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ALPINE METALLOGENESIS OF THE ROMANIAN CARPATHIANS

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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 (Tethyian)-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 Băiţa 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 Rosia 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, Cavnic model with Au-Ag-Pb-Zn veins, Săcărâmb model with Au-Ag-Te veins and Roşia 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 (Tethyian)- 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 Tethyian 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 Tethyian 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 Tethyian 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 Quadrilater 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 rezerves/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 Neamţu 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 Făgăraş 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 Şinca- 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 Borcoş,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. Hornblendite, 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 Borcoş, 1994). The ores are hosted by diorite and hornblendite 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 Căzăneşti-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 Gjerswik type sensu Pearce and Gale (1977). Various veins and stockworks are controlled by brecciated basalts at Căzăneşti-Ciungani, Almăşel, and Roşia 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 Vorţa. 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 Şoimuş-Buceava, Pârneşti and Godinesti.

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

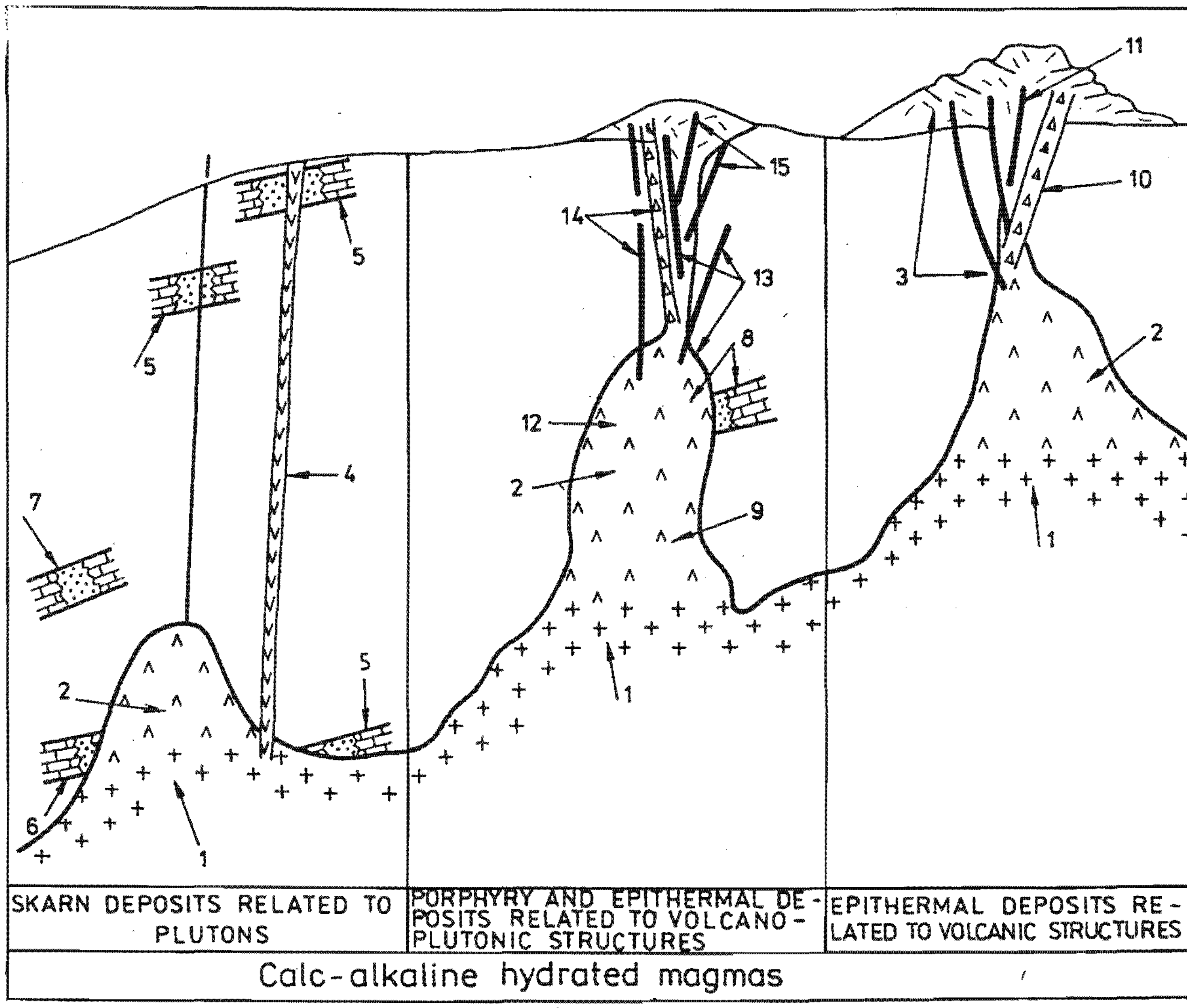

Fig. 1 – Metallogenesis in Upper Cretaceous-Paleocene and Late Tertiary subduction - related settings:
1, Pluton;
2, Apophyses of pluton;
3, Volcanic structure;
4, Dike;
5, Skarn deposits, model M I Băiţa Bihorului;
6, Proximal skarn deposits, model M II Ocna de Fier;
7, Distal skarn deposits, model 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 Roşia Poieni;
13, Porphyry-epithermal deposits, model M IX Valea Morii;
14, Epithermal breccia and vein deposits, model M X Roşia 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 Băişoara, Băiţa Bihorului and Luncşoara-Brusturi-Poiana districts. Băiţa 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, szaibelyite, ludwigite, fluoborite and kotoite. Metasomatised 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 "pentametallic" (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 Luncşoara;

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 Scrind-Rachitele and Bucea-Cornişel districts.

The South Apuseni subbelt is represented by monzodiorite or diorite – granodiorite magmatism with calcic Fe-skarn deposits (Vaţa) and granodiorite – granite magmatism Mo-Cu-pyrite vein deposits (Săvârşin, Cerbia). Recent absolute age data suggest that this magmatism may be of Cretaceous age (Ştefan, 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 Ruscă Mts. exposes granodiorite – granite magmatism with Fe, Cu, Pb-Zn skarn deposits (Dognecea and Ocna de Fier) and Mo-W-Cu skarn deposits (Oraviţa).

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 Borcoş, 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.

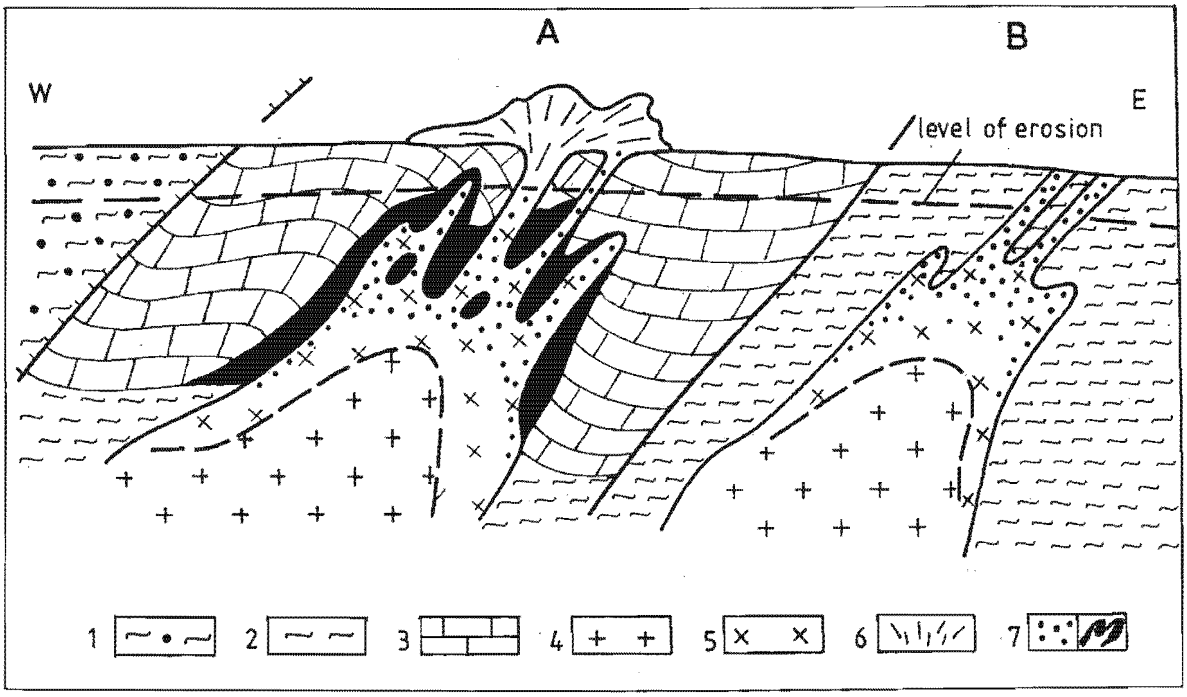

Fig. 2 - Banatitic porphyry copper models (according to Vlad and Borcoş, 1995): A. Model Suvorov; B. Model Bozovici. 1, Supragetic crystalline schists; 2, Getic crystalline schists; 3, Carbonate rocks; 4, Monzodiorite and diorite to granodiorite plutons; 5, Subvolcanic and hypabissal apophyses of dioritic 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 Băiţa 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, Băiţa 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, csiclovaite, veszelyite, and dognacskaite, cf. Udubasa et al. (1992).

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

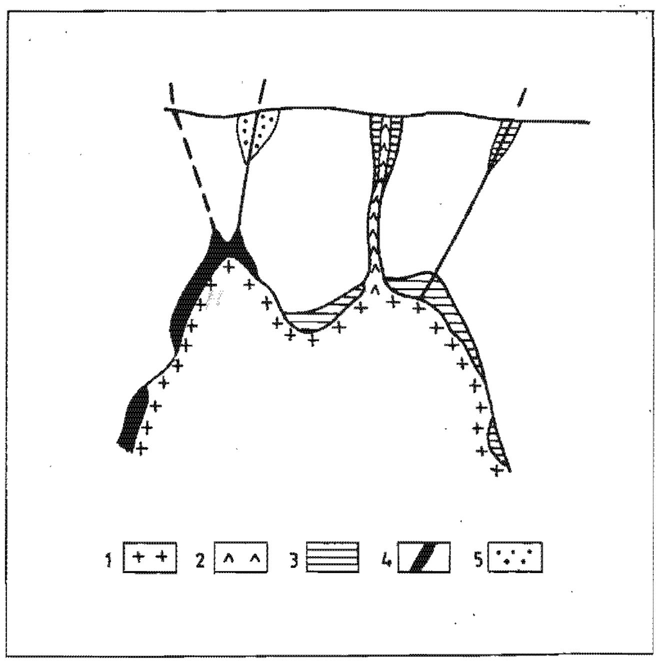

Fig. 3 - Banatitic skarn models (adapted from Vlad, 1990): 1, Granitoid pluton; 2, Dike; 3, Model Băiţa Bihorului; 4, Model Ocna de Fier; 5, Model Dognecea.

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 Ghiţulescu and Socolescu (1941), Giuşcă et al. (1968, 1973), Rădulescu et al (1981), Ianovici and Borcoş (1982), Borcoş, (1994a,b).

The 300 km long East Carpathian volcanic arc occurs in the Oaş, Gutâi, Ţibleş, Bârgău, 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 (Borcoş, 1994a). The epithermal deposits in non-porphyry environment contain base-metal and Au-Ag mineralization. The Oaş 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. Dragoş Vodă fault in association with a major quartz diorite pluton (Borcoş, 1994 a). This regional fracture controls the spatial disposition of ore districts, i.e. Ilba-Nistru, Săsar-Valea Roşie, Dealu Crucii-Băiuţ (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 Cavnic. 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 Cavnic vein deposit. Table 3 and Figure 4 show their main characteristics.

The metallogenetic zone belonging to the subvolcanic bodies of the Tibleş-Bârgău-Rodna Mts. contains especially base-metal veins in the Ţibleş, Toroiaga and Bârgău-Rodna districts (Metallogenetic Unit 5 b in Plate). The Căliman, Gurghiu and Harghita Mts. contain only a minor mineralization in siderite (Vlăhiţa), Hg (Sântimbru), base-metal (Dornişoara-Colibiţa) and a large S deposit (Căliman). This portion of the East Carpathian volcanic arc exhibits aborted porphyry systems (Metallogenetic Unit 5c in Plate).

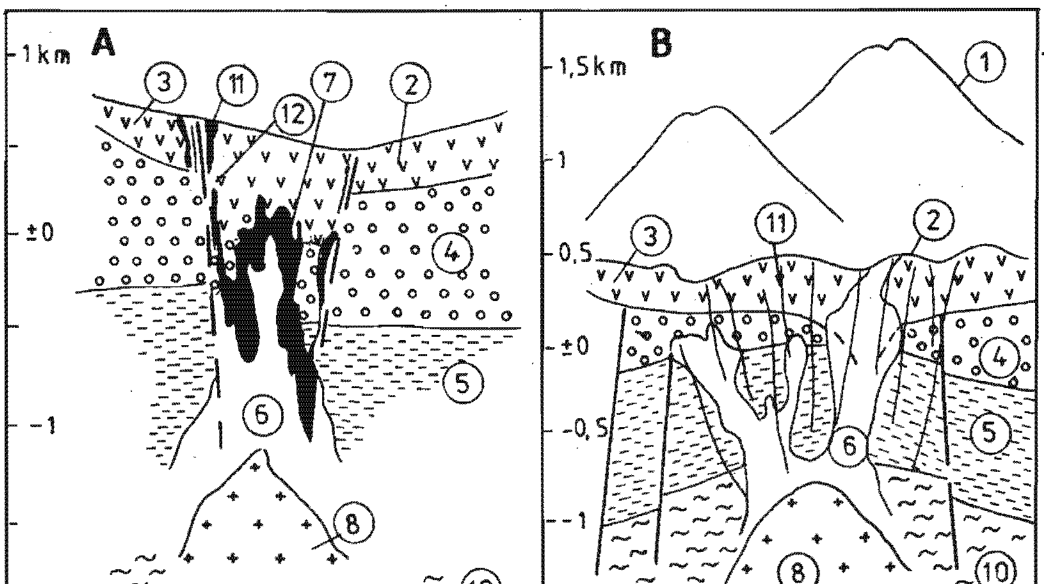

Fig. 4 – Tertiary epithermal models in the East Carpathians: A. Model Baia Sprie; B. Model Cavnic: 1, Syn-ore palaeosurface; 2, Level of erosion; 3, Volcanic products; 4, Siliciclastic rocks of the Tertiary molasse; 5, Hornfels in Paleogene sedimentary host rocks; 6, Subvolcanic body; 7, Phreatomagmatic 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 reactivization 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 (Borcoş, 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 igenous 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 Hondol with peripheral distal metasomatic disseminated mineralization at Coranda as well as porphyry Cu-Au deposits at Bolcana, 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 Almaş-Stănija district is similar, with Au-Ag-Te-Pb-Zn veins at Stănija, Breaza, Baba and Almaş and Cu-Au porphyry at Muncaceasca Haneş-Larga. The Bucium-Roşia district contains Au-Ag veins at Botes, Valcoi, Corabia and breccia (phreatomagmatic explosion type) pipes at Roşia Montană, Cu-Au porphyry at Tarniţa and Cu-Mo porphyry at Roşia Poieni. The Deva district has the Deva Cu-Mo porphyry. The Baia de Arieş district contains Au-Ag in veins and breccia (colapse 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:

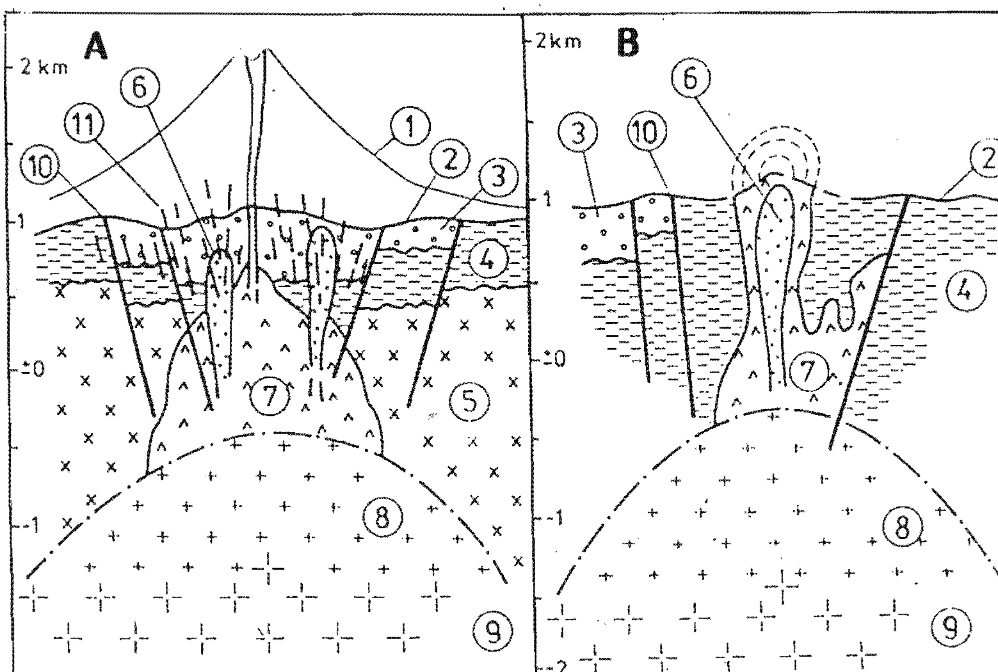

Fig. 5 - Tertiary porphyry models in the South Apuseni Mts (according to Vlad and Borcoş, 1996): A. Model Valea Morii; B. Model Roşia Poieni: 1, Syn-ore palaeosurface; 2, Level of erosion; 3, Siliciclastic rocks of the Tertiary molasse; 4, Mesozoic sedimentary rocks; 5, Ophiolites; 6, Porphyry copper 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 monsmedite were described from these regions for the first time, cf.Udubaşa et al (1992).

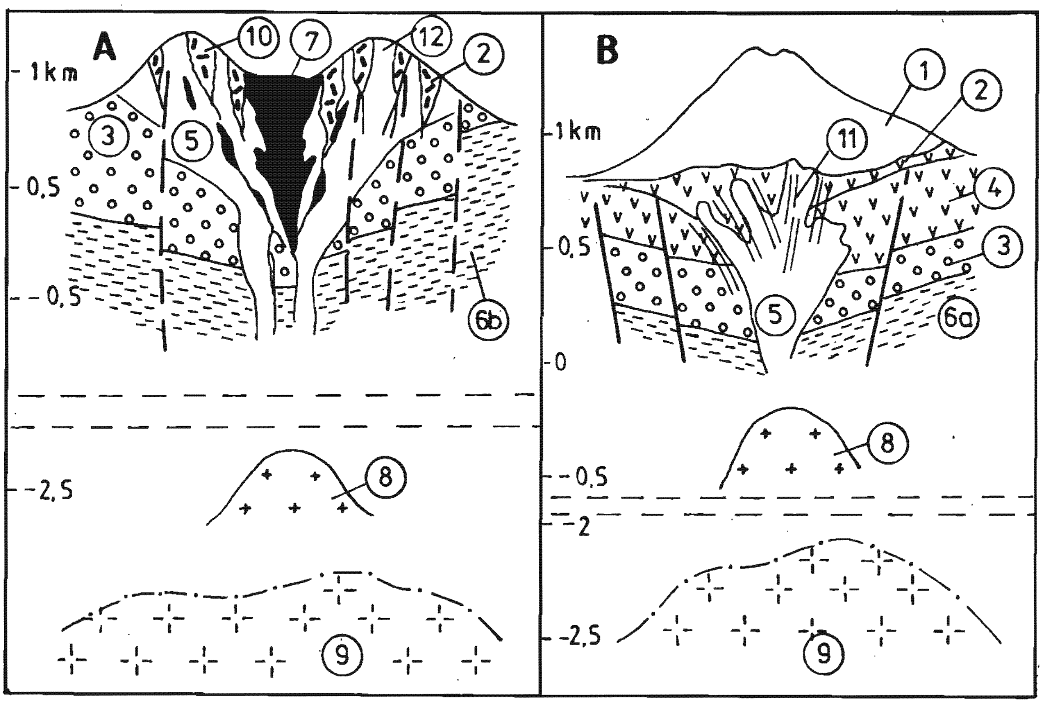

Fig. 6 – Tertiary epithermal models in the South Apuseni Mts: A. Model Roşia Montană; B. Model Săcărâmb: 1, Synore palaeosurface; 2, Level of erosion; 3, Siliciclastic rocks of the Tertiary molasse: 4, Volcanic products: 5, Subvolcanic body; 6, Underlying rocks (a. mesozoic ophiolitic and associated 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 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 metallogenetic model of the shear zone related mineralization in the South Carpathians was defined by Popescu and Lupulescu (1996). This metallogenesis is represented in Plate as Metallogenetic 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 chalcopyrite 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 allochtonous 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-reactivization concept.

TABLE 1. BANATITIC PORPHYRY COPPERS

MODEL SUVOROV-GRANODIORITE TYPE, Cu-Mo MONOASCENDENT EVOLUTION, SKARN HALO (M IV in Plate and Fig. 2)

DESCRIPTION. Chalcopyrite + 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 sotckwork in hydrothermally altered igneous host - skarn Cu ± Mo, W - replacement Pb-Zn - telethermal As-Sb - presumable Carlin gold.

DEPOSIT DESCRIPTION

Mineralogy. Magnetite ± chalcopyrite, pyrite impregnations in potassic zone, pyrite + chalcopyrite ± sphalerite, molybdenite, tetrahedrite veinlets and pyrite + chalcopyrite impregnations in phyllic zone (restricted areas of intensive silicification contain molybdenite ± pyrite, chalcopyrite veinlets and impregnations). Magnetite that replaced andraditic garnet and pyrite + chalcopyrite 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,
Şopot (Lilieci, Purcariu, Nasovăţ).

MODEL BOZOVICI-GRANODIORITE TYPE, Cu-Mo MONOASCENDENT EVOLUTION, PYRITE HALO (M.V. in Plate and Fig. 1)
DESCRIPTION. Stockwork veinlets of quartz, chalcopyrite, 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 subvolcánic-hypabissal 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 chalcopyrite, pyrite, magnetite and molybdenite in the upper part of the potassic zone and sporadic molybdenite, chalcopyrite and magnetite impregnation in the lower part of the potassic zone (Bozovici). Pyrite ± chalcopyrite, magnetite impregnations in phyllic and argillic zone (Teregova-Lăpuşnicel). Disseminated pyrite halo.
Alteration. Pervasive potassic alteration (biotitization) at Bozovici, restricted potassic, phyllic and argillic alterations at Teregova-Lapusnicel. 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.
Deposit/Prospects. Bozovici,
Teregova-Lăpuşnicel.

TABLE 2. BANATITIC SKARN DEPOSITS

MODEL OCNA DE FIER: Fe-Cu SKARN DEPOSITS (MII in Plate and Fig. 1)
DESCRIPTION. Magnetite + hematite, chalcopyrite + 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 ± ludwigite, pyrite, chalcopyrite, sphalerite, galena. Bi minerals may be present.
Alteration. Dolomitic environment: grossularite + vesuvianite inner zone; diopside + phlogopite center; forsterite ± 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 (Măgureaua Vaţei).
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, Băişoara, Măgureaua Vaţei, 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 Supragetic 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, chalcopyrite, 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 ± ilvite 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, Ruşchiţa, Tincova, Brusturi.

MODEL BĂIŢA BIHORULUI: Mo-Bi-W-Cu SKARN DEPOSITS (M in Plate and Fig. 1)
DESCRIPTION. Molybdenite, scheelite, chalcopyrite, 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 Oraviţa and Băiţa Bihorului) and hundreds of meters from the contact by infiltration metasomatism (distal skarns at Ciclova and Băiţa 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 + chalcopyrite + bismuthinite + Bi minerals ± sphalerite, galena, arsenopyrite, lollingite, glaucodote, gold, bornite, tetrahedrite, cubanite. Fluoborite, 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 alterning 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: Băiţa Bihorului, Oraviţa, 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 DESCRIPTIOIN
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, Şuior, partly Băiuţ-Văratic, Vf.Ţapului-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 + orpigment 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: Cavnic, Roata, Herja, Ilba, Nistru, Dealul Crucii.

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

MODEL ROŞIA POIENI-DIORITE TYPE, Cu-Mo POLYASCENDENT EVOLUTION PYRITE HALO (M VIII in Plate and Fig. 1)
DESCRIPTION. Chalcopyrite + pyrite ± 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 reactivization along extensional fault systems.
Large scale zonality associated deposit types. Not expressed.
DEPOSIT DESCRIPTION
Mineralogy. Pyrite + chalcopyrite + molybdenite ± magnetite, hematite veinlets with subordinate pyrrhotite, bornite, sphalerite, galena, digenite, enargite-famatinite, lusonite-stibiolusonite, tetrahedrite-tennantite in potassic zone.
Alteration. Potassic alteration (biotite + quartz ± Q-feldspar and anhydrite) in the porphyritic intrusion, partly replaced by albite ± actinolite. Argillic alteration (kaolinite + illite + montmorillonite ± 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, As, Bi, Se, Ta.
Deposits Prospects: Roşia 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 ± 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 reactivization along extensional fault systems.
Large scale zonality- associated deposit types. Cu-Au stockwork in hydrothermally altered subvolcanic body – Au-Ag ± Te and Pb-Zn ± Cu veins in hydrothermally altered volcanic rocks – pyrite halo in some intruded rocks (e.g. Mesozoic ophiolites).
DEPOSIT DESCRIPTION
Mineralogy. Chalcopyrite ± magnetite with ilmenite or rutile inclusions + pyrite with rutile inclusions ± 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, Haneş-Larga, Trampoiele, Muncăceasca W, Valea Tisei, Tarniţa.

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

MODEL ROŞIA 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 reactivization 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, chalcopyrite, 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: Roşia Montană, Radu-Frasin, Căinel, Draica, partly Baia de Arieş.

MODEL SĂCĂRÂMB-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 reactivization 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 + chalcopyrite + 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. Tentency 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, Stănija, Faţa Băii, partly Baia de Arieş.

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