Cent. Eur. J. Geosci. • 3(3) • 2011 • 318-335
DOI: 10.2478/s13533-011-0031-5

VERSITA

Central European Journal of **Geosciences**

Perspective targeting CuAuMo porphyries of Romanian Carpathians: blind porphyry mineralization and its variable distal expression as vein and skarns

Review article

Serban - Nicolae Vlad[1]*

1 *Ecological University, 1G, Vasile Milea Blvd, RO-061341, Bucharest, Romania*

Received 3 May 2011; accepted 17 August 2011

Abstract: Romania has a genuine accumulation of "blind" porphyry CuAuMo systems associated with Cu skarns or AuAg (PbZn) epithermal vein sets. Many such hidden structures were discovered inadvertently during state exploration based on local tradition that Romanian Carpathians are rich in vein and skarn ore types. Notable dichotomy between porphyries associated with peripheral skarns versus epithermal ores is expressed by age (Mesozoic versus Tertiary), precious metal content, alteration types and zoning, shape/size and extension of ore bodies. Preliminary conclusions on metallic/alteration assemblages around porphyries in addition to geophysical information about inferred deep-seated Alpine plutonism promote potential exploration vectors for what will be an increasingly important deposit type in the future.

Keywords: porphyry CuAuMo • skarns • epithermal veins • Banatitic Magmatic-Metallogenetic Belt • Tertiary-Quaternary Volcanic arc • Carpathians

1. Introduction

The territory of the Romanian Carpathians is rich in ore deposits of vein/skarn/porphyry types connected with Alpine/Mesozoic to Tertiary-Quaternary magmatism. They have been mined since Roman and even pre-Roman times and were described by well-known geologists in the last centuries, since von Cotta of the mid-XIXth century (1), who introduced the generic term of "banatite", up to various contemporaneous ones. Accordingly, Fe-Pb-Zn skarn deposits such as Dognecea – Ocna de Fier (Banat Mountains) of "Hannover –Fierro type" or Au-Ag (Te) epithermal world class deposits such as Rosia Montana and Sacaramb (South Apuseni Mountains) became famous the world over.

The present study does not intend to turn into a mere conceptual presentation of the Alpine magmatism and related metallogeny from the Romanian Carpathians with special regard to CuAuMo porphyry potential. Such a topic was covered by my previous works, alone or with co-workers (e.g., metallogeny of the Romanian Carpathians [2–13] and porphyry topic [14–20][1]).

*E-mail: serban.vlad@caronet.ro

[1] *References in the present paper and many other pub-*

Springer

This paper evaluates the CuAuMo porphyry systems at the regional scale, pointing especially to the hidden structures. Such settings may be an attractive target, promoting the subsurface porphyry potential expressed by peripheral skarn or epithermal occurrences. Its aim is to challenge exploration geologists with a genuine interpretation (maybe a fresh new start) based on the above mentioned personal contributions on ore deposits in the Romanian Carpathians (stemming from interrelated activities such as teaching, research and supervising exploration works) and extended correlation with adjacent areas of the Carpatho-Balkan orogen (e.g. [2, 9, 12, 13, 17]) as well as comparison to the South Western Cordillera of the United States [21]. And moreover, an impetus to resume operations in the stagnating mine industry of Romania is however welcome.

Under such circumstances the paper provides exploration indicators based on early established genetic-typological concepts developed by the author in time. Volume and grade evaluations are original estimations, as a result of field surveys covering the whole area discussed in the paper.

The topic was presented in a simplified version as a powerpoint and abstract at the 9th Biennial Meeting for Geology Applied to Mineral Deposits, "Digging Deeper", Dublin, Ireland 2007 [22]. It led subsequently to the present extended and revised version; i.e., the updated look and related perspective of Cu Au Mo porphyry potential of the Romanian Carpathians by the end of the last decade.

2. History

During the communist regime, the territory of Romania was exhaustively investigated for metallic resources using a wide range of activities imposed by the central administration.

The National Mapping Program conducted by the Geological Institute funded systematic geological, geophysical, ore resource and metallogenetic maps and basic studies. Central and regional state-owned exploration companies extended the economic side of the geological investigations. A complex exploration program strictly planned by the central administration involved activities from reconnaissance to mining works. The primary objective of these activities was to identify new opportunities for mining industry, a branch of the national economy strongly supported but also overestimated by the leadership. Ultimately, lack of a modern strategy coupled with old-fashioned technology, mentality and interpretation approaches led to inefficient follow-up that is exploitation highly subsidized by the state.

lished and unpublished works based on field, laboratory and library experience spanning four decades.

The two genetic couples, porphyry-skarn and porphyry-veins, require different exploration approaches, adjusting traditional exploration practices to varying degrees of erosion. Generally speaking, the historical mining industry focused on gold, while other metals such as copper/base metals triggered largely the scientific interest, allowing description of deposits/districts that became classic models for the whole Alpine metallogeny as mentioned earlier. Based on such cultural background, both skarns and veins were priority targets for valorization, and mining operations in standard areas concentrated on deeper mineralization zones with lower grade or in narrow mineralized zones of moderate grade. Much less attention was paid to low grade mineralization in stockworks or disseminations between sheared vein zones. Near surface gold and copper zones were ignored. Consequently very few mines met market-economic standard.

Anyway, investigations based on such exhaustive works led to advances in understanding classic occurrences, i.e. skarn genesis and zoning, but also reinterpretation of hydrothermal ores and implementation of modern vision in term of epithermal and porphyry concepts. Large volume/low grade deposits were delineated and represented the mainstay of mining production. A significant part is played by blind porphyry coppers discovered inadvertently during state exploration conducted in extension of veins. The porphyry concept was ignored for a large period of time and exploration during the fifties and sixties (XXth century) concentrated on preconceived targets consisting of sub-surface extension of Cu skarns or AuAg (PbZn) veins. In terms of porphyry-skarn couple, skarns at Suvorov – Moldova Noua ("Banatites" of the Banat Mountains) were exploited by underground methods until the early 70's (XXth century) when porphyries became to be recognized as a significant ore type. Subsequent open pit operations at Suvorov have been uneconomically conducted. They involved those low grade ores found in altered igneous rock after exhaustion of upgrade ores of the skarn aureole. When porphyries became legitimate in both "Banatitic" and Neogene environments [14], the system porphyry and related veins emerged as a promising target, resulting in the bulk of occurrences including blind ones of rather low grade but interesting Cu-Au systems.

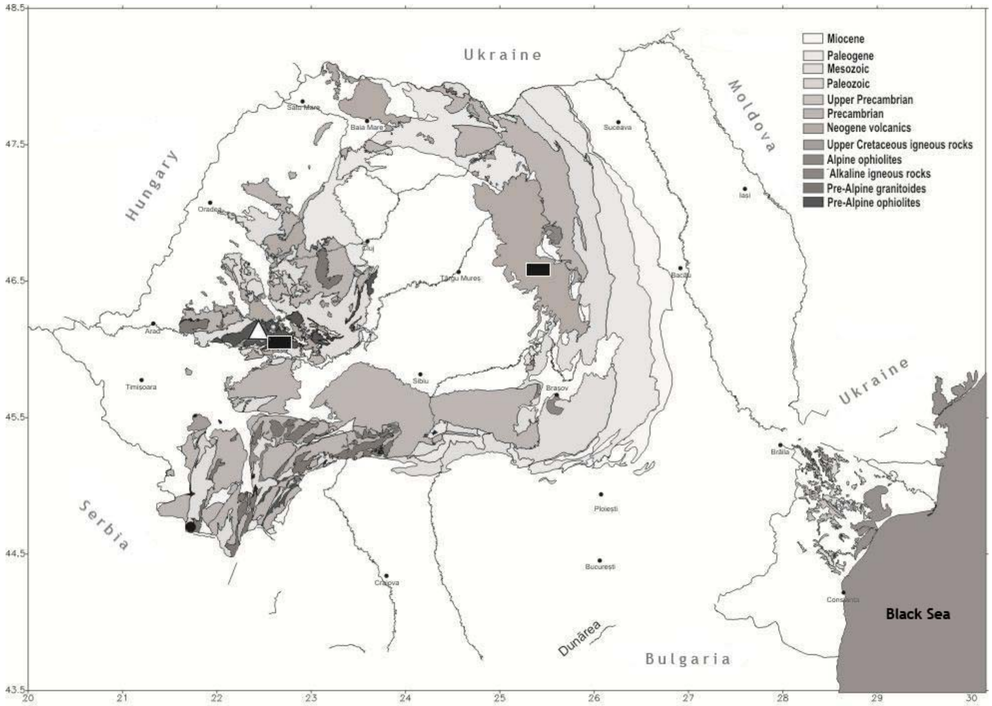

Figure 1. Distribution of porphyry copper settings in the Romanian Carpathians
Geology: Geological Map of Romania 1:1M, simplified (Geological Institute of Romania)
Age: △ Late Jurassic-Lower Cretaceous (undiscovered, inferred); ● Late Cretaceous (discovered + inferred); ■ Neogene (discovered + inferred)

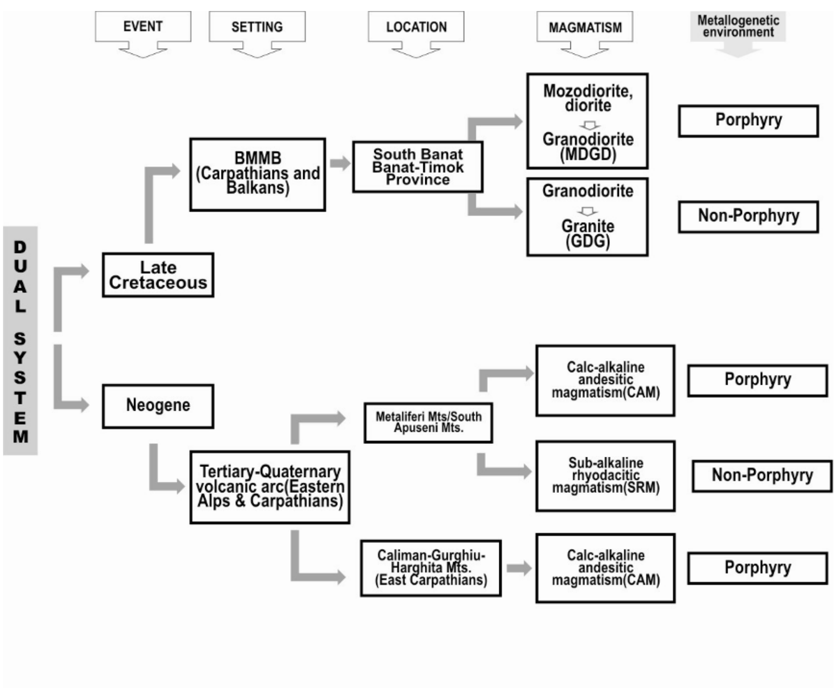

Figure 2. Porphyry coppers of Romania – main characteristics.

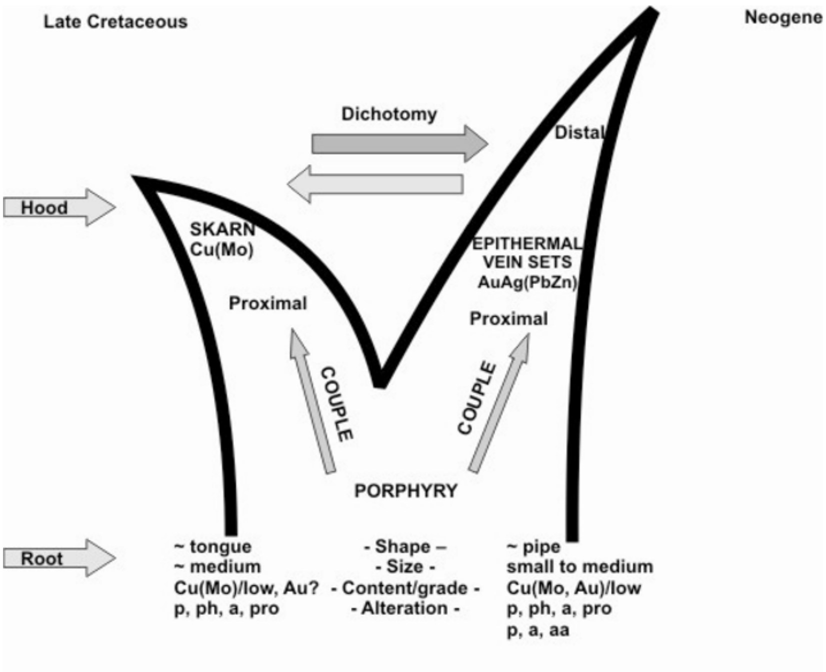

Figure 3. Porhyry environments of Romania.

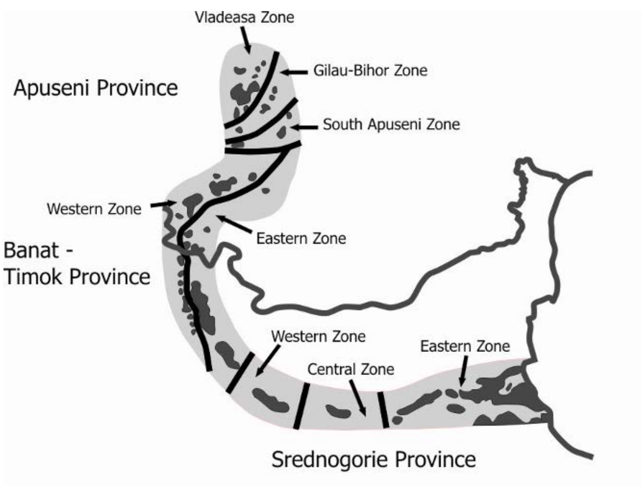

Figure 4. Banatitic Magmatic-Metallogenetic Belt (adapted from [10, 12, 13]).

The South Apuseni Mountains (i.e. South Apuseni Metallogenetic Province related to Neogene volcano-plutonic complexes) provided good evidence for both surface and blind occurrences and became a priority region for new discovery.

Only two copper porphyries, i.e. Suvorov-Moldova Noua (Banat Mountains) and Rosia Poieni (South Apuseni Mountains) were partly exploited in open pits with significant State subsidies during Communist time. The following post-Communism transition period represents a major set back due to a hesitant mineral policy, i.e., incapacity to conceive an appropriate medium to long-term strategy and failure of privatization efforts. At present the porphyry operations are closed whereas economically exploration targets that belong to junior companies such as Devagold and Rosia Montana Gold Co are on stand-by in terms of exploitation permit.

3. Geological settings

The porphyry environment of Romania (Fig. 1) is confined to Alpine metallogenesis in the Carpathians. A brief encounter with the major characteristics of the Carpathian metallogenesis is based on the above mentioned contributions (e.g. [6, 8, 9, 12, 13]) that may be summarized as following:

The ore formation consists of prevailing endogenous typology, involving genetic and spatial association with two major magmatic units: Late Cretaceous Banatites and the Neogene Volcanic Arc (Fig. 2).

Porphyry CuAuMo systems, including a number of genuine blind occurrences, associated with Cu skarns or AuAg (PbZn) epithermal vein sets are related to Late Cretaceous and Neogene subduction-collision episodes of the Alpine orogenic cycle [13]. Notable dichotomy between porphyries associated with peripheral skarns versus epithermal ores is expressed by age (Late Cretaceous versus Neogene), precious metal content, alteration types and zoning, shape/size and extension of ore bodies (Fig. 3). In addition, the early compressional stage of Late Jurassic-Lower Cretaceous age promoted a permissive geology for porphyry coppers to form as hidden structures related to deep-seated intrusions.

The Late Jurassic-Lower Cretaceous event is associated with a volcano-plutonic setting in the South Apuseni Mountains, including extrusive marine rocks, intermediate to felsic, and deep-seated felsic pluton, yielding a composite system with well-expressed "epithermal" massive sulfide-stockwork PbZn (Au) and inferred, but as yet undiscovered, subjacent porphyry CuAu (Vorta-Dealu Mare district)[23].

The Late Cretaceous event is related to the well-known transcontinental **Banatitic Magmatic-Metallogenetic Belt** (BMMB), a narrow elongated belt extending from the Apuseni Mountains southwards to the western South Carpathians, then bending eastward to Srednogorie down to the Black Sea and further to the Pontides [9, 13]. This metallogenetic unit corresponds as "timing" and "setting" to the Laramide belt of the South-western United States (Fig. 4) and contains, on the Romanian territory, the Apuseni Mountains Province with NE-SW lineation, and the northern part of the Banat-Timok Province, with N-S lineation. Whereas the Apuseni Mountains Province is a non-porphyry environment, porphyry systems with distal expression occur within the Banat-Timok magmatic-metallogenic Province, confined to the morphology of the Banat Mountains (South Carpathians). In this region the monzodiorite-diorite evolution line is porphyry productive

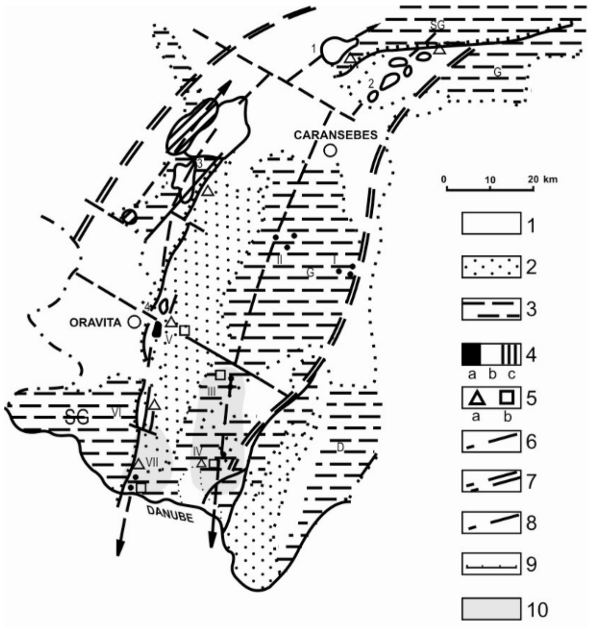

Figure 5. Banatitic magmatism and mineralization in the Banat Mountains (adapted from [5]) 1. Neogene-Quaternary sedimentary rocks; 2. Paleo-Mesozoic sedimentary rocks; 3. Crystalline pre-Mesozoic rocks: SG-Supragetic, G-Getic, D-Danubian; 4. Banatitic igneous bodies:a) monzodiorite, diorite → granodiorite trend (I. Teregova-Lapusnicel, II. Valiug, III. Bozovici, IV. Sopot, V. Ciclova, VI. Sasca, VII. Moldova Noua); b)granodiorite-granite trend (1. Tincova, 2. Ascutita-Ruschita, 3. Bocsa-Ocna de Fier, 4.Oravita); c) sub-alkaline trend (Bocsa-Surduc); 5. Banatitic metallogenesis: a)skarn deposits, b)porphyry deposits/prospects; 6. Banatitic magmatic-metallogenetic alignments; 7. Banat-Timok magmatic-metallogenetic province; 8. Fault: 9. Thrust; 10. Areas of interest for blind porphyries.

whereas the granodiorite–granite trend is a non-porphyry metallogenic unit [10, 13].

Late Cretaceous systems can be divided into plutonic settings with wall-rock carbonate-skarn-porphyry CuMoWAu systems (Oravita-Ciclova) and plutonic-subvolcanic settings with wall-rock carbonate-skarn-porphyry CuMoAu (Sasca-Moldova Noua, Sopot) or metamorphic wall-rock hosted porphyry CuMo systems with pyrite halo (Bozovici)[3, 13] (Fig. 5).

The Neogene event [6–8, 11, 13] stems from the transcontinental **Tertiary-Quaternary volcanic arc** developed from the Eastern Alps to the West and East Carpathians. Its metallogenesis is represented by ore clusters coincidental with fracture systems centered on volcanic-subvolcanic structures with inferred deep-seated plutons. The depositional environment is linked to the East Carpathians magmatism, generating a belt divided into the Northern Zone (Oas-Gutai-Tibles-Rodna-Bargau Mountains, including the well-known Baia Mare Province) and the

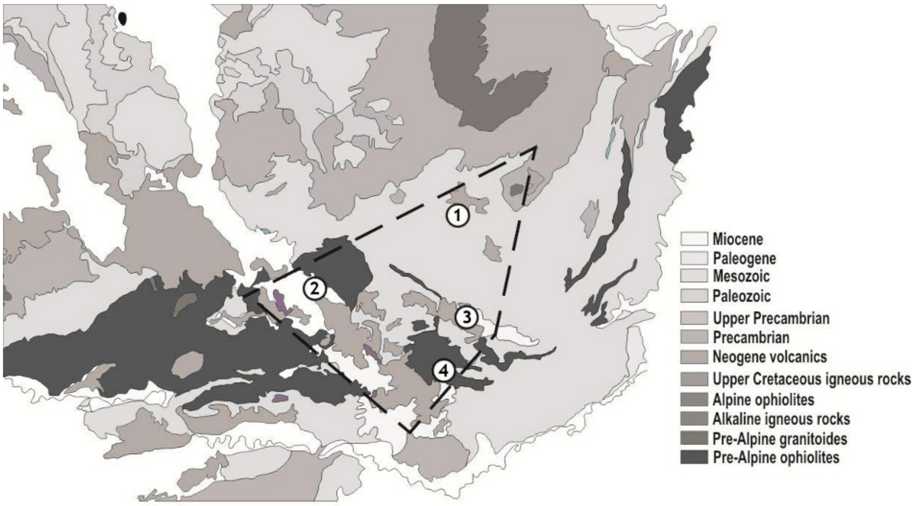

Figure 6. The Golden Quadrilateral (GQ) of the South Apuseni Mts
Geology: Geological Map of Romania 1:1M, simplified (Geological Institute of Romania)
–– Shape, size and outline of the GQ; ◯ Historical world class Au deposits: vein sets +-mineralized breccias; 1 – Rosia Montana, 2 – Barza, 3 – Zlatna, 4 – Sacaramb.

Southern Zone (Calimani-Gurghiu-Harghita Mountains), and, in addition, to the South Apuseni Mountains graben volcanicity (South Apuseni Mountains Province). Surface exposed and blind porphyry mineralization and peripheral vein/stockwork suites occur in the South Apuseni Mountains, including the famous Golden Quadrilateral/GC[2], with one of the world's highest gold endowment at 0.69 t/km^2 [11] (Fig. 6), and, less expressed in the Caliman-Gurghiu-Harghita Mountains (East Carpathians) [13] (Fig. 7). Calc-alkaline andesitic magmatism (CAM) is porphyry productive in these regions, whereas the sub-alkaline rhyodacitic magmatism (SRM) that occurs in the GC yielded exclusively non-porphyry mineralization [11]: CAM volcano-plutonic settings can be divided into porphyry systems as follows (Fig. 7 and 8): - andesite volcanic-subvolcanic level with porphyry CuAuMo and associated weakly expressed related veins of LS/HS epithermal AuAg type, fresh core, adjacent breccia/mineralized pipes (Deva, Rosia Poieni, Bolcana in the South Apuseni Mountains and Mermezeu-Zebrac, Fancel-Lapusna, Sumuleu-Ciumani and Ostoros, but also Caliman, Jirca and Varghis in the Caliman-Gurghiu-Harghita Mountains);

- andesite volcanic-subvolcanic levels with mineralization extending into adjacent clastic rocks, forming composite systems. They include porphyry CuAu with well expressed apical/lateral cap: LS>HS epithermal AuAgPbZn proximal veins to AuAg distal veins, in places skarn or magnetite dissemination in penetrated rocks (Tarnita, Trampoiele, Hanes-Larga, Muncaceasca, Valea Tisei-Runculet, Remetea-Colnic, Musariu, Valea Morii, Talagiu-Bratosin, Voia-Paraul lui Avram in the South Apuseni Mountains).

4. Characteristics

Late Jurassic-Lower Cretaceous metallogeny[13, 23]

Vorta–Dealu Mare district (Trascau Mountains/South Apuseni Mts) contains base-metal (Au?) discordant massive pods/stockworks that are tectonically controlled in silica-adularia and argillic altered dacite-andesite rocks and restricted Cu-pyrite veinlets and impregnations in small micro-diorite porphyry bodies. The Vorta deposit was mined in underground and adjacent minor metallic occurrences explored in detail. They represent the shallow expression of the ore formation related to a deep-seated felsic pluton. Surface indications and geochemical features provide evidence for a composite system with distal massive sulfide ores and proximal porphyry copper (with Au) along a 1km vertical column. A similar style of massive

[2] *This is not a metallogenic unit, but a geometry selected by the local mining tradition to enclose the area with Au world class deposits of the South Apuseni Mountains.*

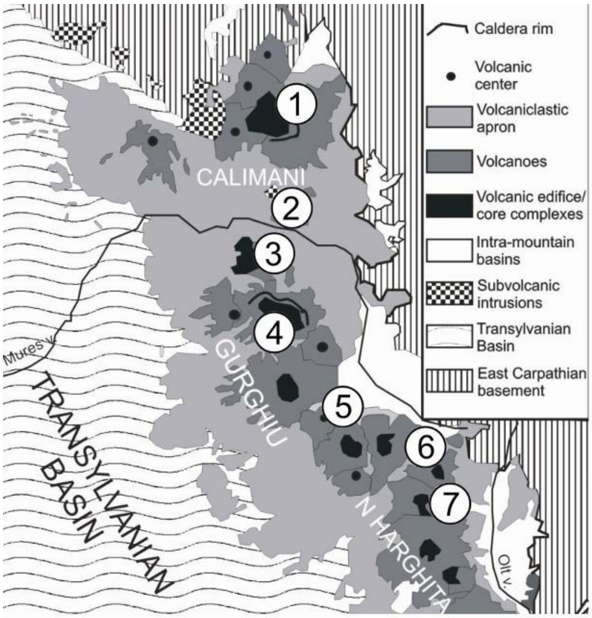

Figure 7. Porphyry setting of the Caliman-Gurghiu-Harghita Mts (East Carpathians)
Geological frame according to [25] Occurences:
1. Caliman caldera, 2. Zebrac-Mermezeu, 3. Jirca, 4.Fancel-Lapusna caldera, 5. Sumuleu-Ciumani, 6. Ostoros, 7. Varghis

high-grade mineralization, although of HS type, has been demonstrated at Choca Marin, in the Timok magmatic-metallogenic complex (Eastern Serbia).

This district of undiscovered porphyry mineralization to date may enclose blind porphyry occurrences. The metallogenic pattern is similar to ore formations from the Timok and Panaguriste portions of the BMMB, wherein the association massive sulfide-porphyry is common.

Late Cretaceous (Banatitic) metallogeny [10, 12, 13]
Skarn-porphyry systems of Banat, i.e. Moldova Noua and Sopot -Bozovici districts, represent the northern extension of the above-mentioned Timok Massif within the Banat-Timok metallogenic province (Fig. 5). Such occurrences belong to two distinctive porphyry models characteri.stic of the Banatitic area north of the Danube (Fig. 9). A significant spatial gap is found north of Moldova Noua, between Sasca, a Cu skarn-shallow intrusion unit which lacks porphyry mineralization, and plutons at Ciclova-Oravita, that are associated with porphyry roots, depleted of economic importance.

Southern Banat occurrences have been uneconomically exploited mainly underground at Moldova Noua or extensively yet inconclusively explored at Sopot-Bozovici. So far, both areas contain blind porphyries capped by skarns with Cu-Mo low potential and undetermined Au potential.

Moldova Noua district covers a meridian distributed contact aureole of a deep-seated pluton. Its branching apophyses were affected pervasively by alteration-mineralization. The metasomatism promoted garnet skarns and peculiar periskarns, as well as potassic, phyllic, argillic and propylitic alteration concentrically developed within and around igneous bodies. Cu-Mo mineralization is mainly connected to apo-skarn propylitic alteration and inner potassic and especially phyllic zones. In the north, at Corcana-Baies, potassic alteration is prevalent and the skarn formation is restricted to minor occurrences. In addition, the central and southern parts of the district, that is Suvorov, Valea Mare and, further south, Garana-Varad, are characterized by widespread and complete alteration-mineralization zoning. The Suvorov body may be considered as representative for the Banatitic porphyry copper systems (Fig. 10). The open pit operation and subjacent areas still enclose circa 400 Mt with 0.3% Cu. There is a MoAu perspective, so far unconsidered.

The Garina – Varad area, south of Suvorov, by the very Danube, represents the sector of interest in terms of blind porphyry style. It displays a 1km high column with well-expressed metasomatic zoning; that is, propylitic-argillic alteration on skarns/periskarns and central phyllic-potassic alteration with low grade Cu-MoPy mineralization. The argillic zone has a larger extent compared to the northern portions of the district.

Sopot metallogenic alignment (Sopot-Bozovici district), by the Danube, is only ~40km north of the famous Maydanpek porphyry system of the Timok Massif, so far the largest Cu porphyry in Europe. At Sopot, a minor Mesozoic sedimentary basin hosts small igneous apophyses with restricted aureoles characterized by propylitized-argillized skarns and central phyllic alterations enclosing CuMoPy low grade mineralization. The deeper part of the system is not yet investigated for blind porphyry setting. The Sopot alignment extends northward in a non-skarn metamorphic environment and exposes CuMo porphyry at Bozovici in a regional setting that contains remobilized Au mineralization. Both Bozovici prospect and adjacent occurrences are not conclusively explored. At Bozovici, a small hypabyssal intrusion exhibits an assemblage of potassic alteration and quartz veins with CuMoPy mineralization, surrounded by an extensive pyrite halo (Fig. 11). Such a setting requires investigations to define more prospective systems with better-developed subsurface porphyry Cu-Au stockwork style. There also remains potential for distal epithermal Au-base metal mineralization overlying the intrusions.

Neogene metallogeny

East Carpathians

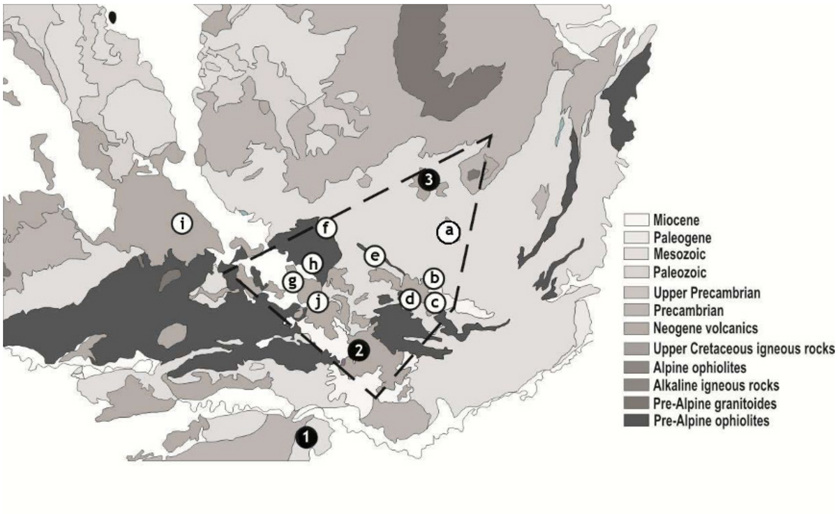

Figure 8. Porphyry setting of the South Apuseni Mts Geology: Geological Map of Romania 1:1M, simplified (Geological Institute of Romania)
– – The GQ
● Occurrences in volcano-plutonic setting, andesite volcanic-subvolcanic level: 1. Deva, 2. Rosia Poieni, 3. Bolcana
❍ Occurrences in volcano-plutonic setting, andesite volcanic-subvolcanic level extending in adjacent clastic rocks: a. Tarnita, b. Trampoiele, c. Hanes-Larga, d. Muncaceasca, e.Valea Tisei-Runculet, f. Remetea-Colnic, g. Musariu, h. Valea Morii, i. Talagiu-Bratosin, j.Voia-Paraul lui Avram.

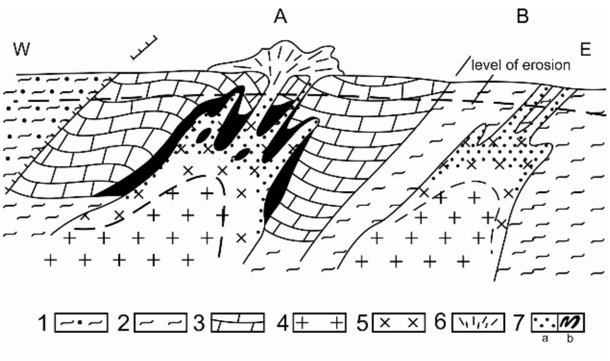

Figure 9. Banatitic porphyry copper models – cartoon representation according to [20]
A. Model Suvorov; B. Model Bozovici
1. Supragetic crystalline rocks; 2. Getic crystalline rocks; 3. Mesozoic carbonate rocks; 4. Monzonite, diorite → granodiorite pluton; 5. Subvolcanic to hypabyssal diorite to granodiorite apophyses; 6. Volcanic andesitic edifices; 7. Ores: a) Cu stockworks, b) Cu skarns.

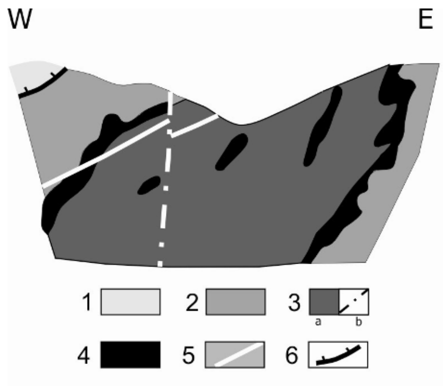

Figure 10. Suvorov – Moldova Noua Cu skarn-porphyry deposit (adapted from [18])
1.Supragetic crystalline rocks; 2. Mesozoic carbonate rocks converted into marble; 3. Banatites; a) Cu-Mo mineralized quartz diorite porphyry – granodiorite porphyry, partky mined out in open pit, b) post-ore lamprophyre; 4. Cu skarns, mainly mined out in underground; 5. Fault; 6. Thrust

The 160 km long volcanic chain Căliman – Gurghiu – Harghita Mountains consists of Neogene volcano-plutonic complexes composed of subvolcanic – volcanic domes and intrusive cores with surficial volcanic cones (lava flows) and outer volcanoclastics. Explosive – effusive activity in such stratovolcanic edifices yielded adjacent or partly overlapping composite structures with volcanoclastic aprons. The magmatism is calc-alkaline (CAM), from basaltic andesites to andesites and dacites, with restricted shoshonite occurrences in the south [25, 26].

Compared to northern portions of the East Carpathians, especially the historically AuAgPbZn highly productive Baia Mare region of a peculiar non-porphyry environment, both ore formation and economic concentrations seem rather insignificant. Scarcity of mineralization to date is interpreted as undisclosed deep-seated occurrences as a result of minimal erosion versus simply non-

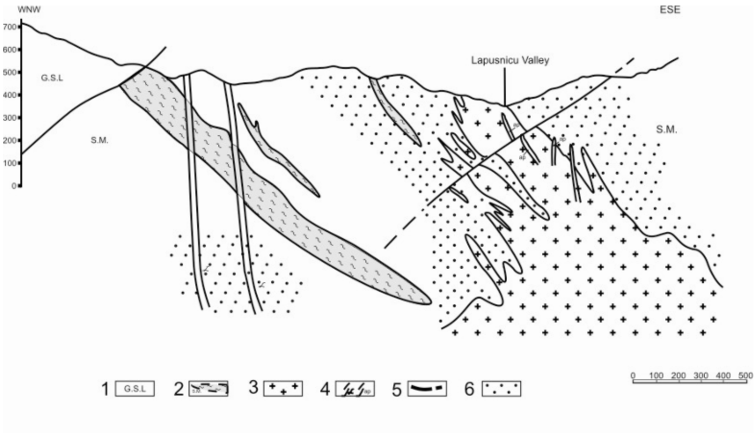

Figure 11. Bozovici (Lapusnicu Mare) Cu porhyry prospect (according to [24], simplified)
1. Getic crystalline rocks: Sebes-Lotru Group; 2. Getic crystalline rocks: Minis Series; 3. Banatites: monzodiorite porphyry with CuMo mineralization at the upper part; 4. Banatites: post-ore aplites and dikes; 5. Fault; 6. Hornfels, partly pyritised.

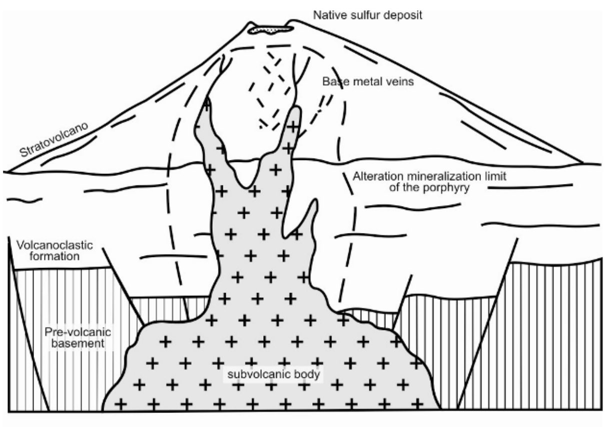

Figure 12. Porhyry-epithermal model, Caliman-Gurghiu-Harghita Mts, Neogene volcanism – cartoon representation (adapted by [8]).

productive magmatism. The metallogenesis is characterized by a better-marked (HS?) epithermal to porphyry style (Fig. 12).

(HS?) porphyry systems related to central type volcano-plutonic structures are developed along 1.5 km vertical columns [8, 13].

The zoned alteration from sub-surface to exposures consists of an inner potassic zone with biotite and amphiboles associated with propylitisation (autometamorphic type) and outer argillic and advanced argillic alteration. In places, silicification centers occur at the surface and quartz + tourmaline veinlets are superposed upon argillic alteration.

Metal zoning is represented by Cu (Au Mo) at deep porphyry levels, followed upward by Cu Pb Zn ⟶ Au Pb Zn (including tellurides) ⟶ py Au ⟶ Hg (cinnabar) ⟶ S (native sulfur) zones as veins, stockwork / breccia pipes and impregnations in argillic / siliceous alteration.

Metallic assemblages occur as minor veins, stockworks and impregnations through extensive alteration areas related to the major volcano-plutonic edifices, e.g. Căliman caldera, Zebrac – Mermezeu, Jirca, Fâncel – Lăpuşna caldera, Şumuleu-Ciumani, Ostoroş, Vârghiş (Fig. 7). Such occurrences of blind porphyry locations have been inconclusively explored. As a result, distinction between presumable "alive" versus "dead" porphyry style is not completed so far. Anyway, the complex of well preserved major volcano-plutonic edifices represents a suitable target for regional modeling of young volcanic arc setting and related metallogenesis.

South Apuseni Mts [8, 11, 13]

The South Apuseni Mountains (Metaliferi Mountains) metallogenic province contains a broad range of ore types, from AuAg (PbZn) LS epithermal vein systems, stockwork deposits, and breccia or PbZn replacement deposits to a restricted number of HS epithermal systems of AuAg character related or not to porphyry CuAu (Mo) mineralization. Related magmatism is SRM in a non-porphyry environment and CAM in a porphyry environment, multiphase and centered on apophyses of deep-seated plutons (volcano-plutonic complexes) coeval with Miocene molasse in extensional basins. This metallogenic unit represents the most famous mining region of Romania with metallic ores exploited since pre-Roman times up to the present. Precious metals represent the landmark of the area with historical production of over 2,000 tones Au, whereas porphyries entered the mining market fairly recently, during the last four decades. In terms of spatial distribution, ore

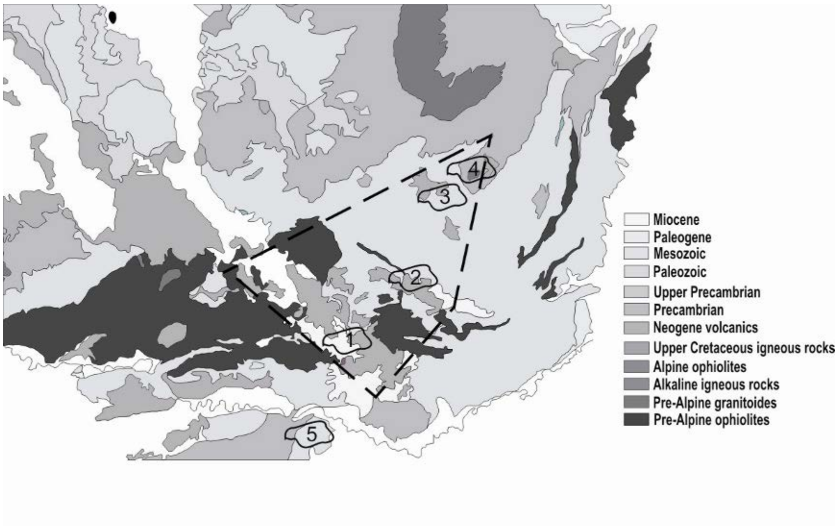

Figure 13. Metallogenic districts of the Neogene South Apuseni Mts province (according to [8])
Geology: Geological Map of Romania 1:1M, simplified (Geological Institute of Romania)
– – The GQ
1.Brad-Sacaramb; 2. Zlatna-Stanija; 3. Bucium-Rosia Montana; 4. Baia de Aries; 5. Deva.

deposits and prospects occur in parallel NW-SE basins of graben type, such as Brad-Sacaramb, Almas-Stanija, Bucium-Rosia Montana and Baia de Aries districts, and along the E-W major Mures fault that controls the Deva (Mures Valley) district (Fig. 13). Porphyry environment (Fig. 14) of various extent, level of emplacement, density of occurrence, type and proportion of exploration and exploitation covers the above mentioned districts, with one marked exception: the Baia de Aries district of characteristic AuAg breccia and PbZn replacement mineralization. Magmatism here is calc-alkaline (CAM), andesitic to dioritic, and centered on apophyses of deep-seated plutons inferred from geophysics (mainly gravity) at 3-4 km depth. Subcrustal parental magma is inferred as re-melted, assimilated Mesozoic igneous rocks.

Metallogeny consists of LS > HS epithermal base metal/precious metal deposits proximally/distally associated with porphyry CuAu (Mo) systems. Mineralization consists of stockwork Cu-Au (Mo) veinlets in porphyritic intrusions of subvolcanic type, volcanic rocks and, presumably, sedimentary rocks. Related Au Ag/Pb Zn (Cu) veins contain 7-20% sulfides and Au/Ag ratio ranging from 1/1 to 1/20. Commonly the couple Au-Cu shows positive correlation, whereas Mo exhibits a negative correlation to the Au-Cu couple.

Alteration consists of potassic +- phyllic, which commonly encloses mineralization, to argillic, to propylitic of marginal and/or pervasive regional distribution. Key proximal alteration of related veins is phyllic (sericite > smectite).

Vein-porphyry relations in the South Apuseni Mountains can be divided into:

-**consanguineous sequences** during the same metallogenic event of porphyry-vein assemblages. The porphyry emplacement is telescoped by epithermal veins, proximal with porphyry roots to distal through the porphyry aureole. Migration of magmatic porphyry related fluids toward shallower levels is reflected by zoned veins showing differentiated mobility of Cu and Au

versus

-**discontinuous sequences** during poly-stage overprinting events. Epithermal veins younger than porphyry systems crosscut the upper part of porphyries. These are derived from porphyry related fluids mixing with meteoric waters.

Vertical extent of mineralized columns is up to 2 km, consisting of base metal/precious metal vein mineralization in the uppermost 300-400m at volcanic level, followed by 1000-1500m of porphyry mineralization in a sub-volcanic setting.

Large scale zoning from outside in consists of Py halo → Au Ag ±Te and/or Pb Zn ± Cu veins & lenses, stockworks → Cu Au (Mo) porphyry.

****

Surface expression of porphyry represents an important exploration indicator provided by discovered or inferred systems in order to guide further exploration on undiscovered targets. The main characteristic of such spatial dis-

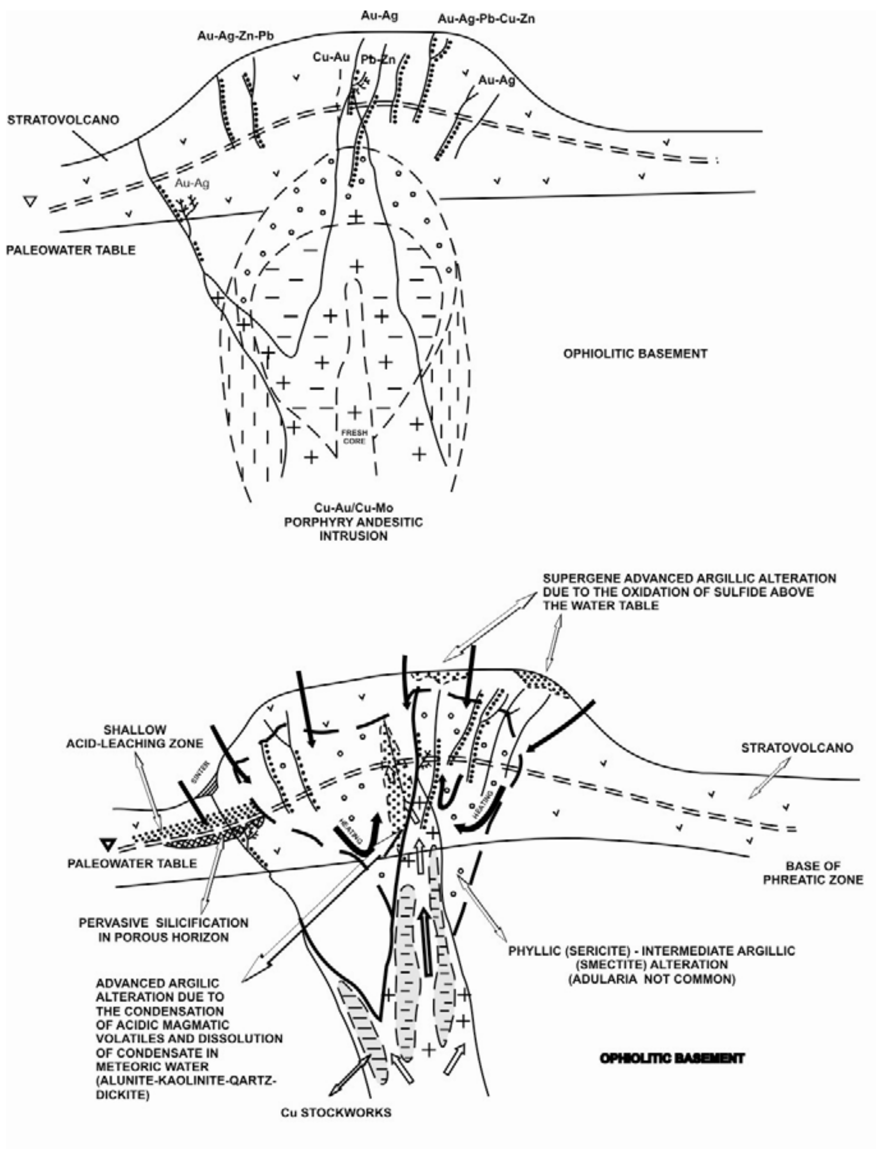

Figure 14. Porphyry-epithermal model, South Apuseni Mts Neogene province – cartoon representation (according to [11]).

tribution is given by interactivity between epithermal hood zone, eroded or not, and porphyry root at various depth. Accordingly, the following sets of occurrences have been distinguished and represented in Tables 1 to 4 and Fig. 15. Of them Tables 3 and 4 exhibit challenging targets, based on high density of documented genuinely **blind** porphyry deposits, with mineralization starting at 300-800 m depth (Table 3) and complex information such as structural setting, vein character, alteration intensity and results of geophysical surveys leading to inferred porphyry at depth (Table 4):

- Porphyries where apical portions cropped out and are partly eroded at present (Table 1)
- Porphyries where apical parts cropped out or were developed at shallow depth (Table 2)
- Blind porphyry deposits (Table 3)
- Systems in which porphyry mineralization have only been inferred (Table 4)

Table 1. Porphyries where apical portions cropped out and are partly eroded at present.

Locality	Reserves/Resources	Characteristics		Operations
		Surface extension	Others	
Deva deposit (Deva/Mures Valley District)	~200 Mt with 1% Cu (upper part)/0.5% Cu (lower part) and ~1g/tAu	Apical part crops out, eroded; collapsed area due to underground operations	Porphyry CuMoAu type, vertical pipe with prevailing potassic alteration that encompasses stockwork mineralization	Mined out in underground –exhausted Complex exploration around the ore body provided no positive results.
Rosia Poieni deposit (Bucium-Rosia district)	Present re-estimated reserves ~>1 billion t with 0.375% Cu, 0.15g/t Au, 0.001% Mo	Apical part crops out: leached cap and Cu veins, exhibiting advanced argillic alteration of HS character	Porphyry CuMoAu type; subvertical pipe of 1,200 m vertical extent with stockwork mineralization in potassic zone, increasing grade in the core, minor breccia pipes	Upper part exploited in open pit, extensive exploration during the sixties/seventies of the last century
Trampoiele prospect (Zlatna-Stanija district)	Resource estimates of ~60 Mt with 0.2% Cu, 0.5g/t Au from surface to -1,000 m.	Outcropping porphyry with specific alterations. The apex of the productive pluton is inferred at 500 m below the surface and the porphyry system extends presumably into adjacent sedimentary rocks as base metal veins and AuPyCu(Te) stockwork/dissemination	Porhyry CuAu type with stockwork mineralization in potassic alteration. Peripheral argillic-propilitic alteration	Grass-roots exploration followed by drillings and micro-pilot tests. Drillings intersected the porphyry system from surface to -1,300 m.
Valea Tisei-Runculet prospect (Zlatna-Stanija district)	Resource estimates of ~40 Mt with 0.2% Cu and 0.5g/t Au	Apical part crops out	Porhyry CuAu type ; stockwork mineralization in potassic-phyllic alteration that crops out along the Tisa Valley. The system is completed by small short Au veins at Runculet, on the slope of the Tisa Valley. The veins of base metal- precious metal character occur in argillic-propylitic apex of the porphyry stockwork and, in spite of their reduced extent, they exhibit high grade ore being exhaustively excavated by local prospectors.	From grass-roots to drillings and mining works
Remetea prospect (Bucuresti-Rovina field, Brad-Sacaramb district)	Reserve evaluation of ~70 Mt with 0.2& Cu and 0.15 g/t Au in addition to adjacent meso-epithermal stockwork at Colnic, that yielded ~30 Mt with 0.2% Cu and 1g/t Au.	Apical part crops out	Porphyry CuAu type; elliptical stockwork with potassic/phyllic mineralized core and rather distal expression at Colnic where AuAg/PbZn veins, breccia pipes and veinlet/impregnation networks occur in phyllic altered volcanics. Furthermore, a deep-seated porphyry may be found at Colnic too.	Punctiliously explored through drillings and mining works

Table 2. Porphyries where apical parts cropped out or were developed at shallow depth.

Locality	Reserves/Resources	Characteristics		Operations
		Surface extension	Others	
Valea Morii deposit (Brad-Sacaramb district) Fig. 16a	~75 Mt with 0.25% Cu and 0.3g/t Au	Porphyry crops out surrounded by veins	Porphyry CuAu type; mineralized stock work in potassic alteration with proximal AuAg (PbZn) veins in argillised volcanics.	Exhausted -mined out in open pit
Tarnita deposit (Bucium-Rosia district)	~750 Mt with 0.3% Cu and 0.2g/t Au, 400m below the surface CuAu grades increase	Mineralized porphyry intrusion crops out	Porphyry CuAu type; stockwork mineralization in potassic and phyllic zones, distal AuAgTe vein cupola in altered volcanics and sedimentary rocks.	Historical mining of peripheral large/high grade AuTeAg veins; suitable target for open pit operation based on extensive/complex exploration
Bolcana deposit (Brad-Sacaramb district)	Reserve estimates for the shallow part of the system is ~12 Mt with 0.3% Cu, 0.3-0.5g/t Au, 0.001% Mo	Apical part crops out	Porphyry CuAuMo type; stockwork, mineralization in potassic and phyllic alteration. The ore body has 800m vertical extent and encloses minor AuAg veins.	Open pit operations are closed as well as development in underground

Table 3. Blind porphyry deposits.

Locality	Reserves/Resources	Characteristics		Operations
		Surface extension	Others	
Musariu deposit (Brad-Sacaramb district) Fig. 16b	The top of the porphyry system contains ~10-15 Mt with 0.2% Cu and 0.3g/t Au	Blind, 300 m beneath the surface	The vertical column consists of CuAu porphyry type with stockwork mineralization in potassic alteration, surrounded by widespread aureole with AuAg(PbZnTe) veins/stockworks in argillic-silica alteration with marginal propylitization (Musariu-Bradisor vein sets).	Historical mining: the porphyry is related to the most extensive vein set in the Brad district with bonanza at vein intersection. In addition to the Rosia Montana deposit, veins at Musariu contained the highest gold accumulation of the Golden Quadrilateral. They have been mined down to ~300 m beneath the surface where the apex of a blind porphyry was encountered. Epithermal ores have been mined underground extensively yet uneconomically during the last decades. Accordingly underground operations were scheduled to close. The porphyry has been explored at two lower levels, but the extension at depth is subeconomic.
Voia prospect (Brad-Sacaramb district)	Resources estimate:~100 Mt with 0.3-0.4% Cu and 0.5g/t Au	Blind: at 500-700 m below the surface down to -1,200 m	Porhyry CuAu; stockwork mineralization in potassic zone, with disseminated magnetite and skarn breccia at depth and later small size AuAg epithermal veins capping the system. Noteworthy distal HS epithermal expression is represented by Paraul lui Avram vein/stockwork AuAg (CuTeSnGa) mineralization in advanced argillic alteration.	Complex geologic-geophysical exploration

Locality	Reserves/Resources	Characteristics		Operations
Talagiu prospect (Zarand Mts, north-western extension of the Brad-Sacaramb district)	Resources of $\sim$3-4 Mt with 1-10g/t Au and 5% PbZnCu in veins and $\sim$100-150 Mt with 0.3-0.4% Cu and 0.4-0.8g/t Au in porphyry	The blind porphyry mineralization starts at 400 m beneath the surface and proceeds discontinuously for about 1,000 m; surface expression consists of Bratosin fracture with PyAuPbZn veins, breccias and disseminations in argillized, pyritised volcanics	Porphyry CuAu type; the mineralized column is demonstrated through complex exploration over 1.5 km vertically. Upper 300-500 m contains base-precious metal veins in argillic alteration; the rest downward is porphyry within potassic, phyllic and propilitic zones	Complex geologic-geophysical exploration
Muncaceasca West-Podul Ionului prospect, a sector of the Almas-Stanija field (Zlatna-Stanija district) Fig. 16c	Resources estimates at level 400 m beneath the surface: $\sim$9 Mt with 0.25% Cu	Blind porphyry capped by a silicified pyrite plate	Porphyry CuAu type; stockwork mineralization in potassic>phyllic alteration with marginal propylitization and small breccia bodies at exo-contact. The mineralized column extends over 1.5 km and Au rich upper Corabia vein set with related stockworks and breccias in volcanics, volcanoclastics and sedimentary rocks was historically exploited. Complex exploration delineated a regional target of potential base metal-precious metal veins/lenses and subjacent exo/endo-porphyry related to fault zones/silicification, shear zones in sedimentary and volcanic rocks.	Complex geologic-geophysical exploration
Hanes prospect, a deeper extension of the Hanes vein sets within the important Hanes-Larga field (Zlatna-Stanija district)	No estimates	Au-Ag-Te vein sets as surface extension. Porphyry-like tongues that cross the main haulage level may represent the culmination of a blind porphyry located at 500 m below the surface	The Hanes-Larga field contains AuAgTe veins and lenses which were historically exploited. The vertical column is 1 km high with epithermal mineralization at upper level and skarn-porphyry at depth	Historical mining, underground operations closing recently. Exploration conducted so far did not concentrate significantly to deeper parts of the underground mining system.

5. Conclusion and perspective

Further study of regional factors in units with appropriate geology for porphyry to form and local factors around Romania's blind porphyries offers potential exploration vectors for what will become an increasingly important deposit style in the future as part of ongoing investigations to updating the metallogenic assessment of the porphyry copper potential.

Large scale factors consist of integrated evaluation of ore formation and space distribution such as porphyry type, density and number of deposits/prospects, quantitative data that are resources/reserves and grades, exploration methods and extent, structural setting and tectonic control, deep-seated plutonism inferred through extensive geophysical survey.

Local factors may be based mainly on mineralization-alteration zoning in both couples, skarn-porphyry and epithermal-porphyry, with special regard to surface expression of blind porphyry.

Favorable environments for estimated undiscovered blind porphyries (Fig. 17) are represented by calc-alkaline magmatism (CAM) related to graben type extensional back arc basins (NW-SE trend in the eastern South Apuseni Mountains) and simultaneous volcanic arc as a result of retracting subduction (meridian trend in the Caliman-Gurghiu-Harghita Mountains) for Neogene cou-

Table 4. Systems in which porphyry mineralization have only been inferred.

Localities	Reserves/Resources	Characteristics		Operations
		Surface extension	Others	
Magura-Faerag (Brad-Sacaramb district) Fig. 16d	No estimates	Surface veins with ~2g/t Au	The vein origin is mezzo-epithermal with AuAgTe ores in quartz-adularia/potassic zone and Au in argillic zone. The structural setting including vein characteristics, in addition to gravimetric and electrometric anomalies, suggest a porphyry inferred at depth at around 300-400 m beneath the vein level.	Historical mining conducted in parallel with extensive exploration for veins, but no investigations for porphyry; partly under development.
Popa-Stanija sector, Almaj-Stanija field (Zlatna-Stanija district)	No estimates	Surface expression: PbZn/AuAg veins/stockworks in potassic/phyllic alteration with marginal argillic alteration. In addition the area contains strongly argillised pyritic andesite between narrow Q+Au veins and surface samples with 0.5 to 2.2g/t Au	A porphyry is inferred at depth based on alteration intensity and results of IP survey. Regional target: disseminated mneralization of exo-porphyry type in altered sediments and shear zones	Historical mining for vein sets. Complex exploration resulting in geochemical and geophysical anomalies

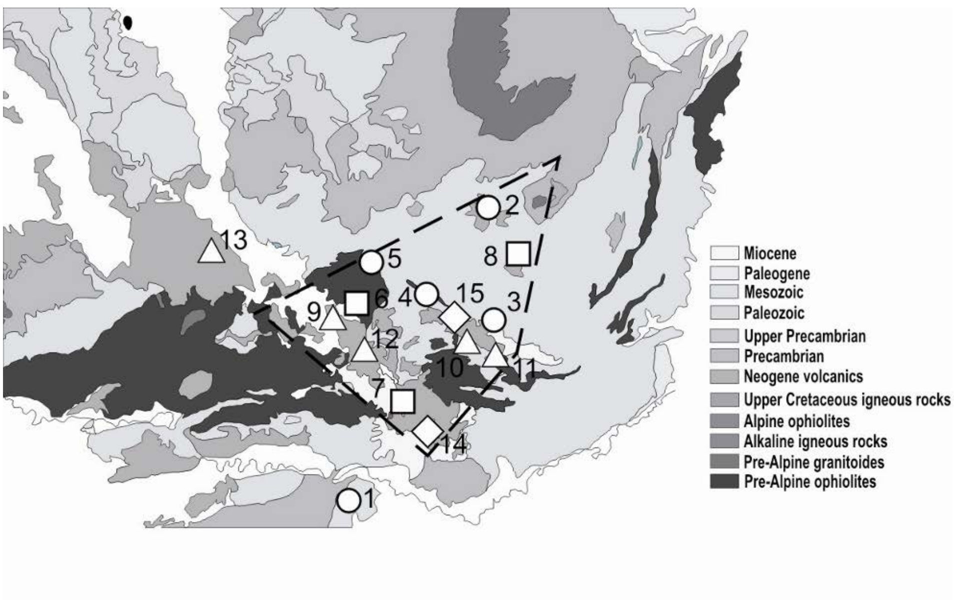

Figure 15. Location of Neogene porphyries from depth to the surface in the South Apuseni Mts (adapted from [13]) Geology: Geological Map of Romania 1:1M, simplified (Geological Institute of Romania)
– – The GQ
❍ Apical parts crop out/eroded (1. Deva, 2. Rosia Poieni, 3. Trampoiele, 4. Valea Tisei-Runculet, 5. Remetea); □ Apical parts crop out/developed at shallow depth (6. Valea Morii, 7. Bolcana, 8. Tarnita); △ Blind / between 300-800 m at depth (9. Musariu, 10. Muncaceasca West-Podul Ionului, 11. Hanes, 12. Voia, 13. Talagiu); Inferred at depth (14. Magura-Faierag, 15. Popa-Stanija).

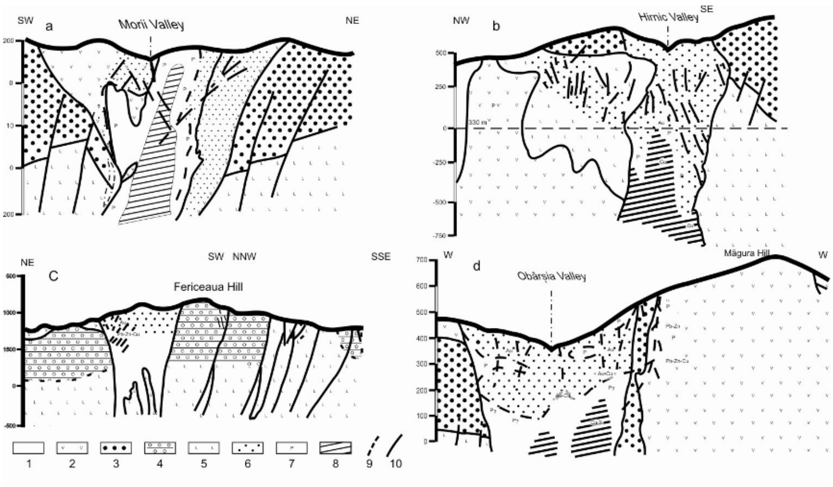

Figure 16. Cross-sections through representative Neogene porphyries of the South Apuseni Mts (according to [11]) a) Valea Morii – apical part crops out/developed at shallow depth; b) Musariu and c) Muncaceasca West-Podul Ionului –blind; d) Magura-Faierag – inferred at depth 1.Sarmatian-Pannonian intrusion; 2. Sarmatian-Pannonian andesite; 3. Miocene sedimentary and volcanic rocks; 4. Mesozoic sedimentary rocks; 5. Mesozoic island arc volcanics; 6. Argillic alteration; 7. Propylitic alteration; 8. Potassic +/- phyllic alteration; 9. Precious and base metal ores: 10. Fault.

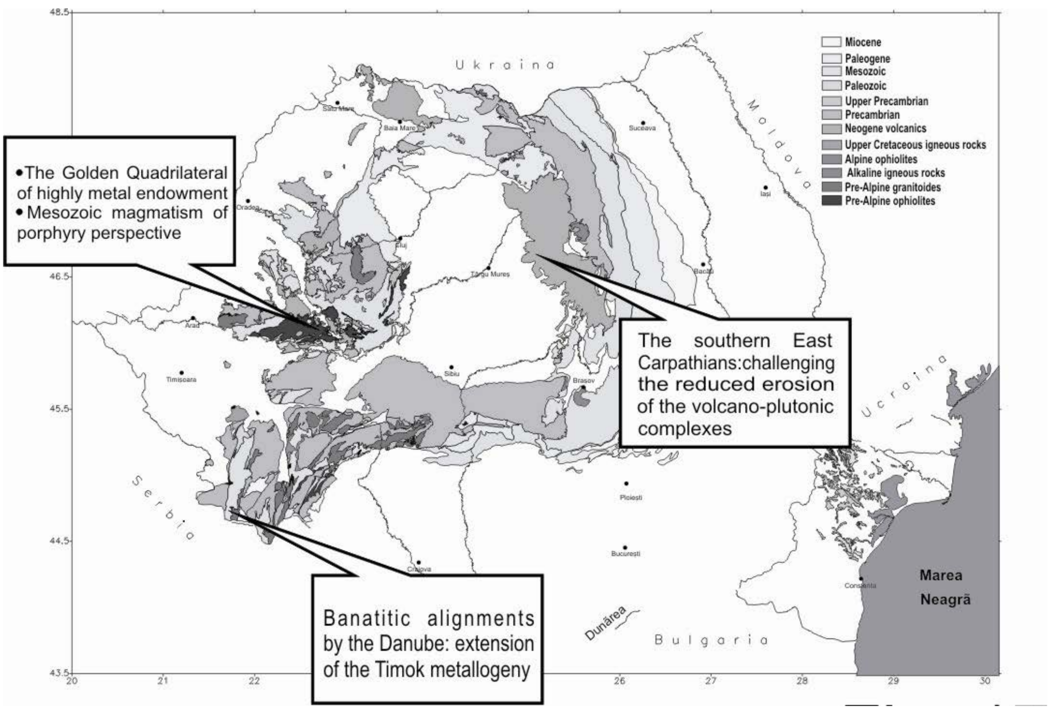

Figure 17. Target areas –favorable environments for undiscovered blind porphyries.

ple epithermal-porphyry, to meridian alignments controlled by post-subduction/collision rifting for Late Cretaceous couple skarn-porphyry (South Banat) and to latitudinal major lineation controlled by subduction for suggested Jurassic-Lower Cretaceous couple "massive sulfide"-porphyry (western South Apuseni Mountains). A dual approach that is investigation of hidden intrusions inferred through geophysics versus surface expression of presumable porphyry is recommended.

Acknowledgements

The author is grateful to Vertrees "Mac" Canby for suggesting this topic and perceptive discussions during the preparation of this article.

References

[1] Cotta, B. von, Erzlagerstþtten im Banat und in Serbien. [About igneous rocks and ore deposits in Banat and Serbia] Braunmuller W., Vienna,1864 (in German)

[2] Cioflica G., Vlad S., The correlation of Laramian metallogenetic events belonging to the Carpatho-Balkan area. *Revue Roumaine de Geologie*, 1973, 17, 217-224

[3] Vlad S., A survey of Banatitic (Laramian) metallogeny in the Banat region. *Revue Roumaine de Geologie*, 1978, 23, 39-44

[4] Cioflica G., Vlad S., Alpine metallogeny in România. *Annales of the Institute of Geology and Geophysics*, 1984, 54, 175-184

[5] Vlad S., The Romanian Carpathians: Alpine geotectonic evolution andmetallogeny. In: Petrascheck W. E., Jankovic S. (Eds.) Geotectonic evolution and metallogeny of the Mediterranean area and Western Asia, Schriftenreihe der Erdwissenschaftlichen Kommissionen, Springer, Vienna-New York, Austria, 1986, 113-126

[6] Vlad S., Borcos M., Alpine metallogenesis of the Romanian Carpathians. *Romanian Journal of Mineral Deposits*, 1997, 78, 5-21

[7] Vlad S., Borcos M., 1997, Alpine metallogenesis of the Romanian Carpathians. *Romanian Journal Mineral Deposits*, 1997, 77, 5-20

[8] Borcos M., Vlad S., Udubasa G., Gabudeanu B., Qualitative and quantitative metallogenetic analysis of the ore genetic units in Romania: Geological Institute of Romania, Bucharest. *Romanian Journal of Mineral Deposits*, 1998, 78, 1-158

[9] Berza T., Constantinescu E., Vlad S.N., Upper Cretaceous Magmatic Series and Associated Mineralisation in the Carpathian-Balkan Orogen. *Resour. Geol.*, 1998, 48, 291-306

[10] Vlad S. N., Berza T., Banatitic magmatic and metallogenetic belt: metallogeny of the Romanian segment. *Studia Universitatis Babes-Bolyai Geologie*, 2003, 48, 113-122

[11] Vlad S.N., Orlandea E., Metallogeny of the gold quadrilateral: style and characteristics of epithermal-subvolcanic mineralized structures, South Apuseni Mts, Romania. *Studia Universitatis Babes-Bolyai Geologie*, 2004, 48, 125-132

[12] Vlad S., Berza T., Seghedi A., Marincea St., Ilinca Gh., The Upper Cretaceous Banatitic Magmatic and Metallogenetic Belt in the Alpine Carpathian-Balkan Chain of Europe. Backbone of the Americas. Speciality Meetings Geological Society of America Mendosa, Argentina, Abstracts & Progress 2006, 2, 79

[13] Vlad S. N., Tipologia si Gestiunea resurselor Minerale Metalifere [Typology and management of metallic mineral resources]. Editura Casa Cartii de Stiinta, Cluj-Napoca, 2005 (in Romanian)

[14] Ianovici V., Vlad S., Borcos M., Bostinescu S., Alpine porphyry copper mineralizations of West Romania. *Miner. Deposita*, 1977, 12, 307-317

[15] Cioflica G., Vlad S., Copper sulphide deposits related to LaramianMagmatism in România. In: Jankovic S., Sillitoe R.H. (Eds.), European copper deposits. Proceedings of an International Symposium 18-22 September, 1979, Bor, Yugoslavia. Belgrade, 1980, 62-72

[16] Vlad S., Monoasacendant and polyascendant porphyry copper systems. *Revue Roumaine de Geologie*, 1981, 25, 95-100

[17] Vlad S. N., [Geology of the porphyry copper deposits]. Editura Academiei Bucureşti, Bucarest, 1983 (in Romanian)

[18] Vlad S., Alpine porphyry copper occurrences in Romania. *Bulletin de l'Academie Serbe des Sciences et des Arts, Sciences Naturelles*, 1984, 86, 111-127

[19] Vlad S., Porphyry coppers-Petrometallogenetic systems. *Studia Universitatis Babes-Bolyai Geologie*, 1995, 40, 27-40

[20] Vlad S., Borcos M., Alpine porphyry models in România. In: Knezevic V., Krstic B. (Eds.), Terranes of Serbia. Faculty of Mining and Geology, Belgrade, 1996, 371-376

[21] Vlad S. N., Comparative Mesozoic-Cenozoic metallogeny of the Carpathian-Balkan and Southern Cordillera Orogens. *Studia Universitatis Babes-Bolyai Geologie*, 1998, 43, 15-42

[22] Vlad S. N., "Blind" porphyry CuAu(Mo) mineralization in Romania and its variable peripheral expressions as veins and skarns. In: "Mac" Canby V., Large D., Molnar F., Moritz R. (Eds.), Exploration advances in the Tethyan Belt. Proceedings of the 9th Biennal SGA meeting: "Mineral exploration and research: digging deeper". Trinity College, Dublin, Ireland 20-23 August 2007'. Irish Association for Economic Geology, Dublin, 2007, 197-201

[23] Vlad S.N., Tamas C.G., Vorta metallogenic district (South Apuseni Mts, Romania). *Studia Universitatis*

Babes-Bolyai Geologie, 1998, 43, 109-121 (in Romanian with English abstract)

[24] Cioflica G., Jude R., Lupulescu M., Calota C., Porphyry copper mineralization at Lapusnicu Mare. *Studii si cercetari de Geologie, Bucharest*, 1996, 41, 17-29 (in Romanian with English abstract)

[25] Szakacs A., Seghedi I., The Calimani-Gurghiu-Harghita volcanic chain, East Carpathians, Romania: volcanologic features. *Acta Volcanologica*, 1995, 7, 145-155

[26] Pecskay Z., Lexa J., Szakacs A., Seghedi I., Balogh K., Konecny V., Zelenka T., Kovacs M., Fulop A., Poka T., Marton E., Panaiotu C., Cvetkovic V., 2006, Geochronology of Neogene Magmatism in the Carpathian arc and intra-Carpathian area. *Geologica Carpatica*, 57, 6, 511-530