

METALLOGENY OF THE GOLD QUADRILATERAL: STYLE AND CHARACTERISTICS OF EPITHERMAL – SUBVOLCANIC MINERALIZED STRUCTURES, SOUTH APUSENI MTS., ROMANIA*

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ABSTRACT. The Romanian territory contains numerous ore deposits mined since pre-Roman times. An assessment of historical gold production of the Gold Quadrilateral (GQ) yielded a total estimate of 55.7 Moz of gold throughout an area of 2400 km². Interpreted in terms of mineralization density this is 23,208 oz of gold/ km².

The geological setting of the GQ is represented mainly by Tertiary (14.7 My to 7.4 My) calc-alkaline volcano-plutonic complexes of intermediate character in sedimentary basins of molasse type. These basins are tectonically controlled by NW-SE lineation across early Alpine magmatic products, i.e. subduction related Jurassic-Lower Cretaceous igneous association (island arc ophiolites and granitoids) and Upper Cretaceous igneous association (banatites). The Tertiary magmatism is associated with extensional tectonics caused by NE escape of the Pannonian region during Upper Oligocene-Lower Miocene times.

As a result of tectono-magmatic and mineralization-alteration characteristics, two metallogenetical types were separated in the GQ, i.e. calc-alkaline andesitic (CAM) and sub-alkaline rhyodacitic (SRM). Both develop almost entirely low-sulfidation type of Au epithermal mineralization. However, two subtypes, -rich in sulfide (2-7%) and -poor in sulfide (7-20%) were delineated and correlated with CAM type and SRM type respectively. Furthermore, CAM is connected at deeper levels with Cu-Au+-Mo porphyry systems in contrast with SRM, which is a non-porphyry environment.

The Brad-Săcărâmb district contains mainly CAM type andesitic structures. It is a porphyry environment with epithermal low-sulfidation-rich sulfide vein halo (Barza, Troița-Bolcana deposits). However, a few SRM type patterns, such as Măgura Țebii, Băița-Crăciunești and Săcărâmb, deposits exhibit Au-Ag-Te low-sulfidation-poor sulfide epithermal vein halo.

The Zlatna-Stănița district exhibits similar characteristics, with Au-Ag+-Pb, Zn veins in Cu-Au subvolcanic-porphyry environment (CAM type). An exception is the Fața Băii Au-Ag-Te vein system that corresponds to SRM type.

Rosia Montana-Bucium district is more elaborated in terms of a porphyry-epithermal relationship. Both CAM type (Roșia Poieni, Bucium Târnița deposits) and SRM type (Roșia Montană deposit) exist.

The Baia de Arieș district is definitely the non-porphyry environment of SRM type, with Au-Ag-Te veins and breccia pipes hosted in sub-alkaline andesitic rocks.

Key words: Gold production, Au metallogenetical types, epithermal-porphyry relationship, Gold Quadrilateral, South Apuseni Mts., Romania.

INTRODUCTION

The Gold Quadrilateral (GQ) of the Metaliferi Mts., South Apuseni Mts., Romania, was considered at the beginning of the 20th century as an “European Eldorado”. Due to its richness, the area has been known for centuries. Early mining

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works are related to Roman Times. Remnants can be seen nowadays at Roșia Montană, Barza, Stănița and Vîlcoi-Bucium. The main commodity has been gold, exploited from high-grade deposits. During the Middle Ages other deposits were discovered, such as Săcărâmb ore deposit, the type locality of five tellurides: nagyagite, krennerite, petzite, stuetzite, and munthmanite. At the same time, other metals activated the mining industry, i.e. silver, lead, zinc, copper and mercury.

There is no geological significance concerning the borders of the GQ. They simply link the extreme North-South and West-East gold mines. Anyway Tertiary volcanic rocks prevail over the sedimentary molasse and basement rocks inside tectonically controlled basins of the GQ. The corners of the GQ are located not so far from small, but famous mining sites such as Brad, Baia de Arieș, Zlatna and Deva (Tschermack, 1868).

The present paper is an attempt at a regional scale reinterpretation of the Tertiary volcanic related metallogeny of the GQ in terms of sulfur content of the epithermal systems, redox potential of mineralising fluids and, last but not least, the connection and deeper passage through subvolcanic-porphyry environment associated with the major tectonic setting of ore deposition.

Recent intensive studies of the above mentioned topics belong to Borcoș (1994), Vlad (1995), Vlad & Borcoș (1996, 1998), Udubașa et al. (2001).

New concepts in gold modelling

A modern approach involving epithermal gold deposition might start with the case of the Wild Dog system in Papua New Guinea. It became famous recently after the interpretation of the Au-Ag epithermal environment in terms of sulfidation degree (Ashley, 1982; Sillitoe, 1993). This deposit comprises massive wall rock silification that contains tellurides and high-sulfidation copper dominated sulfides associated with sericitic rather than the expected advanced argillic alteration.

The Au-Ag metallogeny of the GQ is not so far from such an “unconformable” occurrence. In fact, epithermal deposits showing a combination of characteristics from high-sulfidation and low-sulfidation types, suggest generation of fluids intermediate in composition between those two above mentioned models.

It is widely believed and generally accepted by economic geologists that high-sulfidation epithermal deposits form in part by interaction of magmatic volatiles with cooler ground water (Hayba et al., 1985; Hedenquist, 1987; Berger & Henley, 1989; Gammons & Williams-Jones, 1997). As a consequence and in addition to specific structural-geochemical arguments, the high-sulfidation systems are proximal to subvolcanic porphyry intrusions (Bonham, 1986; Sillitoe, 1989; White & Hedenquist, 1995). Rather in a distal position, the low sulfidation systems it have been divided from the beginning in several subtypes, e.g. alkalic model (Bonham, 1988), hot spring model (Nelson, 1989) and more recently rich sulfide/poor sulfide models (Sillitoe, 1993) or even a kind of transitional term, i.e., intermediate sulfidation (Hedenquist et al., 2000). The last three models refer especially to andesitic terrains (Sillitoe, 1989, 1993, Noble, 1990, Hedenquist et al., 1996, Sillitoe & Hedenquist, 2003).

In addition, the issue of advanced argillic alteration in epithermal environments was the subject of a long, but profitable debate at the end of the 2nd Millennium. A distinction of three types of advanced argillic assemblages was very important because of their relationship to gold-silver ore. Three types of alunite (Sillitoe, 1993) are distinguished, as follows: below the paleo-water tables in high-sulfidation systems that may host ore, above the paleo-water tables in high-sulfidation or low-sulfidation systems that are barren, but may overlie ore and supergene assemblages which may/ may not accompany ore.

The surficial parts of epithermal environments are often the most difficult to comprehend, largely because any precious metals that might be present remain concealed. For instance, only minor gold mineralization is exposed at Landolam – Lihir Island in Papua New Guinea (Moyle et al, 1990), which is actually the largest epithermal, both terrestrial and submarine, gold deposit all over the world (Peterson et al., 2002). The question is how many shallow eroded systems have not been drilled deeply enough, because of a mistake in complete understanding of epithermal-porphyry (subvolcanic) limit and relationship.

These features are common to the GQ, where the spatial distribution of epithermal suites is more expressive, i.e. depending of sulfide amount, redox potential of fluids and igneous rocks petrochemistry, whether gold-silver epithermal deposits are related or not to a porphyry subvolcanic environment.

HISTORICAL GOLD PRODUCTION OF GOLD QUADRILATERAL

Our assessment of historical gold production since Roman Times, yielded values of 2.25 Moz (67 t) at Săcărâmb, 8.5 Moz (255 t) at Stănița, 21.0 Moz (630 t) at Roșia Montană, 12.75 Moz (382 t) at Barza-Brad and 11.2 Moz (336 t) at Baia de Arieș and 25 other small old mines (Fig. 1). The total estimate is of 55.7 Moz (1670 t) throughout an area of 2400 square kilometers of the GQ. This remarkable fact is to be interpreted in terms of world-class density of gold that is 23.208 oz/km² (0.69 t/ km²).

According to early papers and historical documents (Mac Laren, 1908; Palfy, 1912; Stanciu, 1929; Voicu, 1934; Vajda, 1967) it seems that an amount of 30.5 Moz (915 t), more than a half of historical gold estimate, was extracted, processed and transported to Rome by the Romans. In the Middle Ages, the gold mines of the GQ produced around 16.5 Moz (495 t), partly as property of the Hungarian-Austrian Empire (Helke, 1934).

The 20th Century and Modern Times registered a dramatic reduction in gold production in the GQ due to exhausting of the high-grade gold veins, nests and ore-sheets. However, the Romanian or foreign, state-owned or private companies such as “Mica Brad” (a Romanian-German Joint Venture) produced around 8.4 Moz, i.e. 252 t (Helke, 1938).

The almost continuous mining activity in the GQ triggered the interest of numerous geologists resulting in various theoretical and applied contributions. Furthermore, several metallic minerals have been described as “locus typicus”. Worth mentioning are the notorious discovery of a new metal named “Tellurium” at Fața Bșii (Zlatna-Stănița district) in the 18th century.

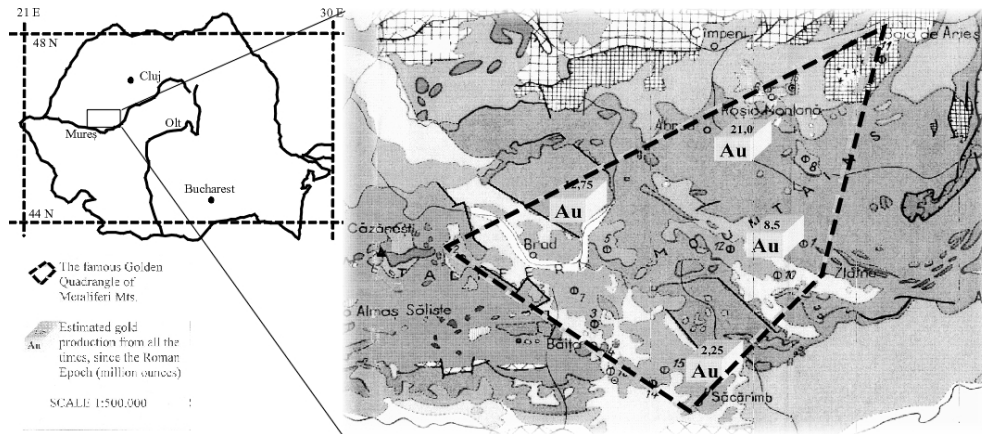


Fig. 1. Geological map of the Metaliferi Mountains (South Apuseni Mountains) with the distribution of the Neogene ore deposits. 1- The famous Golden Quadrilateral of Metaliferi Mts., 2- Estimated gold production from all the times, since Roman Epoch (millions of ounces).

Sedimentary deposits		Igneous rocks	
	Quaternary		Quaternary (?) basalts
	Neogene		Neogene volcanites
	Paleogene		Laramian magmatism (Banatites)
	Cretaceous		Eocretaceous magmatites
	Permian-Jurassic		Mesozoic ophiolites
CRYSTALLINE BASEMENT			
			Hercynian metamorphic formations
			Baikalian metamorphic formations
			Pre-Baikalian metamorphic formations
			Thrusts and overthrusts
NEOGENE METALLOGENY			
			Porphyry copper type
Ore deposits associated with neogene volcanism			
	Deposit	Host rock	Metallogenic formations
1	Izvorul Ampoiului	volcano-sediments	Hg
2	Caraci	andesites	Au-Ag
3	Câinel	andesites	Au-Ag
4	Băița	rhyodacites	Au-Ag
5	Bucureșci-Rovina	andesites	Au-Ag;Cu
6	Roșia Montană	dacites	Au-Ag
7	Barza	andesites	Au-Ag(Pb-Zn);Cu-Au
8	Bucium	andesites	Au-Ag (Pb-Zn);Cu-Au
9	Săcărâmb	andesites	Au-Ag-Te
10	Haneș-Fața Băii-Breaza	andesites	Au-Ag-Te;Au-Ag-Pb-Zn
11	Baia de Arieș	andesites, limestones	Au-Ag-Te;Pb-Zn
12	Almaș-Stănița	andesites	Au-Ag;Au-Ag-Pb-Zn
13	Troița-Trestia	andesites	Pb-Zn;Au-Ag;Cu-Mo
14	Hondol	andesites	Au-Ag-Pb-Zn
15	Pârâul lui Avram	andesites	Cu-As
16	Roșia-Poieni	andesites	Cu-Mo-As
17	Deva	andesites	Cu-Mo

MAJOR TECTONIC SETTING OF THE GOLD QUADRILATERAL: METALIFERI MTS. (SOUTH APUSENI MTS.)

The geological setting of the GQ is associated with the Alpine evolution of the Tethys Ocean and related Mesozoic-Tertiary tectono-magmatic events in the South Apuseni Mts. Early magmatism is represented by subduction related Middle Jurassic-Lower Cretaceous island arc ophiolite-granitoid assemblages (Nicolae & Saccani, 2003). The subsequent magmatic event yielded an Upper Cretaceous granitoid association (banatite), i.e. diorite-granodiorite association.

After closure of the Transilvanian-Tethyan Ocean and Tisia-Dacian collision, the architecture of the South Apuseni Mts. underwent slight or incipient extensional tectonics during the Tertiary. The north-eastward escape of the Pannonian region during Oligocene – Miocene times, coupled with clockwise rotation involving the South Apuseni realm (i.e. Tisia-Dacia Block of Inner Carpathians) and retractant subduction in the Outer Carpathians are responsible for such extensional back-arc setting with associated Neogene magmatism and metallogenesis (Balintoni & Vlad, 1997).

Reactivated NE-SW Laramian fractures during Neogene times across early Alpine magmatic lineations controlled the occurrence of molasse basins. They form triangular grabens with increased extension northwestward and pull - apart tendency, due to NW-SE transverse fracturing. The molasse grabens represent the preferential site for Tertiary vulcano-plutonic edifices with prevalent Badenian rhyodacite-rhyolites and especially Sarmatian-Pannonian andesite volcanic piles at their upper part. This calc-alkaline magmatism with slightly sub-alkaline tendency was generated by melting of thinned-metasomatized pre-Apulian Continental margin (Tisia-Dacia Block).

Superposition of ophiolite, granitoid, banatitic and Tertiary-Neogene magmatism in the restricted domain of the South Apuseni Mts. is interpreted in terms of the inheritance – reactivation concept. Neogene metallogenesis involved significant metal remobilization from preexisting sources. The GQ and Metalliferous Mts. show an increasing of gold-silver background values/grades, related mainly to ophiolitic basement crossed by Neogene magmatites, in contrast with the lead-zinc affinity of Baia Mare Neogene igneous rocks that penetrated a basement of crystalline schists. In addition, rich telluride deposits of the GQ (Săcărâmb, Fața Băii) are connected with uplifted zones of crystalline basement.

METALLOGENETICAL TYPES OF THE GOLD QUADRILATER

The upper part of the Tertiary vulcano-plutonic complexes represents the preferential site of precious metals-base metals epithermal deposits and Cu-Au-Mo porphyry systems. The main features that have led to a sharp distinction among different metallogenetic types/models are represented by the sulfide amount and sulfidation degree of the epithermal suite, in direct correlation with pH – redox potential of the mineralizing fluids and host rocks.

However, other characteristics are to be taken into account, such as the connection with deeper porphyry systems, the type and position of advanced argillic alteration assemblage, respectively the genesis of acid leaching-oxidized zones, the occurrence of sericite-adularia alteration, and last but not least, the base metal content of each system.

The petrochemistry of Tertiary magmas is also an important factor in our attempt to delineate different models. It is conspicuous that the most important part of Tertiary mineralized volcanic products of the GQ belongs to a calc-alkaline event. Local alkaline barren trends were described at Zimbrița-Brad and Pârâul lui Toader – Săcărâmb (Ianovici & Borcoș, 1982; Roșu et al., 1997). Anyway, a gradual passage toward sub-alkaline petrotypes was recorded recently. Away from the rhyolitic-rhyodacitic structures (Roșia Montană, Rodu, Frasin, Contu, Băița-Crăciunești) this group might include the mineralized andesitic structures of Măgura Țebii, Baia de Arieș, Săcărâmb and Fața Băii.

The mineralogy of auriferous ore deposits of the GQ is well expressed by gold-silver tellurides (Săcărâmb, Fața Băii, Bucium, Baia de Arieș) and native gold (Barza, Hondol, Roșia Montană) associated with base metal ores (pyrite, sphalerite, galena+/- chalcopyrite). The gangue of the telluride ores consists of quartz, clay minerals, and rhodochrosite. The gangue is predominately quartz in the case of the native gold veins.

As a result of petrochemical evolution and mineralization-alteration characteristics, two metallogenetic types are represented in the GQ:

- Calc-alkaline andesitic type (CAM – Fig. 2A)
- Sub-alkaline rhyodacitic type (SRM – Fig. 2B)

Calc-alkaline andesitic metallogenetic type (CAM)

The CAM type is related to calc-alkaline andesitic rocks, developing commonly a central andesitic porphyry structure. Beyond the mineralized porphyry environment, low-sulfidation-rich sulfides (7-20%) and epithermal Au-Ag veins are dominant (Fig. 2A). The main features of this type are enclosed in Table 1.

It is significant that only two occurrences, i.e. Paraul lui Avram and Musca-Rosia Poieni contain the enargite-acid sulfate assemblage of high-sulfidation systems. In the hypogene advanced argillic alteration with alunite, kaolinite is mentioned. At Musca-Roșia Poieni, the overlying enargite bearing level was mined out (Boștinescu, 1984). At Pârâul lui Avram, the N – S oblique high -sulfidation alignment joins the typical low-sulfidation system of Voia-Coasta Mare with a porphyry copper developed in depth. The system is not fully explored as a whole so far.

The most important part of low-sulfidation-rich sulfide type deposit contains 7-20% sulfides in veins or stockworks. The key proximal alteration is a sericite-smectite assemblage that is a phyllic association depleted commonly of adularia.

The main commodities are Au-Ag, Pb-Zn+/-Cu in the epithermal suite and Cu-Au-Mo or Cu-Au related to the deeper-seated porphyry system. The hydrothermal fluid conduit is characterized by convection cells resulting from mixed-connate fluid boiling and restrictive hypogene circulation which is confined to subvolcanic intrusion boundaries.

The basement is often built up of ophiolite/basaltic uplifted blocks or compartments, associated with Mesozoic flysh or fliohoid formations.

Except for those two early mentioned structures, acid leaching zones with kaolinite +/- alunite and/or vuggy silica (silicification) occur in various calc-alkaline andesitic environments (Muncăceasca, Coranda) as a result of supergene or shallow alteration. Supergene advanced argillic alteration due to the oxidation of sulfides above the water table in such cases might cap only low-sulfidation-rich sulfide epithermal environment.

METALLOGENY OF THE GOLD QUADRILATERAL, SOUTH APUSENI MTS., ROMANIA

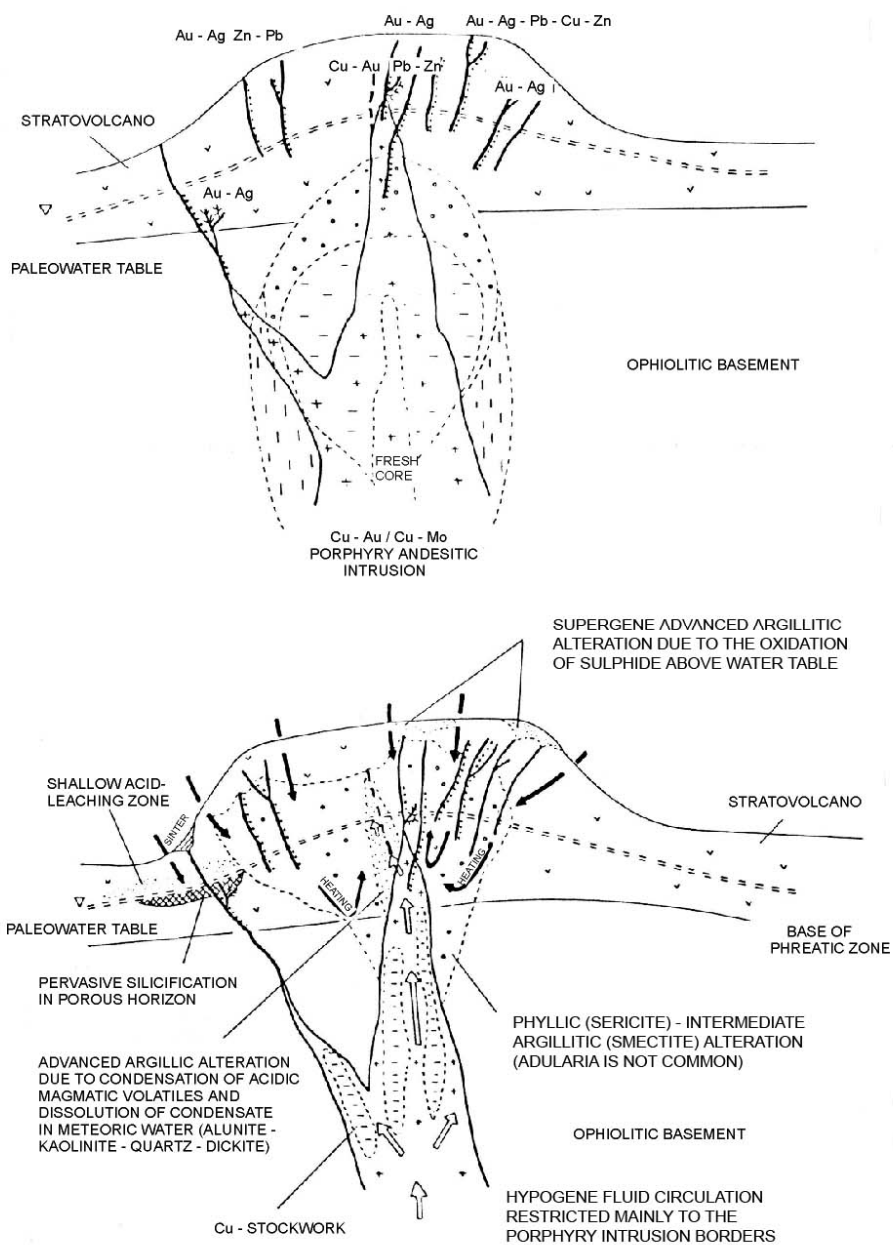


Fig. 2A. Calcalkaline – andesite metallogenetic type.

Table1

Main features of calc-alkaline - andesitic (CAM) and sub-alkalic - rhyodacitic (SRM) types in the Gold Quadrilateral, South Apuseni Mts.

TYPES	C A M	S R M
TYPE DEPOSITS	MĂGURA, CORANDA, PĂRĂUL LUI AVRAM, VOIA, BOLCANĂ, BUCIUM, ROȘIA POIENI, MUNCĂCEASCA-POPA, HANEȘ, BARZA.	ROȘIA MONTANĂ, RODU, FRĂȘIN, CONTU, BAIA DE ARIEȘ, MĂGURA ȚEBII, SĂCĂRĂMB, FAȚA BĂII, BĂIȚA CRĂCIUNEȘTI
STYLE OF SULFIDES ABUNDANCE IN EPITHERMAL SUITE	LOW-SULPHIDATION-RICH SULPHIDE (7-15% S) SYSTEMS ARE DOMINANT	LOW-SULPHIDATION-POOR SULPHIDE (2-7% S) SYSTEMS ARE DOMINANT
FORM OF DEPOSITS	OPEN SPACE VEINS / STOCKWORKS ARE COMMON	BRECCIA PIPE/STOCKWORKS; SUBORDINATE VEIN SYSTEMS; MASSIVE SULPHIDE VEINS AND REPLACEMENT BODIES MINOR
KEY PROXIMAL ALTERATION MINERALS	SERICITE -SMECTITE	SERICITE – ADULARIA; QUARTZ- SERICITE
MAIN METALS PRESENT IN EPITHERMAL SUITE (MAJOR ELEMENTS)	Au, Ag, Pb, Zn, Cu	Au, Ag, Te
HYDROTHERMAL CONDUIT	LARGE BOILING ZONE DEVELOPMENT; HYPOGENE FLUID CIRCULATION IS RESTRICTED	LOCALLY DEVELOPED BOILING PHENOMENA; NON-RESTRICTIVE HYPOGENE FLUID CIRCULATION
BASEMENT TYPE	OPHIOLITE BASEMENT	MESOZOIC / CRYSTALLIN ROCKS
MINERALIZED SUBVOLCANIC ENVIRONMENT	PORPHYRY Cu, Au, Mo; CHALCOPYRITE AS THE MAIN COPPER MINERAL	NON- PORPHYRY ENVIRONMENT, MAGMATIC-HYDROTHERMAL BRECCIA, MESOTHERMAL MASSIVE SULPHIDE VEINS AND REPLACEMENT BODIES
DIAGNOSTICS OF ACID MINERAL ALTERATION	KAOLINITE- ALUNITE ASSEMBLAGE AS A RESULT OF SUPERGENE ALTERATION DOMINANT; LOCALLY DEVELOPED IN "HIGH SULPHIDATION" SYSTEMS OR SHALLOW ACID ZONE	SHALLOW (SURFICIAL) ACID LEACHED ZONE WITH ALUNITE + KAOLINITE + CHLORITE
GOLD – SILVER RATIO FOR EPITHERMAL SYSTEM	BETWEEN 1: 1 – 1: 20	BETWEEN 1: 10 – 1: 150
MINOR AND TRACE ELEMENTS	As, Te, Se, Ge, Mo, Hg, Bi, Sb, Sn.	Pb, Zn, Cu, Sb, As.

The gold/silver ratio of the epithermal vein suite of this type commonly ranges between 1:1 and 1:20, showing an important hypogene component of mixed fluids or a lower rate of erosion (still in the upper part of the epithermal system). The geochemical signature of the CAM type is featured by As, Te, Se, Ge, Mo, Hg, Bi, Sb, Sn. Numerous ore deposits of the GQ are to be included in CAM, e.g. Barza, Măgura Făerag, Coranda, Pârâul lui Avram-Voia, Troița-Bolcana, Bucium Complex, Roșia Poieni, Muncăceasca, Popa Stănița, Haneș, etc.

Sub-alkaline rhyodacitic metallogenetical type (SMR)

The SMR type of the GQ is a non-porphyry environment related to rhyolite – rhyodacite-dacite or even andesite rocks with a slightly subalkaline tendency. This trend is pointed out both in chemistry and the mineralogical-petrographical pattern of some andesite host rocks, i.e. occurrence of trachyandesite – latite, apparently not related to the mineralizing event (Săcărâmb, Măgura Țebii), or the presence of Na rich types of ferrous hornblende – ferrohastingsite (Baia de Arieș).

The main feature of SRM is expressed by the low sulfide amount of the epithermal ore bodies (2-7%) and a reduced to neutral pH of the mineralizing fluids that suggest a low-sulfidation-poor sulfide type (Fig. 2B).

The main metals of the epithermal suite are Au, Ag and Te. The ore bodies are breccia pipe structures, stockworks, and subordinately vein systems. Minor sulfide mesothermal veins and replacement bodies occur at deeper levels, spatially or genetically associated with subvolcanic to volcanic intrusions. The peripheral parts of the intrusive are often controlled by phreato-magmatic, hydrothermal or tectonic brecciation.

The key alteration consists of a typical sericite-adularia assemblage, developed in a rich silica halo. The circulation of reduced hypogene fluids is not restricted to sub-alkaline intrusive boundaries and boiling may occur too. However, shallow (surficial) acid leached zones with alunite, kaolinite, and chlorite are found in a few deposits (Roșia Montană, Măgura Țebii). The advanced argillic alteration is caused this time by the absorption of boiled-off volatiles and subsequent oxidation of H₂S in the vadose zone, near the water table. Advanced argillic alteration caps develop in the vicinity of low-sulfidation-poor sulfide gold-silver epithermal environment, related to the SRM type.

In contrast with the CAM type, the gold/silver ratio varies through an extended interval, i.e. between 1:10 and 1:150 suggesting both a deeper epithermal environment and an intense rock leaching. The basement is represented by pre-Baikalian to Hercynian crystalline schists or Mesozoic sedimentary rocks. Minor elements such as Pb, Zn, Cu, As, and Sb are frequently registered in the SRM metallogenetical type of the GQ.

The type deposit is the Roșia Montană gold bearing breccia pipe and veins. This is the largest Romanian gold deposit, known and mined since Roman times.

Other deposits such as Bucium Rodu, Frasin, Coțu, Măgura Țebii, Băița Crăciunești, Baia de Arieș, Săcărâmb, and Fața Băii may be included in the SRM type: the last three occurrences are gold-silver tellurides rich.

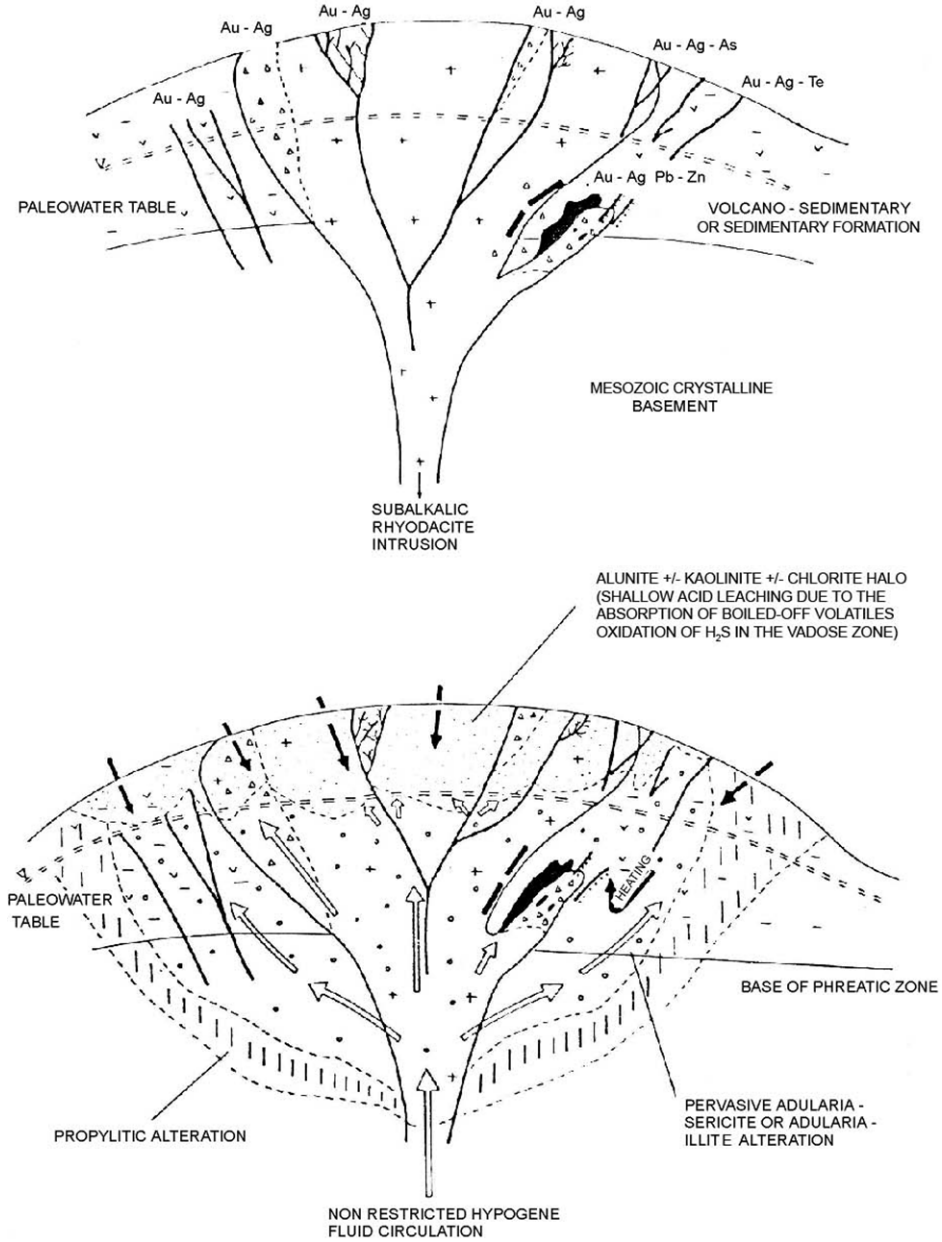


Fig. 2B. Subalkaline rhyodacitic metallogenetic type.

METALLOGENETICAL DISTRICTS OF THE GOLD QUADRILATERAL

The Tertiary volcano-plutonic setting of the GQ comprises the following metallogenetical districts:

- Brad – Săcărâmb
- Zlatna – Stănița
- Roșia Montană – Bucium
- Baia de Arieș

The Brad – Săcărâmb district contains mainly the CAM type andesitic structures / porphyry environment (Cu-Au+/-Mo) with epithermal low-sulfidation-rich sulfides subtype vein halo (Au, Ag, Pb, Zn). However, some slightly sub-alkaline trending structures such as Săcărâmb, Măgura Tebiei and the typical rhyolitic pattern of Băița – Crăciunești may belong to the SRM metallogenetical type (Au-Ag-Te veins or stockworks in low-sulfidation-poor sulfide epithermal environment).

Based on a synthesis of all the available data and particularly on the authors' own experience and previous works, the most important part of the Brad – Săcărâmb ore deposits are considered as “composite systems” (Orlandea&Velcirov, 1996), with a subvolcanic – porphyry Cu-Au+/-Mo “core” surrounded or overlain by low-sulfidation – rich sulfides, epithermal Au-Ag-Pb-Zn veins or stockworks. This feature of the CAM metallogenetical type is well expressed in Fig. 3.

A controversial issue seems to be the Bucuresti-Rovina porphyry copper system. Vlad & Borcoș (1998) assigned a pyrite halo to the margin of the porphyry intrusion. This may lead to a metallogenetical type which includes also Roșia Poieni (Roșia Montana – Bucium district) and Deva porphyry deposit (out of the borders of the GQ). At least in the case of the Bucuresti-Rovina deposit, several rich native gold veins (Rovina-Câlnic) surround the porphyry intrusive.

However, the porphyry systems of the GQ and particularly those of the Brad – Săcărâmb district have to be the subject of debate. That is the occurrence of phyllic – argillic alteration in correlation with diorite, rather than tonalitic magmas and further the types of fluids or the relations with adjacent sets of veins. Despite the genetic link between porphyry and epithermal systems belonging to the same metallogenetical phase, the mineralizing processes and the passage from porphyry to epithermal systems may be continuous or discontinuous.

But many “composite” systems of the Brad – Săcărâmb district and epithermal veins cut the porphyry intrusion and/or the porphyry copper mineralization, e.g. at Musariu, Valea Morii, Bolcana Troița. Recent fluid inclusion data show different types of fluids involved and consequently discontinuous mineralizing processes (Cioflica et al., 1997).

The Zlatna – Stănița district is similar to the Brad – Săcărâmb district. It contains especially CAM type Au-Ag-Pb-Zn epithermal low-sulfidation –rich sulfides vein systems in andesitic structures that may pass to deeper Cu-Au porphyry mineralization related to subvolcanic intrusions (Muncăceasca, Trimpolele, Ruculeț-Valea Tisei, Popa-Stănița, Haneș, and Breaza).

As an exception, Fata Baii Au-Ag-Te low-sulfidation-poor sulfide vein system is related to slightly sub-alkaline andesitic rocks and is to be included in the SRM metallogenetical type.

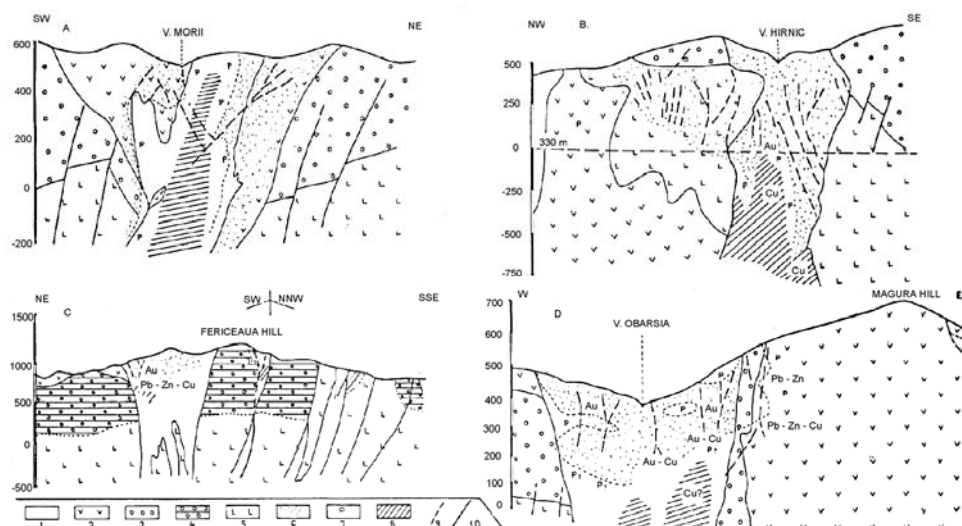


Fig. 3. Schematic cross section in calcalkaline andesitic structures (CAM) of the Gold Quadrilateral: Valea Morii (A), Musariu (B), Muncăceasca – Podul Iovanului (C) adapted from Borcoș et al. (1985), and Măgura Făerag (D) after Orlandea (1992). 1) Intrusion of andesite, quartz andesite + diorite (Sarm. – Pan.); 2) Andesite, quartz andesite (Sarm. – Pan.); 3) Miocene sedimentary and volcanic rocks; 4) Mesozoic sedimentary rocks; 5) Mesozoic island arc volcanites (Jur. – Cret.); 6) argillic alteration; 7) propylitic alteration; 8) potassic alteration; 9) Au – Ag and polymetallic vein mineralization; 10) Fault.

One of the most interesting structure of this district is Muncăceasca-Podul Iovanului (Fig. 3), where rich native gold bearing veins (ex. Vein no. 25 Corabia) exploited since Roman Times and gold – pyrite stockworks mined during the Middle Age (Acra, Vilanela, Cerbița, Barbușița) overlie a low grade Cu – Au porphyry intrusion. The epithermal suite is partly hosted in strongly silicified Upper Cretaceous conglomerates that form a “silica cap”. Such a pervasive silicification in porous horizon below, but nearby the paleo- water table is interpreted a result of a direct silica precipitation from acidic solutions formed by mixing of hypogene fluids with cool meteoric water. The acidic alteration halo caps a low-sulfidation- rich sulfides epithermal vein system, but contain gold bearing disseminated or stockwork mineralization, both at the level of silica plate and underlying structurally/lithologically-controlled formations.

Other important features of the Zlatna-Stănița district may be observed at Breaza, where manganese sulfides (alabandite) or carbonates (rhodochrosite) are commonly found in Au-Ag-Pb-Zn veins, or at the Izvorul Ampoiului deposit that contains epithermal lens-shaped bodies of cinnabar- pyrite in an argillic +/- silica alteration halo. This minor mercury deposit was intensively mined at the beginning of the 20th century (Ianovici et al., 1976).

The Roșia Montana – Bucium district is more elaborate in terms of a porphyry-epithermal relationship. It comprises both CAM metallogenetical type (Roșia Poieni, Bucium Tarnița, Vâlcoi Corabia, Bucium Izbița, Bucium Arama) and SRM metallogenetical type (Roșia Montană, Bucium Rodu, Frasin, Contu) deposits.

The CAM type structures contain Au-Ag-Pb-Zn-Cu epithermal veins which may surround a subvolcanic porphyry Cu-Au intrusion, e.g. Bucium Tarnita porphyry Cu-Au deposit. Sets of veins with different metallic signature occur in the vicinity of this porphyry intrusive, e.g. Vâlcoi-Corabia (Au-Ag-Pb-Zn), Bucium Arama and Bucium Izbita (Au-Ag-Cu).

Rosia Poieni andesitic porphyry Cu-Au-Mo is the largest porphyry deposit of Romania; there is no evidence of adjacent sets of veins, and Vlad & Borcoş (1996, 1998) described it as porphyry copper deposit with pyrite halo. However, at Musca (upper part of the Rosia Poieni structure) some small veins exhibiting an acide sulfate type mineralization with pyrite, enargite, native copper and cuprite in an alunite bearing alteration halo are known in the vicinity of the porphyry intrusion (Boştinescu, 1984). However, this assemblage was mined out in order to create a large open pit within the porphyry copper intrusion. Such an enargite bearing set of veins represent minor/incipient high-sulfidation type, where acidic fluids have been rapidly aborted/diluted and neutralized by the host rock. Together with Pârâul lui Avram deposit (Brad – Săcărâmb district), these two occurrences are somehow exceptions of the GQ mineralized epithermal environment involving more neutral fluids.

The SRM type is well expressed at Rosia Montana in relation to rhyodacitic Tertiary rocks (Fig. 4). The ore bodies form commonly magmatic-hydrothermal and/or phreato-magmatic breccia pipe structures (Cetate, Cîrnic), subordinately stockworks (Cârnic-Napoleon, Corhuri, Cantaliste) and veins (Țarina Orlea, Brădişor, Carpen). The epithermal suite is low-sulfidation – poor sulfide type and contains pyrite, native gold, marcasite and Ag-sulphosalts (proustite, argentite, pearceite, polibasite) in a gangue of sericite-adularia-quartz, clay minerals and carbonates. The host rocks are Miocene dacites, different types of breccia and pyroclastic formations that pierce or overlay Upper Cretaceous flishoid formations and possible crystalline schists set up as detachment nappe related to Muncel – Lupşa Series. High grade gold occurs in so called “chinga” black veins that represent strongly silicified terrigenous material injected along the fractures or in breccia matrix.

The Baia de Aries district is definitely the non-porphyry environment of the SRM metallogenetical type with Au-Ag-Te low-sulfidation-poor sulfide epithermal veins and breccia pipes structures hosted in andesitic rocks, with slight sub-alkaline petrochemical signature, that pierce crystalline schists basement (Fig. 4).

The sub-alkaline tendency of the igneous association is stressed by the occurrence of latites-trachyandesites or Na-rich forms of brown hornblende (Colţii Lazărului, Feredeş).

Mesothermal Pb–Zn sulfide veins and replacement bodies in limestones occur at Baia Roşie, Obârşia (Fig. 4). Despite some characteristics of the epithermal suite of SRM (i.e., poor sulfide content), the Baia de Arieş environment is somehow richer in base metals (>7% sulfides). The main feature is the occurrence of both gold and base metal mineralization at the same level of erosion. These facts suggest a high permeability of brecciated host rock and different metals and fluids related to distinctive mineralizing stages.

The key alteration is sericite-adularia (Afiniş), sericite-carbonates (Fundoaia, Obârşia) and sericite-smectite (Baia Roşie, Valea Lacului-Ambru). At Afiniş, gold-silver tellurides (silvanite type locality) – alabandine occur in gangue of calcite, quartz,

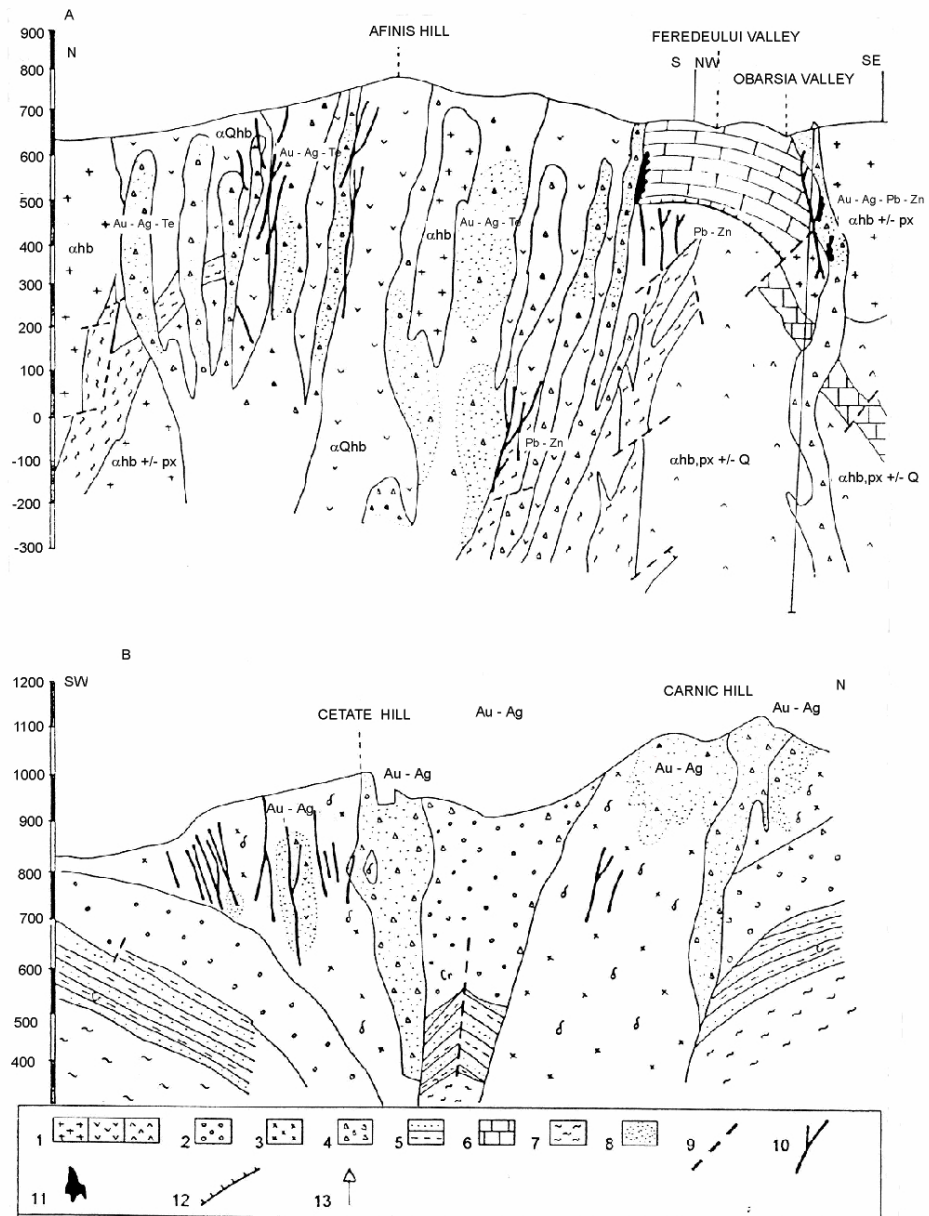


Fig. 4. Geological cross section through non – porphyry SRM structures of Gold Quadrilateral: A- Baia de Arieș, B- Roșia Montană. 1) Homblende + quartz + pyroxene andesite (Afiniș, Ambru, Colțul Lazărului type); 2) Miocene volcano – sedimentary formation; 3) Dacite – rhyodacite; 4) Phreato – magmatic and/or hydrothermal breccia; 5) Cretaceous sedimentary rocks; 6) Hercynian crystalline limestone; 7) Pre-Alpine metamorphic rocks; 8) Au – Ag + Te, As mineralized stock bodies with sericite – adularia halo; 9) Faults, Fractures; 10) Veins; 11) Replacement bodies (Au – Ag – Pb – Zn); 12) Overthrust plane; 13) Drill hole.

rhodochrosite, and barite. Native gold is deposited from As rich fluids, i.e. intimately associated with arsenopyrite. A constant Au/As ratio of 1:2.500 is worth to be mentioning at Baia de Arieş.

CONCLUSIONS AND REMARKS

The purpose of this paper is to provide useful exploration tools for geologists who are working in the GQ and adjacent areas. Appreciation of the broad spectrum of epithermal deposits, style and geometry, the sulfidation degree, the diagnostics of alteration assemblages are all very important to predict often concealed mineralization styles. Potential for subvolcanic-porphyry related mineralization at deeper levels in all, but especially low-sulfidation-rich sulfides epithermal environments needs to be carefully assessed.

Consequently, the GQ of the South Apuseni Mts. is peculiar among almost exclusive low-sulfidation type epithermal environments. However, the large variation in metals and total sulfide content might allow us to define different mineralized systems (Table 1).

A low-sulfidation-poor sulfide epithermal and a non porphyry deeper environment are mainly related to sub-alkaline rhyodacitic Tertiary rocks which contain the most important part of actual Au-Ag-Te bulk mineral resources of the GQ (SRM type). The key alterations are sericite-adularia or quartz-sericite assemblages that affect large areas of the intrusive-feeder zones and adjacent rocks.

A low-sulfidation-rich sulfides epithermal subtype that commonly passes at deeper level into Cu-Au+/-Mo porphyry system is more widespread throughout the GQ. It is related to calc-alkaline Tertiary andesitic rocks (CAM type). Au-Ag-Pb-Zn are commodities produced in such epithermal environments hosted by a sericite-smectite alteration halo.

Therefore, the GQ seems to represent -in terms of Au-Ag epithermal mineralization- a transitional phase between low-sulfidation and high-sulfidation types, respectively so called low-sulfidation-rich sulfides and low-sulfidation-poor sulfides subtypes. The andesitic-rhyodacitic terrain of the GQ was not capable of developing high-sulfidation systems due to the high capacity of the host rocks to neutralize the initial acidic magmatic volatiles.

Rich Au-Ag-telluride mineralization is hosted in atypical environments (i.e. non-alkaline), that may be correlated with the presence of crystalline basement. This fact warrants further discussions about a possible, at least partial, non-magmatic source of tellurium and even gold. The delineation of those two metallogenetical types, i.e. CAM and SRM, as well as recent K-Ar dating of Tertiary volcanic products of GQ (Roşu et al., 1997) indicate the necessity of reinterpretation of the cyclicity of both volcanic and metallogenetic processes.

The advanced argillic alteration in the GQ caps or overlies either low-sulfidation deposits or barren areas. However, there are two exceptions (Roşia Poieni-Musca and Pârâul lui Avram), where incipient high-sulfidation occurs as a result of condensing acidic magmatic volatiles and dissolution of condensate in meteoric water. Finally, it is important to stress the inverted correlation between adularia and base metal content in low-sulfidation systems of the GQ.

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REFERENCES

- Ashley, R. P. 1982, Occurrence model for enargite – gold deposits. *United States Geological Survey, Open file report*, 82-795: 144-147.
- Balintoni, I., Vlad Ș. 1997, Tertiary Magmatism in the Apuseni Mts. and related tectonical setting. *Studia Univ. Babeș-Bolyai*, XLII, 1: 1-11.
- Berger, Br., Henley, R. W. 1989, Advances in the understanding of epithermal gold-silver deposits with special reference to the western United States. *Economic Geol., Monograph* 6: 405-423.
- Bonham, H. F. Jr. 1986, Models for volcanic - hosted epithermal precious metal deposits. *International Volcanological Congress, Symposium 5, Hamilton, University of Auckland, New Zealand*: 13-17.
- Bonham, H. F. Jr. 1988, Models for volcanic hosted precious metal deposits. Review in *Bulk Mineable Precious Metal Deposits of the Western United States*, Geological Society of Nevada, 259-271.
- Borcoș, M. 1994, Volcanicity, Metallogeny in the South Apuseni Mts. (Metaliferi Mts.), *IGCP Project 356, Field Trip Guide*: 32-37.
- Boștinescu, S. 1984, Porphyry copper systems in the South Apuseni Mts., Romania. *An. Inst. Geol. Geofiz.*, LXIV: 163-172.
- Cioflica, G., Colombo, F., Lupulescu, M., Rossetti, P., Popa, G. 1997, Relationship between porphyry-type and epithermal deposits in the Barza Region, Southern Apuseni Mts., Romania. *Rom. J. Min.*, 78 (1): 12-13.
- Gammons, C. H., Williams-Jones, A. E. 1997, Chemical mobility of gold in porphyry-epithermal environment. *Economic Geology*, 92: 45-50.
- Hayba, D. O., Bethke, P. M., Heald, P. 1985, Geologic, mineralogic and geochemical characteristics of volcanic-hosted epithermal precious metal deposits. *Econ. Geol.*, 2: 129-167.
- Hedenquist, J. W. 1987, Mineralization associated with volcanic-related hydrothermal systems in the circum Pacific basin. *4th Circum Pacific Energy and Min. Resources. Conf., Singapore*, 513-524.
- Hedenquist, J. W., Arribas, A., Jr., Gonzalez-Urien, E. 2000, Exploration for epithermal gold deposits. *Reviews in Economic Geology*, 13: 245-277.
- Hedenquist, J. W., Izawa, E., Arribas, A. 1996, Epithermal gold deposits: Style, Characteristics and Exploration. *Special Publ. No.1, Soc. of Resource Geol. of Japan*, 32 pp.
- Helke, A. 1934, Die Goldtellurzerzlagertstätten von Sacarimb in Rumänien. *Neues J. Min. Geol. Pal.*, 67B, Abt. 17 (1): 19-85.
- Helke, A. 1938, Die Jungvulkanischen Gold-Silber Ertzlagertstätten des Kapathenbogens. *Preu. Geol. Landen., Arch. Lagerst. Forschung*, 66 pp.
- Ianovici, V., Borcoș, M. 1982, South East Europe. In *Mineral Deposit in Europe*, London, 55-142.
- Ianovici, V., Borcoș, M., Bleahu, M., Patrulius, D., Lupu, M., Dimitrescu, R., Savu, H. 1976, *Geologia Munților Apuseni*. Ed. Acad. Rom., București, 632 pp.
- Mac Laren, J. M. 1908, Gold, its geological occurrence and geographical distribution. *The Min. Journal*, London, 687 pp.

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- Moyle, A. J., Doyle, B. V., Hoogvliet, H, Ware, A. R., 1990, Landolam gold deposit, Lihir Island. In *Geology of the mineral deposits of Australia. and Papua – New Guinee*. The Austral. Inst. of Min. and Metall.: 1793-1805.
- Nelson, C. 1989, Gold deposits in the hot spring environment. *Economic Geology*, 80, Monograph 6: 418-429.
- Nicolae, I., Saccani, E. 2003, Petrology and geochemistry of the Late Jurassic calc-alkaline series associated to Middle Jurassic ophiolites in the South Apuseni Mountains, Romania. *Schweiz. Mineralog. und Petrograph. Mitteil.*, 83: 81-96.
- Noble, D. C., 1990, *Epithermal silver and gold deposits in the Andes of Peru*, Soc. of Min. Eng. of AIME, 119th Ann. Meet., Salt Lake City, UT, 105 pp.
- Orlandea, E., Velciog, G. 1996, Native gold bearing mineral assemblages in the Magura Făerag hydrothermal vein deposit, Metaliferi Mts., Romania. *Rom. J. Min.* 77: 21-32.
- Palfy, M. 1912, Geologischen Verhältnisse und Erzgänge des Siebenburgischen Erzgebirges. *Jahrb. d. k. k. Ung. Geol. Inst.*, XVIII, 45: 4.
- Peterson, S., Herzig, P. H., Hannington, M. P., Jonasson, J. R., Arribas, A. 2002, Submarine gold mineralization near Lihir Island, New-Ireland fore-arc, Papua-New Guinee. *Economic Geol.*, 97 (8): 1795-1813.
- Roșu, E., Pecskay, Z., Ștefan A. 1997, The evolution of the Neogene Volcanism in the Apuseni Mts., Romania; Constraints from new K-Ar data. *Geol. Carpatica*, 48 (6): 1-7.
- Silitoe, R. H. 1989, Gold deposits in western Pacific arcs; the magmatic connection. *Economic Geology*, Monograph 6: 274-291.
- Silitoe, R. H. 1993, Epithermal models: genetic types, geometrical controls and shallow features. *Mineral Dep. Modelling. Geol. Assoc. of Canada, Special Paper* 40: 403-417.
- Silitoe, R. H., Hedenquist, J. W. 2003, Linkages between volcanotectonic settings, ore-fluid compositions, and epithermal precious-metal deposits. In *Volcanic, geothermal and ore-forming fluids: Rulers and witnesses of processes within the Earth* (Simmons, S., F and Graham, I., J., Eds.): Society of Economic Geologists and Geochemical Society, Special Publication 10, Chapter 16: 315-343.
- Stanciu. V. 1929, *Zacaminte minerale ale Daciei superioare in Transilvania, Banatul, Crisana și Maramures*. Ed. Cultura Nationala, Bucuresti.
- Tschermack, H. J. 1868, Das Siebenbürgische Goldene Viereck. *Jb. d. k. k. geol. Reichsanst.*, 18: 1-24.
- Udubașa, G., Roșu, E., Seghedi, I., Ivășcanu, P. M. 2001, The Golden Quadrangle in the Metaliferi Mts., Romania: what does really mean? *Rom. J. Min. Deposits*, ABCD-GEODE workshop Vața-Băi, 79 (2): 24-34.
- Vajda, L. 1967, Extracția și prepararea metalelor neferoase în Transilvania. In *Acta Musei Napocensis* (nr. 4, Arh. Stat. Deva, fond Arh. Capitan. Minier Zlatna), 239-248, Cluj Napoca.
- Vlad, Ș. N. 1995, Porphyry copper-petrometallogenetic systems. *Studia Univ. Babeș-Bolyai, Geologia*, XL (1): 28-39.
- Vlad, Ș. N., Borcoș, M. 1996, Alpine porphyry copper models in Romania. In *The formation of the geologic framework of Serbia and adjacent regions* (Knezevic, V. & Krstic, B., Eds.): 371-376.
- Vlad, Ș. N., Borcoș, M. 1998, Alpine metalogenesis of the Romanian Carpathians. IGCP Project 356, *Rom. J. Min. Deposits*, 78: 5-21.
- Voicu, I. 1934, *Aurul din Romania*. Ed. Adevărul, București, 134 pp.
- White, N. C., Hedenquist, J. W. 1995, Epithermal gold deposits, style, characteristics and exploration. *Newsletter of Soc. of Econ. Geol.*, 23: 1-13.