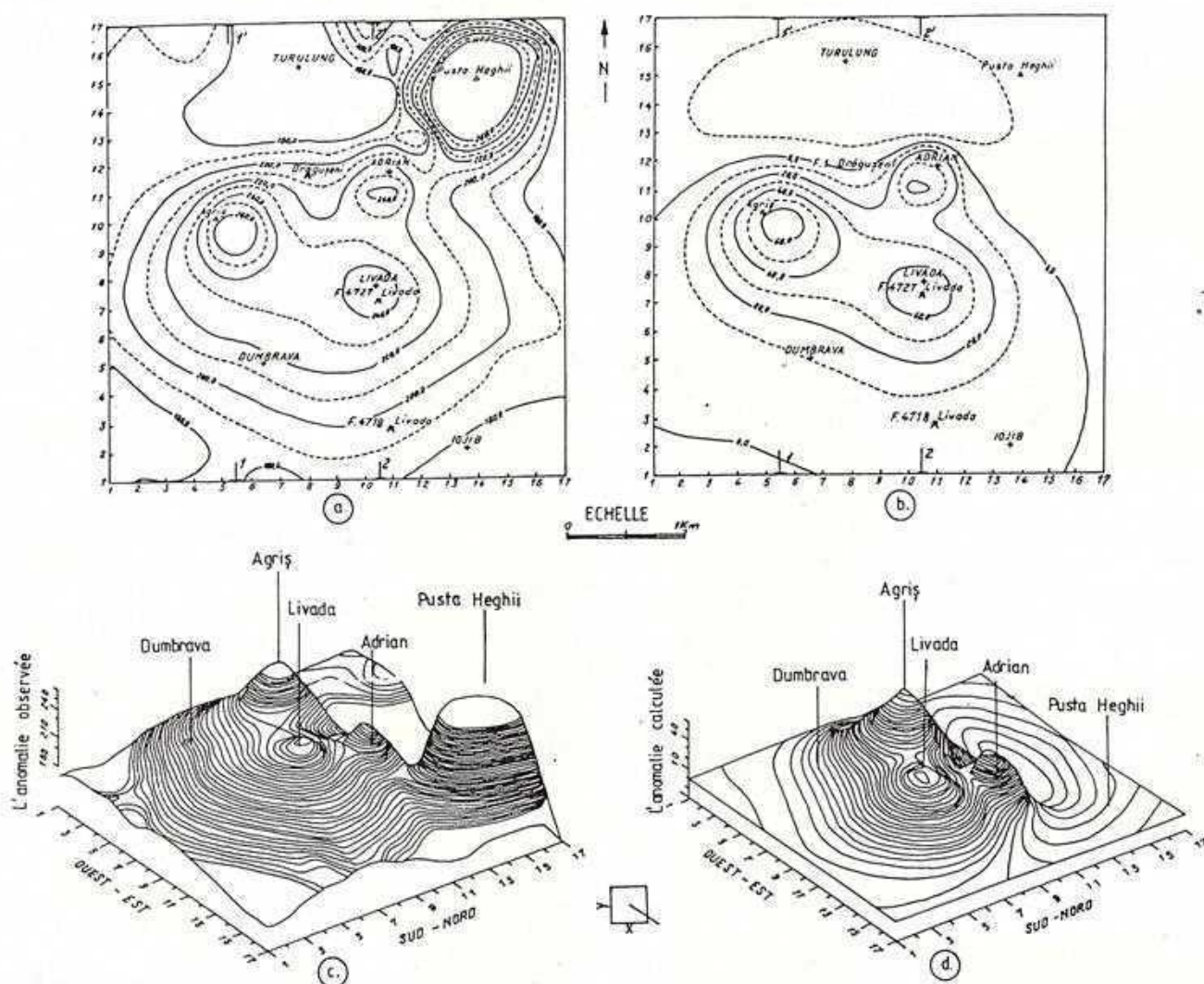


Fig. 1 - Les effets anomaux de la structure de Livada: a, carte aéromagnétique observée; b, carte magnétique calculée; c, effet anormal observé, en perspective 3D; d, effet anormal calculé, en perspective 3D

ages de toute la région et dans une structure éruptive du nord-est de l'anomalie.

Malheureusement, dans notre cas les valeurs pétromagnétiques ne sont pas très rélevantes (susceptibilités moyennes entre 850 - 1250 mu CGS), parce qu'elles ne peuvent pas justifier l'amplitude et l'extension de l'anomalie aéromagnétique. Pour la principale source anormale modélisée, nous avons utilisé des valeurs équivalentes, extrapolées des structures plutoniques du Sud des monts Gutâi et de l'alignement de Carei-Moftinu-Terebești.

La modélisation magnétique en 3D

Afin de pouvoir établir un premier modèle interprétatif, on a exécuté dans une première étape 3 coupes de modélisation 2D, qui ont traversé les zones apicales de l'anomalie aéromagnétique.

Ensuite, nous avons utilisé un procédé classique de modélisation en 3 dimensions, dans lequel on considère les sources anormales comme des plaques polygonales aux épaisseurs constantes. L'effet total calculé est représenté par le cumul des effets individuels, générés par chaque plaque polygonale à part (Talwani, 1965).

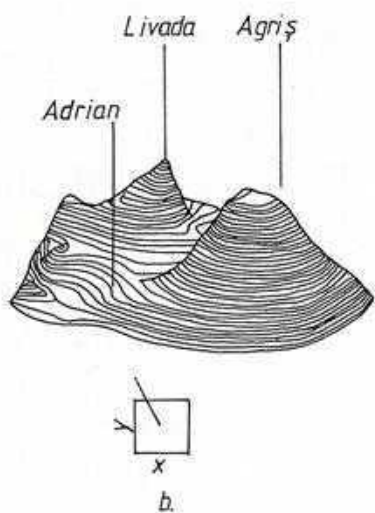
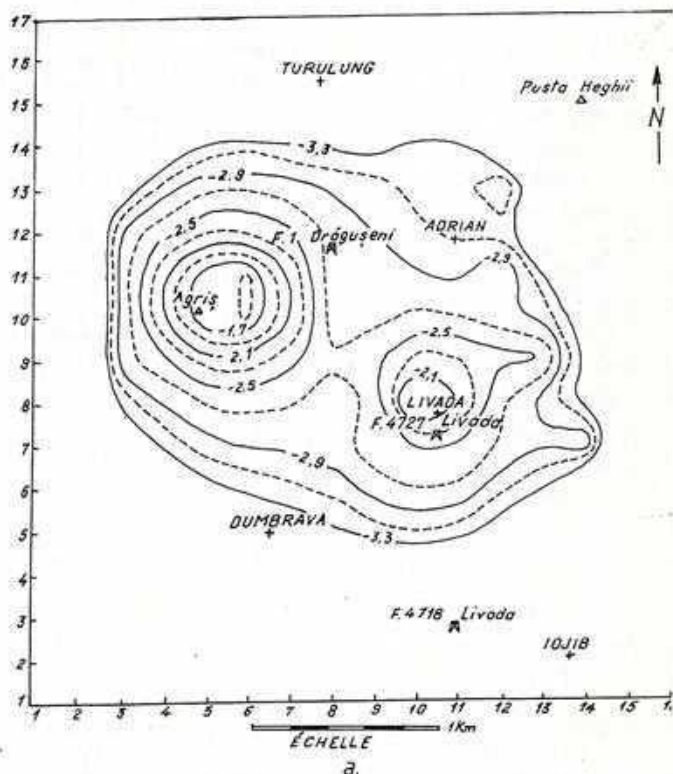


Fig. 2 - Corps plutonique modélisé: a, carte bathymétrique à la surface du corps plutonique; b, la surface du corps plutonique en perspective 3D.

Les paramètres géométriques et physiques des plaques ont été modifiés selon un procédé itératif jusqu'à la meilleure concordance entre les valeurs observées et celles calculées.

Pour des raisons méthodologiques et pratiques, nous n'avons pas modélisé la structure volcanique de Pusta Heghi, mais cela n'a pas affecté de manière essentielle les résultats dans la zone d'intérêt.

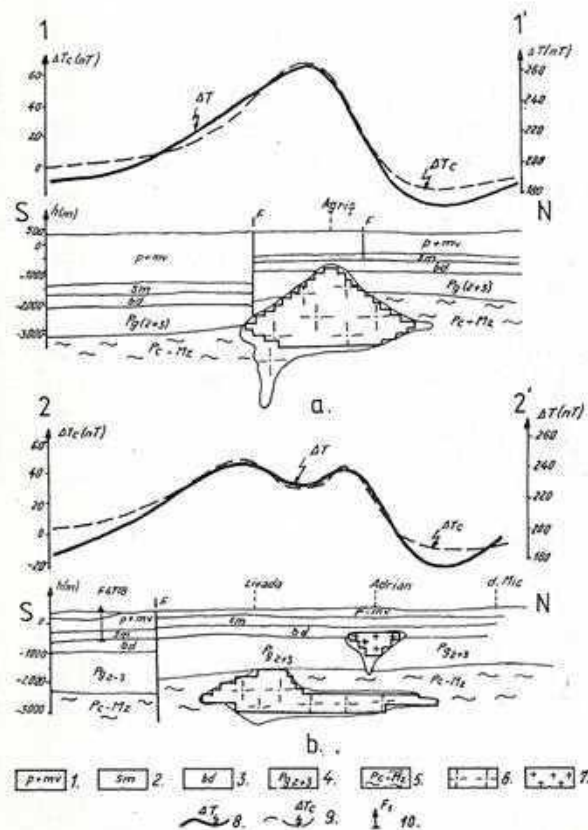


Fig. 3 - Sections interprétatives sur la structure modélisée de Livada: a, section 1-1'; b, section 2-2'; 1, Pontien-Malvensien; 2, Sarmatien; 3, Badénien; 4, Oligocène-Eocène; 5, Précambrien-Mésozoïque; 6, corps plutonique; 7, structure intrusive; 8, anomalie aéromagnétique observée; 9, anomalie magnétique calculée; 10, forage.

Dans les images de la dernière variante modélisée (Fig. 1), on peut constater, dans la zone centrale, la bonne concordance entre les effets observés et ceux calculés (les isodinammes de 220 nT et 20 nT), également pour les trois zones apicales. L'absence de la structure de Pusta Heghi n'a influencé que la zone de minimum de l'anomalie aéromagnétique, sans avoir une influence négative sur notre interprétation (Crahmaliuc en Borcoș et al., 1994).

Les profils coupant les zones apicales indiquent une bonne corrélation pour les secteurs centraux aussi (Fig. 3); les différences entre les extrémités sont données par deux catégories de facteurs:

- raisons méthodologiques, propres aux modélisations en 3D;
- l'influence latérale de quelques sources intrusives limitrophes.

L'interprétation intégrée

Les itérations ont été corrélées avec l'analyse des images géophysiques initiales et préparées par quelques méthodes de filtrage. Par exemple, à partir des cartes magnétiques et gravimétriques nivelées et résiduelles, on a constaté que l'anomalie magnétique locale d'Adrian était donnée par une structure tout à fait superficielle, du fait qu'elle n'était pas doublée d'une anomalie gravimétrique résiduelle (Fig. 3).

La source de l'anomalie aéromagnétique majeure est représentée par une structure de type laccolithe aplati, emplantée à des profondeurs de 2-4 km. L'aspect du corps plutonique est presque elliptique, avec un axe majeur orienté approximativement O-E. Les zones apicales de Livada et Agriș sont en directe correspondance avec deux élévations du corps plutonique (Figs. 2 et 3).

L'analyse intégrée des images gravimétriques, magnétiques et des données sismiques indique:

- un compartiment du soubassement élevé dans l'extrémité Est de Livada (révélé par un maximum de l'anomalie gravimétrique de Bouguer), qui est intégré dans le horst de Livada-Negrești (Andrei en Borcoș et al., 1994);

- le corps plutonique est développé en directe liaison avec une fracture majeure, qui représente la continuation vers l'Ouest de l'alignement tectonique de Bogdan Vodă;

- le secteur le plus épais de la structure plutonique est en bonne corrélation avec l'axe gravimétrique de maximum;

- l'alignement de minimum gravimétrique est en concordance avec une structure synclinale du soubassement, déterminée par les profils sismiques (Fotopolos, 1967; Visarion et al, 1977);

- l'absence d'une anomalie gravimétrique en corrélation avec celle magnétique est expliquée par les valeurs de densité comparables entre les magmatites intrusives et les roches métamorphiques du soubassement ($2.70 - 2.75 \text{ g/cm}^3$) et l'absence d'un contraste de masse. Ces valeurs de densité sont caractéristiques pour les structures intrusives avec une probable composition quartz-dioritique au monzo-dioritique;

- les maxima gravimétriques résiduels sont déterminés par le contraste entre les apophyses du pluton et les dépôts sédimentaires néogènes;

- l'élévation d'Agriș a percé les sédiments jusqu'à 800 m de la surface, tandis que celle de Livada, emplantée dans une zone de jonction tectonique, s'élève jusqu'à 1300 m.

Conclusions

Par ses particularités, la structure plutonique de Livada a offert, outre les conditions idéales de modélisation 3D, une bonne corrélation entre toutes les données géophysiques.

L'ensemble des traitements et l'interprétation intégrée, en dépit du manque d'informations géologiques directes, se sont constitués dans une procédure méthodologique susceptible d'être utilisée sur d'autres structures d'intérêt géologique et économique.

Quelques indicateurs de transformation hydrothermale obtenus sur des échantillons prélevés par d'autres forages de cette région qui ont intercepté des roches magmatiques plaident à la faveur de l'existence d'une activité métallogénique dans la partie supérieure de cette structure plutonique.

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CORRELATION BETWEEN THE ORAVIȚA-KREPOLJIN AND THE BOR-SREDNJEGORIE METALLOGENIC ZONES

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Key words: Metallogenic zone. Subduction. Base metals. Association of elements.

Abstract: The Alpine metallogenic unit in the southern sector of the Carpatho-Balkan arc ("Banat-Srednjegorie zone") is represented by two metallogenic zones: the Oravița-Krepoljin zone in the west, and the Bor-Srednjegorie in the central part. They were formed in front of the Jurassic-Cretaceous oceanic slab, subducted from the Vardar zone beneath the Eurasian plate. The mineralization is associated mainly with late Upper Cretaceous calc-alkaline igneous activity. Although both metallogenic zones contain many common major elements, they differ with regard to the styles of mineralization and environments of deposition. The Oravița-Krepoljin metallogenic zone is linked with a major deep-fractured zone, located along the western margin of the Carpatho-Balkan block. A longitudinal mineral zoning is displayed along this metallogenic zone: in the north high plutonic skarn-hydrothermal deposits (iron oxides, base-metals, copper, molybdenum, occasionally porphyry copper mineralization) prevail, while in the area of and south of Krepoljin hydrothermal carbonate-hosted base-metal mineralization, and low temperature mineralization (antimony, antimony-tungsten, copper in the Permian red sandstones and barite) dominate. This zoning is most likely due to erosional levels, or due to different depth of magma emplacement. The Bor-Srednjegorie metallogenic zone extends from Lilieci-Liubcova and Bozovici in the north, over Bor to Burgas, proceeding into the Black Sea and Tracia in Turkey. This metallogenic zone is associated with a rift-graben environment, where volcano-intrusive complexes are developed, but the polygenic volcanics of central type prevail. Copper and gold/silver are the dominant metals, accompanied by iron (sulphide, oxide) and base-metals, molybdenum, sporadically PGE, exceptionally manganese. The most prominent morphogenetic types of deposit are porphyry copper/molybdenum, volcanogenic cupriferous pyrite, massive base-metal sulphides, and hydrothermal veins, skarns of iron oxides, volcanogenic epithermal gold mineralization of high sulphidation type, volcano-sedimentary manganese, and exceptionally clasts of copper sulphide ore mechanically accumulated in the small sedimentary basin filled by pyroclastics. The ore deposits are grouped into several ore fields and districts, each characterized by some specific metallogenic features.

Introduction

The Banat-Srednjegorie zone is situated between the Serbo-Macedonian Massif and the Rhodope block in the west and the south, and the Inner Carpathians and the Balkan range to the east and the north. It is defined as a regional metallogenic unit by specific types of ore deposits associated with the Upper Cretaceous-Paleocene magmatic complexes of predominantly calc-alkaline composition. This metallogenic unit is in reality composed of two separate metallogenic zones:

1. **The Oravița-Krepoljin metallogenic zone**, developed along a deep-fractured zone, situated close

to the western margin of the Southwest Carpathians, running subparallel with the contact with the Serbo-Macedonian Massif (SMM) ("western metallogenic lineament" of Ianovici et al., 1977). This regional dislocation zone can be continuously traced from the Jurassic ophiolitic melange of the Drocea Mts in the north to the Rhodope block in the south-southeast, striking north-south from the Bocșa Mts over the Danube to Krepoljin. Northward of the Boska Mts, it deviates to the NE-SW direction, subparallel with the contact of the SMM and the SW Carpathians, reaching the Poiana Ruscă area and the Jurassic ophiolites. The southwards extension of this dislocation zone, beyond

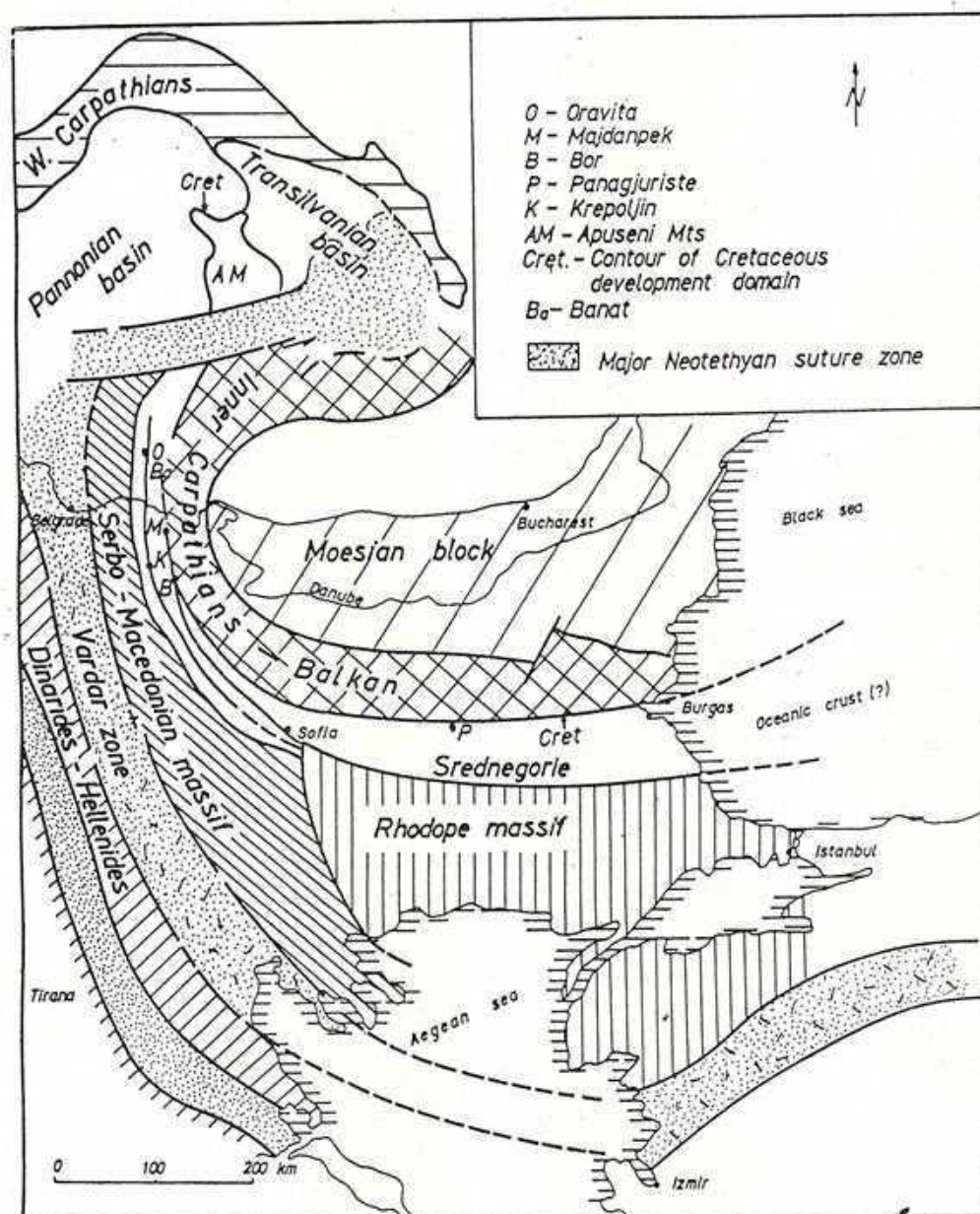


Fig. 1 - Sketch of regional tectonic position of the Oravița-Krepoljin and the Bor-Srednjegorie metallogenic zones

Krepoljin, slightly changes its direction to the south-southeast, but still running subparallel with the contact of SMM.

Some Romanian geologists (Cioflică, Vlad, 1973, 1984; Ianovici et al., 1977; Vlad, 1984; Ianovici, Borcoș, 1982) reported on a continuous north-south trending banatitic mega-alignment from the Northern Apuseni and to and beyond the Danube. But having in mind that Burtman (1984) demonstrated, relying on paleomagnetic data, that the Carpathian loop is of

Paleogene-Lower Miocene age, it seems that such a concept is no more tenable (Strutinski et al., 1986).

Therefore, the northern boundary of the Oravița-Krepoljin metallogenic zone is the Jurassic ophiolitic melange of the Drocea Mts. Its extension northwards of the Jurassic ophiolites is possible, but not certain, at least as a continuous metallogenic unit. Even if such extension exists, its development may have taken place in the different geotectonic environment. Thus, our discussion of the Oravița-Krepoljin zone will be

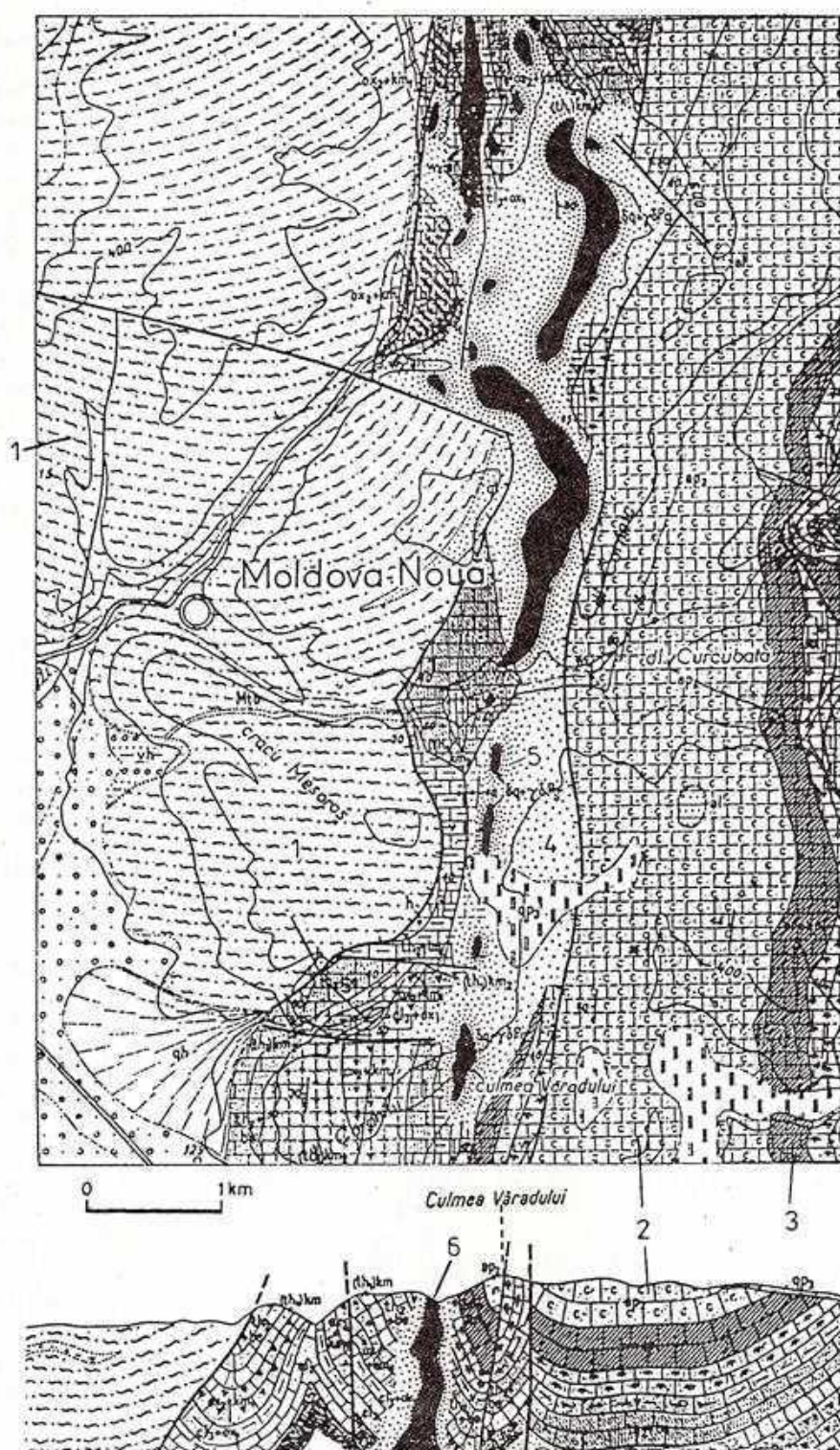


Fig. 2 - The simplified geological map and cross-section of the Moldova Nouă area (Năstăseanu, S., Maier, O., red. 1972). 1, Ante-Proterozoic crystalline schists; 2, Jurassic-limestone; 3, Permian conglomerate a.a.; 4, Cretaceous sediments; 5, Skarn and contact metamorphosed rocks; 6, Paleogene granitoids (granodiorite, diorite a.a.).

limited to the ophiolites only.

2. The Bor-Srednjejorie metallogenic zone, developed from the Liliaci-Liubcova area in the north (southernmost part of Banat), over Bor and Srednje-

gorie to the Black Sea in the east - a distance of over 600 km. Its northwards extension as metallogenic units is uncertain; occurrences of magmatic activity controlled by tectonic structures, if identified northwards,

can become of metallogenic significance only if they are accompanied by ore mineralization. The eastwards continuation of this metallogenic zone plunges under the Black Sea, proceeding into the Pontides and Lesser Caucasus (Janković, 1977).

The Oravița-Krepoljin and the Bor-Srednjegorie metallogenic zones run almost subparallel each other in the sector of Banat-East Serbia, at the distance of 10-25 km. They exhibit certain common features, but they differ as well in many metallogenic characteristics such as regional structural pattern, styles of mineralization, distribution patterns of ore deposits, and others.

This paper aims to briefly review the principal metallogenic peculiarities of these two metallogenic zones.

Geotectonic setting

Both the Oravița-Krepoljin and the Bor-Srednjegorie metallogenic zones are related with a subduction-setting, resulting from subduction of the Jurassic oceanic crust beneath the Eurasian plate, following the closure of Neotethys. Figure 1 shows the position of these metallogenic zones and the major suture zones in the Southwest Carpathians-Balkan domain and the adjacent areas.

While the concept of subduction of the Jurassic oceanic crust is, more or less, generally accepted, a distinct disagreement arises on the direction of subduction. Some geologists (Rădulescu, Săndulescu, 1973; Herz, Savu, 1974) assume that in the domain of South Carpathians and the Transylvanian basin, oceanic crusts subducted westwards. Bogdanov (1977) suggested a southward movement of the basaltic layer, from the Moesian Platform, beneath the Srednjegorie. On the other hand, many geologists related the Upper Cretaceous-Paleocene igneous activity in the Bor-Srednjegorie zone with subduction resulting from the consumption of the oceanic slab of the Vardar zone (Dewey et al., 1973; Boccaletti et al., 1974; Janković et al., 1974; Aiello et al., 1977; Hsu et al., 1977; Boyadziev, 1979; Nachev, 1993).

The westward subduction of the oceanic crust, following the closure of the western basin is possible in the domain of the Apuseni Mts, northwards of the ophiolites of the Drocea Mts, but the volcano-plutonic complexes and related ore deposits of both the Oravița-Krepoljin and the Bor-Srednjegorie metallogenic zones are more likely associated with the eastward subduction in the Vardar zone, and the northward subduction in the Aegean-Izmir zone.

It is beyond the scope and intention of this paper to discuss this controversy. It should be expected from the IGCP Project 356 activity to clarify at least some aspects of this situation.

Magmato-tectonic features

The Oravița-Krepoljin metallogenic zone developed along a regional, almost vertical dislocation zone, the width of which is mostly up to 1 km, but at local intervals - up to 2-10 km. A major fracture is, at intervals, accompanied by second-order fractures. The regional fracture penetrates deep into the continental crust, close to its contact with the upper mantle (the occurrences of the basaltic alkaline rocks south of the Danube). It is not proved whether this deep fracturing was followed by horizontal movements (precursor of rifting?). The ore mineralization is associated with high plutonic intrusions of predominantly calc-alkaline magma(s), emplaced as narrow dyke-like bodies, discontinuously distributed along dislocation, or dislocation zone; the intrusions are accompanied by the intense contact and hydrothermal metamorphism of wallrocks (hornfels and skarn) (Fig. 2).

South-southeastward from Krepoljin, this regional dislocation zone and accompanied igneous rocks are partly covered by the nappe (near Senj), partly they are indicated, at intervals, by geomagnetic data and/or ore mineralization of telethermal type (hypabyssal and/or subvolcanic intrusions unexposed by erosion).

The Bor-Srednjegorie metallogenic zone is formed in a quite different magmato-tectonic environment than the Oravița-Krepoljin zone. The ore deposits associate with the Upper Cretaceous ± Paleocene multistage igneous complexes, are located within a narrow basin of rift-graben structure, filled by sedimentary and volcano-sedimentary rocks, mainly of Upper-Cretaceous age. This basin is, at present, 1.0-80 km wide and over 600 km long. It can be traced from Majdanpek in the north, to the Black Sea in the east. The ore mineralization northwards of Majdanpek is related to a regional dislocation which reaches the southernmost part of Banat (the area of Lilići-Ljubcova), while in the area of Srednjegorie, the basin continues into the Black Sea.

The nature and the models of its development have been subject of discussion and disagreement among geologists. It was defined by various terms such as "subduction zone between Moesia and the Rhodope" (Dewey et al., 1974; Bončev, 1978; Bogdanov, 1977), "Upper Cretaceous paleorift" (Antoničević et al., 1974), "Banat-Srednogorie rift" (Popov, 1981), "back-arc through" (Boccaletti et al., 1974; Hsu et al., 1977), "inter-arc through" (Nachev, 1993), "rift with spreading" (Dabovski, 1980) etc.

Irrespective of the term, this basin and its evolution are characterized by the structures found with rift-graben environments. It was developed in multistage process mainly during the Late Cretaceous. The rift stage began, in the Timok sector, in the Upper Aptian and lasted through to the Paleogene (Anto-

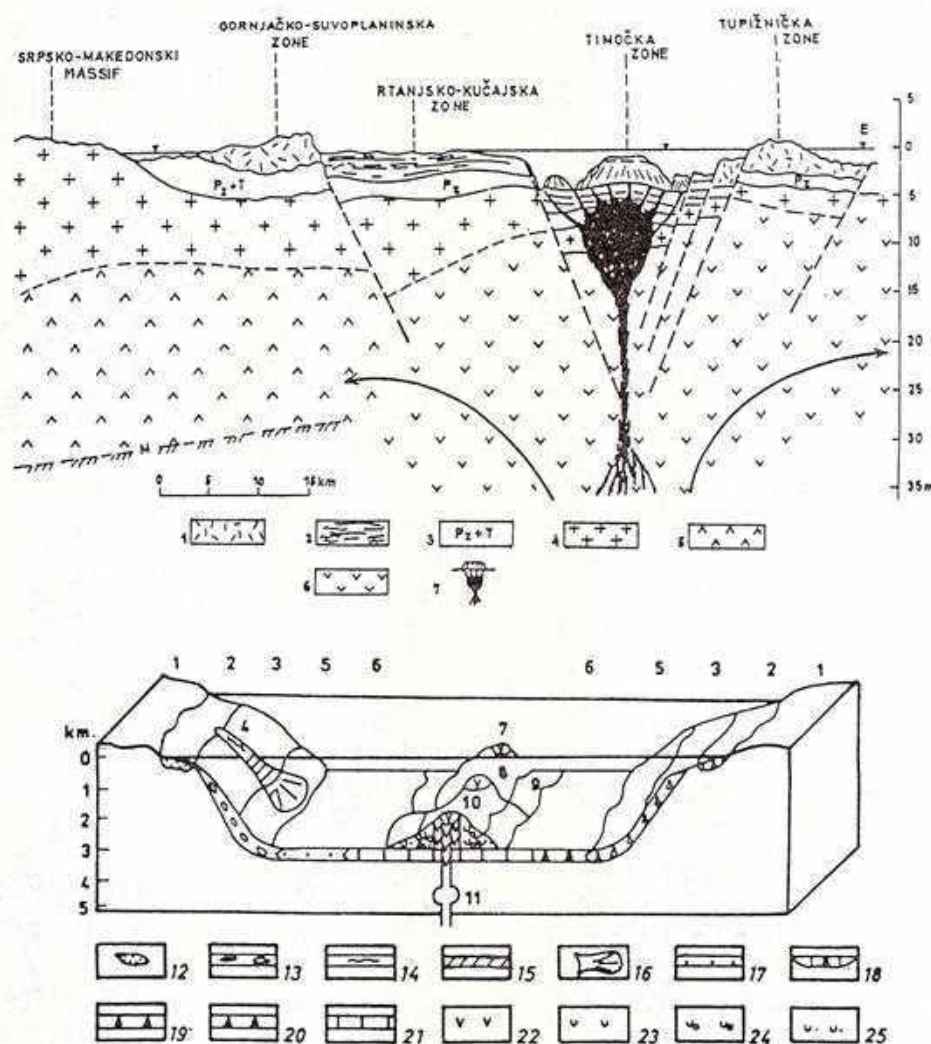


Fig. 3 - Models of rift-graben structures in the Bor-Srednjegorie metallogenic zone (diagrammatically only): **A.** Diagrammatic crustal section through the East Serbian-Upper Cretaceous rift (from the Middle Albian to the close of the Upper Cretaceous-Antonijević et al., 1974): 1, and 2, parts of the Kučaj-Tupižnica carbonate para-platform; 3, Lower Paleozoic metamorphics and Triassic sediments; 4, Second geophysical layer; 5, Third geophysical layer; 6, Upper mantle; 7, Volcanic reservoir with conduits, volcanic focus and volcanic vents. **B.** Model of the Srednjegorie trough (from: Nachev, 1993): 1-11, Sedimentation and volcanic environments: 1, Continents (drylands); 2, Shelf; 3, Basin slopes; 4, Submarine canyons; 5, Foot; 6, Basin bottoms plains; 7, Submarine volcanoes; 8, Submarine volcano slope; 9, Submarine volcano foot; 10, Depression between volcanoes; 11, Volcano channel and chamber; 12, Primary shelf extraclastic sediments; 13, Thick-bedded proximal grauwaacke-siltstone flysch; 14, Thin-bedded distal grauwaacke-siltstone flysch; 15, Upper deep-water fan; 16, Middle deep-water fan; 17, Lower deep-water fan; 18, Primary shelf bioproducing limy sediments; 19, Thick-bedded proximal interclastic-limestone flysch; 20, Thin-bedded distal interclastic-limestone flysch; 21, Hemipelagic micritic limestones; 22, Effusive rocks; 23, Volcanic tephra and tuffs; 24, Thick-bedded proximal tephra-turbiditic flysch; 25, Thin-bedded distal tephra-turbiditic flysch.

nijeć et al., 1974). The rift regime, involving intensive fracturing and the opening of rift, followed by further subsidence, particularly during the Senonian, sedimentation and intensive magmatic activity, lasted during the entire Upper Cretaceous and the lowest part

of the Paleocene, when the final consolidation took place.

Figure 3a shows a sketch of crustal section through the Upper Cretaceous rift in the eastern Serbia, and Figure 3b-model of the Srednjegorie trough.

Magmatic complexes

The ore mineralization in both metallogenic zones, the Oravița-Krepoljin and the Bor-Srednjejorie, is associated with predominantly calc-alkaline complexes of Upper Cretaceous-Paleocene age. Figure 4 shows the area of distribution of the volcanic and plutonic rocks and volcano-sedimentary series in the Banat-Srednjejorie zone.

Based on the $\text{Na}_2\text{O} + \text{K}_2\text{O}/\text{SiO}_2$ ratio, AFM diagrams, relations between normative composition of plagioclase and Al_2O_3 content, and the $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratio, Popov (1981) classified all igneous rocks in four series, each of them involving comagmatic volcanic and intrusive facies:

1. **The calc-alkaline series** (rhyolite-dacite-andesite, with the dominance of andesite). The gabbro-diorite-granodiorite series comprises mostly diorite and granodiorite, whilst basic and acidic differentiates are of restricted development.

2. **The tholeiitic series** includes andesite-basalt and gabbrodiorites; granodiorites and granites are found mainly as dykes.

3. **The potassic-alkaline series** is represented by the latitandesite, latitbasalt, and gabbro-monzonite-syenite.

4. **The superalkaline series** is represented by the tephryite-trachyte of limited development.

Magmatic activity lasted from early Upper Cretaceous through to Paleocene, i.e. from 105 my to 45 my, but mainly between 90 and 65 my. The igneous complexes of Paleocene age are identified in the Southwest Carpathians. (Classification of igneous rocks as Upper Cretaceous or Paleogene depends on the boundary between Cretaceous and Tertiary - 65 or 69 my).

The igneous complexes of these metallogenic zones display many similarities, but also some specific features. In the Oravița-Krepoljin zone plutonic rocks prevail over volcanics, which are developed only sporadically, while in the Bor-Srednjejorie the volcanics are prevalent, particularly in volcano-sedimentary formation.

The Oravița-Krepoljin metallogenic zone. The petrochemical characteristics, mode of occurrence, and age of igneous complexes are not uniform along the strike of the metallogenic zone.

The magmatic complexes are developed, at intervals, from the area of Poiana Ruscă in the north over the Bocșa Mts, Ocna de Fier, Oravița, Moldova Nouă to Ridan, Reškovića/Krepoljin, south of the Danube, to beyond the Ruj Mts in the south.

The igneous intrusions occur mostly as linear-extended hypabyssal bodies (dykes and other morphological types) in the regional dislocation zone (the Bocșa pluton is an exception). They are much more frequent and deeply eroded in the Banat than in the

east Serbia. In the Banat (southwest Carpathians) the igneous complexes formed within four stages, which are grouped into the Upper Cretaceous (95-65 my), and the Paleogene (65-45 my - Russo-Săndulescu et al., 1984). The magmatic complexes south of the Danube are mainly of Upper Cretaceous age (see further).

In this metallogenic zone, three sectors are distinguished, each displaying some specific features of igneous complexes:

- the northernmost part, in the area of Poiana Ruscă (Ianovici, Borcoș, 1982, link the Rușchița lineament with the Timok via Bozovici), the igneous complexes involve the volcanic rocks, mostly andesite, and the plutonic rocks (granodiorite, granite, minor quartz-porphyry and diorite porphyry). The Upper Cretaceous volcano-sedimentary formation is relatively widespread, more than in any other part of the metallogenic zone (Russo-Săndulescu, Berza, 1979).

The magmatic activity lasted from 82 my through 64 my (based on K/Ar determination - Strutinski et al., 1986);

- the sector between the Bocșa Mts and the Danube; the igneous rocks are of calc-alkaline composition with local alkaline tendency (Vlad, 1984; Cioflică, 1989). The composite granitoid of the Bocșa pluton, formed in three main stages (from gabbro to quartz monzonite, granodiorite, intruded by dykes of rhyolite-granophyres, andesites and lamprophyres), and the elongated, narrow magmatic bodies of granodiorite composition (Oravița), and monzodiorite and diorite (the latter prevail - Moldova Nouă, Ciclova) are developed in this sector (Russo-Săndulescu et al., 1984). The age of these plutonic complexes ranges from 87 to 55 my mainly according to Russo-Săndulescu, (1986). The Bocșa pluton, 87-67 m, but the Bocșa 3 intrusion - 65-55 my, the Oravița intrusion - 67-55 my;

- The sector south of the Danube. Two groups of igneous rocks are distinguished: the calc-alkaline, and the alkaline basaltic rocks (Jankovic, 1990).

The calc-alkaline rocks are represented by subvolcanic intrusions of dacite and andesite, locally developed as pyroclastics, and minor quartz diorite porphyry. The absolute age of dacites and andesites in the area of Krepoljin (K-Ar determination) ranges from 72.6 my to 60.6 my, but mostly between 72.6 and 67.1 my (Počkay et al., 1994 - in print; only one age determination of hornblende andesite did show 60.6 my, but its plagioclase - 56.4 my, and hornblende 76.9 my).

The alkaline basaltic rocks occur sporadically as dykes of olivine-nephelinite, limburgite, nephelinite, teschenite. Genesis of these rocks is still uncertain (they derive from a basaltic magma from upper mantle intruding along deep fracture?). The age of this alkaline rocks is not yet established, except that their dykes cut Jurassic and Lower Cretaceous sediments.

The Bor-Srednjejgorie metallogenic zone. The volcano-plutonic and volcano-sedimentary complexes of this metallogenic zone are characterized by the followings:

1. They are predominantly of Upper Cretaceous age (105-65 my). The occurrences of igneous activity during the Paleocene are recorded only in the northernmost sector of the metallogenic zone; they are of subordinate volume and of small metallogenic significance.

The magmatic activity did not start and did not terminate simultaneously in this zone and with the same intensity.

2. They are mainly of calc-alkaline composition, but in some sectors alkaline rocks prevail. A longitudinal zoning is distinctly expressed in the Srednjejgorie sector. The changes of petrochemical features of volcano-plutonic rocks are in close connection with the changes of tectonic development of the rift-graben environment.

3. Plutonic complexes are of composite nature. The plutonic bodies are represented by single or clustered hypabyssal intrusions.

4. The prevalence of volcanic rocks over plutonic rocks. The volcanic activity takes place usually within volcano-tectonic depression or grabens. The structural features of volcanic environment indicate central type, and related ring-radial fractures. Numerous submarine volcanoes are identified, mainly displaying a linear character of distribution.

5. Variable thickness of tuffaceous and volcano-clastic sediments (500-5000 m). Pillow lavas are found sporadically only.

The specific features of the magmatic rocks in the selected sectors of the Bor-Srednjejgorie metallogenic zone will be briefly reviewed.

The sector northward of Majdanpek. In the northernmost part of the metallogenic zone, where the rift-graben structure grades into a regional dislocation zone in the Precambrian crystalline schists, the igneous bodies are represented by elongated hypabyssal intrusions. They have so far been identified at intervals, between Majdanpek and Lilići-Liubcova (Banat).

Magmatic bodies occur as minor intrusions and dykes of andesite, quartz diorite, quartz monzonite, granodiorite, locally even as dykes of lamprophyre. Among them, the magmatic complex of Lilići-Liubcova is the best studied (Cioflică et al., 1991). The magmatic rocks of Lilići-Liubcova are represented by the main intrusion of monzodiorite accompanied by microdiorite and andesite dykes. The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios of monzodiorites range from 0.703 to 0.706 ‰, but more close to 0.703 ‰. The age of igneous rocks is post-Campanian, probably Paleocene (the K/Ar age: 67-50 my).

The Bor-Nevlje sector. The volcano-plutonic

complexes are represented by the volcanic, volcano-sedimentary and plutonic rocks. They derived from subcrustal, contaminated magma(s) - Karamata, Djordjević (1980). The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios range from 0.707 to 0.712 ‰. The calc-alkaline series is prevalent with respect to tholeiitic rocks.

The volcanic rocks formed within three stages during the Upper Cretaceous. They are of andesitic composition, whilst dacite occurs sporadically. The plutonic granitoids belong to the composite complexes (from gabbro to diorite, monzonite and granodiorite). The Upper Cretaceous volcano-sedimentary formation spreads over the whole sector, proceeding into Srednjejgorie.

The igneous activity lasted from 105 my through 65 my, but locally up to 60 my (Janković et al., 1981).

The Srednjejgorie sector. The volcano-plutonic complexes of Srednjejgorie are subdivided into three areas: West, Central and East. A longitudinal zoning, from the west to the east, is represented by a general increase in the intensity and volume of igneous rocks, and the change of their petrochemical features, from calc-alkaline in the west and central sectors to alkaline, K-enriched rocks in eastern Srednjejgorie (Stanisheva-Vassileva, 1980, 1989).

1. *The West Srednjejgorie.* The magmatic rocks are developed mainly as volcanic facies, sporadically as subvolcanic intrusions (sills, dykes). The Vitoša is a composite plutonic complex; its age is established as 84 my, and initial strontium ratio - 0.704 (Lilov, 1989). The igneous rocks are calc-alkaline with a slight alkaline tendency.

2. *Central Srednjejgorie.* The igneous rocks are represented by the volcanic rocks (andesite, sporadically andesite basalt; in the southern parts of Panagjurishte, dacite and rhyodacite are also developed, while the trachyandesite-latitude varieties have a more restricted development - Popov (1989). The Senonian subvolcanic-hypabyssal intrusive bodies, located mainly in close connection with volcanic centres, sporadically in the basement (Medet) are of particular metallogenic significance (granodiorite, quartz-diorite, quartz-monzodiorite).

The Senonian volcano-sedimentary formation is widespread in the area of Panagjurishte.

The igneous rocks are of calc-alkaline composition, partly subalkaline.

3. *The East Srednjejgorie.* This area is characterized by a wide development of potassium-enriched igneous rocks (shoshonite, high-K trachyte). The eruption of the large amount of K-rich magma is associated with the tensional rifting that affected eastern Srednjejgorie during Late Cretaceous (Boccaletti et al., 1978). The alkali content increases from south to north due to the gradual migration of the volcanic centres with the

Table 1

Comparative characteristics of magmatic areas and regions in Srednegorie volcano-intrusive zone (dabovski et al. 1989)

Main features	WSVIA	CSVIA		ESVIA			
		PVIR	MIR	SVIR	YBVIR	NBVR	LKVR
Basement	Complexes of the platform margin	Complexes of the collage zone		Complexes of the margin and collage zone	Unknown		Allochthonous Triassic, Jurassic
Crustal thickness (km)	35-40	40-45		27-30			35
Magnetic field	Linear	Linear-mosaic		Mainly linear	Mosaic	Linear	Not well expressed
Gravity field	Positive	Negative	Positive	Positive, of highest intensity on Bulgarian territory			
MAGMATISM							
1. Facies: volcanic	+++	+++	+	++	++++	++++	++
subvolcanic	+	++		+++	++	+	+
hypabyssal	+	++	++++	+++	++		
2. Explosion index	> 80	> 80	?	> 90	> 70	> 50	> 80
3. Pillowlava, palagon. tuffs	++	+		+	+	++++ ++++	
4. Type of magmatic structures	Dominantly linear with rare central structures				Typomorphic central	Linear	
AGE							
1. volc. compl. faunistic	Coniacian -Campanian	Coniacian -Campanian?		Turonian-Coniacian	Coniacian -Campanian	Campanian	Cenomanian, Senonian
K-Ar Ma		64-94			73-84	70-77	
2. intr. compl. K-Ar	73-89	69-80	69-91	81-84	80		
Rb-Sr	91±10						
SEDIMENTATION							
calcareous	+++	++		+	++	+++	++
greywacke-sandstone-turbiditic	+++	+++		+++	+		++++
tephroidal-turbiditic	++	+++		++	++++	++++	++
THICKNESS of volcano-sedimentary complexes (km)	< 3	0.3-3		< 1 (2)	2-6	> 5	< 1

WSVIA: West Srednegorie volcano-intrusive area

CSVIA: Central Srednegorie volcano-intrusive area

ESVIA: Eastern Srednegorie volcano-intrusive area

MIR : Medet intrusion region

SVIR : Strandja volcano-intrusive region

YBVIR: Yambol-Burgas volcano-intrusive region

NBVIR: North Burgas volcano-intrusive region

LKUR : Luda Kamchaya volcanic region

opening of the rift (Popov, 1981, 1987).

Table 1 summarizes the comparative features of the igneous complexes and their geological environments in the Western, Central and Eastern Srednjegorie.

Associations of elements

The associations of elements concentrated in the ore deposits are specific metallogenic feature of the Oravița-Krepoljin and the Bor-Srednjegorie zones.

The Oravița-Krepoljin metallogenic zone. The elements as the constituents of ore are classified as:

Major elements: Fe (oxide, py), Pb/Zn, Cu, $\pm$ Au/Ag

Significant elements: B, Ni, Mo, W, Sb, Ba

The principal associations of elements identified in the ore deposits are:

Fe (mgt, he, py)-Pb/Zn-Cu $\pm$ Au/Ag	Skarn
Fe (O,S) - B	Skarn
Cu, Mo, Au/Ag $\pm$ Pb/Zn	Skarn/Porphyry copper dep.
Pb/Zn-Au/Ag, Fe (py) $\pm$ Cu	Hydrothermal replacement
Pb/Zn-Cu, Mo, Fe (py) $\pm$ Bi, W	Skarn/Hydrothermal
Cu/S $\pm$ Ag, Mo	Epithermal
Sb-W	Epithermal
Ba $\pm$ Sb, Hg	Epithermal

The distribution of association of elements is characterized by a regional zoning (from the north to the south):

SW Poiana Ruscă: Pb/Zn/Fe (py) $\pm$ Cu, Mo (skarn/hydrothermal);

Ocna de Fier: Fe (oxide), Pb, Zn, Cu $\pm$ B, Bi, Ag, Cd (skarn);

Dognecea: Pb, Zn, Cu, Fe $\pm$ Au, Ag, As, Bi, Sb, Mn (skarn);

Oravița: Cu, Mo $\pm$ Zn, Sb, Co, W, As, Bi (skarn/hydrothermal);

Ciclova: Cu, Mo, W $\pm$ Bi, Pb/Zn, Au, Ag, Te, Se (skarn); Cu, Fe (py) $\pm$ W, Mo, Co, Au (porphyry copper)

Sasca Montană: Cu, Pb-Zn $\pm$ Au, Ag, As, Mo, Co, Ni, Sb (skarn);

Moldova Nouă: Cu, Pb-Zn, Au, Ag (Bi, Mo, Sb, Co, Ni) (skarn); Cu, Mo $\pm$ Au, Ag (Zn, Sb, As) (porphyry copper);

Reșkovița: Cu, Pb-Zn $\pm$ Mo, Bi (skarn);

Krepoljin/Osanica: Sb, W $\pm$ Au (epithermal);

Bancarevo: Cu-Fe (py), Ag $\pm$ Mo, Ba (telethermal);

Ruj: Ba

The Bor-Srednjegorie metallogenic zone. The associations of elements in the ore deposits of this metallogenic zone are similar to those of the previous metallogenic zone. The main difference is the higher con-

centrations of copper and gold in the ores of the same genetic types in the Bor-Srednjegorie zone.

Major elements: Cu, Au, Mo, Fe (py) $\pm$ Pb-Zn

Trace elements (recoverable): Se, PGE, Ag, Cd

Trace elements (unrecoverable): W, Sn, Bi, Sb, As (Ba).

The principal associations of elements are classified as follows:

Cu, Au, Mo $\pm$ Ag, PGE	porphyry copper)
Cu, Pb/Zn, Fe (py), Au/Ag $\pm$ Se, Bi, Sb	(massive sulphide)
Cu, Au, Fe (py), As $\pm$ W, Sn, Se, Sb	(cupriferous massive sulphide/replacement)
Fe-S $\pm$ Cu	(massive pyrite)
Cu, Fe(py) $\pm$ Mo, Bi, W	(skarn)
Au-Ag $\pm$ Fe (py) (As, Sb, Ti)	epithermal

The longitudinal zoning of the distribution of associations of elements (from north to south and southeast-east):

Lilici-Ljubcova: Cu, Fe (py)	
Majdanpek: Cu, Mo, Au/Ag, Fe (py) $\pm$ PGE, Pb/Zn	(prphyry)
Coka Marin: Cu, Pb/Zn, Fe (py), Au/Ag	(massive sulphide)
Bor: Cu/Fe (py), Au, As $\pm$ Se, Sb, W, Ag	(massive sulphide)
Cu-Au $\pm$ Mo, Ag	(porphyry copper)
Panagjurishte (Bogdanov, 1987): Elshitsa, Radka: Fe (py) $\pm$ Cu (Zn)	(massive sulphide)
Chelopech: Cu, Fe (py) Au $\pm$ Zn, As, Pb, Ag, Se, Sb, Bi	(massive sulphide)
Assarel: Cu, Fe (py) $\pm$ Au, Ag, Mo, Pb/Zn	(porphyry copper)
Medet: Cu, Mo, Fe (py) $\pm$ Re, Au, Se, Te	(porphyry copper)
East Srednjegorie: Zidarevo: Cu, Pb/Z, Fe (py) $\pm$ Ag, As, Sb, Au, Bi	(veins)
Malo Trnovo: Cu, Fe (py) $\pm$ Mo, Bi, W	(skarn)
Vrilyi Bryag: Cu, Fe (py) $\pm$ Bi, Pb/Zn	(veins)
Bi, Pb/Zn	
Rossen: Cu, Mo, Fe (py), Co, W	(veins)

Morphogenetic types of ore deposits

Although associated with predominantly calc-alkaline complexes, the ore deposits of the Oravița-Krepoljin and the Bor-Srednjegorie metallogenic zones display some specific features. This is mostly due to different magmato-tectonic environments in which ore mineralization took place.

The Oravița-Krepoljin metallogenic zone. The ore deposits formed in this regional metallogenic unit are classified into the following main types:

1. *Skarn deposit.* The ore deposit formed in the contact zone of hypabyssal granitoids (granodiorite, diorite, monzodiorite) with carbonate-bearing wallrocks are the most specific and most frequent deposits in the Oravița-Krepoljin zone, particularly in its Banat sector. The calcic and magnesian skarns are identified.

The ore deposits of this type involve (i) iron oxides (magnetite, hematite) accompanied by Fe-, Cu- and

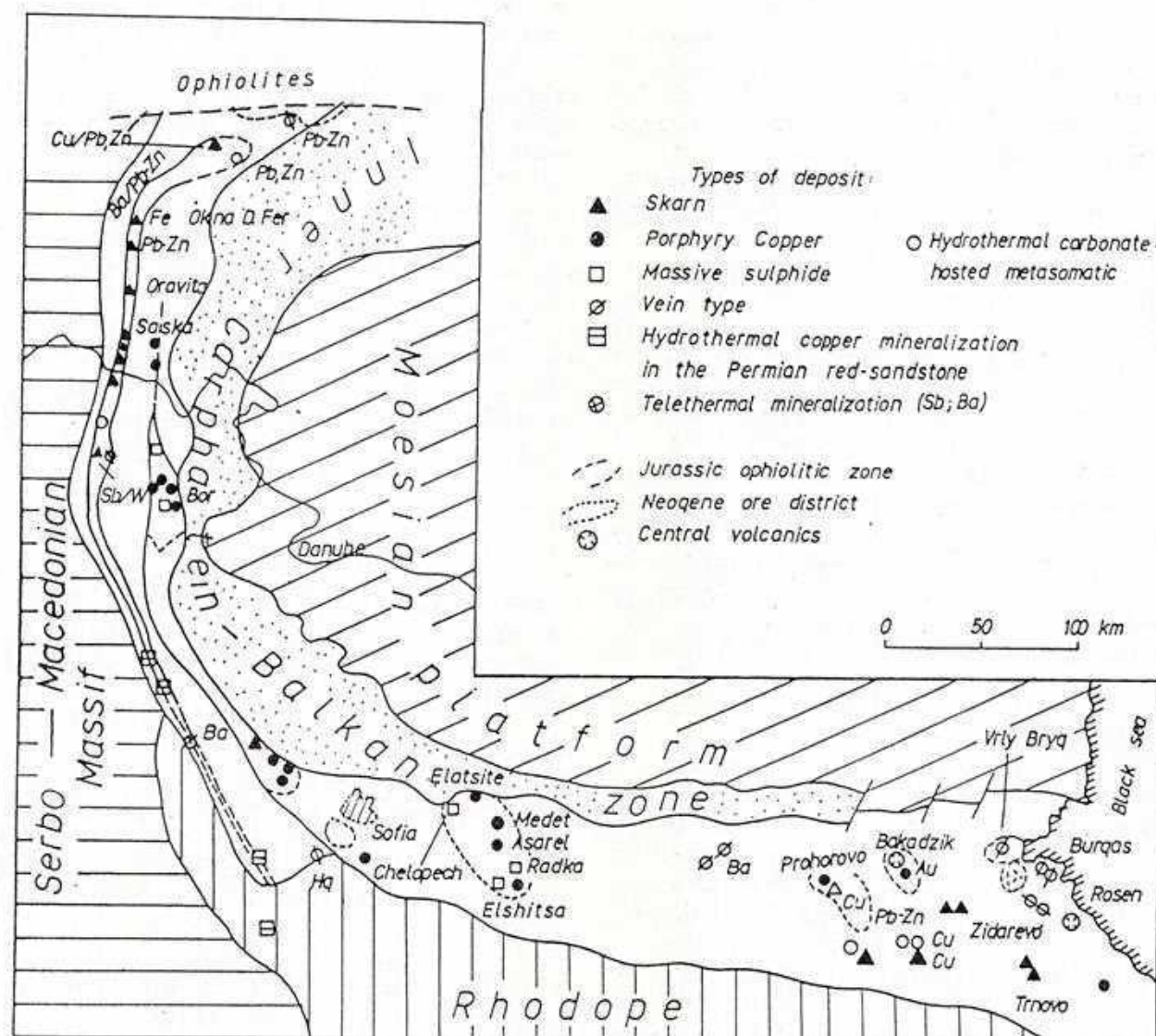


Fig. 5 Principal ore deposits in the Oravița-Krepoljin and the Bor-Srednjegorie metallogenic zones

minor Pb-Zn sulphides (the Ocna de Fier deposit contains, apart from other ore minerals, ludwigite, wolframite, Bi-minerals as well), (2) the copper ores accompanied by Mo, minor Pb-Zn (Sasca Montana, Oravița, Moldova Nouă), (3) the base metal ores with minor Cu, Bi, W (the Ruschița and Reshkovitsa deposits).

2. *Porphyry copper deposits.* This type of mineralization related with hypabyssal intrusions of diorites, quartz monzodiorites, granodiorites is known in the southernmost part of Banat (Ciclova, Moldova Nouă).

The mineralization is in close connection with the

skarns. The mineralization extends laterally into argillized and propylitized skarns and hornfelses forming an aureole of cupriferous veinlets and impregnations (Cioflică, 1989).

The ore is mostly low grade (0.2 - 0.3 %), but locally enriched in gold (the Suvorov ore contains as the mean, 0.23 % Cu, 25 ppm Mo, 2 ppm Au and 23 ppm Ag - Ianovici and Borcoș, 1982).

3. *Hydrothermal base metal carbonate-hosted deposits.* This type of mineralization occurs sporadically only. The base metal deposits formed in the contact zone of subvolcanic intrusions and carbonate rocks,

grading often into the skarn-type mineralization.

Such ore deposits contain often high-grade ore (in the Kuchajna deposit high concentrations of gold and silver are found, as well - Janković, 1990).

Low temperature hydrothermal copper mineralization in the Permian red sandstones. Numerous but very small deposits of this type are known south of the Danube through to the Suva Mts, near the Yugoslav-Bulgarian border (Janković, 1990).

The mineralization occurs along faults in the Permian red sandstone, accompanied by hydrothermally altered wallrocks.

4. *Epithermal Sb, W and Ba deposits* are mainly found in the eastern Serbia (barite mineralization northward of the Danube is known only near Bočša).

The mineralization is mostly of vein type, partly of jasperoid type (Sb). Among them, only the Osanica deposit (stibnite - wolframite accompanied by gold) is of small economic significance (Janković, 1990).

The Bor-Srednjegorie metallogenic zone. The ore deposits of this metallogenic zone formed in much more diverse environments than those of the Oravița-Krepoljin zone. The copper and gold are the dominant metals in the ores from the Bor-Srednjegorie zone; the base metal ores are sporadically of the economic significance. The copper deposits contain often high-grade ore and significant tonnage (the mineral potential of the Bor ore field exceeds 12 million tons of copper and 300 tons of gold).

The endogenous ore deposits of the Bor-Srednjegorie metallogenic zone belong to volcanogenic, plutonic and volcano-sedimentary types. Unlike in the Oravița-Krepoljin zone, the ore deposits formed in the volcanic environments are prevalent in this metallogenic zone.

The principal types of deposit in the Bor-Srednjegorie will be very briefly mentioned here.

1. *Porphyry copper deposits.* The porphyry copper mineralization shows many common characteristics corresponding to a general model of porphyry copper systems. The differences and unique features exhibited by individual deposits reflect the imprint of local variables.

Copper mineralization is mostly confined to subvolcanic intrusions and/or shallow emplacement of porphyritic dykes (quartz diorite, granodiorite and/or monzonite porphyritic) in and above the cupola zone of a calc-alkaline comagmatic stock. The spatial relation of plutonic intrusion and porphyry copper mineralization is evident (Assarel, Crni Vrh) or it is assumed on the ground of the development of porphyry dyke suites (Majdanpek, Borska Reka, Veliki Krivelj). Sporadically, parent magmatic complex intruded crystalline schists (Medet), or porphyry copper mineralization is associated with skarn (Prohorovo, Brdseto).

2. *Volcanogenic cupriferous pyrite deposits.* This type of mineralization is hosted by andesitic volcanics, and it is of replacement type. The ore contains often an increased content of gold (Bor and Chelopech). In some of these deposits, the enargite ore is abundant.

3. *Volcano-sedimentary deposits.* This type of mineralization is infrequent in the Bor-Srednjegorie metallogenic zone. It includes some small manganese deposits.

4. *Volcanogenic vein type deposits.* The vein orebodies of economic importance are known in the Eastern Srednjegorie ore district. They contain the copper/molybdenum +/- cobalt ore (Rossen), the copper and base metal ore (Zidarevo).

5. *Epithermal gold mineralization* occurs in the volcanic environment (high sulphidation type).

Figure 5 shows the position of the most important ore deposits and ore districts in the Oravița-Krepoljin and the Bor-Srednjegorie metallogenic zones.

Conclusions

The Oravița-Krepoljin and the Bor-Srednjegorie are two separate regional metallogenic units, situated in the Banat-Srednjegorie zone. Each of them displays some specific metallogenic features:

1. Both metallogenic zones occur in a subduction-related setting. The Upper Cretaceous (partly Paleocene) igneous complexes of predominantly calc-alkaline composition, and with them associated ore deposits derived from subducted oceanic slab. The direction of subduction is still debatable. The parent magmas are partly contaminated by the material from continental crust.

2. The magmato-structural environments of generation and distribution of ore deposits are different: in the Oravița-Krepoljin metallogenic zone, the ore deposits are related with a regional, narrow deep-fractured tectonic zone, whilst in the Bor-Srednjegorie, they are associated with regional rift-graben environment.

3. The associations of element/metal differ to some extent in these metallogenic zones: the Fe (oxides, sulphides), Pb-Zn, Cu (Mo, Au association of major elements prevails in the Oravița Krepoljin zone, whilst the Cu, Au, Mo, Fe (py), to some extent base metals as the major elements association is dominant in the Bor-Srednjegorie metallogenic zone.

4. The Oravița-Krepoljin zone is characterized by predominantly high plutonic deposits of skarn-porphyry copper types, and the Bor-Srednjegorie metallogenic zone is the domain of the prevalent volcanogenic types of deposits (copper, gold, less base metals, molybdenum).

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UPPER CRETACEOUS ANDESITIC VOLCANISM IN THE SURROUNDING OF BELGRADE

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Key words: Debris flow. Trachyandesite. Pebbles. Volcanic arc. Vardar Zone. Subduction suture zone. Upper Cretaceous.

Abstract: Trachyandesitic volcanic rocks are abundant as fine clasts in Turonian-Early Senonian sediments south of Belgrade; an occurrence of andesitic debris flow deposit interlayered into these sediments was found and studied. The field and petrographic study reveals a submarine slump of the volcano(epi)clastic debris predominately composed of holo/hypocrystalline porphyritic trachyandesitic fragments within the finegrained volcanogenic and marly matrix. Volcanic pebbles of high sodic Ca-alkaline character correspond to trachyandesites, to trachytes and benmoreites, respectively, while their trace element ratios indicate VAG (volcanic arc affinity). This represents the first indication of the Senonian volcanic activity in the central/eastern part of the Vardar zone and, together with the presence of the Campanian limestone xenoliths within diabases and spilites near Krupanj, indicates the age of the closing of the westernmost branch of the Vardar ocean by an eastward subduction of the Cretaceous oceanic crust in that area.

Introduction and geological setting

The Vardar zone composite terrane is considered here in the sense of Dimitrijević (1974), but without the Jadar block (as a different terrane) in the west, and divided into three subzones (Karamata et al., 1994). The Western subzone of the Vardar composite terrane represents an oceanic area originating in the Upper Triassic between the detached Kopaonik block, in the east, and the main part of the Drina-Ivanjica terrane, in the west (Fig.1). The remnants of this subzone are represented by an olistostrome deposited in the trench and occurring now over the area of collision. The olistostrome melange contains fragments of basaltic rocks (of MORB and Island arc type), Triassic and Jurassic limestones and cherts, as well as fragments of early Upper Cretaceous limestones. Such Cretaceous limestones were found also as inclusions in the basalts. Almost 150 km to the NE, south of Belgrade, Turonian-Early Senonian sandy-marly-clayish sediments with abundant andesitic clasts (fine to middle grains) occur. These grains were small and mostly

altered, thus inconvenient for study, but some years ago in those Turonian-Early Senonian sediments south of Belgrade an outcrop with andesitic fragments (up to 30 cm in diameter) was found. These andesitic rocks were studied in order to give additional data for the evolution of the Western subzone of the Vardar zone during the Upper Cretaceous.

Petrography of the volcanoclastics

Volcanogenic rocks of andesitic character were found within a Turonian/Lower Senonian sedimentary series composed of greywackes, shales and marls, south of Belgrade (10-15 km) and briefly described about 25 years ago (Marković et al, 1985; Terzić & Karamata, 1968 - unpublished report).

These rocks are exposed in a new outcrop (oriented WNW-ESE), in a mainly covered area, as a 20 m long and up to 7 m high unit. The unit can be divided into three levels - lowermost and uppermost levels with marls and sandstones, and the middle level

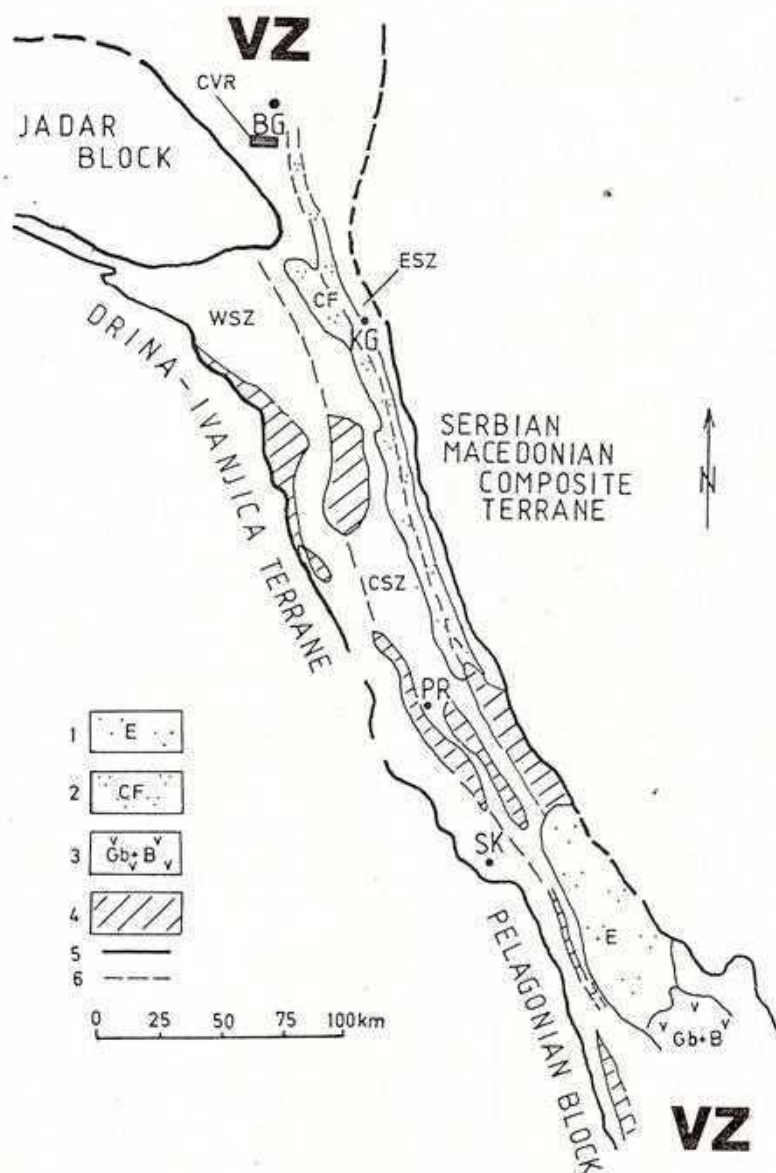


Fig.1 - The Vardar zone and the position of the studied volcanoclastic rocks (after Karamata et al, 1994). Signs: BG - Belgrade, KG - Kragujevac, PR - Pristina, SK - Skoplje; 1, eocene flysch; 2, cretaceous flysches; 3, Gb+B gabbro-diabase massif of Gvgevlja; 4, Paleozoic and Triassic blocks in the Vardar zone; 5, boundary of the Vardar zone; 6, boundary of the subzones. Signs: VZ-Vardar zone, CSZ-Central subzone, WSZ-Western subzone, ESZ-Eastern subzone, CVR-Cretaceous volcanoclastic rocks.

predominately composed of conglomerates with volcanogenic fragments. The sharp contact between the lower parts of the conglomeratic level and the sedimentary rocks underneath is shown (Pl.I, Fig.1).

The middle level probably represents a submarine slump from an andesitic high. It is about 3 m thick, built of accumulated well rounded (in lower) to

subrounded (in higher parts) andesitic and rare sedimentary rock fragments within a finegrained andesitic to mixed andesitic + marly matrix (Pl.I, Fig.2).

The andesitic pebbles (up to 30 cm in diameter) are pink, reddish, grey to black or green porphyritic rocks. The phenocrysts are represented by andesine (32-41% an), biotite (chloritized), and in some samples rare

augite. The hypo- to holocrystalline groundmass consists of plagioclase, K-feldspar and quartz. Accessories are apatite, magnetite (?) and very rare zircon. Secondary chlorite, calcite, sericite and argillite minerals are always present and often abundant. Some volcanic fragments have completely calcitized groundmass with almost invisible plagioclase microlites.

Rock Chemistry

These rocks are Ca-alkaline trachyandesites with SiO_2 content ranging from 55 to 64%, mostly between 61 and 63%, and with relatively high potassium (1.35 to 2.6%) but very high (6 to 8%) sodium content. Only some highly altered rocks are poorer in silica.

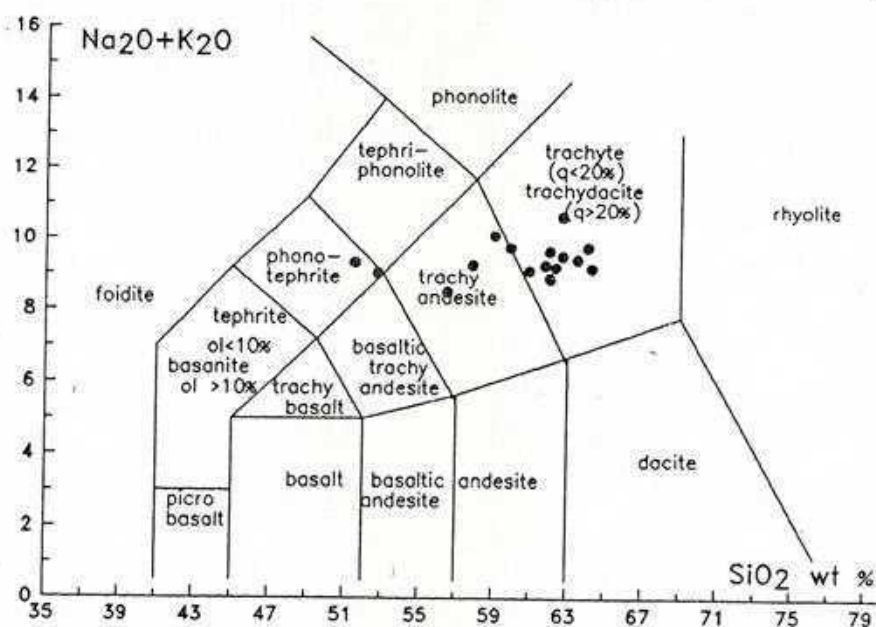


Fig. 2 - Total Alkali vs Silica diagram (after Le Bas et al., 1986); dotted circles represent the Upper Cretaceous volcanics near Belgrade

Table 1
Trace element content of the trachyandesites

Sample No	Zr (ppm)	Nb(ppm)	Y (ppm)	Sr (ppm)	Rb (ppm)
1 B6D-BR2/8	217	14	19	322	13
2 B6D-BR2/9	229	17	22	473	17
3 B6D-BR2/10	238	15	30	520	30
4 B6D-BR2/11	242	17	22	558	29
5 B6D-BR2/12	229	15	28	379	26
6 B6D-BR2/13	242	19	28	605	31
7 B6D-BR2/14	282	19	25	296	9
8 B6D-BR2/15	318	16	26	407	24
9 B6D-BR2/16	253	17	23	461	19
10 B6D-BR2/17	265	15	21	375	16
11 B6D-BR2/18	238	18	23	501	20
12 B6D-BR2/19	300	17	21	318	20
13 B6D-BR2/20	228	18	21	467	17
14 B6D-BR2/21	241	15	23	472	21
15 B6D-BR2/22	141	11	22	521	26
16 B6D-BR2/23	215	15	21	433	17
17 B6D-BR2/24	237	17	25	294	18
18 B6D-BR2/25	300	16	22	291	23

Analyses: T.Marchenko, IGM, Moscow

According to Le Bas *et al* (1986) (Fig.2), these rocks correspond to sodic types and belong to benmoreites and sodic trachytes.

The contents of some characteristic trace elements (analyzed in the laboratories of the IGEM of the Russian Academy of Sciences, Moscow), presented in Table 1, are without any significant variance. Even the rock alteration does not influence their contents and ratios.

In order to define the geological setting of the origin of these rocks, the discrimination diagrams for granitic rocks elaborated by Pearce *et al.* (1984) were used.

These diagrams consider the granitic rocks of calc-alkalic suites of the "Volcanic arc" belts, as well as the ones among the "Within plate" and "Collision" granites, including rocks of those associations with more than 56% SiO_2 , and can be used for the determination of the geological setting of their volcanic equivalents, too. The studied andesitic rocks correspond to the required criteria. According to the Nb/Y, Rb/Y+Nb (Fig.3 a,b) discrimination diagrams the studied rocks are of volcanic arc affinity, while the Rb/ SiO_2 (Fig.3 c) ratios plot into the VAG + WPG field and the Y/ SiO_2 ratios (Fig.3 d) into the VAG + COLG + ORG field.

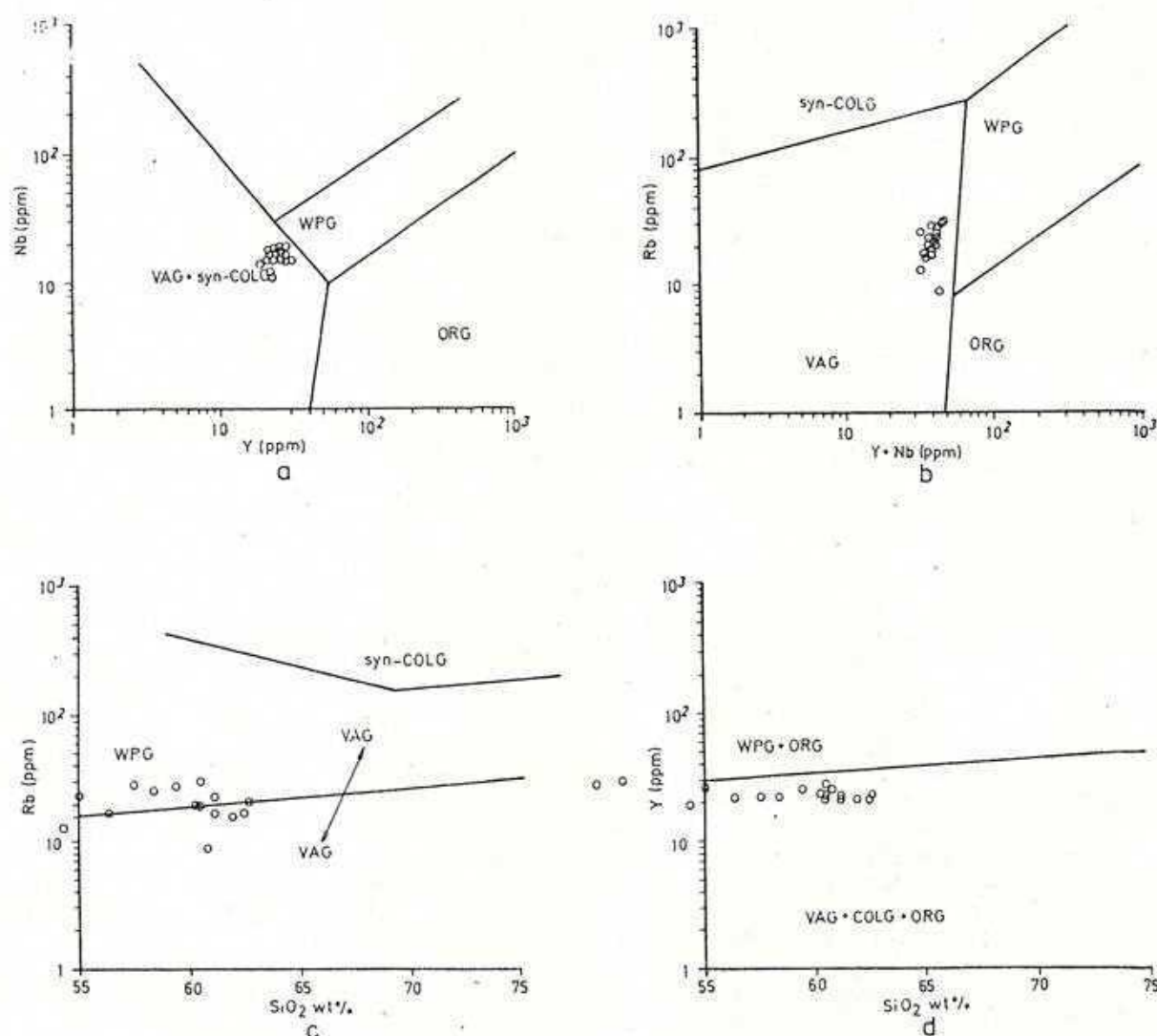


Fig. 3 - Nb-Y (a), Rb-Nb+Y (b), Rb- SiO_2 (c) and Y- SiO_2 (d) discrimination diagrams (after Pearce *et al.*, 1984). Open circles represent the Upper Cretaceous volcanoclastic rocks near Belgrade; VAG - volcanic arc granites; WPG - within plate granites; ORG - Oceanic ridge granites; COLG - Collision granites; syn-COLG Syn-collision granites.

Since these andesites are situated in the Vardar zone, i.e. in an ophiolitic melange belt, the WPG character is excluded, and the COLG and ORG affinities cannot be accepted because of the Nb/Y and Rb/Y+Nb ratios. These rocks, according to the presented chemical characteristics, belong to a volcanic arc granitic association, i.e. they are related to subduction processes.

Conclusion

The volcani(epi)clastic debris flow of submarine slump features, considered together with the abundance of small clasts in surrounding Turonian-Early Senonian graywackes, in the vicinity of Belgrade indicates the existence of a significant volcanism in this area during the Upper Cretaceous. According to major and trace element contents and ratios these volcanogenic rocks mostly correspond to trachyandesites of volcanic arc affinity.

The features of the andesitic rocks together with the age of oceanic basalts (with inclusions of Campanian limestones) and of the olistostrome near Krupanj and further southwards, i.e. of the western branch of the Vardar zone, indicate that the Western subzone of the Vardar ocean was closed by an eastward oriented subduction in the Senonian before the docking of the Jadar block (Karamata et al., 1994). By the subduction and collision processes, as well as by the later horizontal movements of blocks, the primary distant subduction related trench melange and the volcanic arc were first approached (Senonian) and later on (at the end or after the Cretaceous) moved aside by pushing of the Jadar block into the suture zone.

These new results of the closure of the western branch of the northern part of the Vardar zone in the Senonian.

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Plate

Fig.1 - The lower parts of the conglomeratic level and the underlying sandstones and marls (bottom left)

Fig.2 - Volcanic fragments (centre, bottom right) and small sandstone fragment (top left)

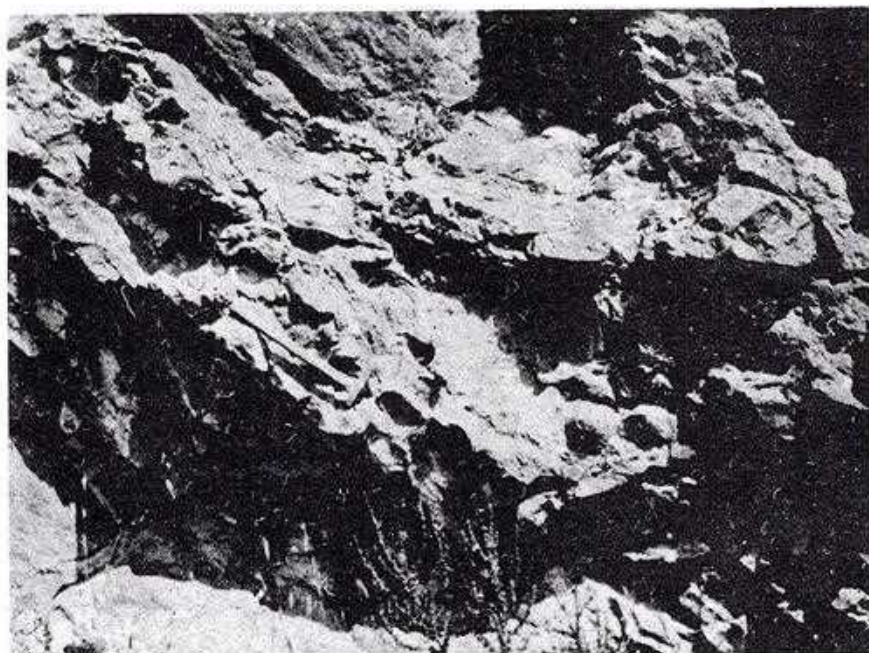


Fig. 1

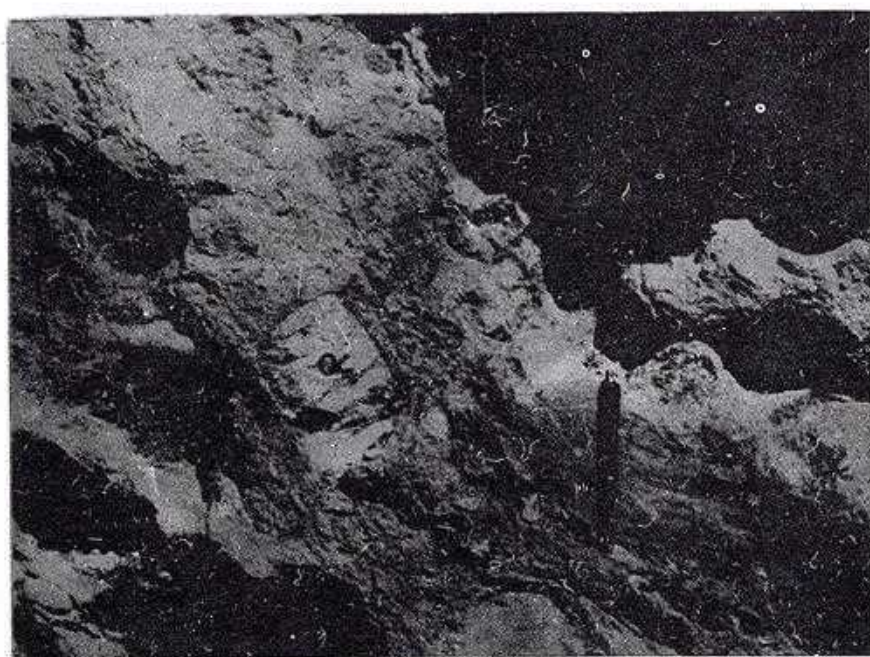


Fig. 2

GEOLOGICAL SETTING AND AGE OF THE COKA MARIN POLYMETALLIC ORE DEPOSIT (EASTERN SERBIA)

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Key words: Massive polymetallic ore deposit. Mineral assemblage. Hydrothermal alterations.

Abstract: The polymetallic (Au-Ag-Cu-Zn-Pb-BaSO₄) Coka Marin ore deposit is situated in the northern part of the Timok magmatic complex (TMC). This massive ore deposit differs in its mineral assemblage, association of elements, importance of precious metals, etc. from all other massive ore deposits of the TMC. The ore deposit is situated in a large volcanic system and consists of three bodies occurring in brecciated marginal parts of dacito-andesitic dykes, at their contact to weakly altered volcanoclastic deposits of hornblende-biotite andesites. The ore bodies are steep dipping lenses with apophyses. They consist of collomorphic to very finegrained pyrite in which veinlets and nests of enargite, luzonite, chalcopyrite, sphalerite, galena, sulfosalts, barite and other ore and gangue minerals were deposited later in several phases. Hydrothermal alterations in/and around the ore bodies are silification, kaolinization, sericitization, alunitization, etc., grading sideways to chloritization and epidotization. The neighbouring hornblende-biotite, hornblende and pyroxene andesites belong to the Santonian (85-83 Ma, but with some minerals rejuvenated). The mineralized dacito-andesitic dykes are of Lower Maastrichtian age (72.6 ± 3.2 Ma) and the unmineralized diorite porphyry dykes in the neighbourhood of the ore bodies consolidated in the Upper Maastrichtian (69-63 Ma). Finally a group of data scatter between 59 and 56 Ma indicating a rejuvenation (heating phenomenon). The mineralization occurred around $71 (\pm 1)$ Ma ago and was related to volcanic processes.

Introduction

The Coka Marin polymetallic ore deposit, situated in the northern part of the Timok magmatic complex, differs from other massive sulphide deposits in this area and is therefore of special interest.

This mineralization was indicated by systematic successive exploration works during 1970's; after detailed geological mapping (1:5,000), when the area of hydrothermally altered rocks was separated (Fig. 1), systematic mapping of alterations by investigation of fragments in soil and geochemical prospecting were

performed. The drilling began in 1981 and two Cu-Zn-Pb-pyrite ore bodies were detected. In the eighties drilling continued followed by other necessary investigations and the ore bodies are now well determined in their composition, shape and other peculiarities important for explanation.

The similarity of volcanic rocks in this area and their tectonic or intrusive relationships made difficult to explain the evolution in the discovered volcanic system. For this reason isotope age determinations were needed, and 8 analyses were performed in the ATOMKI Institute at Debrecen by Z. Pecskey. The

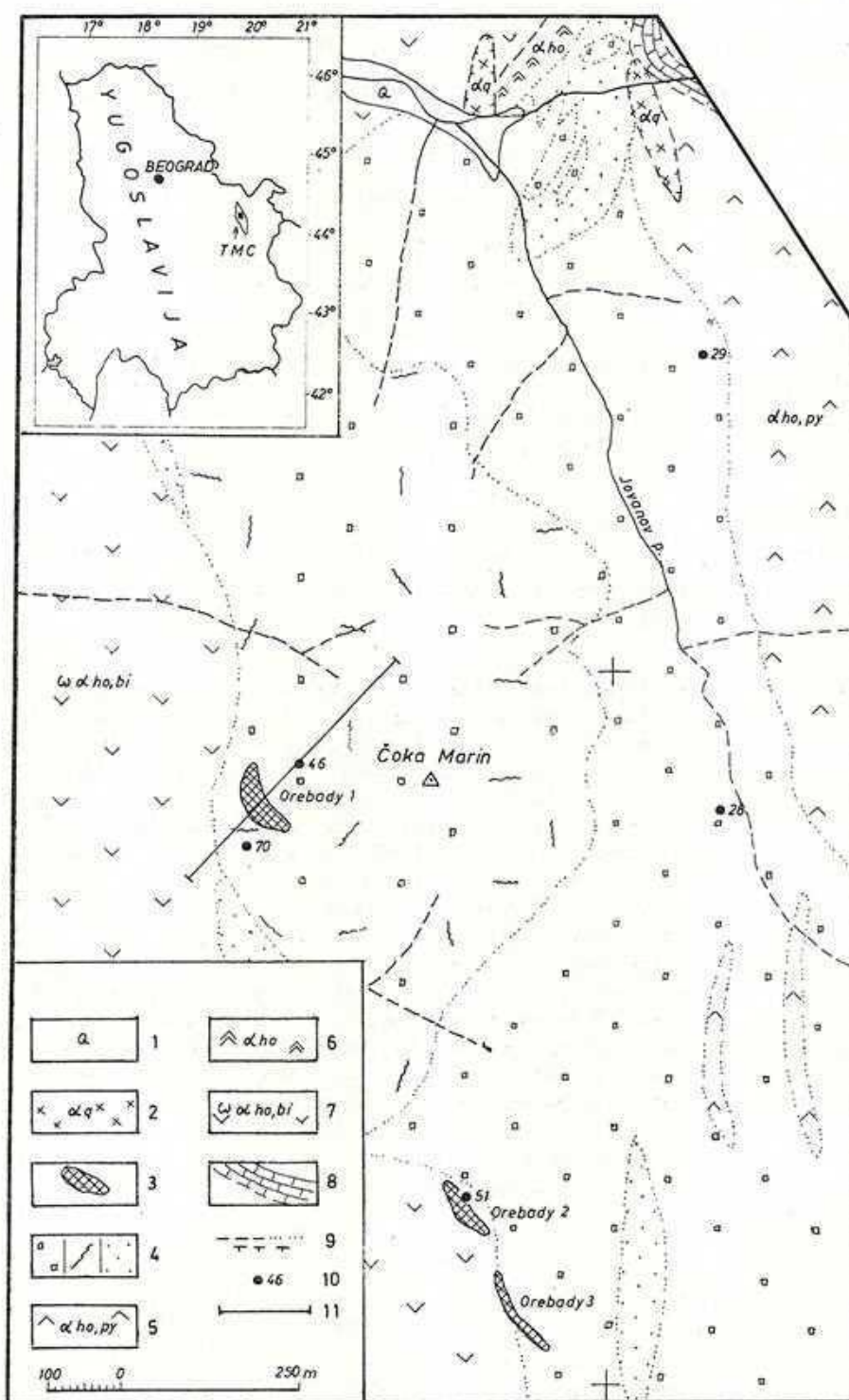


Fig. 1 - Geological map of the Čoka Marin area (according to mapping in sixties by GEO AVOD, Belgrade) and its position in Yugoslavia (upper left, TMC - Timoc magmatic complex). Explanation of signs: 1, Alluvium; 2, Dacite; 3, Projection at the surface of the latter by drilling detected ore bodies; 4, Hydrothermally altered rocks: chloritized, pyritized and silicified; 5, Pyroxene-bearing hornblende andesites; 6, Hornblende andesite; 7, Biotite-hornblende andesite volcanoclastics; 8, Senonian marls and limestones; 9, Boundaries of geological units: sharp (covered), transitional and intrusive (covered); 10, Drillholes; 11, Cross-section presented at Figure 2.

Table 1
K/Ar age determinations of rocks in the area of the Coka Marin deposits, Majdanpek

Lab no.	Locality, borehole depth	Rock	Dated fraction	K (%) content	K/Ar age (Ma)
2277	B-533 38.5 m	Biotite-hornblende	whole rock	0.54	58.8 ± 2.5
		andesite fragment	amphibole	0.24	85.5 ± 3.4
		from pyroclastics	feldspar	0.48	56.3 ± 2.8
2279	B-528 577.0 m	Pyroxene-bearing hornblende andesite	whole rock	1.23	83.8 ± 3.8
29/2*	B-529 439.2 m	Hornblende andesite weakly altered	whole rock	1.38	82.89
2281	B-570 174.5 m	Dacitoandesite (mineralized dyke)	whole rock	2.34	72.6 ± 3.2
2280	B-528 577.0	Dioriteporphyry	whole rock	1.59	69.6 ± 4.1
2282	B-551 346.5 m	Quartzdioriteporphyry	whole rock	0.94	69.1 ± 3.5
2278	B-603 58.5	Biotite hornblende andesite	whole rock	2.25	63.9 ± 2.4
35-K-9*	B-535 286 m	Dacitoandesite	whole rock		62.92

* Determination by A. Lovrić at the Department of Geochronology University of Geneva others by Z. Pecskey, ATOMKI-Debrecen

results are presented in Table 1.

For measurements samples with the lowest grade of alterations were used; however, only in one case mineral fractions could be separated, all the other analyses were made on the whole rock. The samples were degassed in a conventional extraction system using induction heating and measured by mass spectrometric isotope dilution with an ^{38}Ar spike using a mass spectrometer (magnetic sector type of 150 mm radius and 90° deflection) in the static mode. Recording and evolution of Ar spectrum were controlled by a microcomputer. Potassium analyses were made using standard flame photometric techniques. K- and Ar-determinations were checked regularly by interlaboratory standards LP-6, GL-0, HD-B.1 and Asia 1/65.

Atomic constants suggested by Staiger and Jäger (1977) were used for calculating the age. All errors represent on standard deviation (i.e. 68 % analytical confidence level).

Details of the instruments, the applied methods and results of a calibration have been described elsewhere (Balogh, 1985).

Geological position of the Coka Marin ore deposit

The ore deposit, i.e. the three discovered ore bodies are situated in the central parts of a deeply eroded volcanic system. The rock units and the ore body in this system are presented by a cross-section presented in Figure 2. The volcanic system was built of biotite-hornblende volcanoclastics with hornblende andesites

in its core intruded by dykes of pyroxene-bearing hornblende andesites. These rocks are of Santonian age, i.e. they were consolidated 85.5 ± 3.4 m.y. ago (age of an amphibole concentrate from volcanoclastics) to about 83 m.y. (two whole rock age determinations).

In the central, andesitic part of this Santonian volcano new melts were much later (72.5 to 63 m.y. ago) intruded. First were the dacito-andesitic ones which gave the dacitoandesite (1) of Lower Maastrichtian age (72.6 ± 3.2 m.y. ago). This rock was partially altered in its higher level; in the inner zone silicified, alunitized, with kaolinite, sericite and diasporite and chloritized, zeolitized, calcitized, kaolinitized and sericitized with albite and epidote locally in the outer zone.

Ore minerals were deposited in the strongly altered zone. Younger Upper Maastrichtian (69.6 to 69.1 m.y. ago) dioriteporphyry and quartzdioriteporphyry dykes, as well as Paleocene (63.9 and 62.9 m.y. ago) biotite-hornblende andesites and dacitoandesites (2) cut the older andesites and dacitoandesites (1). The Upper Maastrichtian to Paleocene magmatic activity probably partly rejuvenated some rocks, especially in overheated water easily percolating volcanoclastics rich in feldspars, which are the mineral with the lowest closing temperature.

The mineralization is younger than the Lower Maastrichtian dacitoandesite (1), which is the host rock, and older than the cutting it dioriteporphyries of the Upper Maastrichtian age. The rock alterations and the mineralization belong probably to the same magmatic activity which gave the dacitoandesite (1), i.e. it originated about $71 \pm$ m.y. ago.

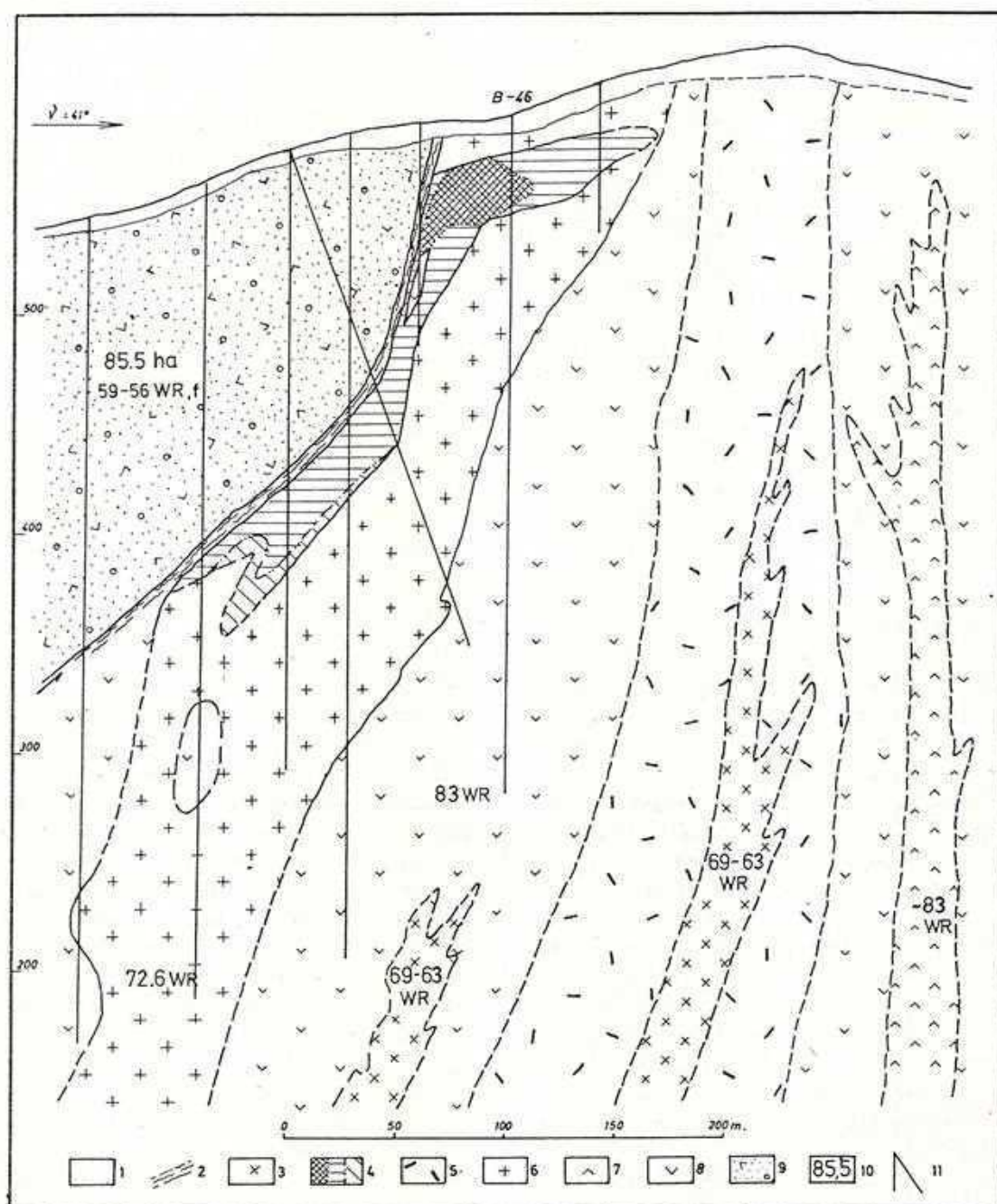


Fig. 2 - Cross-section through the Coka Marin ore body 1: 1, Soil and debris; 2, Shear zone; 3, Diorite porphyry; 4, Ore: polymetallic, Cu-pyritic, and pyritic aureole; 5, Silicified neck-shaped body; 6, Dacite andesite; 7, Pyroxene-bearing hornblende andesite; 8, Hornblende andesite; 9, Biotite-hornblende andesite volcanoclastics; 10, Age in million years, determined on whole rock (WR) sample, hornblende (ho), or feldspar (f) concentrate; 11, bore hole.

The time of origin of the silicified dyke-shaped body in Santonian hornblende andesites is unclear, probably it is connected with the early magmatic activity - it is sterile and with disseminated Cu-mineralization in the

depth and therefore differs from the silicified and alunitized zones with mineralization.

After the deposition of ore minerals and before the intrusions of Upper Maastrichtian dyke rocks the cen-

Table 2
Content of metals in the Coka Marin ore deposits

Coka Marin-1 (Ore body - 1)			
A. Cu-pyrite ore (older)		B. Polymetallic ore (younger)	
Cu	0.3 - 7.5 %	Cu	0.75 - 22.25 %
S	8.0 - 33.0 %	S	24.00 - 39.00 %
Au	0.5 - 10.0 g/t	Pb	0.30 - 14.00 %
Ag	0.5 - 10.0 g/t	Zn	0.70 - 38.00 %
		Au	2.00 - 64.00 g/t
		Ag	44.00 - 46.00 g/t
Coka Marin-2 (Ore body - 2)			
A. Cu-pyrite ore (older)		B. Polymetallic ore (younger)	
Cu	0.4 - 28.00 %	Cu	0.28 - 6.00 %
S	12.0 - 44.00 %	S	20.00 - 44.00 %
Au	1.0 - 70.00 g/t	Pb	0.20 - 10.00 %
Ag	12.0 - 289.00 g/t	Zn	0.60 - 28.00 %
		Au	1.00 - 25.00 g/t
		Ag	88.00 - 690.00 g/t
Coka Marin - Ore deposit			
A. Cu-pyrite ore (older)		C. Polymetallic ore (younger)	
Cu	0.3 - 28.00	Cu	0.28 - 22.25 %
S	8.0 - 44.00	S	20.00 - 44.00 %
Au	0.5 - 70.00 g/t	Pb	0.20 - 14.00 %
Ag	0.5 - 289.00 g/t	Zn	0.60 - 38.00 %
		Au	1.00 - 64.00 g/t
		Ag	44.00 - 690.00 g/t
B. Pyrite aureole			
Cu	0.10 - 0.40 %		
S	11.0 - 41.00 %		
Au	0.10 - 12.00 g/t		
Ag	1.00 - 29.00 g/t		

Ore composition

In the Coka Marin 1 body and in central parts of the Coka Marin 2 ore body, the ore bodies consist of massive to dense stockwork ore grading into impregnations of ore minerals in a silicified, alunitized, sericitized and argillitized rock with occurrences of diaspore dacitoandesitic rocks. In the upper parts of the polymetallic mineralization occurs, grading sideways into Cu-pyritic ore and further sideways into an aureole with strong pyritization. The fault at the SW cuts this zonal distribution in the first ore body immediately next to the polymetallic ore, and in the second one in the Cu-pyritic zone.

According to Rakić (unpublished report, quoted by Janković, 1990) four phases of mineral deposition can be distinguished: (1) deposition of gel-pyrite and gel-marcasite, with subordinate enargite, luzonite, sphalerite, galenite and locally chalcopryrite, (2) deposition of crystalline luzonite, enargite, sphalerite and subordinate galena, pyrite and rare arsenopyrite, associated with the recrystallization of the gels, (3) transformation of enargite to tenantite and later into chalcocite and covellite, as well as of chalcopryrite into bornite and later chalcocite and covellite, (4) the youngers are sphalerite and galena deposited from colloidal solutions, chalcopryrite, tethraedrite and sulfosalts. The sphalerite is rich in cadmium, and the ore is rich in silver and gold. Gold occurs as native in quartz and

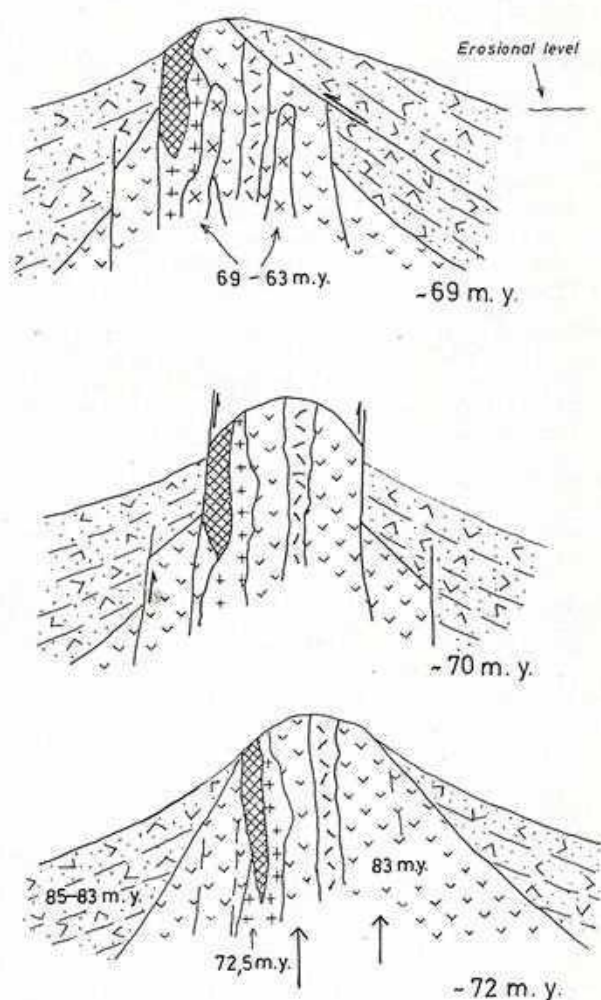


Fig. 3 - Evolution of the Coka Marin volcano and explanation of the present distributions of units, for circa 72, 70 and 69 m.y. ago. Signs as in Figure 2. Ages of units are given in million years (m.y.).

tral part of the hornblende andesite plug was uplifted along faults at its margins and the ore bodies were brought in tectonic contact to the volcanoclastics and volcanics of Santonian age. Along the fault a narrow shear zone originated, which separates the ore bodies with strongly altered rocks from the only weakly altered volcanoclastics.

The relationships among rock units and the ore body about 72, 70 and 69 m.y. ago and the evolution of the Coka Marin volcano in its late phases is presented in Figure 3.

as interstitial in chalcopyrite, pyrite, enargite etc. The gangue minerals are quartz, barite, anhydrite, carbonates and in deeper levels fluorite.

According to these data the ore is in general rich in Au and as exception for the mineralizations in the Timoc magmatic complex rich in Zn. The chemical compositions of Cu-pyrite and the polymetallic ore in both ore bodies are given in Table 2. The same table presents the contents of the main ore compounds in the Coka Marin deposit in total but separately for the Cu-pyritic ore, the pyrite aureole and the polymetallic ore.

Conclusions

The Coka Marin polymetallic ore deposit is unique in the Timoc magmatic complex. It is a volcanic ore deposit with high Zn, Cu and less Pb, and with high gold and silver contents. In its peculiar mineral and metal composition it differs from all other deposits in the Timoc magmatic complex: they are Cu-rich, very poor in Zn and almost without Pb.

The Coka Marin ore deposit differs from other ore deposits in the Timoc magmatic complex also by age and its geologic setting; the other Cu-ore deposits are related to older magmatic activities (Janković et al., 1981) or deep intrusions. This can be the reason for the special character of this new-discovered ore deposit.

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GEOTECTONIC SETTING AND METALLOGENIC CHARACTERISTICS OF PORPHYRY COPPER DEPOSITS IN THE SERBO-MACEDONIAN PROVINCE

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Key words: Porphyry copper deposits. Metallogeny. Strontium ratio. Post-collision setting.

Abstract: The porphyry copper deposits of the Serbo-Macedonian metallogenic province are associated with the Oligocene-Miocene calc-alkaline complexes. The origin of these igneous complexes cannot be unequivocally related to subduction of an oceanic slab and its partial melting, although they are situated in the vicinity of a suture zone, formed after the closure of the Vardar-Izmir-Ankara ocean in the late Jurassic-early Cretaceous. It is more likely that the widespread calc-alkaline igneous suits resulted from an anatectic partial melting of the lowermost continental crust, in post-collision activation processes. These processes took place during the late Palaeogene through early Neogene along the oceanic suture, preceded by the uplift of the central parts of the suture zone owing lateral compression. The absolute age of the igneous rocks ranges from 18 to 37 m.y., but mainly between 29 and 23 m.y. The porphyry copper deposits are emplaced at hypabyssal and subvolcanic levels, the latter occasionally associated with caldera structures, but near serpentinized peridotites. In some of these deposits, such as in Kiseljak of the Lece ore field, quartz-topaz greisen is identified. Most porphyry copper deposits contain increased contents of gold (over 0.5-0.7 g/t), and traces of PGE. They are usually of small size to 10-80 million tons of low-grade ore.

Introduction

Several porphyry copper deposits have been discovered since 1963 in the Serbo-Macedonian metallogenic province (Zachos, 1963). Systematical studies carried out during this period, particularly in the last decade, provide information on their genesis, mineralogy and controlling factors of their distribution (Bučim: Čifliganec, 1987, 1993; Borov Dol: Mitevski, Čulev, 1986; Tudžarov, 1994; Kiseljak: Seke, 1988; Serafimovski, 1993; Eastern Chalkidiki: Antoniadis et al., 1971; Kalogeropoulos, 1987; Kocke et al., 1975; Papadakis, Michailidis, 1976; Perantonis, 1982).

All the deposits are paragenetically related with the Oligocene-Miocene volcano-plutonic complexes of calcic-alkaline composition, confined to a post-collision tectonic environment between the African and the Eurasian plates. Though such a tectonic setting and geochemical features of parent magmas are not, generally, considered favourable for porphyry copper mineralization, the discovered porphyry copper deposits

prove that even in such an environment this type of mineralization can be of economic importance (the Bucim mine is in operation).

It is interesting to point out that porphyry copper deposits occur only in the southern part of the volcano-plutonic chain of the Serbo-Macedonian metallogenic province, while the complexes of the same petrochemical composition situated in the northern part are devoid of copper deposits. On the other hand, significant lead-zinc mineralization linked paragenetically with calc-alkaline complexes is developed over the whole metallogenic province. The variable concentration and spatial distribution of lead-zinc and copper require a metallogenic explanation.

This paper aims to briefly review the general features of the tectonic setting and metallogeny of the porphyry copper mineralization on the Serbo-Macedonian province. A previous study by Jancović et al. (1980) on the same subject was later completed by more detailed data on individual porphyry copper deposits of the former Yugoslavia by Čifliganec (1987), Jancović (1982, 1990) and Serafimovski (1993).

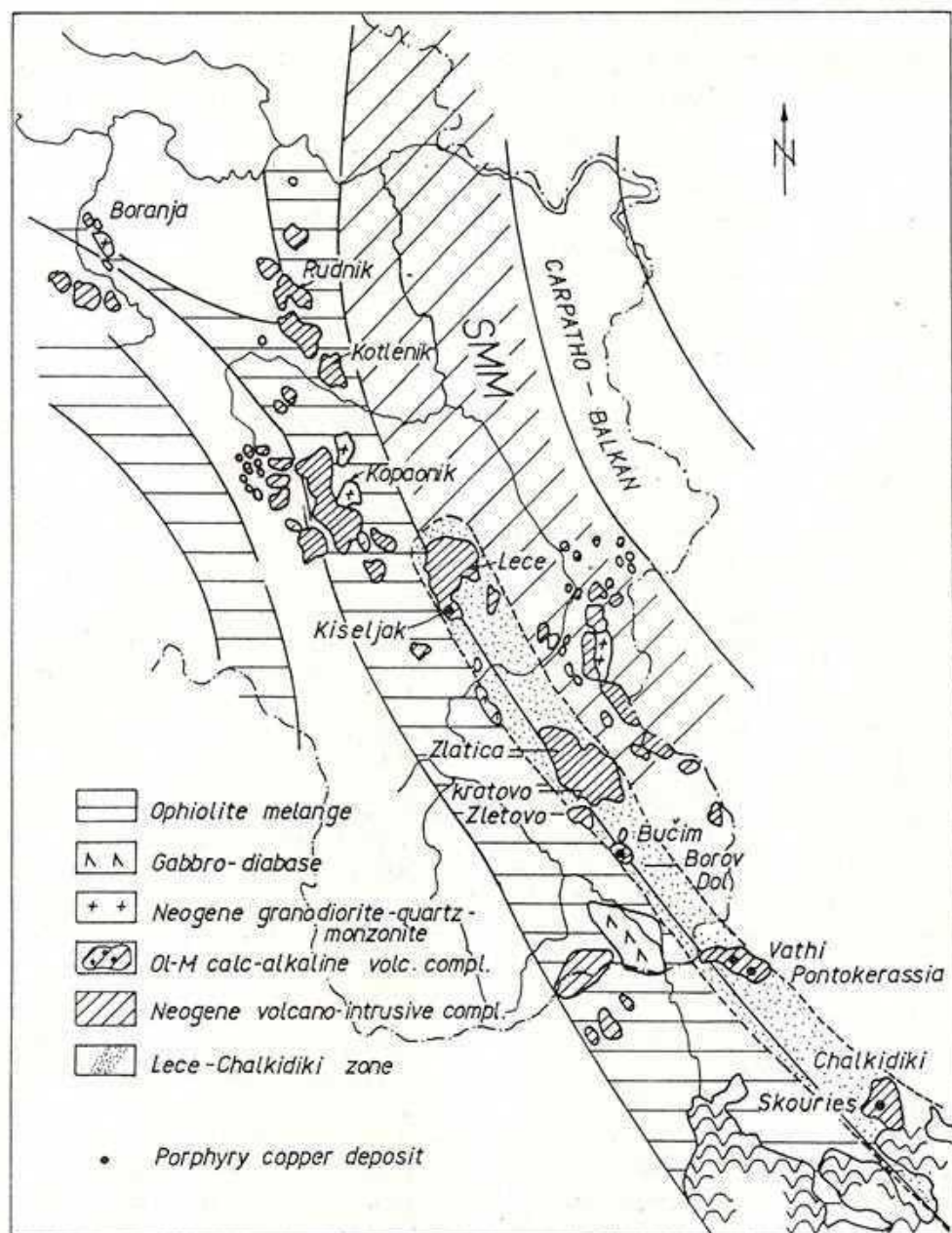


Fig. 1.— Position of porphyry copper deposits in the Serbo-Macedonian metallogenic province.

Geotectonic setting

The porphyry copper mineralization of the Serbo-Macedonian metallogenic province occurs along the contact zone between two regional metallogenic units, the Serbo-Macedonian Mass (SMM) and the Vardar zone (Fig. 1).

The SMM is situated between the Carpatho-Balkanides, in the east, and the Vardar zone, in the west (Dimitrijević et al., 1967; Grubić, 1980). It incorporates mostly Precambrian and early Paleozoic

rocks: crystalline schists (gneisses, amphibolites, micaschists, marbles a.a.) of the lower complex, and volcano-sedimentary series metamorphosed up to the greenschist facies of the upper complex. The contact between these two units is tectonic.

The Vardar zone represents a suture zone, the extension of which continues beyond the border of the Serbo-Macedonian metallogenic province. It consists dominantly of Jurassic ophiolites (gabbro-peridotite complexes and volcano-sedimentary series such as diabase-hornstone formation a.a.), covered by Creta-

ceous flysch. Paleozoic and Triassic sediments are locally preserved.

Occurrences of peridotite "dikes" in the SMM are developed along its contact with the Vardar zone. The porphyry copper mineralization is usually located in the vicinity of these "dikes" of serpentinite.

During the late Paleozoic, the SMM was an island arc, welded with the Eurasian plate during the Cretaceous. This tectonic unit as a whole represents at present a rigid block.

The process of closure of the Tethys and the subduction of the oceanic slab beneath the SMM during the Cretaceous was followed by the collision of the African plate with the Eurasian plate. Minor underthrusting of one continental crust beneath the other caused thickening of the continental crust in the zone of collision. These processes triggered up doming, formation of regional dislocation and graben-like structures. From the metallogenetic viewpoint, deep-fracture zones developed along the western margin of SMM are of particular importance (active continental margin).

The regional dislocation, particularly those running subparallel with the suture zone, acted as conducting parths for later upward movements of calc-alkaline magmas and hydrothermal ore-bearing solution. These regional structures are the main control for the distribution of the volcano-plutonic zones and the regional metallogenic units (zone, ore district, ore field).

The regional ring-radial structures are associated with up-doming and volcano-intrusive complexes of central type. Such structures are a characteristic feature of the Serbo-Macedonian metallogenetic province.

Volcano-plutonic complexes. Besides the regional structural pattern, the volcano-plutonic complexes of calc-alkaline magma display a strong link with base metals mineralization in the Serbo-Macedonian metallogenetic province.

Volcano-plutonic complexes are discontinuously developed along the principal dislocations in the Vardar zone and in the SMM (Fig. 1). Andesite, dacite, to some extent quartzlatite, latite, less rhyolite are the most common volcanics. The plutonic facies are more frequent in the northern part of the metallogenetic province. Stock and dikes are often found in the subvolcanic level.

Petrochemical compositions of volcano-plutonic rocks indicate that this calc-alkaline magma is similar to the magma of continental margins (Ewart, 1982).

The origin of the parent magma is closely associated with the tectonic setting. It was generated from the lowest part of the thickened continental crust in the collision zone, due to friction and warming up, caused by the underthrusting of one continental crust. Temperatures resulting from friction between two colliding con-

tinental crusts are sufficiently high to generate granite magmas. Some underthrust parts of continental crust, penetrated deeper, can be heated by thermal fluxes from upper mantle, causing partial melting of continental crust, and generation of granitic-granodioritic magmas. So formed magmas move upward along deep dislocations. Karamata (1982) emphasizes that such magmatism occurs above the zone of thickening of the continental crust due to compression (i.e. in the zone of ophiolitic mélange) and/or along the contact zone of overthrust continental block. This model envisaged by Karamata (1982) fits the environment in the Vardar zone, and the volcano-plutonic complexes of calc-alkaline magmas formed during the Oligocene-Miocene period.

The evidence that parent magma was contaminated by material from continental crust, including local contamination by peridotites, can be found in the strontium ratios ($^{87}\text{Sr}/^{86}\text{Sr}=0.706-0.710\%$).

The paragenetic association of calc-alkaline magma and base metals of ore deposits is supported by the common distribution patterns of lead isotopes (Jančović, 1990; Serafimovski, 1993).

Porphyry copper deposits

So far discovered porphyry copper deposits are confined to a narrow zone along the western margin of SMM, with subvolcanic-hypabyssal stocks and/or dikes of andesite, rhyodacite, occasionally to stocks of granodiorite porphyry. The general features of these deposits are reviewed in Table . It should be noted that porphyry copper ore contains very low Ag and Mo, and is locally enriched in gold (copper-gold deposits, such as Bučim and Skouries).

Ore reserves of individual deposits are relatively small, from 10 million tons to 80 million tons of low grade ore.

The size of the deposits depends on its copper and gold contents, and cut-off grade. Vertical dipping of the ore body and small mineralized surface at horizontal cross-section contribute greatly to the overburden ratio.

The morpho-structural types of porphyry copper deposits in the Serbo-Macedonian metallogenetic province can be classified into two main groups (Fig. 2 A, B):

1) Ore bodies formed in magmatic stocks and/or dikes and in their contact zone with gneisses. Such deposits/ore bodies have a tube-like or columnar shape dipping vertically or very steep (Fig. 2 A).

In these deposits, two subgroups are distinguished:

- The copper mineralization is mainly in crystalline schists (gneisses), along the contact of the magmatic body; the intrusion itself is barren or slightly mineralized.

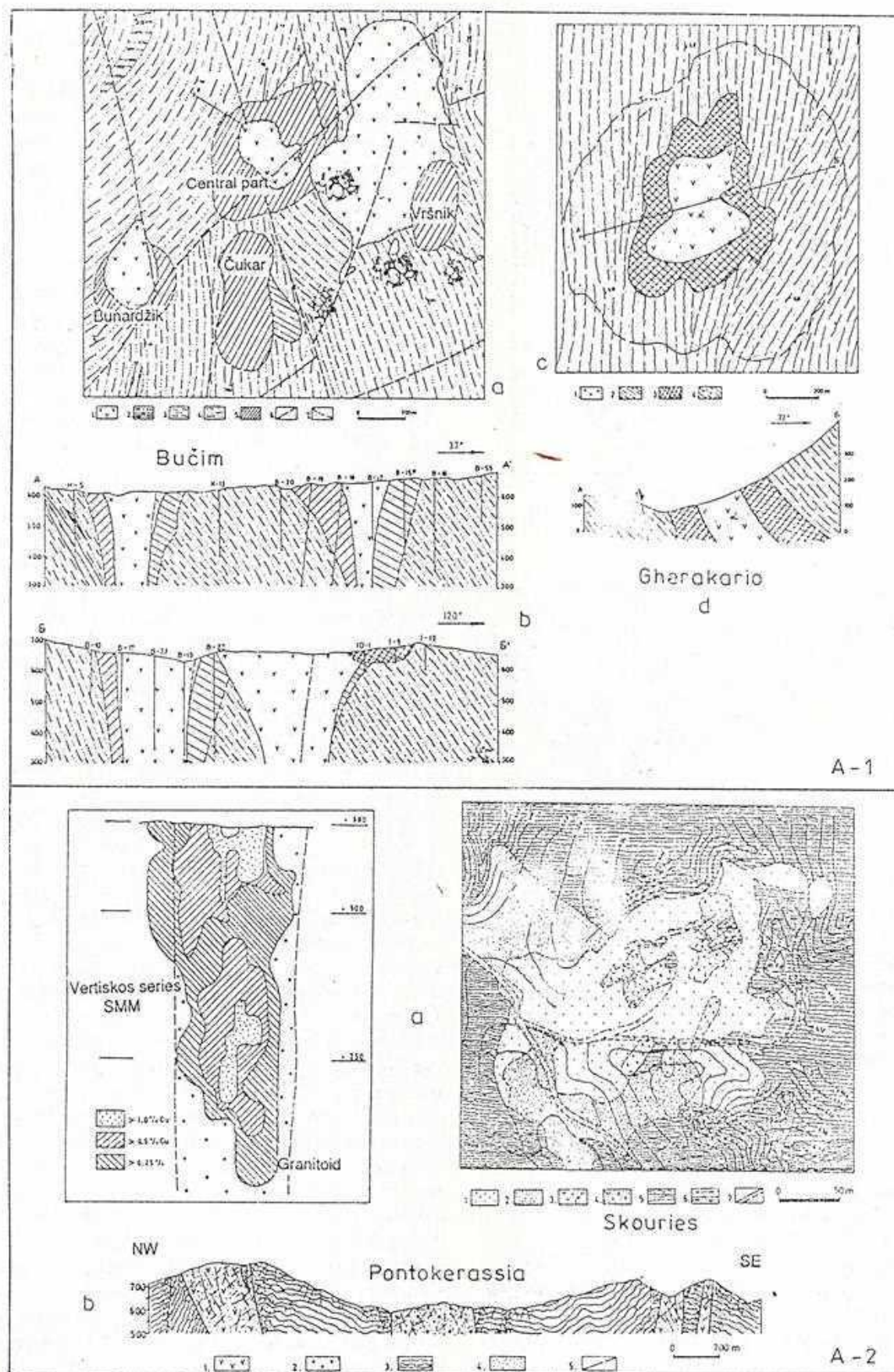
Tab. 1

Table 1
General features of porphyry copper deposits in the
Serbo-Macedonian metallogenic province
(x: Serafimovski, 1993; y: Čifliganec, 1993; z: Serafimovski, 1993; Kalogeropoulos, 1987)

Deposit Host rock	Kiseljak (x)	Bucim (y)	Borov Dol (x)	Vathi (x)	Pontokerasia (x)	Skouries (z)
Parent igneous rock	Andesite	Gneiss/and Andesite	Andesite	Brecciated rhyodacite	Rhyodacite/ granosyen.	Granodiorite porphyry
Absolute age, my	Subvolcanic stock/ andesite	Subvolcanic stock/ andesite	Subvolcanic stock/ andesite	Rhyodacite dyke/ Subvolcanic	Subvolcanic stock/dyke. Subvolcanic	Stock: Granodiorite porphyry
Horizontal projection	12-23	25-28	24-28	30 -	32	29.6
Vertical extent	0.24 km ²	0.25 km ²	0.15 ²	150 x 700 m	300 x 400 m 200 x 400 m	100 x 200 m
Hydrothermal alteration	300-500 m	250 m	300 m	500 m		700 m
Association of minerals	Biot, Ser, Sil, Pyr, Arg, Ch, Ty, Di, Cd, Gr	Pot, Biot, Ser, Sil, Ch	Pot, Biot, Ser, Sil, Arg, Ch, Ep, Ka	Pot, Biot, Ser, Sil	Ser, Sil, Ch Ar, Pyr	Pot, Ser, Arg, Ch
Ore constituents	Cy, Py, Mgt, Mo, Au, T, Ga Sp, E, Bi	Cy, Py, Mgt, Au, He, B, Bi, E, Ga, Sp, Te, Ag, Pd	Cy, Py, Mgt, He, Mo, Au, B, Sp	Cy, Py, B, E, Ga, Sp, Mgt, He	Cy, Py: Stock= work-diss. Ga, Sp: Veins	Cy, Py, B, Au, Mgt, Sp, Ga, T
	0.33 % Cu 0.3 ppm Au 1.0 ppm Ag 23 ppm Mo 4-10 % pyrite	0.3 % Cu 0.6 ppm Au 1.1 ppm Ag 13 ppm Mo 1-4 % pyrite Traces Pd, Se, Te	0.3 % Cu 0.25 ppm Au 150 ppm Ag 24 ppm Mo 2 % pyrite	0.3 % Cu 0.15 ppm Au 0.35 ppm Ag 20 ppm Mo	0.3 % Cu 0.3 ppm Au 0.35 ppm Ag 10 ppm Mo	0.5 % Cu 0.7 ppm Au 2.5 ppm Ag Traces: Pd, Te, Pt

Cy=chalcopryrite; Py=pyrite; B=bornite; Ga=galena; Sp=sphalerite; Mgt=magnetite; He=hematite; T=tetrahedrite; E=enargite;
Bi=bismuthine; Au=native gold; Ag=silver minerals; Pot=K-feldspar; Biot=biotization; Ser=sericitization; Sil=silicification;
Arg=argillization; Ch=chloritization (prophyllitic); Gr=greisenization (topaz, cassiterite, wolframite); E=epidiotization;
Ka=karbonitization; Py=pyritization; Ty=tourmalinization; Di=diaspor; Cd=corundum.

Fig. 2 - Morpho-structural types of selected porphyry copper deposits in the Serbo-Macedonian metallogenic province. Fig. 2A - Ore bodies formed in magmatic stocks and/or dikes and in their contact zone with gneiss: A-1, the copper mineralization in crystalline schists through: - a,b Bučim (Čifliganec, 1993): 1, andesit, latite; 2, amphibolite; 3, micaschist; 4, gneiss; 5, ore body; 6, fault; 7, contour of ore body; - c,d Gherakario: 1, hydrothermal altered andesite; 2, crystalline schists (gneiss); 3, copper mineralization; 4, gneiss mineralized; A-2, the mineralization within the intrusion: - a Skouries (Kalogeropoulos, 1987): 1, granodiorite stock; 2, alluvial; 3, trachyte; 4, hydrothermally altered and mineralized trachyte; 5, crystalline schists (SMM); 6, hydrothermally altered and mineralized crystalline schists; 7, fault; - b Cross-section through Pontokerasia (from: Serafimovski, 1993): 1, rhyolite; 2, granosyenite; 3, crystalline schists; 4, copper mineralization; 5, fault.



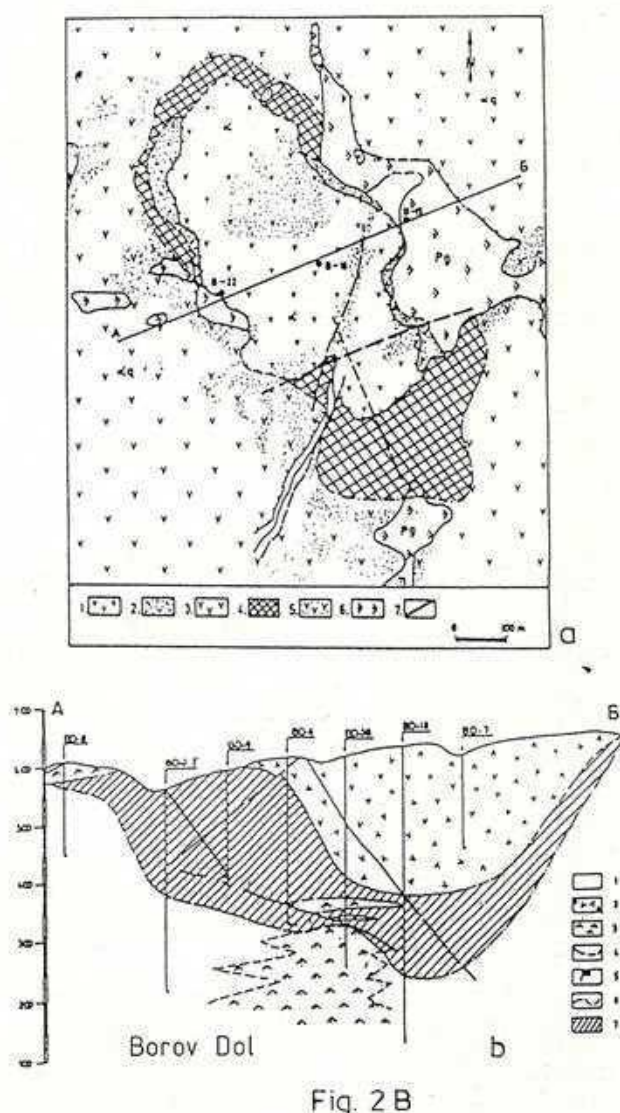


Fig. 2 B

Fig. 2 - Morpho-structural types of selected porphyry copper deposits in the Serbo-Macedonian metallogenic province. Fig. 2B - Ore bodies formed in volcanic Borov Dol (Mitevski, Čulev, 1986; Tudzarov, 1994): - a: 1, andesite; 2, volcanic breccias; 3, latite, quartzlatite; 4, Copper mineralization; 5, hydrothermally altered andesite; 6, volcano-sedimentary series; 7, fault. - b Cross-section through Borov Dol: 1, coarse-grained andesite; 2, fine-grained andesite; 3, andesitic tuff; 4, fault; 5, borehole; 6, outline of copper deposit, 7, ore.

Such ore bodies have in horizontal cross-section the shape of a mineralized ring (the deposits at Bučim, and Gherakario) (Fig. 2 A-1).

- The copper mineralization is within the intrusion; the surrounding crystalline schists of SMM are slightly mineralized along the contact zone (the deposits at Vathi and Skouries) (Fig. 2 A-2).

2) Deposits/ore bodies formed in volcanics have various shapes, often elliptical in horizontal cross-section

(the deposits at Kiseljak, Borov-Dol) (Fig. 2 B).

Though all porphyry copper deposits in the area under consideration have similar metallogenic characteristics, some of them, such as Bučim and Pontokerassia exhibit certain peculiarities. The Bučim deposits can be defined as an anomalous copper geochemical field (a few sq Km) within which several ore bodies are delineated by cut-off grades. At the same time, the contour of the geochemical field corresponds approximately to the anomalous geomagnetic field, generated as a response to the subvolcanic stocks which intruded the SMM. The Pontokerassia deposits, consisting of several ore bodies, are surrounded by large anomalous geochemical anomalies of copper and lead/zinc several times larger than the ore bodies.

A specific style of stockwork-disseminated copper mineralization in volcanic occurs in the Plavica deposit, located in the Zletovo volcanic complex. The large tonnage of low-grade mineralization was formed in a caldera (Serafimovski, 1993). Enargite veins, containing gold, occur occasionally in this deposit, and are associated with advanced argillic alteration. It seems that the copper mineralization represents the highest level of a hydrothermal system, within which a porphyry mineralization could have been formed at lower levels, but from hydrothermal solutions whose characteristics would be somewhat different from those identified in that part of the Plavica caldera that has been so far explored (Čifliganec, 1993).

Origin of copper and gold. Primary calc-alkaline magma was not enriched in these metals, as it can be inferred from the systematical study of trace elements in volcano-plutonic complexes over the whole Serbo-Macedonian metallogenic province, even within its extension to Anatolia in Turkey (Karamata, 1974). According to Karamata (1974), the Tertiary igneous rocks have both as a whole and their K-feldspars higher Pb-contents than the average contents in analogous rocks and, consequently, this area corresponds to the Pb-geochemical province. These igneous rocks have lower or higher copper contents than the average copper contents of analogous igneous rocks. The copper contents in Tertiary calc-alkaline complexes range mostly between 3 and 40 ppm, but mainly 10-30 ppm. However, some of the volcanic complexes with which the porphyry copper mineralization is associated display the increased copper contents: Bučim, 80 ppm (andesite); Borov Dol, 200 ppm (quartz latite); Gherakario, 200 ppm (rhyolite) (Serafimovski, 1993).

Where does copper in porphyry copper mineralization come from. It seems, most likely, that copper and gold originate from peridotite. They were mobilized by passing-through magma and/or by hydrothermal solutions. Such a conclusion is supported by:

- Volcanic complexes accompanied by porphyry cop-

per mineralization display increased copper (and gold) contents. Of course, the increased copper contents in igneous rocks does not mean that porphyry copper system must be formed. (The volcanics of Lojane contains 200 ppm Cu, but copper mineralization is not identified);

- Association of Au-Pd (Pd-Au) with chalcopyrite and pyrite in the Bućim deposit (Čifliganec, 1994 unpubl.) and high values of Pb and Au (480 ppb and 7,200 ppb, respectively) in the mineralized porphyry rocks (Eliopoulos, Economou-Eliopoulos, 1991) and presence of merenskyite in the Skouries deposit (Tarkian et al., 1991) may indicate ultramafics as their source along with copper;

- Increased contents of Cr, Ni and Co, identified in some porphyry copper ores, may also be considered a support for the copper origin from peridotites. For instance, porphyry copper ore from the Skouries deposit contains on an average 68 ppm Ni and 13 ppm Co (Serafimovski, 1990).

Criteria for selection of favourable tectono-magmatic environments

The Serbo-Macedonian metallogenic province is dominated by the Pb-Zn/Sb deposits. Copper occurs in porphyry copper mineralization and associated with skarn deposits and/or hydrothermal lead-zinc sulphides as minor constituent. In both these types of deposit, copper is only a by-product of lead-zinc ore. It is of interest to recognize and define, certain criteria for selection of tectono-magmatic environment favourable for porphyry copper mineralization in the Serbo-Macedonian metallogenic province. This paper introduces tentatively some of such criteria and indications, which can be applied to looking for new porphyry copper deposits in the Serbo-Macedonian metallogenic province.

Structural-tectonic setting. The western margin of SMM as an active continental margin is the most favourable environment for porphyry copper mineralization.

Regional fractures and sites of their crossings, as well as volcanic structures of Tertiary calc-alkaline igneous rocks along the western margin of SMM, are the most significant structural control of deposition and distribution of porphyry copper mineralization.

Igneous complexes. Minor subvolcanic to hypabyssal intrusions of calc-alkaline igneous rocks are a promising prospecting target for porphyry copper mineralization, particularly if such igneous complex has the following characteristics:

- 1) Increased contents of Cu, Au, Pb, Ni and Co.
- 2) Strontium ratio: $^{87}\text{Sr}/^{86}\text{Sr}$ of the igneous rocks seem to be another source of information to discriminate productive and barren magmatic complexes re-

garding copper mineralization, at least on the regional scale. Though present data of strontium ratios of the volcanics in the Serbo-Macedonian metallogenic province are scant, the available number of analyses allow to make a preliminary conclusion: the porphyry copper mineralization is related with volcanics having lower strontium ratios than those paragenetically associated with lead-zinc deposits.

Volcanics/Copper deposits

	$^{87}\text{Sr}/^{86}\text{Sr}, \text{ }^{\circ}/_{\infty}$
Bućim (1)	0.706928
Borov Dol (1)	0.706817
Zletovo (1)	0.706318

Volcanics/Lead-zinc deposits

	$^{87}\text{Sr}/^{86}\text{Sr}, \text{ }^{\circ}/_{\infty}$
Sase(1)	0.709543
	0.710641
	0.710244
Rogozna (2)	0.707-7085
West Anadolia (3)	0.7078

(1) Boev et al., 1992; (2) Karamata (unpubl.); (3) Innocenti et al., 1982.

Hydrothermal alteration of volcano-plutonic igneous complex and their surrounding rocks is, as in other porphyry copper mineralization, an important indication of ore. Potassium and sericitic alteration, as well as silicification, are the dominant facies, accompanied by argillization and chloritization.

Enargite-gold association situated in volcanics, accompanied by advanced argillic alteration occurs occasionally on the top of the porphyry copper hydrothermal system.

Geochemical indications. As in other districts with porphyry copper mineralization, geochemical anomalous fields are a significant indication of porphyry copper mineralization in the Serbo-Macedonian metallogenic province. Such fields involve contents and distribution pattern of association of elements-indicators such as Cu, Mo, Be, As, Pb, Zn, Au, Ag a.a.

The determination of erosion depth is based on the zonal distribution of elements-indicators: (B, W, Co, Sn)-(Mo, Cu)-Bi-Au-(Zn, Pb, Ag)-Sb-As-Ba and index zoning.

Conclusions

The porphyry copper deposits of the Serbo-Macedonian metallogenic province are characterized by the following features:

1. They are located along the western margin of the Serbo-Macedonian massif (SMM), i.e. along the active margin of the Euroasian continent.

2. They are related to the Oligocene-early Miocene calc-alkaline subvolcanic-hypabyssal intrusions (stocks, dykes).

The magma originates from the lowest part of the thickened continental crust, in the collision setting between the African and Eurasian plates. The strontium ratios of igneous complexes situated in the Serbo-Macedonian metallogenic province range from 0.706 to 0.71‰. The volcanic complexes with porphyry copper mineralization have the strontium ratio of 0.706‰. Such igneous complexes display the increased contents of Cu, Ni, Co, Cr.

3. Mineralization occurs in magmatic bodies (andesite, rhyolite, occasionally granodiorite porphyry) and/or in the surrounding crystalline schists.

Intense hydrothermal wallrock alteration is developed in/and around the mineralized rocks (potassium, sericitization, silicification, accompanied by argillization and chloritization).

4. Primary mineralization consists of chalcopyrite and pyrite, accompanied by bornite, magnetite, minor Pb-Zn sulphides. In some deposits the gold content is high (over 0.5–0.7 ppm). Silver and molybdenum are low (up to 2 ppm and 10–20 ppm, respectively). Palladium occurs as traces.

5. The deposits are of small size. Reserves of individual deposits vary from 10 to 80 million tons (order of magnitude) of low-grade ore (0.2–0.5% Cu, but mostly 0.2–0.3% Cu, and 0.1–0.7 ppm Au, but mainly around 0.2 ppm Au).

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PRINCIPAL METALLOGENIC FEATURES OF THE LECE-CHALKIDIKI ZONE

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Abstract: The Lece-Chalkidiki metallogenic zone is related to and situated along the contact zone between the Vardar tectonic unit and the Serbo-Macedonian block over a distance of 350 km. It is up to 20 km wide and is associated with a post-collision tectonic setting. Several volcano-intrusive complexes of calc-alkaline composition are developed locally along two principal regional dislocations: a) at the contact zone of ophiolitic Jurassic-Cretaceous melange with the Precambrian crystalline schists of the Serbo-Macedonian Massif (SMM) and b) within the SMM in the east. In the northern sector volcanic rocks of the central type prevail, while in the southern sector minor hypabyssal intrusions dominated. The absolute age of the calc-alkaline complexes ranges from 37 to 16 m.y. (K-Ar determination). The mineral deposits are paragenetically associated with calc-alkaline volcano-intrusive activity. Lead and zinc are the dominant metals, followed by antimony, arsenic, and locally copper, molybdenum, gold, silver. Uranium, PGE, bismuth, mercury also occur locally, but are less abundant. Hydrothermal volcanogenic types 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. Ore deposits are grouped into several metallogenic districts and ore fields, each characterized by specific styles of mineralization and a mineral/elemental association.

Introduction

The Lece-Chalkidiki metallogenic zone is a part of the Serbo-Macedonian metallogenic province (Fig.1). This regional metallogenic unit formed along the contact between the SMM to the east, and the Vardar zone to the west. The ore deposits are located close to the western margin of SMM.

The Lece-Chalkidiki metallogenic zone is defined by specific mineral and metal associations, as well as morphogenetic types of mineralization, formed during the Neogene following the intrusion of Oligo-Miocene volcano-plutonic calc-alkaline magmatic complexes. The metallogenic zone strikes NNE-SSE, and can be traced, from Crni Vrh in the north, through Lece to Chalkidiki in the south for over km. It is covered by Neogene sediments to the north, but its extension is suggested by geomagnetic data. It extends southwards beyond Chalkidiki below the Aegean Sea.

This paper briefly reviews the principal geological features of the Lece-Chalkidiki metallogenic zone. Janković (1990) and Serafimovski (1993) provide detailed information and references to this regional metallogenic unit.

Geotectonic setting

The Lece-Chalkidiki metallogenic zone developed along two regional tectonic units, the Vardar zone and the Serbo-Macedonian Massif, which differ in many respects (Arsovski, Ivanov, 1977; Dimitrijević, 1967, 1974; Dumurdzanov, Petrov, 1990; Grubić, 1980; Karamata, 1981; Kockel et al, 1975).

The Vardar zone is a suture zone that developed following the closure of a branch of the Tethyan ocean by late Jurassic-early Cretaceous time.

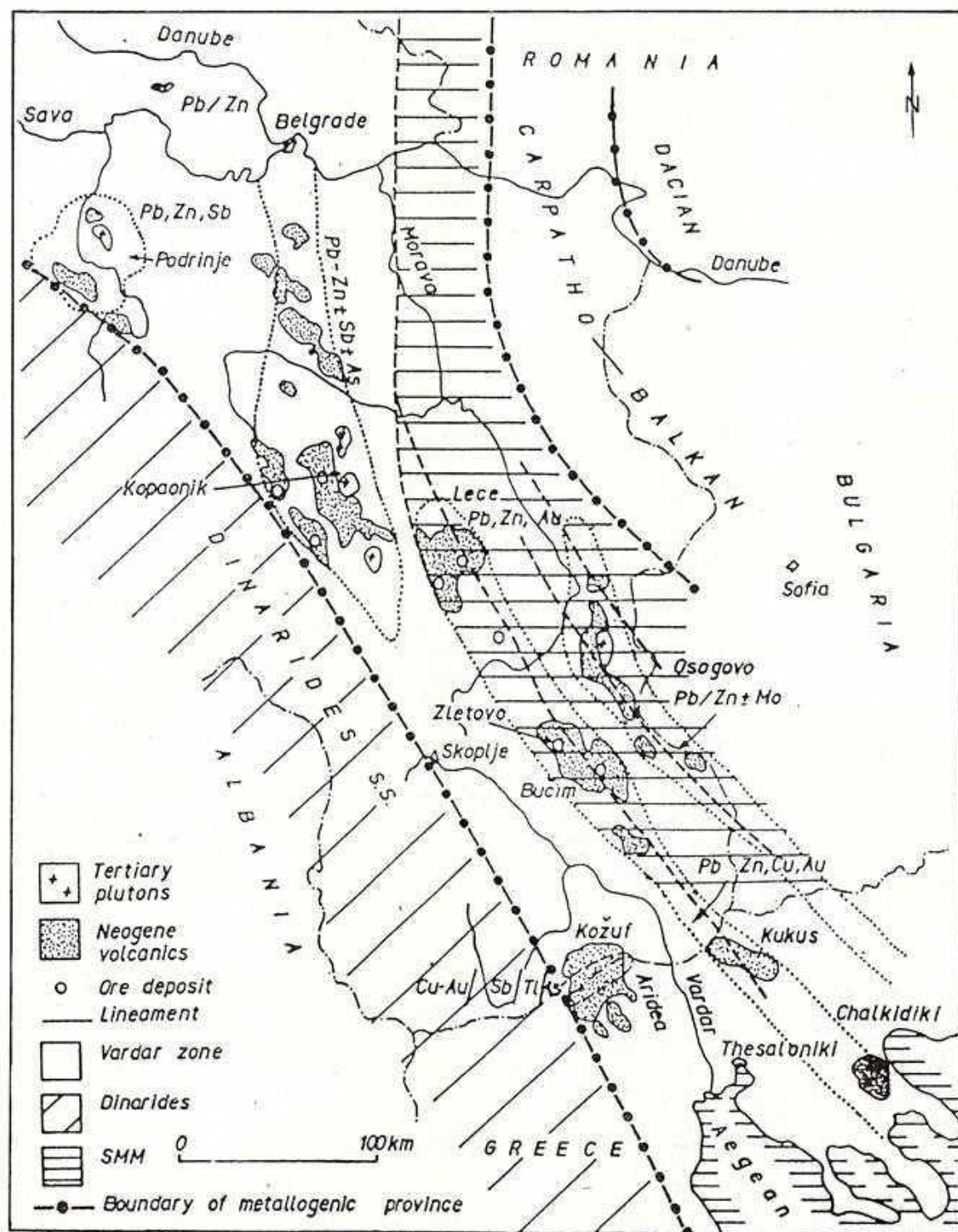


Fig.1 - Metallogenic zone Lece-Chalkidiki

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The Serbo-Macedonian Massif (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-Balkanides. 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 a 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.

Magmatic complexes. Volcano-intrusive complexes of the Lece-Chalkidiki zone consist of various facies of calc-alkaline magma such as andesite, dacite, trachyandesite, quartz latite, and latite, accompanied by their plutonic equivalents, mostly as minor intrusions. The volcanic rocks prevail; some of the volcanic complexes, such as Lece and Zletovo, cover a surface of over 1,000 sq km.

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-collision zone, yielded calc-alkaline magmas (Karamata, 1981).

The petrochemical composition of the volcanics in the Lece-Chalkidiki zone is shown in Figure 2. The high alkaline contents, particularly potassium, are a characteristic feature of some volcanic complexes.

The strontium ratios indicate a contamination of magma by material from the continental crust (Boev et al., 1992):

Locality	$^{87}\text{Sr}/^{86}\text{Sr}$ %	$^{87}\text{Rb}/^{86}\text{Sr}$ %
Zletovo	0.706318	0.4087
Borov Dol	0.706897	0.1246
Bucim	0.706928	0.2908
Damjan/Borov Dol	0.706633	0.1459

The strontium ratios of other volcanics in the Serbo-Macedonian metallogenic province, particularly those which are more distant from the Vardar zone, display higher values - Sasa; from 0.709 to 0.710641 %, Toranica: 0.709785 % (Boev et al., 1992).

Pee (1975) established that the strontium ratios for the northern group of volcanics in the Hellenic arc vary in the range 0.706 - 0.709%, while in the southern

group - 0.704- 0.706%. The values for the volcanics of the Lece-Chalkidiki zone are in good agreement with those of the northern group.

Such origin of the parent magmas is also supported by trace element contents (Tab.1), particularly the rare earth elements (Tab.2). The REE data may indicate similarities of igneous rocks in the Lece-Chalkidiki zone with those related with active continental margin (or, island arcs?).

Based on absolute age determination, it is concluded that the volcano-plutonic complexes formed mostly within the range between 37.5 my and 16 my (Tab.3). There are some indications of a late Cretaceous volcanism in this metallogenic zone, but this needs to be verified.

General metallogenic characteristics

Selected metallogenic features of the Lece-Chalkidiki zone are briefly reviewed here.

Source of ore constituents. The major constituents of mineralization (Pb, Zn, Cu, Au, Sb, U, S) originate from various sources, but mainly from Neogene calc-alkaline magmas.

Lead-zinc. Those two metals are dominant in the Lece-Chalkidiki zone. Based on the composition patterns of lead isotopes of galena and magmatic rocks, it can be concluded that the two have a common ultimate source. The calc-alkaline igneous rocks show increased lead and zinc contents, both in rocks as a whole and in individual petrogenic minerals such as feldspar (Karamata, 1983). Having in mind that some lead-zinc deposits in this metallogenic zone contain significant tonnage of metals, their ultimate source is situated much deeper than the subvolcanic level.

Copper and gold. Judging from the copper content of the volcanics, the parent magma was not enriched in copper (Karamata, 1983). This conclusion may be valid for the volcanics of the Serbo-Macedonian metallogenic province as a whole. However, some volcanic complexes of the Lece-Chalkidiki zone, formed along the western margin of the SMM, close to the ophiolites of the Vardar zone, display increased contents of copper: Lojane (200 ppm), Bučim (80 ppm Cu), Borov Dol (200 ppm Cu), Chalkidiki (200 ppm Cu); porphyry copper mineralization is paragenetically associated with such volcano-plutonic complexes, except in the area of Lojane, where copper mineralization is not known. Thus, it is most probable that copper, at least partly, was mobilised from ophiolites.

Gold most likely originated from ultramafics, along with copper. This is supported by the intimate Au-Pd association found in chalcopyrite and pyrite (Pd-bearing gold in the Bučim porphyry copper deposit - unpublished; Pd- and Au-Ag tellurides in close

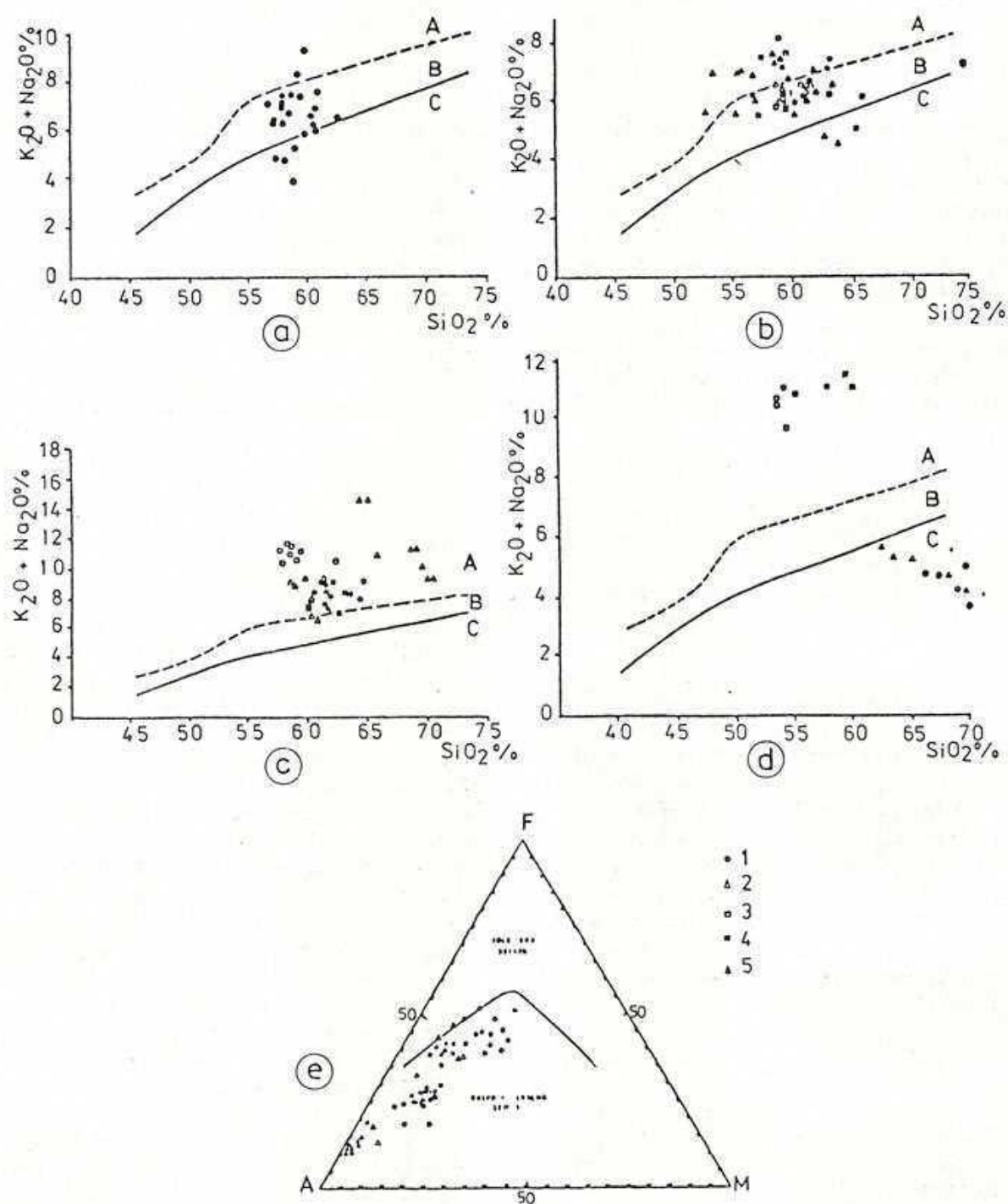


Fig.2 - $K_2O + Na_2O/SiO_2$ and A-F-M diagram for volcanic rocks in the Lece-Chalkidiki zone (A = $K_2O + Na_2O$; F = $FeO + Fe_2O_3$; M = MgO). A - Alkaline series; B - Highaluminous basalts; C - Tholeiitic series. 1, andesite; 2, latite; 3, quartzlatite; 4, trachyte; 5, rhyolite.

Table 1
The micro-element contents of the volcanic rocks in Lece-Chalkidi zone
(Serafimovski, 1990)

	1	2	3	4	5	6	7	8	9	10
Sm	4.5	5.3	3	4.9	5.9	6.3	4.7	7.6	7.9	4.4
Mo	18.5	—	—	—	—	—	—	—	—	—
Ce	65	90	42	58	50	80	76	93	102	35
Yb	0.9	3	1.1	1.3	2.1	2.7	2.9	1.3	2.4	4
Lu	0.13	0.27	0.15	0.24	0.3	0.41	0.54	0.41	0.26	0.96
U	3.2	4.4	0.9	2.5	5.1	4.9	8.9	9.6	6.7	13
Th	18.8	23.5	9.9	18.2	14.2	18.6	23.3	29.9	26	43
Cr	19	21	73	8	46	16	—	20	—	4
Au	0.077	0.032	—	—	—	0.003	0.187	0.003	—	—
Hf	3.7	5.1	1.7	3.1	3.7	4.2	6.8	3.3	4.3	5.2
Ba	1230	1110	460	1170	590	1290	890	2060	1040	140
As	—	1.3	18.7	7.2	434	21.20	375	4.7	—	9.9
Cs	8	3.6	2.3	11.4	2.9	19.20	21.4	1.3	4.4	6.8
Ni	—	—	—	—	—	—	—	1.6	—	—
Tb	—	1.1	—	—	—	3.6	1.9	1.9	1.3	0.4
Sc	12.2	14	12.8	10.6	8.3	13.5	11.5	10.1	10.8	7.3
Rb	67	54	—	9.5	148	225	295	64	107	450
Fe %	2.95	4.77	3.35	3.33	1.98	6.05	0.56	3.22	3.85	1.59
Zn %	0.01	0.02	52	0.01	0.057	0.06	0.02	0.009	0.014	0.042
Ta	0.4	0.3	—	0.4	0.8	0.6	1.1	0.7	0.7	1
Co	18.8	13	14.1	8.8	8.5	14.4	1	9.8	11.4	—
Eu	1.4	1.7	0.9	1.2	0.7	1.7	1.1	1.8	1.8	1.1
La	38	50	26	35	28	41	40	56	55	21
Sb	0.6	0.3	2.3	4.6	180.5	14.6	102	4.1	1.1	2.9
K %	1.44	1.45	—	4.20	703	4.13	3.99	1.08	—	3.73

1. Andesite, Lece; 2. Hydrothermally altered andesite, Tulare; 3. Fresh andesite, west of Tulare, 4. Coarse-grained andesite, Bakrenjača; 5. Rhyolite, Lojane; 6. Hydrothermally altered andesite, Plavica; 7. Hydrothermally altered andesite (?), Plavica; 8. Andesite, Borov Dol; 9. Rhyodacite, Vathi; 10. Rhyolite, Gerakario. The analysis performed by the Laboratory Geol. Committee, Sofia. Method: Neutron-activation.

Table 2
The contents of rare-earth elements in volcanic rocks in the Lece-Chalkidiki zone,
ppm (Serafimovski, 1993)

	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
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	66.96
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, Bakrenjača; 5. Rhyolite, Lojane; 6. Hydrothermally altered andesite, Plavica; 7, the same as 6; 8. Andesite, Borov Dol; 9. Rhyolite, Vathi; 10. Rhyolite, Gherakario. Neutron-activation analysis, Lab. Geol. Committee, Sofia.

Table 3
Absolute age of selected magmatic rocks in the
Lece-Chalkidiki zone (K/Ar method) (Serafimovski, 1993)

Rock, Site	K, %	Absolute age, m.y.	Average, m.y.
Andesite, Lece	2.12	29.2±1.5	
Pyroclastic, Lece Gajtan		27.6±1.5	
Dacite, Lece Tupalski Vis	1.66	37.5±1.5	
Andesite, Lece Tulare, Cu-ore		23.0±3.0	
Quartz latite, Zletovo mine	3.56	26.5±2.0	
Quartz porphyry, Zletovo, Šljegovo	2.31	26.5±2.0	
Andesite, dyke Zletovo, Plavica		16.0±3.0	
Trachyandesite, Zletovo, Bajalovci	4.15	26.0±2.5	
	3.20	32.0±2.5	29.0
Latite, Bučim Centralen Del	3.04	26.7	
		28.3	27.5
Latite, Bučim II phase	3.88	23.6	
		26.2	24.9
Andesite, Bučim Vršnik	3.12	26.0	
		26.8	26.4
Latite, Bučim Pilav Tepe		24.6	
	2.56	24.8	24.7
Andesite, Borov Dol		29±3	
Rhyodacite, Gherakario	3.44	31.5±2.5	
Granodiorite, Straton, E. Chalkidiki		29.6	

association with chalcopyrite in the Skouries porphyry copper deposit (Tarkian *et al.*, 1991).

The increased gold contents occur in porphyry copper deposits in the SMM, close to ophiolites (Bučim, Gherakario, Skouries), and in stockwork-disseminated copper mineralization in Zletovo.

Sulphur: Based on the $\delta^{34}\text{S}$ values, it can be concluded that sulphur of sulphide minerals is of magmatogenic origin. Figure 3 shows the variations of $\delta^{34}\text{S}$ in selected ore deposits in the Lece-Chalkidiki zone.

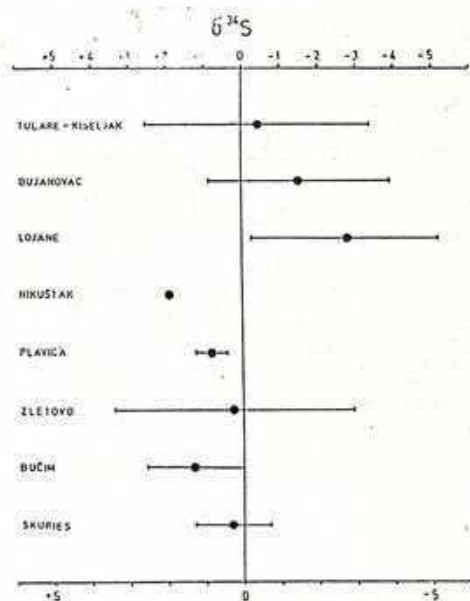


Fig.3 - The $\delta^{34}\text{S}$ ratios of the selected ore deposits in the Lece-Chalkidiki zone

Uranium: Uranium mineralization occurs sporadically only, both in volcanics and in crystalline schists. It derives most probably from the crystalline schists of SMM (Zletovo, Podareš), and from granites (in the area of Strumica).

Ultimate source of some other ore constituents such as *antimony* and *arsenic* have not been unequivocally established, but they, very likely, originate from volcanic sources. Tungsten in the stibnite-wolframite association (Philadelphion in Greece, Janković, 1979) derives, most probably, from the crystalline basement.

Associations of elements. The ore deposits in the Lece-Chalkidiki zone are composed of a number of elements such as:

1. Major or dominant elements: Pb, Zn, Sb, As, Cu, Fe, Mn, U;
2. Accessory elements: Cd, Au, Ag, Bi, Ni, Co, Hg, Tl, Ba;
3. Disseminated elements: In, Ga, Ge, Se, Te, Re, Pd.

As a result of the recent research work and exploration undertaken in this metallogenic zone, the following associations are defined:

1. *Lead and zinc* accompanied by cadmium, indium, silver, and locally gold are the most typical constituents of lead-zinc deposits.

2. *Copper-gold-silver-molybdenum* followed by minor lead, zinc, bismuth, selenium, and rarely Pd, and traces of Pt, is the most characteristic association of porphyry copper deposits.

3. *Copper-gold-lead-zinc* accompanied by silver, molybdenum, indium, selenium, bismuth and other

elements are typical of the hydrothermal stockwork-disseminated mineralization related to volcanic centers.

4. *Antimony and arsenic-antimony association* includes minor lead, zinc, silver, barium, mercury (Bujanovac), nickel, cobalt, chromium, uranium (Lojane), nickel, mercury (Nikustak) and tungsten (Lahanas, Philadelfion).

Morphostructural types of ore deposits. Based on the mineral composition, the conditions of deposition and controlling factors of distribution, the ore deposits of the Lece-Chalkidiki zone are divided into the following types:

1. *Skarn deposits.* These deposits are infrequent in the zone, particularly those of economic importance. The most significant is the Damjan deposit. This magnetite-hematite deposit is located within skarn formed at the contact between Tertiary andesitic intrusions and Paleogene flysh.

2. *Porphyry copper mineralization.* It is distinguished by the following features:

- Ore bodies are small (20-80 million tons), containing 0.20-0.30 % Cu, locally 0.5 % Cu. In some ore deposits, gold contents increase the economic value of the ore (0.30-0.70 g/t Au).

- Mineralization is usually confined to the contact of intrusive stocks and surrounding crystalline schists of the SMM, or volcanic rocks; some intrusive bodies are mineralized as well. Ore bodies are mostly cylindric in shape, with relatively short vertical interval of mineralization (mostly 200-500 m - order of magnitude).

- Secondary sulphide enrichment is poorly developed or absent (locally eroded).

- Besides gold, the ore contains minor silver and traces of palladium. Low silver content and high Au:Ag ratio are the characteristic features of the porphyry copper mineralization.

3. *Volcanic stockwork-disseminated copper mineralization.* This type of mineralization is found in some volcanic structures (Plavica in Zletovo, Djavolja Varos in Lece). Mineral paragenesis and facies of hydrothermal alteration are similar to those of porphyry copper, but the mode of deposition and controlling factors of distribution differ. Mineralization is very irregular and low grade (0.2-0.3 % Cu).

3.1. *Ore veins hosted by volcanics.* Systems of hydrothermal veins of lead-zinc sulphides occur in some volcanic complexes (Lece, Zletovo). Dislocation faults and/or systems of dislocation are the main control of spatial distribution of ore veins. Mineralization formed by open space filling and/or replacement of wallrocks. Quartz reefs often mark the outcrops of lead-zinc veins, particularly in the Lece volcanic complex.

Mineralized faults and/or ore-bearing systems or faults can be traced along strike for 1-3 km. The verti-

cal interval of mineralization reaches several hundreds of meters, occasionally even more (Zletovo).

This type of mineralization is of economic importance. Some of these deposits contain significant concentrations of gold (lead-zinc-gold mineralization in the Lece mine); gold is mainly developed in the uppermost part of the deposit.

3.2. *Hydrothermal carbonate-hosted lead-zinc deposits.* Significant lead-zinc deposits formed by replacement of carbonate rocks (limestone and marble), interbedded with in the SMM (Olympias at Chalkidiki), or the Palaeozoic metamorphic series in the Vardar zone (Novo Brdo and Farbani Potok in Yugoslavia). The ore bodies occur mostly as elongated lenses, composed often of massive sulphides.

Besides the lead-zinc-iron sulphides, the ore contains high concentrations of silver. Manganese carbonates and oxides occur locally in the upper part of the deposit.

3.3. *Epithermal antimony-arsenic, antimony-mercury or antimony-tungsten mineralization* is frequent in the Lece-Chalkidiki zone. It occurs as veins and mineralized zones: veinlets and disseminations. Wallrocks are of various lithologic composition - crystalline schists of the SMM, Jurassic serpentinites, and Palaeozoic schists in the Vardar zone. Silicification is the most characteristic facies of hydrothermal alteration. Quartz is the main gangue mineral.

Epithermal disseminated gold mineralization: This type of gold mineralization was recently identified in several localities (Zletovo-Plavica, Borov Dol-Damjan).

Principal metallogenic units. Ore deposits and occurrences of the Lece-Chalkidiki metallogenic zone are grouped into several units such as ore districts and ore fields (Fig.1). Due to limited available space, their characteristics are only briefly summarized here - from the north southwards:

1. *Crni Vrh ore field.* Several small stibnite deposits are known in this ore field. The mineralization is associated with the intercalations of marble (lenses, beds) in the crystalline schists of SMM. It occurs as lenses, veinlets and dissemination in the highly silicified marble (jasperoid type of antimony mineralization).

2. *Lece ore district.* This metallogenic unit formed within a large volcanic complex, composed predominantly of andesite and its pyroclastic equivalent characterized by volcanic structures (calderas, ring-radial fractures etc.). The volcanics themselves host ore mineralization.

Lead-zinc, gold and, to some extent, copper are the main metals of the ore districts. The most significant ore deposits are grouped into four ore fields (Fig.4). Several types of mineralization are recognized:

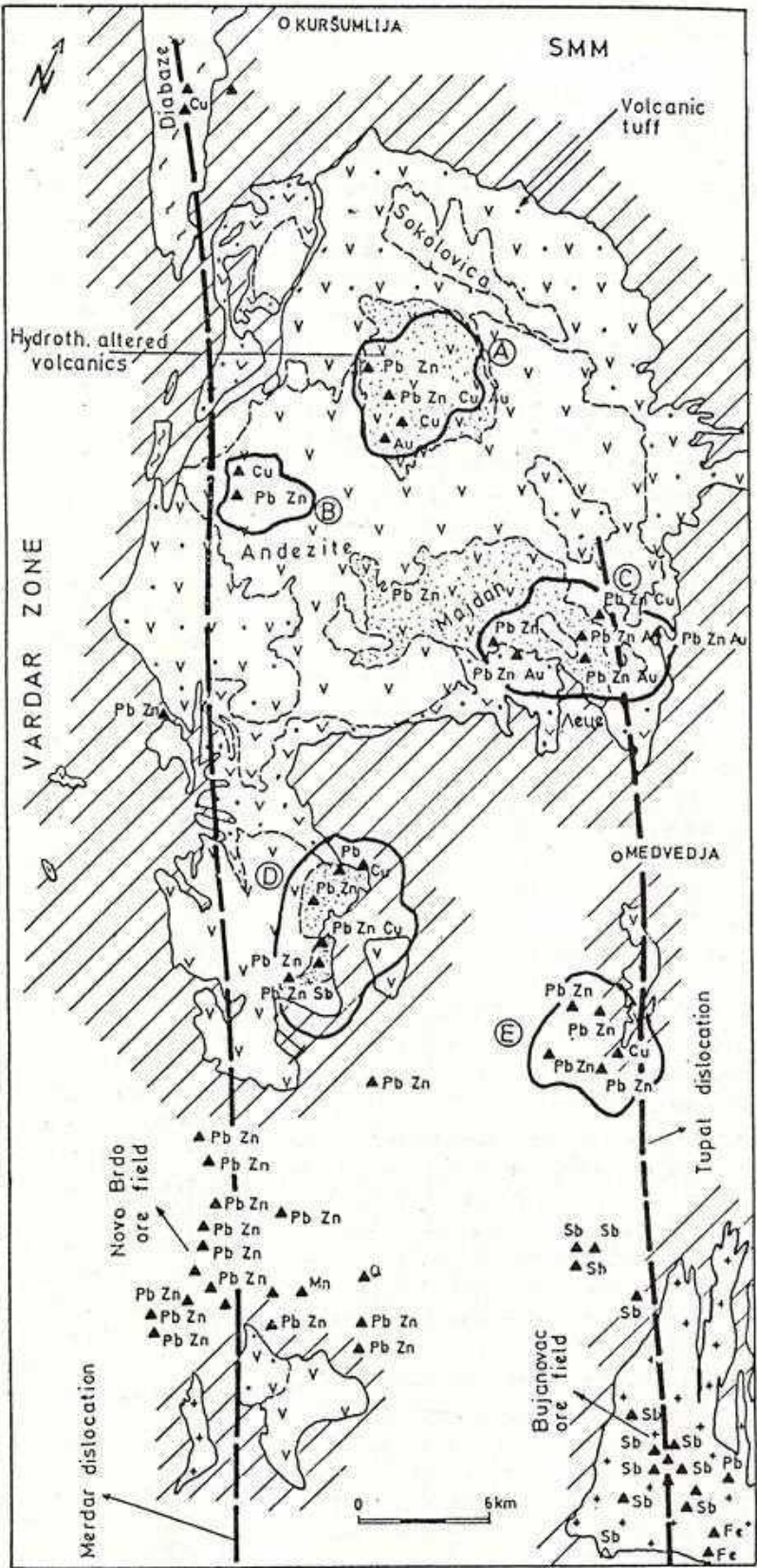


Fig.4 - The Lece-metallogenic district

- Vein lead-zinc-gold mineralization is related with brecciated zones in andesite; fragments are cemented by hydrothermal quartz. The ore-bearing zone in the Lece Mine is up to 5 km long and up to 20 m wide, averaging 5.0 m. Vertical extent of mineralization exceeds 600 m, but concentration of Pb-Zn sulphides and native gold of economic importance are restricted to a vertical interval of 200-300 m. This mine is in operation.

Vertical zoning is a characteristic feature of mineralization (from top to bottom): gold - lead/zinc $\pm$ gold - zinc/lead - copper, minor zinc.

- Stockwork-disseminated copper mineralization along fractured zones is characteristic of the Džavolja Varoš ore field.

- Porphyry copper mineralization is identified only in the western part of the volcanic complex, near ophiolite (the Kiseljak deposit in the Tulare ore field).

- Epithermal disseminated gold mineralization of both low and high sulphidation types are identified in the Tulare ore field and in the vicinity of the Lece mine.

3. *Novo Brdo ore field.* This ore field lies in the Vardar zone, near its contact with the SMM. The lead-zinc deposits, Novo Brdo and Farbani Potok, are the most important mines. They are of replacement type. Mn-carbonate ore bodies are developed with the lead-zinc sulphides. Both deposits are in operation.

4. *Bujanovac ore field.* Numerous quartz-stibnite veins are known within a narrow zone, the length of which exceeds 30 km. Wallrocks are mostly granitoids of the SMM. Kaolinization of wall rock is the typical alteration facies.

Stibnite is locally accompanied by pyrite, and traces of cinnabar, realgar, orpiment, and native arsenic.

Over 2,000 tons of antimony have been mined so far from this ore field.

5. *Lojane-Nikuštak ore field.* The Lojane deposit is the largest Sb-As deposit in the former Yugoslavia. It was formed along fractures in Jurassic serpentinites of the Vardar zone, andesites or along the contact of serpentinites and andesite (Antonović, 1961). Sb-As mineralization near chromite bodies occurs as thin fissures within chromite aggregates.

The Lojane vein deposit grades into stockwork type. The ore contains an average of 4% Sb and 5% As.

The mineral association is a complex one, involving stibnite, realgar, orpiment, pyrite, baravoite, molybdenite and pitchblende. The last two minerals were derived from granite intruding serpentinite, while the nickel in baravoite probably originates from serpentinite. Sb-concentrate contains up to 0.8% Ni and traces of uranium.

6. *The Nikuštak ore field.* It lies SW of Lojane and involves several small antimony deposits. It is hosted

by the Palaeozoic schists and controlled by local dislocations.

Quartz-stibnite veins are the most frequent type of mineralization, but locally veinlets and stockwork types occur. Stibnite is the main mineral, accompanied by minor realgar, orpiment, cinnabar, pyrite, sphalerite, chalcopyrite. Some thin quartz veins in serpentinite contain an unusual mineral association: pyrite-lineite-enargite-tetrahedrite-cinnabar.

7. *Zletovo ore districts.* Several ore deposits are known in this regional metallogenic unit. They are paragenetically associated with a volcanic complex, and controlled by both regional dislocations and volcanic structures. Three main ore fields are recognized in this ore district (Fig. 5). The most significant ore deposits lie in the Kratovo-Zletovo ore field.

Based on mineral paragenesis and mode of formation, the mineralization in the Zletovo ore district is classified as follows:

- The Zletovo/Dobrevo vein type deposit contains significant reserves (the mine is in operation). Mineralization is related with a system of dislocations, forming an ore-bearing zone approx. 5 km long. The length of individual ore veins ranges from 100 to 3,000 m. Vertical extent of mineralization exceeds 600 m. The ore is both massive sulphides and stockwork-disseminated. It consists of numerous minerals (over 40). Besides Pb-Zn sulphides, the ore contains sulphosalts, Cu sulphides, native gold, Bi-minerals, locally skarn minerals. Tiny occurrences of pitchblende is a specific feature of the mineral association of this deposit.

- Quartz-enargite veins occur only in a few places (e.g. Zlatica). Hydrothermal alteration facies involve advanced argillic alteration and alunitization. The ore contains copper, native gold and Au-tellurides. The gangue minerals are quartz, locally barite and siderite.

- Stockwork-disseminated copper mineralization associated with caldera (the Plavica deposit) displays some specific features. Mineralization took place around feeder channels of a crater, in a structural environment dominated by ring-radial fractures. Mineralization occurs in dacite-andesite subvolcanic intrusions and their ignimbrites, stratified tuffs and breccias. A pervasive alteration of wallrock indicates acid hydrothermal solutions and a high sulphidation environment (advanced argillic alteration, including intense alunitization).

Vertical interval of mineralization is up to 800-1,000 meters. As there were several pulses of inflow of ore-bearing solutions and since they did not always take the course along the same dislocation structures, as well as due to precipitation of ore minerals at different levels of ore-bearing structures, the rate of copper concentration is very variable within the volcanic

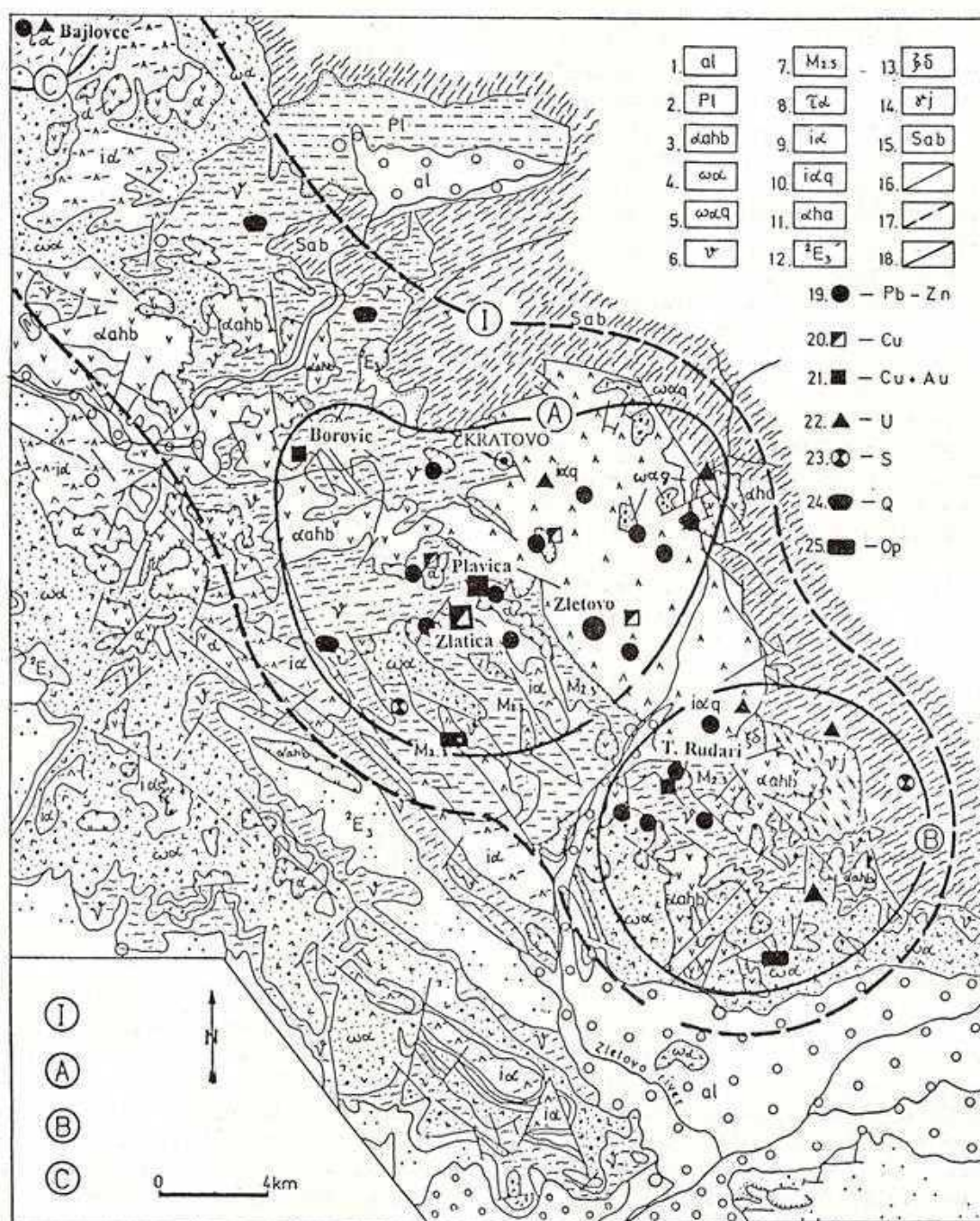


Fig. 5 - Metallogenetic scheme of Kratovo - Zletovo ore district: I, Kratovo - Zletovo ore district; A, Zletovo ore field; B, Tursko Rudari; C, ore occurrences Bajlovce. 1, alluvium; 2, marl slates, sands and pebble; 3, augite - hornblende - biotite andesites; 4, volcanic breccias with andesitic composition; 5, volcanic breccias with dacitic composition; 6, volcanics tuffs and breccias; 7, conglomerates sandstones marls and slates, tuffs; 8, trachytes; 9, ignimbrites of andesite composition; 10, ignimbrites of dacitic composition; 11, hornblende - biotite andesites; 12, flysch; 13, quartzmonzonite porphyry; 14, gabbro; 15, chlorine - sericitic schists; 16, faults structures; 17, ore district border; 18, border of the ore fields; 19, lead-zinc deposits and occurrence (vein type); 20, copper deposits and occurrences (vein type); 21, porphyry deposits and occurrences of copper and gold; 22, uranium occurrences (vein type); 23, sulphur occurrences; 24, deposits and occurrences of quartzites; 25, opaline breccias deposits.

mineralized. Mineralization is of low grade (0.2-0.3 % Cu).

Pyrite and chalcopyrite are the main ore minerals, accompanied by other Cu, Pb-Zn sulphides and numerous sulphosalts.

- Uranium mineralization occurs not only with vein lead-zinc sulphides, but forms its own deposit (Zletovska reka). Pitchblende-bearing veins are related with local fractures in the volcanics (Jankovic, 1982).

8. *Bučim-Borov Dol ore field.* This metallogenic unit is defined by mineralization controlled by structural factors (linear dislocations, and/or ring radial fractures), and magmatic factors (minor subvolcanic intrusions of andesite in the SMM - Bučim, in the Paleogene flysch - Damjan). Two main morphogenetic types of mineralization have been so far identified in this ore field:

- Porphyry copper mineralization formed in the crystalline schists (gneiss) around "pipe-like" intrusive bodies of andesite (Bučim), and within the volcanics and subvolcanic intrusions of andesite and their pyroclastic associates (Borov Dol - Čifliganec, 1993). Copper mineralization is of modest scope, but still of economic importance (the Bučim deposit is in operation). Vertical intervals of mineralization, outlined by cut-off grade, are mostly 200-400 m. Some ore bodies are rich in gold (Bučim: 0.5-0.8 g/t).

- Calcic skarn mineralization at Damjan is developed along the contact between andesite dikes, and the Paleogene flysch containing calcareous intercalations. The scope of mineralization is very modest and the ore has been mined out.

Magnetite and hematite are the main ore minerals accompanied by minor Fe-, Cu-, Pb-Zn sulphides, and traces of scheelite (Serafimovski, 1982).

9. *Kukuš ore district.* This metallogenic unit formed along the contact of the SMM and the Vardar zone. It covers a surface of 400 sq km.

The mineralization is paragenetically associated with minor subvolcanic intrusions of calc-alkaline type. Several mineral associations and morphogenetic types of mineralization are distinguished:

- Porphyry copper mineralization at Vathigherakario and Pontokerassia is related with the contact of rhyodacite and gneiss of the SMM. Silicification and sericitization are the typical alteration facies (Kockel et al., 1975; Melidonis, 1973; Serafimovski, 1993);

Mineralization is of modest scope and low grade (0.2-0.3 % Cu). The vertical intervals of mineralization reach 200-500 m. Apart from copper, vein type of lead zinc mineralization has been identified in the Pontokerassia deposit as well;

- Polymetallic (Pb, Zn, Cu, Fe-sulphides) vein type mineralization occurs sporadically along the contact of trachytic dykes and surrounding Palaeozoic sediments (the Mrdaja - Dorjan mineralization);

- Epithermal antimony mineralization - the Lahanas ore field - is a part of this ore district (Jankovic, 1979).

Stibnite veinlets, nests and lenses are associated with local fractures in the crystalline schists of the Vertikos formation. Wallrocks are distinctly silicified and less sericitized and argillized.

Quartz-stibnite association is the most common. Locally only, stibnite is associated with wolframite (the Pilaf Tepe deposit). Over 2,000 tons of antimony have been so far mined out of this ore field (Janković, 1979).

10. *Eastern Chalkidiki ore district.* This metallogenic unit is situated in the SMM. It covers approximately 300 sq km. The basement of SMM is intruded by subvolcanic stocks and dykes, as well as by hypabyssal granitoids (granodiorite, quartz diorite a.a.). The ore district involves lead-zinc and copper mineralization, both paragenetically associated with the Oligocene volcano-plutonic complexes (Fig. 6).

Metallogeny of this ore district has been studied by Antoniadis et al., 1971; Kalogeropoulos, 1987; Kalogeropoulos et al., 1988; Kockel et al., 1975; Kockel, Walther, 1977; Nikolau, 1960; Papadakis, Michalidis, 1976; Papantonis, 1987; Perantonis, 1982; Zachos, 1963.

Based on types of mineralization and mineral associations, the deposits are classified as follows:

- Porphyry copper deposits are related with subvolcanic stocks. In some deposits, such as Skouries, deposition of copper mineralization took place not only in the volcanic stock, but also in the surrounding crystalline schists as well.

Vertical extent of mineralization is locally considerable - over 700 m in the Skouries deposit.

The largest deposit is Skouries: 72 mil. tons - 0.5% Cu, 0.7 g/t gold and 2.5 g/t silver. Other occurrences are Fissoka, Alatini, Tsikara a.a.

- Hydrothermal carbonate-hosted lead/zinc mineralization is economically important. It occurs along the contact of granitoids and intercalated marble within the SMM.

The most significant deposit of this type is Olympias. Elongated lenses and veins, 10-12 m wide, are located within a zone 1.8 km long. The ore, partly massive sulphide, contains besides lead, zinc, and minor copper, 6 g/t gold and 130 g/t silver. The size of the deposit - 10 million tons of ore (Papantonides, 1987).

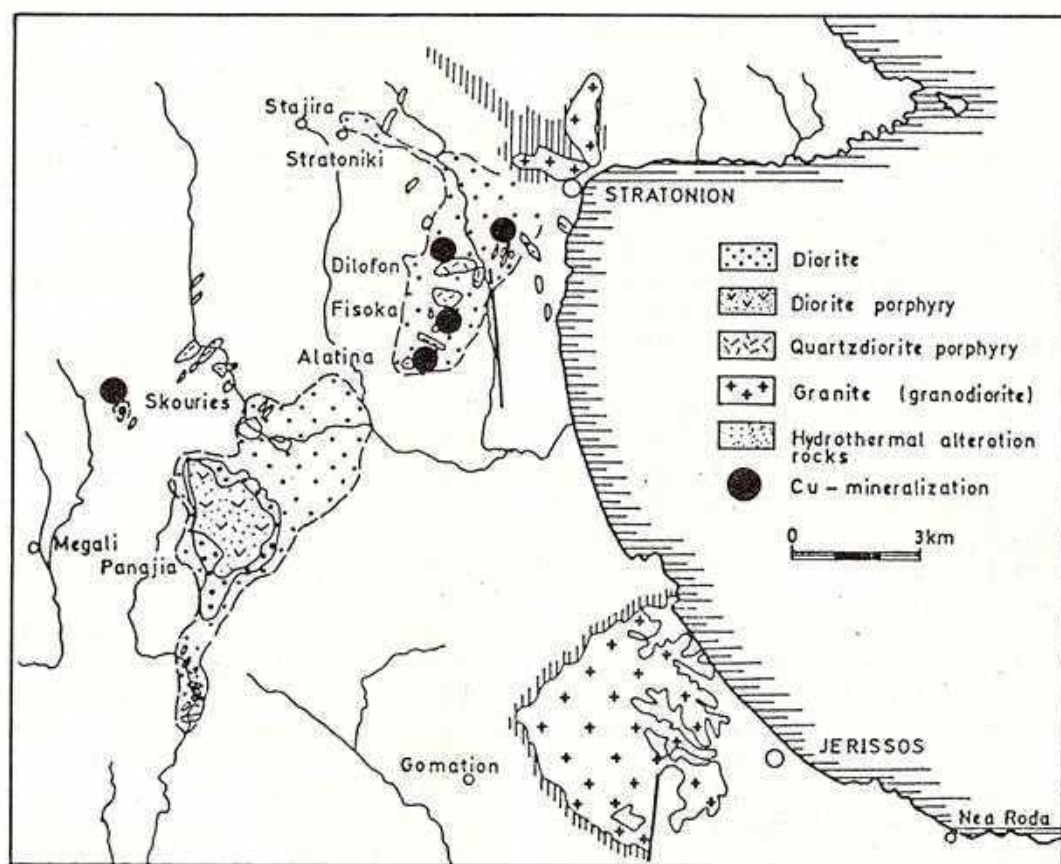


Fig. 6 – Magmatic complexes and copper mineralization of the Eastern Chalkidiki district (Kockel et al, 1975).

Conclusions

The principal metallogenic features of the Lece-Chalkidiki metallogenic zone are briefly summarized as follows:

1. Regional dislocation along the contact zone of the SMM and the Vardar zone outline the metallogenic zone. Distribution of ore fields and ore deposits is controlled by local dislocations and volcanic structures.

2. The volcano-plutonic complexes of calc-alkaline type derive from the domain of lowest level of continental crust-upper mantle, formed in a post-collision tectonic environment. Strontium ratios of parent magmas range between 0.706 and 0.709. Locally, magma apparently mobilized some copper and gold during passing through ophiolites.

Volcano-plutonic activity took place during the Oligocene-Miocene. Mineralization is paragenetically associated with igneous complexes.

3. The principal ore metals are lead-zinc, antimony-arsenic and, to some extent, copper and gold.

4. Based on the mode of deposition and associations of metals, several types of mineralization are distinguished:

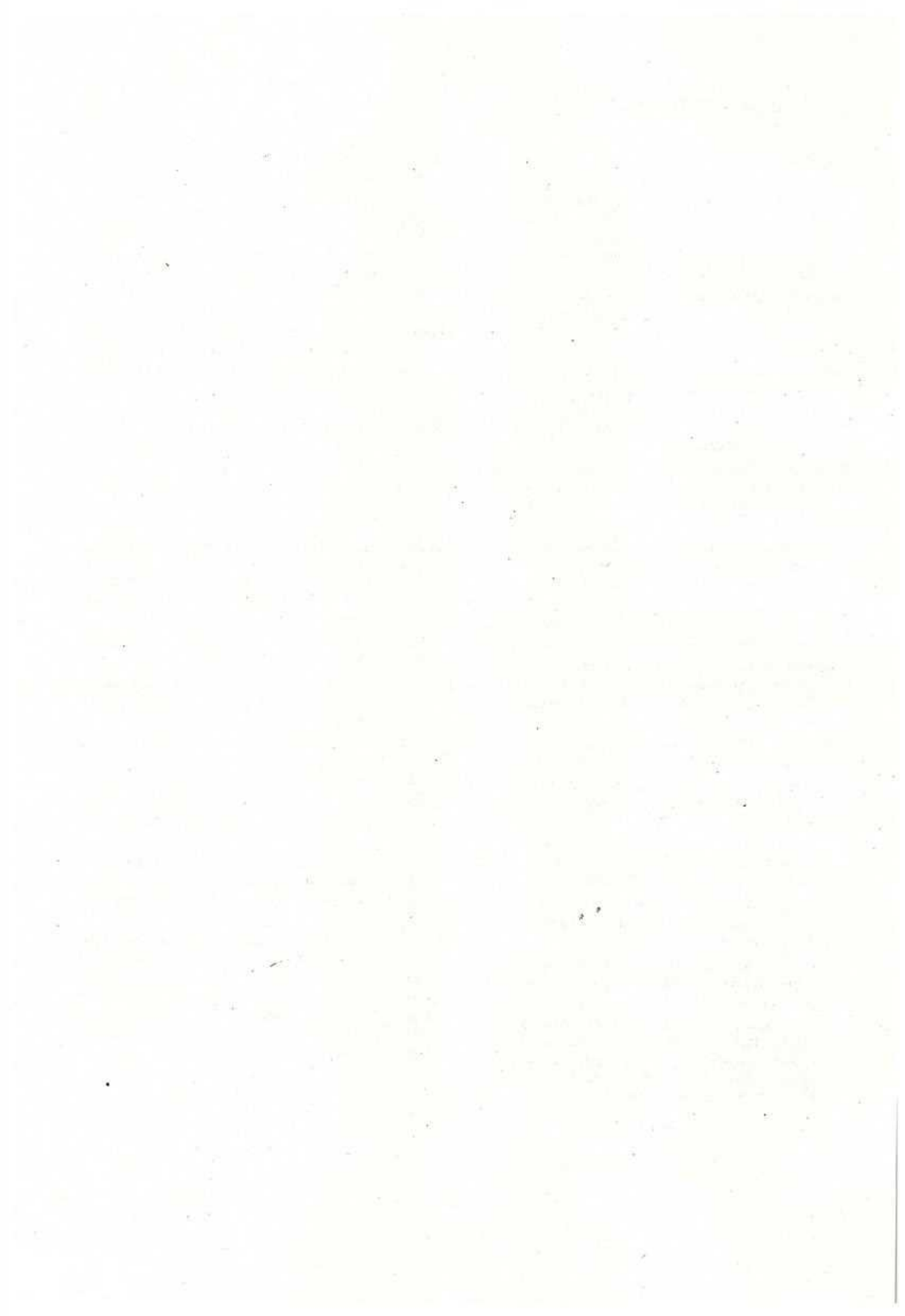
- Volcanic hosted hydrothermal lead-zinc veins;
- Hydrothermal carbonate-hosted lead-zinc mineralization;
- Stockwork-disseminated copper mineralization hosted by volcanic centers;
- Porphyry copper mineralization, low in silver, locally high in gold;
- Epithermal antimony-arsenic mineralization, both vein and jasperoid types;
- Epithermal disseminated gold mineralization.

Metallogenic zone includes several deposits of considerable economic importance.

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REGIONAL METALLOGENESIS IN NORTHERN GREECE

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Key words: Metallogenesis. Volcanism. Porphyry systems. Manto. Karst. Shear-controlled. Epithermal Deposits.

Abstract: Base and precious metal mineralization is widespread throughout northern Greece. The main styles are: a) Large manto replacement sulphide deposits in Chalkidiki associated with the porphyry copper systems, b) Hydrothermal karst mineralization of Pb-Zn sulphides, calamine and hematite-barite on Thassos island emplaced at the margins of sedimentary basins in large horst-graben structures, c) Shear-controlled vein and replacement quartz-gold-sulphides throughout the region, and d) Epithermal precious metal deposits within Tertiary volcanic rocks in eastern Rhodope. All the main styles of mineralization are linked to Tertiary plate tectonic movements accompanied by extensive migration of hydrothermal fluids and basinal brines in pulses along deep-seated channel ways and to basins margins. A broad volcanic belt developed in the Carpatho-Balkan region during the early-mid Tertiary and subsequently moved south through northern Greece. This belt was flanked on the west side by horst-graben structures which delineated sedimentary and volcano-sedimentary basins. Solution movement within the volcanic belt formed epithermal gold and industrial mineral deposits, and brine migration from the graben basins emplaced hydrothermal karst sulphide, calamine and possibly Carlin-style deposits in carbonate units of the horst blocks. Contemporaneous intrusion of porphyries into the Serbo-Macedonian Massif produced proximal porphyry copper±gold mineralization and distal manto polymetallic deposits within carbonate units of the Massif. Continued southern movement of the volcanic belt and flanking horst graben structures caused repeated overprinting of mineralization styles in some areas.

Introduction

There is widespread base and precious metal mineralization within carbonate sequences of northern Greece and the Aegean Islands. The most significant deposits are those of the active mines of Olympias and Madem Lakkos and the epithermal prospects to the east.

An international project, financially supported by the European Union and the Greek Institute of Geology and Mineral Exploration (IGME), used a multi-disciplinary approach, ranging from isotopes and fluid inclusions to remote sensing techniques, in order to generate a regional metallogenic picture and ascertain local controls for the main types of mineralization.

Geological setting

North-eastern Greece contains three main litho-stratigraphic units: the Rhodope and Serbo-Macedonian metamorphic basement massifs and the Circum-Rhodope Belt (Fig.1). Volcanic activity, with associated sub-volcanic intrusives, appears to have been in the east, whereas in the west the area contains mainly co-magmatic plutons.

The Rhodope Massif rocks can be divided (Zachos & Dimadis, 1983) into two main units:

1. A lower unit of basement gneisses with intercalated mica schists and rare amphibolites.
2. An upper carbonate unit comprised of marbles, calcareous schists and minor chert layers (Fig.1).

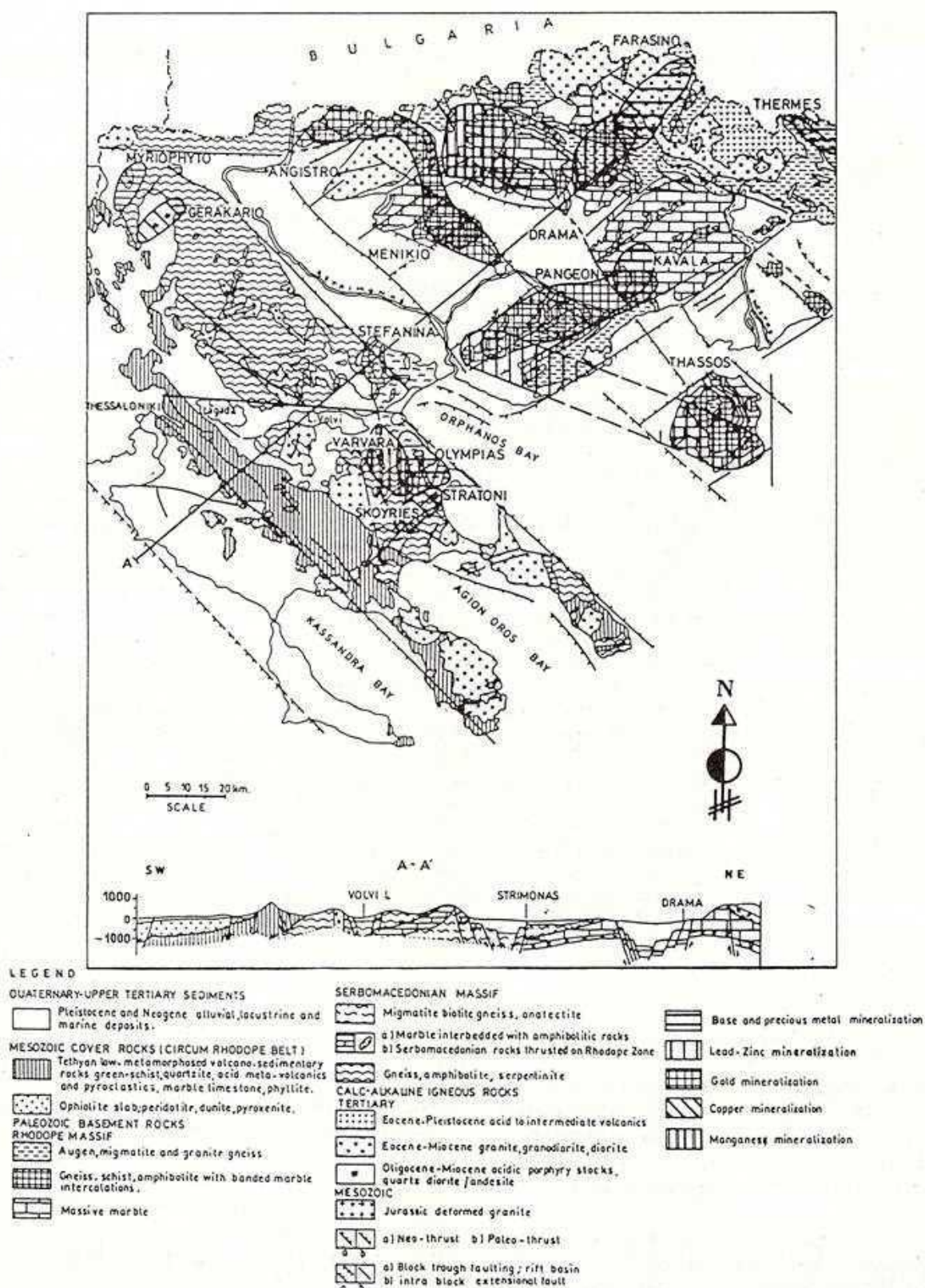


Fig. 1 – Regional Variation of metallic elements ore districts
(Compiled by: N.D. Arvanitidis, D.C. Constantinides).

A series of calcareous schists, gneisses, thin marble layers and minor amphibolites, interpreted as a regional-scale shear, forms a transitional zone between basement gneisses below and massive marbles above and is therefore named the T-Zone (Fig.1).

The Serbo-Macedonian Massif contains two major units (Kockel et al., 1977, Fig.1):

1. the Kerdyllia formation in the east which consists of biotite gneiss interbedded with hornblende gneiss, amphibolite and marble layers and 2. the Vertiskos formation in the west overlies the Kerdyllia and consists mainly of two-mica gneiss with some garnet, tourmaline, and sillimanite, quartz-feldspar gneiss and ortho-amphibolites.

Mineralization

Most of the mineralization appears related to Tertiary tectonic, volcanic and intrusive activity. There are five main styles of mineralization in the region (Fig.1):

- large (17 mt) manto style polymetallic bodies, such as Olympias and Madem Lakkos, within Serbo-Macedonian marble in the west;
- substantial (70 mt) low-grade porphyry copper deposits in the same area as the manto polymetallic deposits;
- moderately sized hydrothermal karst fillings of Zn-Pb sulphides (1-3 mt), calamines and hematite-barite (10 mt) in Rhodope massif marbles, mainly on Thassos island;
- small vein and replacement quartz gold sulphide occurrences in fault zones and marble units throughout the Western Rhodope region;
- large zones with potential for epithermal precious metal mineralization within Tertiary volcanic rocks in the east.

Metallogenic concept

Three important new concepts concerning ore genesis and controls of mineralization in particular areas and deposit types and a new concept of regional metallogenesis throughout north-eastern Greece have been developed.

Local scale

Polymetallic Sulphide Deposits and Porphyry Coppers

Metallogenic modelling (Arvanitidis et al., 1993) on the major Olympias, Madem Lakkos and Mavres Petres polymetallic sulphide deposits supports Frei's,

1992 suggestion that they are related to the porphyry copper systems of Skouries and Fisoka rather than the Stratoní granodiorite. This model is based on fluid inclusion, isotope and field studies implemented during the project, and the integration of literature data.

Our model envisages intrusion of the porphyries into the Serbo-Macedonian Massif. Copper was mainly concentrated within and in the immediate vicinity of the porphyries, whilst fluids rich in a variety of metals together with S, Si and Ca, migrated along structurally favourable zones until they reached major marble units and sulphide minerals replaced the carbonates. The marble units acted as filters by removing the sulphides, and the depleted fluids continued along favourable structures into the epithermal zones where silica-gold assemblages were deposited.

The metallogenic model is schematically presented in Figure 2. The ore deposits and occurrences have been arranged according to their temperature of formation (Naden et al. 1994), structural control and regional distribution. The distribution of the deposits shows a consistent behaviour with respect to fluid temperature zoning around major intrusives. Most, if not all the deposits were formed syn-magmatic (Madem Lakkos, Olympias), syn-shearing (Stanos, Pirinia) to slightly later post-shearing syn-block faulting (Zepkos).

The concept suggests a clear set of mineral assemblages indicating temperature zones ranging from hypothermal to epithermal and linked to porphyry copper systems. It should be possible, therefore, to use epithermal assemblages exposed at the surface to detect high temperature mixed sulphide mineralization at depth. On this basis, new prospects have already been identified. In terms of exploration, this genetic link can be incorporated into exploration strategies both in the project region and in similar areas in the former Yugoslavia and Bulgaria.

Shear and Fault Controlled Mineralization

Work carried out during the project showed that small scale base and precious metal mineralization is emplaced along thrusts between marble units and schists within the T-zone in the Rhodope massif. Most prospects at Palea Kavala, Pangeon and Symvolon have vertical mineralized fault zones which extend upwards through the underlying schists and appear to be feeders for the main mineralization.

The metallogenic model (Fig.3) developed during this project envisages:

- thrusting throughout the region, with thrust zones concentrated in the T-zone along marble-schist contacts;
- horst-graben faulting, accompanied by granitoid intrusions, with vertical fault systems developed

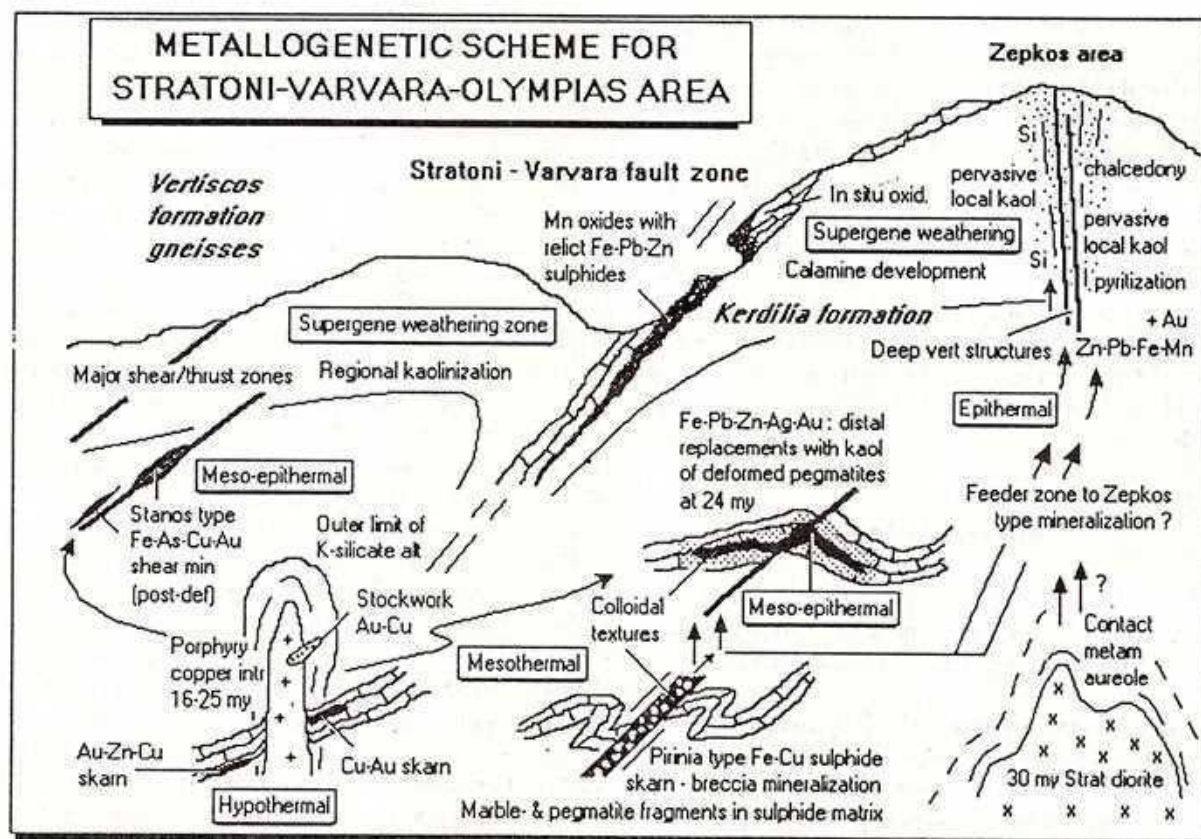


Fig. 2 - Metallogenic scheme for Stratoni-Varvara-Olympias area.

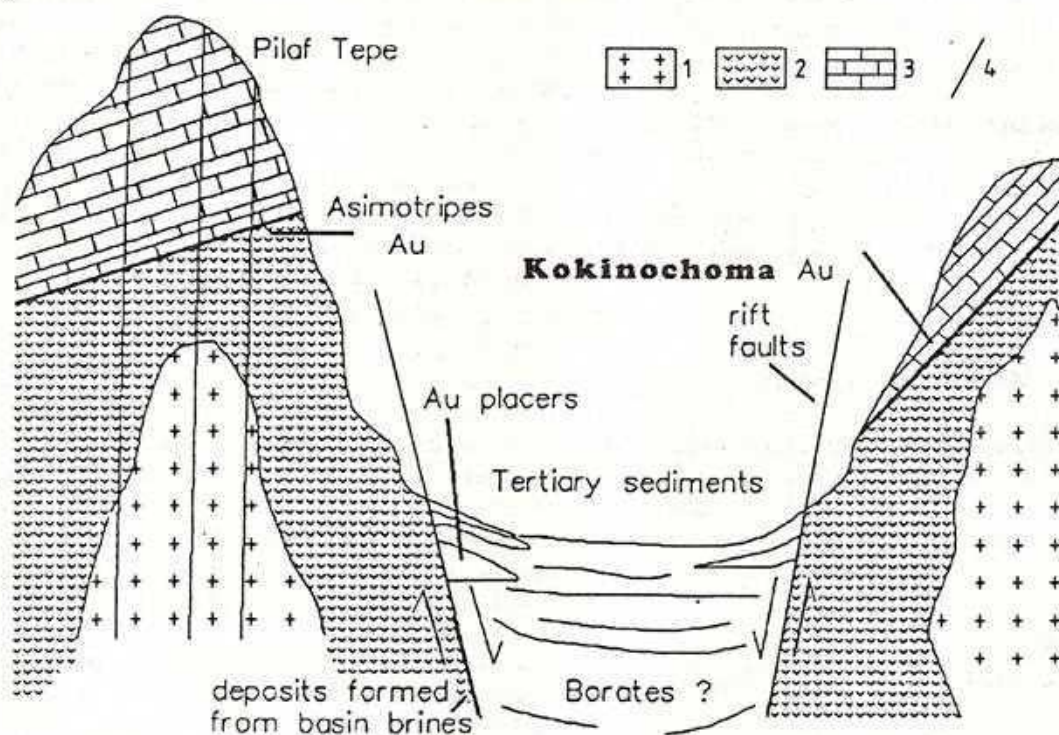


Fig. 3 - The metallogenic model.

along the horst margins,

– upward movement of metalliferous fluids (temperature range 275–330°C, Naden et al., 1994) along the vertical faults, and replacement sulphide mineralization produced where the fluids intersected sheared marble-schist contacts and spread laterally along the contact, and-hypergene re-working of the mineralization leading to extensive gossans.

In terms of exploration, the T-zone represents, on a regional scale, a major low-angle fertile lineament, hosting vein/shear zone controlled precious and base metal sulphide deposits. The largest deposits will be where several factors combine: substantial vertical fault systems, tensional sectors of the main shears, and receptive carbonate units. The economic significance of this mineralization depends entirely on its gold content and the dimensions of the prospects.

"Hydrothermal Karstic" Mineralization

Data obtained during the project on the "hydrothermal karstic" mineralization on Thassos island (S, Sr and Pb isotope determinations on ore and oil-brines from the Prinos field, fluid inclusions, C and O isotopes, etc) completed and revised the existing ore genetic model.

The hydrothermal karst deposits of calamine and Zn-Pb sulphides on Thassos island were emplaced at the margins of sedimentary basins in large horst-graben structures rather than along the Kraistide-Strymon lineament and result from movement of early Miocene hot brines into carbonate units of the western Rhodope Massif (Fig.4). Therefore, the new exploration targets should be along boundary faults where they intersect thick basement carbonate units.

The depositional mechanism and the style of mineralization is markedly similar to the much larger Silesian-Cracow deposits which constitute the largest known Pb-Zn district in the world. However, $\delta^{34}\text{S}$ values from Prinos oil field (-3.7‰) demonstrate that this oil or oil-derived H_2S were not involved in ore formation process (De Groot, 1993). Moreover, Sr isotope composition for the Prinos oil-field water (with $^{87}\text{Sr}/^{86}\text{Sr}$ mean 0.7089, Shepherd & Naden, 1993) show that this fluid is too radiogenic to be the source of the mineralizing brines associated with the Thassos and Palea Kavala lead-zinc deposits. Fluid inclusion investigations indicate low temperature of formation (< 100°C) and seawater may have been the main mineralizing fluid (Naden et al., 1994).

There is potential on both Thassos and the mainland for larger deposits than that already discovered by drilling at Marlou. In terms of future exploration, it should be emphasized that the long extended edges of the basins, when bounded by rift-faulted thick carbonate sequences are potential targets for karstic Zn-Pb

metal sulphide deposits.

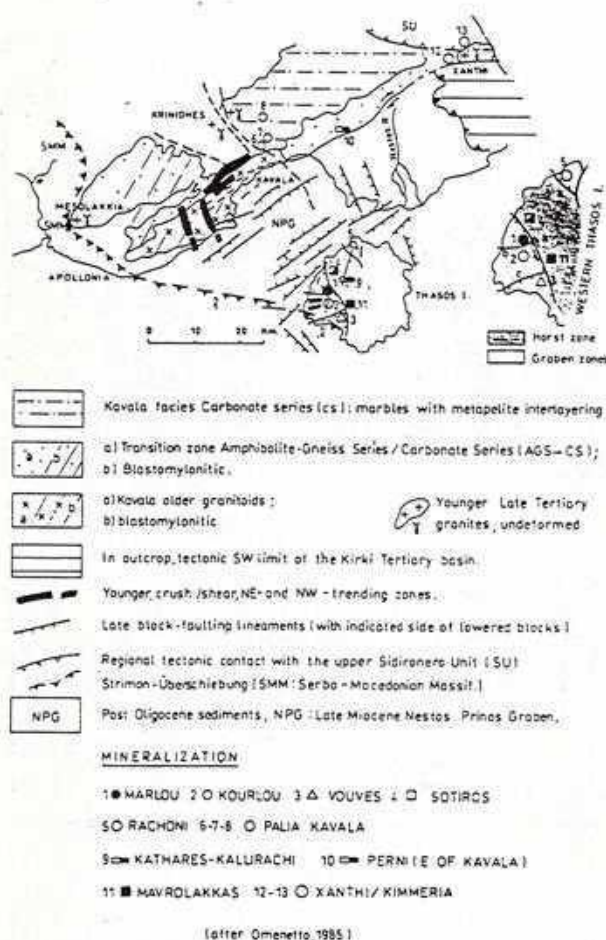


Fig. 4

Regional scale

The concept of regional ore genesis (Fig.5) suggests that all the main styles of mineralization are linked to Tertiary plate tectonic movements. A dynamic tectonic regime facilitated extensive movement of hydrothermal fluids and basinal brines in pulses along deep-seated channel-ways and basin margins.

During the early-mid Tertiary, a broad volcanic belt developed in Bulgaria and moved south through northern Greece. This belt was flanked on the west side by horst-graben structures which delineated sedimentary and volcano-sedimentary basins. Solution movement within the volcanic belt formed epithermal gold (Michael, 1993) and industrial mineral deposits, and fluid migration along the margins of the graben basins emplaced hydrothermal karst sulphide and calamine deposits in carbonate units of the horst blocks.

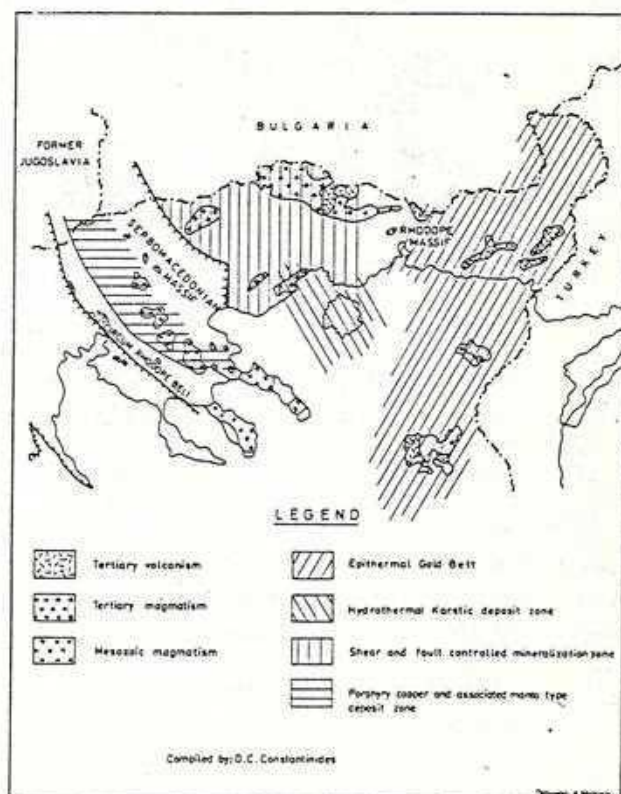


Fig. 5

Contemporaneous intrusion of porphyries into the Serbo-Macedonian Massif produced proximal porphyry copper type mineralization and distal manto style polymetallic deposits within carbonate units of the massif. Continued southern movement of the volcanic belt and flanking horst graben structures caused repeated overprinting of mineralization styles in some areas.

Thus, the margins of present-day grabens and the intersections of deep-seated fractures with thick carbonate units have exploration potential for carbonate-hosted base and precious metals, whilst the volcanic belt has potential for epithermal Au and industrial minerals (Fig. 5), possibly with Carlin style Au at its margins.

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