

NEW OCCURRENCES OF TELLURIDES AND ARGYRODITE IN ROȘIA MONTANĂ, APUSENI MOUNTAINS, ROMANIA, AND THEIR METALLOGENIC SIGNIFICANCE

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ABSTRACT

New investigations by optical microscopy, scanning electron microscopy (SEM) and electron-probe micro-analysis (EPMA) have been performed on samples of silver-rich, gold-poor veins from the Roșia Montană ore deposit, South Apuseni Mountains, in Romania. Common base-metal sulfides and sulfosalts consist of galena, Fe-poor sphalerite, argentiferous tetrahedrite, alabandite, pyrite and marcasite. They are intimately associated with abundant tellurides, among which hessite, altaite, sylvanite, petzite and cervelleite. An alloy of Au–Ag is subordinate, and mainly observed as micro-inclusions in hessite. A Te-rich argyrodite with a mean composition close to $\text{Ag}_{8.04}\text{Ge}_{0.90}\text{Te}_{2.07}\text{S}_{3.77}$ was also identified in one of the veins investigated. The Ge content of sphalerite and tetrahedrite is below the detection limit (~400 ppm). The dilemma concerning the presence or absence of tellurides in the Roșia Montană deposit is now solved; most of the ore deposits of the South Apuseni Mountains have a Te-rich signature. These results, combined with previous observations in the field and mineralogical and microthermometric studies, suggest that ore deposition at the Roșia Montană deposit evolved from an early Au–(Ag) low-sulfidation character to a late Ag–Te–(Ge–Au) intermediate-sulfidation character, and may be correlated with late magmatic pulses.

Keywords: tellurides, Te-bearing argyrodite, Roșia Montană, South Apuseni Mountains, Romania.

SOMMAIRE

Des échantillons provenant de veines riches en argent et pauvres en or du gisement de Roșia Montană, situé dans le Sud des monts Apuseni, en Roumanie, ont été étudiés par microscopie optique, microscopie électronique à balayage et microsonde électronique. La paragenèse métallique à galène – sphalérite – tétraédrite argentifère – alabandite – pyrite – marcasite est complétée par d'abondants tellurures, hessite, altaïte, sylvanite, petzite et cervelleïte. Un alliage Au–Ag se présente sous forme d'inclusions dans la hessite. Une variété d'argyrodite riche en Te, de composition moyenne $\text{Ag}_{8.04}\text{Ge}_{0.90}\text{Te}_{2.07}\text{S}_{3.77}$, a été identifiée dans l'une des veines étudiées. Les teneurs en Ge de la sphalérite et de la tétraédrite sont inférieures à 400 ppm. L'incertitude concernant la présence ou l'absence de tellurures à Roșia Montană est à présent levée. Roșia Montană partage cette caractéristique avec la plupart des gisements du sud des monts Apuseni. À l'échelle du gisement, ces résultats, combinés aux observations de terrain et aux études minéralogiques et microthermométriques précédemment réalisées, montrent une évolution des conditions de dépôt de la minéralisation d'un stade précoce à Au–(Ag) vers un stade à Ag–Te–(Ge–Au). Il y aurait eu une augmentation du degré de sulfuration du système épithermal en relation avec la poursuite de l'activité magmatique.

(Traduit par la Rédaction)

Mots-clés: tellurures, argyrodite riche en Te, Roșia Montană, montagnes Apuseni Sud, Roumanie.

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INTRODUCTION

A number of precious metal and telluride-bearing epithermal ore deposits are known within the so-called Golden Quadrangle, South Apuseni Mountains (Ghițulescu & Socolescu 1941, Udubaşa *et al.* 1992, Cook *et al.* 2004). The Săcărâmb deposit is the only true gold–telluride deposit, in which the majority of the gold is present as telluride minerals, accompanied by minor native gold and gold–silver alloy. Despite this, important quantities of tellurides have been described in other epithermal deposits, *e.g.*, Stăniş, Baia de Arieş, Musariu and Faţa Băii, among others. Many precious-metal tellurides were described for the first time within deposits of the Golden Quadrangle. Săcărâmb is the type locality for krennerite, muthmannite, nagyagite, petzite, stützite and, more recently, museumite (Bindi & Cipriani 2004); Baia de Arieş is the type locality for sylvanite. Native tellurium and tellurite were first identified in the Faţa Băii deposit (Udubaşa *et al.* 1992a).

Generally speaking, epithermal deposits of the Baia Mare region are noted for their enrichment in sulfosalts, whereas the Golden Quadrangle is known for the presence of tellurides associated with gold. Up until now, however, the world-class Roşia Montană ore deposit has been considered an exception. This deposit (Leary *et al.* 2004) has been regarded as a typical non-telluride gold–silver epithermal ore deposit, with the gold occurring mainly as free gold (*e.g.*, Petruşian 1934, Ghițulescu & Socolescu 1941, Mărza *et al.* 1997, Tămaş 2002). However, it is worth noting that the presence of Te- and Ge-bearing minerals has been postulated. For example, Andronescu (1962) examined concentrates from Roşia Montană furnished by ICECHIM and identified Ge enrichment in one type of pyrite flotation concentrate. No Ge-minerals were identified at that time, but Andronescu (1962) was able to show that the Au-rich pyrite concentrate has a low Ge content, whereas the Ge-rich pyrite concentrate has a low content of gold. Andronescu considered the gold and germanium contents to relate to different types of pyrite in the ore. Mărza *et al.* (1995) also suggested the possible occurrence of tellurides in the so-called “*chinga*” from the Cetate massif (Roşia Montană). Bismuth tellurides were detected in recent mineralogical studies (Townsend *et al.* 2000) undertaken within the program of metallurgical tests during the feasibility study conducted by Roşia Montană Gold Corporation (RMGC).

A small open-pit exploitation by ROŞIAMIN, a branch of C.N.C.A.F. MINVEST S.A. Deva is still ongoing; several hundred kg Au are produced each year. Gabriel Resources Ltd (Toronto, Canada) and its Romanian subsidiary Roşia Montană Gold Corporation S.A. (RMGC) started in 1997–1998 an exploration program (surface and underground survey), which outlined a total resource of 400.1 million tonnes at an average grade of 1.3 g/t Au and 6 g/t Ag for a total contained

resource (measured, indicated and inferred) of 501 t Au and 2,282 t Ag. The proven and probable reserves to date (Leary *et al.* 2004) contain about 218 Mt at an average grade of 1.52 g/t Au and 7.5 g/t Ag for a total metal reserves of 330 t Au and 1,628 t Ag (with a 0.6 g/t Au cut-off). A large open-pit exploitation by RMGC will soon come on-stream at Roşia Montană.

In order to determine if the presence of tellurides in the Roşia Montană deposit could be confirmed, new mineralogical investigations were performed on samples collected in the Cărnicele vein found by RMGC during a channel-sampling program and also in a second occurrence, namely a vein swarm rich in Mn-gangue minerals that is hosted by the Cetate breccia (within the so-called Glamm Formation). In the present contribution, we report the results of combined optical microscopy, scanning electron microprobe (SEM) and electron-probe micro-analysis (EPMA) on these samples, which led us to identify and characterize several telluride species, as well as Te-bearing argyrodite.

GEOLOGICAL SETTING

The Metaliferi Mountains

The Apuseni Mountains are situated at the interior of the Carpathian chain (Fig. 1) and separate the Transylvanian from the Pannonian Basin. The main geotectonic units making up the Apuseni Mountains are the Apusenides (mainly in the North Apuseni Mountains), and the Transylvanides (mainly the South Apuseni Mountains; Balintoni 1994, 1997). The North Apuseni Mountains and South Apuseni Mountains underwent different geotectonic evolutionary histories, and they consist of different tectonic units (Ianovici *et al.* 1976, Săndulescu 1984, Balintoni 1994, 1997, Seghedi 2004).

The so-called Metaliferi Mountains contain the richest occurrences of ore deposits within the South Apuseni Mountains. Neogene volcanic activity took place in several NW–SE-trending extensional basins (Roşia Montană – Bucium, Stăniş–Zlatna, Zarand, Brad–Săcărâmb), as well as in two isolated areas, *i.e.*, Baia de Arieş in the northeast and along the Mureş valley in the south of the area (Ianovici *et al.* 1976). K/Ar geochronology and paleobotanical evidence (Pécskay *et al.* 1995, Rögl 1996, Balintoni & Vlad 1996, Roşu *et al.* 1997, 2004, Har 1998) suggest that three main magmatic episodes can be recognized during the Neogene and Quaternary. The first (at *ca.* 15 Ma), limited in extent, is represented by rhyodacitic to dacitic tuffs. The second, and main, episode, between 14.8 and 7.4 Ma, is represented by calc-alkaline, medium- to high-K quartz andesites and dacites. The third episode consisted of minor trachyandesites of alkaline affinity at around 1.6 Ma.

The numerous epithermal and porphyry-type ore deposits related to this Neogene volcanism have been described elsewhere (Ianovici *et al.* 1976, Boştinescu

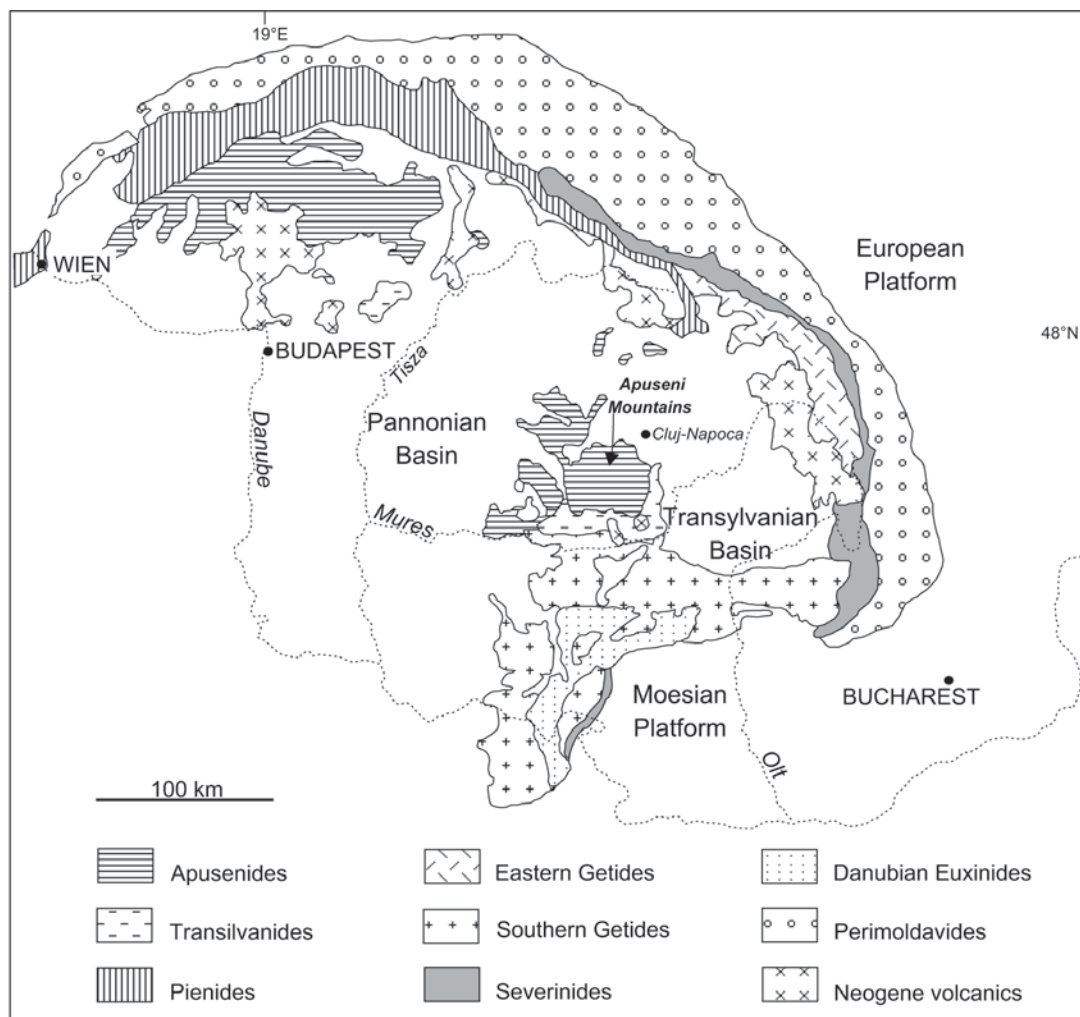


FIG. 1. Simplified geotectonic map of the Carpathian fold belt, modified from Săndulescu (1984), and Balintoni (1997).

1984, Ciobanu *et al.* 2004a). Among the most important epithermal deposits, we mention Săcărâmb, Coranda-Hondol, Ruda Barza, Roșia Montană, and Baia de Arieș. Roșia Poieni, Deva, Valea Morii, Bucium Tarnița, *etc.* are the major porphyry deposits (Fig. 2).

With respect to the genesis of the Neogene magmatism and volcanism from the Apuseni Mountains, Balintoni & Vlad (1996) invoked metasomatism of the continental lithosphere due to long-term Jurassic–Upper Cretaceous subduction of the Getic plate beneath the Tisia plate. In their opinion, the source of the Neogene calc-alkaline magmatism is represented by consolidated and refertilized banatitic source-rocks that were extensionally reactivated. Seghedi *et al.* (1998) expressed similar views, considering that the Neogene magmatic

activity resulted from a transtensional tectonic regime by decompressional melting of lithosphere mantle, during translation and rotation of Tisia–Getia block. Seghedi (2004) stated that the mechanism of Neogene magma genesis from the South Apuseni Mountains is decompression melting of a heterogeneous source situated at the crust–lithosphere mantle boundary induced by extensional tectonic regime and intensified by variable rotational movements of the blocks.

The Roșia Montană ore deposit

The Roșia Montană epithermal deposit, situated in the northern part of the South Apuseni Mountains (Fig. 2), is a giant precious-metal deposit related to

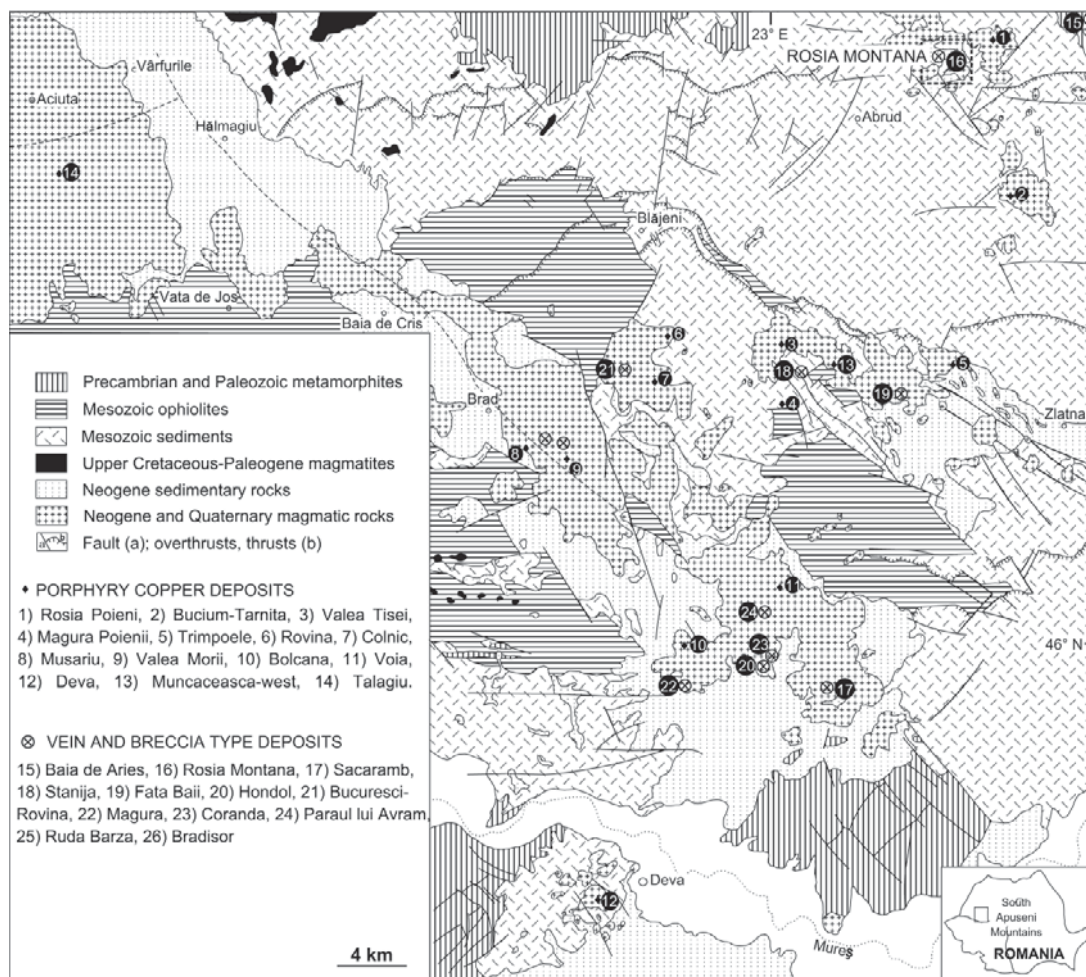


FIG. 2. Simplified geological map of the South Apuseni Mountains and the location of the major Neogene ore deposits. Modified from Dumitrescu & Săndulescu (1978), and Boștinescu (1984).

Neogene volcanism. The deposit has a long mining history. Recent archeological evidence (Cauuet *et al.* 2003) confirms that mining activity began at Roșia Montană during pre-Roman times (^{14}C on wooden propping), flourished during the Roman period (106–273 B.C.) (^{14}C and archeological artefacts), and continued during the Middle Ages (^{14}C , artefacts, written vestiges) up to the present day. We can therefore envisage more than two millennia of continuous mining focused on a large, and at least in the early days of mining, incredibly Au–Ag-rich ore deposit.

In the Roșia Montană area, the crystalline basement does not outcrop; it only occurs as fragments within various breccia-pipe structures. Taking their lithologies into account, these fragments suggest the existence of a

hidden crystalline basement similar to that seen in the Baia de Arieș Nappe, part of Biharia Nappe System (Ianovici *et al.* 1976, Bordea *et al.* 1979, Balintoni 1994, 1997). Sedimentary rocks in the area are represented by Upper Cretaceous flysch and Neogene rocks (Badenian and Sarmatian; Borcoș & Mantea 1968, Bordea *et al.* 1979). Whereas the Cretaceous flysch is widely distributed, the Neogene sedimentary rocks only occur as narrow sequences within a so-called volcano-sedimentary formation, considered by Leary *et al.* (2004) a diatrema. Volcanic rocks are represented by the Cetate dacite (Cetate and Cărnice domes), which is responsible for the associated ore deposit. Volcanic activity continues with a post-dacite barren andesite (Rotunda type) rooted zone, lava flows and pyroclastic

rocks (Cioflica *et al.* 1973, Ianovici *et al.* 1976, Bordea *et al.* 1979, Borcoş 1994) (Fig. 3). An early rhyolite event was proposed by Cioflica *et al.* (1973).

During the nineties, Roşia Montană was considered a low-sulfidation deposit (Mârza *et al.* 1997, Tămaş & Bailly 1998, 1999), but recently, it was reconsidered an intermediate-sulfidation mineralized system (Sillitoe & Hedenquist 2003, Leary *et al.* 2004). The deposit is hosted in 13.65 Ma dacitic bodies (Roşu *et al.* 2004) and related phreatomagmatic breccias, located within a diatreme hosted in upper Cretaceous flysch sequences (Leary *et al.* 2004). The brecciation and its role in metallogenesis are largely presented elsewhere (Tămaş 2002, Tămaş *et al.* 2004a).

PREVIOUS MINERALOGICAL STUDIES

Pošepny (1870) drafted the first geological map of the Roşia Montană area in 1868. The first modern mineralogical study was made by Petruşian (1934). He was one of the first Romanian scientists to apply ore microscopy and made an accurate and detailed ore-microscopy study of the mineralogy in the Roşia Montană deposit. He pointed out (Sfântul Gheorghe ore field, Cetate massif) the abundance of silver minerals (argentite, proustite, pearceite, polybasite) as well as common sulfides (pyrite, chalcopyrite, sphalerite, galena, marcasite, arsenopyrite, alabandite, tetrahedrite) and, of course, gold in the Roşia Montană deposit.

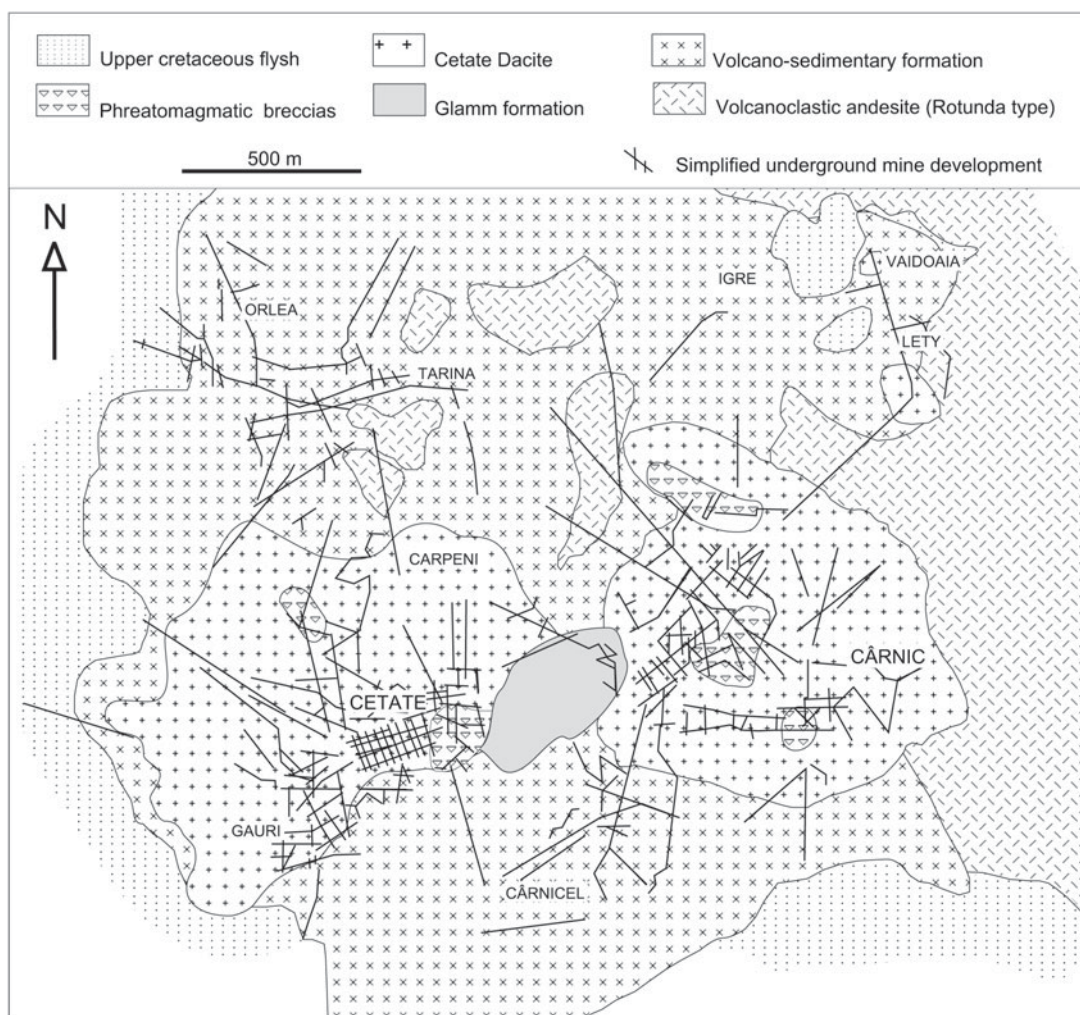


FIG. 3. Simplified geological map of the Roşia Montană ore deposit. Modified from Tămaş (2002).

The mineralogy of the Roşia Montană deposit was addressed again almost 70 years later when Tămaş (2002) advanced the mineralogical characterization of several orebodies. Among the new results found in that study, one can mention the first identification of native gold, native silver, stephanite, polyargyrite, acanthite and tennantite, which accompany other minerals (Au–Ag alloy, polybasite–pearceite, tetrahedrite, Ag-bearing tetrahedrite, and common sulfides (pyrite, chalcopyrite, sphalerite, galena and Ag-rich galena). Tămaş (2002) also gave semiquantitative evidence for the presence of argyrodite, proustite–pyrargyrite and miargyrite, as well as data suggestive of unnamed minerals or submicroscopic intergrowths. Several gold-bearing associations were also described. Tellurium was mentioned as a trace element (0.13–0.21 wt%) within galena and Au–Ag alloy, as well as in several Ag-rich minerals that could not be unequivocally identified.

Preliminary information concerning the occurrence of tellurides at Roşia Montană has been briefly given by Tămaş *et al.* (2004b). The study of telluride assemblages in similar samples (Ciobanu *et al.* 2004b) has emphasized the role of hessite as a carrier of gold.

SAMPLING AND ANALYTICAL TECHNIQUES

Three series of samples allowed identification of tellurides at Roşia Montană. These new telluride occurrences were observed in underground workings of the Cărniceş massif, namely in the Cărniceş mining field (RM611A and B, LPC42112), as well as from the surface in the Cetate open pit, Cetate massif (RM95).

The Cărniceş vein structure, accessible at the mining level +853 m, has a N–S strike and a dip to the west at angles between 70 and 80°. The vein itself has a visible length of about 170 m and a variable width, generally around 25 cm. Its internal structure is characterized by a very well-marked banded structure (Figs. 4a to d), with ore-mineral sequences alternating with zones of gangue minerals. There are several zones where the vein underwent post-mineralization brecciation. Angular fragments of ore and host rock, ranging in size from mm to tens of cm, are held together by a cement of rhodochrosite and rhodonite. Toward the southern edge of the vein, marcasite is very widespread. Aggregates of marcasite, up to 5 cm in diameter, as well as banded zones with central open spaces, can be seen in the vein filling. The fissures that contain marcasite cross-cut the previously deposited ore and gangue mineral sequences and appear to result from the last stage of mineralization. The southern edge of the Cărniceş vein is represented by a fault that cuts the orebody. Larger blocks of weakly silicified diatreme phreatomagmatic breccia (host rock), up to 30–40 cm in size, are still present in the unstable faulted zone. Preliminary chemical analyses of the Cărniceş vein, performed by RMGC, reveal an extremely rich Ag grade, with some Au grades (*ca.* 1,150 g/t Ag and 5 g/t Au).

The second telluride occurrence is found within the so-called Glamm Formation, which represents the fluidized channel of the Cetate phreatomagmatic breccia-pipe structure (Tămaş 2002). It was for centuries considered a barren zone within the deposit. The occurrence is found at the entrance of the Cetate open pit, from level +886 m. Owing to the extremely clay-rich breccia matrix, ore grades in the Glamm Formation are low, and this area has not been exploited.

A single swarm of N–S-striking parallel veins is found within this unfavorable host-rock and occurs in the open-pit benches that exposed the breccia (glamm) on the benches (Fig. 4e). The vein swarm displays a mean dip of 70° towards west. The average width of the veins varies from a few mm up to 10 cm. The veins are banded, with several sequences of Mn-gangue minerals (Fig. 4f). Toward the final stage of deposition of Mn-gangue minerals, metals were deposited, clearly cross-cutting previous assemblages. The existing vugs were infilled with hydrothermal quartz.

Following reflected-light microscopy to identify the ore-mineral assemblages, the polished sections were studied by SEM equipped with a back-scattered-electron (BSE) detector to study complex and fine-scale assemblages. Quantitative compositional data were determined using a Cameca SX 50 microprobe at BRGM, Orléans. The associated program used 16 elements with an acceleration voltage of 20 kV, a beam current of 12 nA, and a counting time of 6 s. For standards, we used pure metals for Cu, Ag, Ge, Cd, Au, plus FeS₂ for Fe and S, AsGa for As, PbS for Pb, Sb₂S₃ for Sb, SnO₂ for Sn, MnTiO₃ for Mn, Pb₅(VO₄)₃Cl for V, ZnS for Zn. We used K α lines for Cu, S, Fe, Zn, V, and Mn, L α lines for As, Ag, Ge, Cd, Sn, Se, Te, and Sb, and M α lines for Pb and Au. The calculated detection-limit was ≤ 0.1 wt% for Cu, S, Fe, V, Ge, Mn, Sn, Se, Te, and Sb, and below 0.2 wt% for As, Zn, Pb, Ag, Cd and Au.

MINERALOGY

Both telluride occurrences presented in the paper are represented by vein structures, but their host rocks are different.

The host rock

The host rock of Cărniceş vein is a diatreme phreatomagmatic breccia (vent breccia). Macroscopically (Fig. 4a), this breccia has angular, subangular to subrounded fragments of rock and a coarse to silty-clay matrix. The dominant clasts are K-metasomatized dacite fragments, but sedimentary and metamorphic rock fragments as well as crystal fragments also occur. Of the two generations of K-feldspar of adularia habit (I and II of Tămaş 2002), the first one corresponds to pre-brecciation K-metasomatism, and the second one, to post-brecciation hydrothermal cementation.

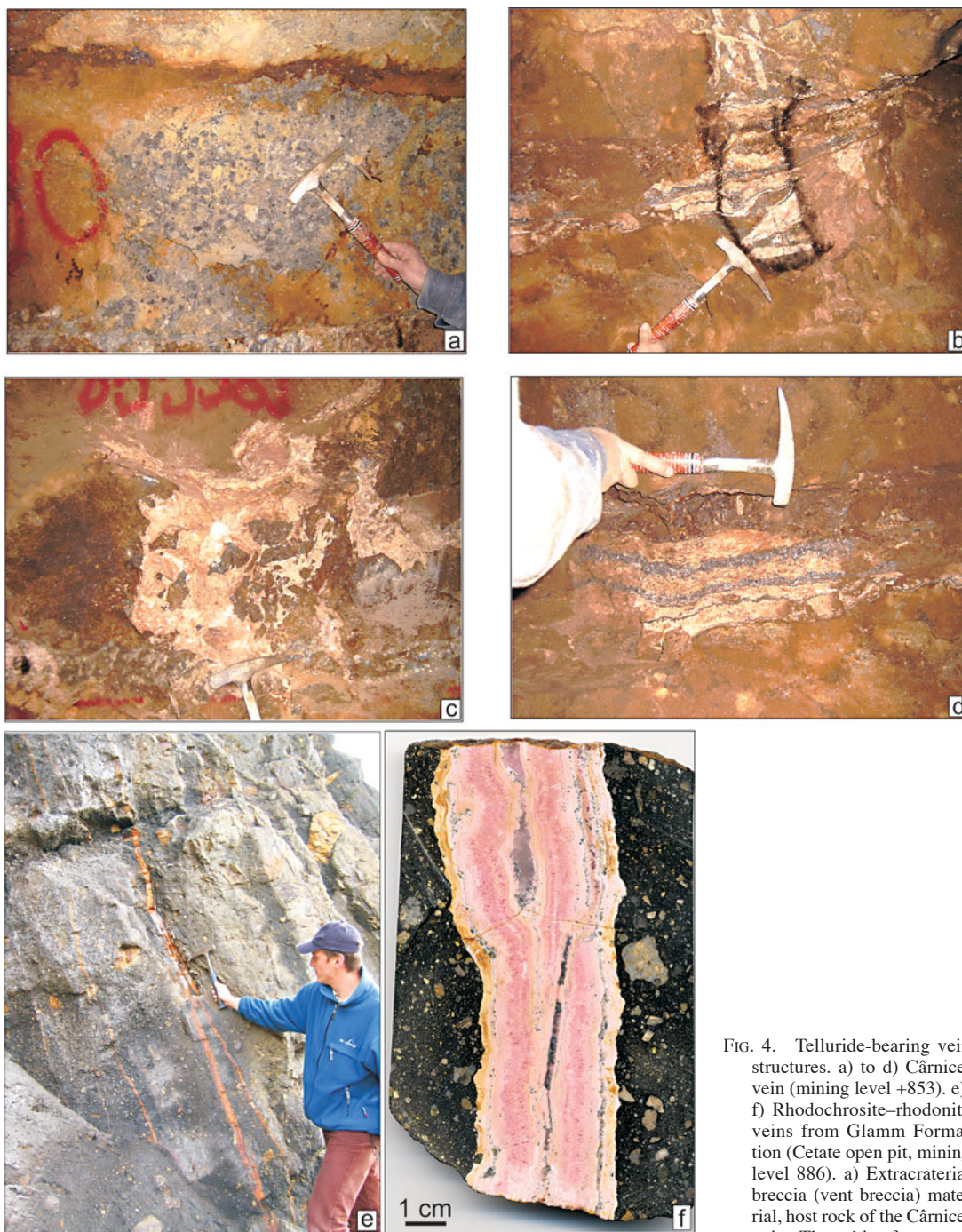


FIG. 4. Telluride-bearing vein structures. a) to d) Cârniceș vein (mining level +853). e), f) Rhodochrosite-rhodonite veins from Glamm Formation (Cetate open pit, mining level 886). a) Extracraterial breccia (vent breccia) material, host rock of the Cârniceș vein. The white fragments correspond to altered dacite,

the black and grey fragments, to Cretaceous sediments (hanging wall). b) Channel sampling on the roof transversal to Cârniceș vein. c) Brecciated zone of Cârniceș vein. Phreatic breccia clasts are cemented by rhodochrosite-rhodonite (hanging wall). d) Typical texture of the Cârniceș vein showing alternating bands of rhodochrosite-rhodonite and sulfides-tellurides. e) General view of telluride-bearing veins hosted by the so-called Glamm Formation, part of the Cetate phreatomagmatic breccia-pipe structure. f) Banded vein from Glamm (detail) containing rhodochrosite – rhodonite – (quartz) – rare sulfides – tellurides.

Hydrothermal quartz crystals, zoned in cases with calcite- and rhodochrosite-rich inclusions, are abundant in the Cârnicel vein. Rhodonite was locally observed among gangue minerals, whereas clay minerals (mainly illite) are more frequent in the ore-mineral deposition sequences.

The host rock of the second telluride occurrence, the parallel rhodochrosite – rhodonite swarm of veins from Cetate, is represented by a breccia called by the local miners “glamm”. The Glamm or Black Breccia (Leary *et al.* 2004) is a typical rock-flour-matrix breccia (Figs. 4e, f). The silty-clay matrix (around 90%) includes a heterogeneous array of rock fragments: metamorphic, sedimentary (Cretaceous), dacite as well as crystal fragments. Carbonized wood fragments are not unusual (Tămaş 2002). The rock fragments do not usually exceed several centimeters, but larger clasts may occur. Usually they are rounded to subrounded, but more angular clasts may occur subordinately. The metamorphic and Cretaceous fragments are more rounded and smaller compared to the dacite fragments.

The Glamm is friable, but close to the rhodochrosite–rhodonite veins, it is silicified and becomes harder. From these veins, Benea *et al.* (2000) and Tămaş (2002) described rhodochrosite, rhodonite and K-feldspar with the adularia habit. The rhodochrosite and rhodonite are intimately mixed, and rhodonite is replaced by rhodochrosite. Pyrolusite and a Mn-dominant pyroxenoid also occur (Ciobanu *et al.* 2004b).

Ore mineralogy

The ore assemblage from Cârnicel vein consists of dominant galena, yellowish sphalerite and tetrahedrite, associated with minor amounts of chalcopryrite and pyrite. Besides the common base-metal sulfides, the samples studied are also rich in anhedral grains of hessite up to 100 µm in size that occur either as inclusions in tetrahedrite and galena or at the interface between the two phases (Fig. 5). More rarely, hessite is observed as an inclusion in sphalerite, together with numerous inclusions of chalcopryrite, galena, and tetrahedrite. These inclusions are found in the colorless core of sphalerite crystals, whereas the corresponding yellowish rim is free of inclusions. Rare grains of altaite (Figs. 5f, g) and Au–Ag alloy (<5 µm in size) are included in hessite. Some of the alloy grains are also observed in cavities. More commonly, complex assemblages have been observed between hessite and a second grey-blue phase, argyrodite, characterized by a reflectivity lower than that of tetrahedrite. A late pyrite–marcasite assemblage is observed in some samples from the Cârnicel vein, rimming the previously described sulfide assemblages and preceding a final episode of carbonate brecciation.

EPMA data (Table 1) show that sphalerite is nearly free of Fe (max. 0.3 wt%), whereas the Mn content ranges from 3.4 to 6.3 wt%. This Mn-rich character is

also confirmed by the identification of rare green inclusions of alabandite in sphalerite. Alabandite contains Zn at concentrations below 2 wt% (Table 1). Tennantite was not observed in the samples studied; tetrahedrite was only found in samples from the Cârnicel vein, where it is characterized by a lack of chemical zoning, by low As content (2.4 to 4.3 wt%) and relatively constant Ag contents ranging from 2.0 to 2.8 wt% (Table 1). Significant amounts of Sb are systematically detected in hessite. A grain of Au–Ag alloy sufficiently large to be analyzed gave the composition $\text{Au}_{0.76}\text{Ag}_{0.23}$ (Table 2). Where included in hessite, the contact between hessite and the alloy is systematically rimmed by sylvanite (Figs. 5c–e), characterized by an Au:Ag ratio close to one (Table 2). Both SEM and EPMA analyses confirm the presence of argyrodite (Ag_8GeS_6). SEM observations also reveal complex associations involving argyrodite, hessite and petzite (Figs. 5h–k). The argyrodite is characterized by a Te-content that ranges between 19.1 and 23 wt%, corresponding to a S:Te atomic ratio close to 2 (ranging between 1.28 and 2.11; Table 3), Sn and Se being below the detection limit. The observed S:Te ratio suggests a possible solid-solution between Ag_8GeS_6 and Ag_8GeTe_6 , a synthetic equivalent of argyrodite not known in nature (Boucher *et al.* 1993). Furthermore, the EPMA study showed also that Sn is below the detection limit, indicating no solid solution between argyrodite and canfieldite (Ag_8SnS_6).

Common sulfides are also present in the rhodochrosite–rhodonite veins of the Cetate massif. As compared to Cârnicel vein, the amount of sulfides is very minor. Previous studies reported chalcopryrite, sphalerite,

FIG. 5. SEM microphotographs of telluride occurrences. a) Hessite and galena in tetrahedrite. The hessite grain at upper right contains argyrodite inclusions. b) Hessite inclusions in tetrahedrite. Micrometric inclusions of galena are observed in hessite (lower right). c) Detail of the previous microphotograph showing Au–Ag alloy (in white), sylvanite (light grey) and hessite (dark grey). d) Galena, hessite, Au–Ag alloy in tetrahedrite. Sylvanite is observed at the contact of the alloy grain. e) Hessite, Au–Ag alloy and sylvanite in tetrahedrite. f) Assemblage of sphalerite (black with galena inclusions), tetrahedrite, hessite and altaite. g) Altaite inclusion in hessite. h) Hessite (light grey) included in argyrodite. i) Argyrodite rich in hessite wires in tetrahedrite. j) Argyrodite, hessite associated with chalcopryrite (black) in tetrahedrite. k) Complex argyrodite (dark grey) – hessite (light grey) – undetermined AuAgTe phase. l) Undetermined AgCuTeS phase in hessite. Photos a), f) and j): sample RM 611B, Cârnicel vein. Photos b), c), d), e), g) h) and i): sample LPC 42 122, Cârnicel vein. Photo k): sample RM 611A, Cârnicel vein. Photo l): sample RM 95 (vein in the Glamm Formation, Cetate breccia). Symbols: gal: galena; hes: hessite; arg: argyrodite; tet: tetrahedrite; alt: altaite; syl: sylvanite; el: Au–Ag alloy; qz: quartz; rho: rhodochrosite. Scale bar: 5 µm.

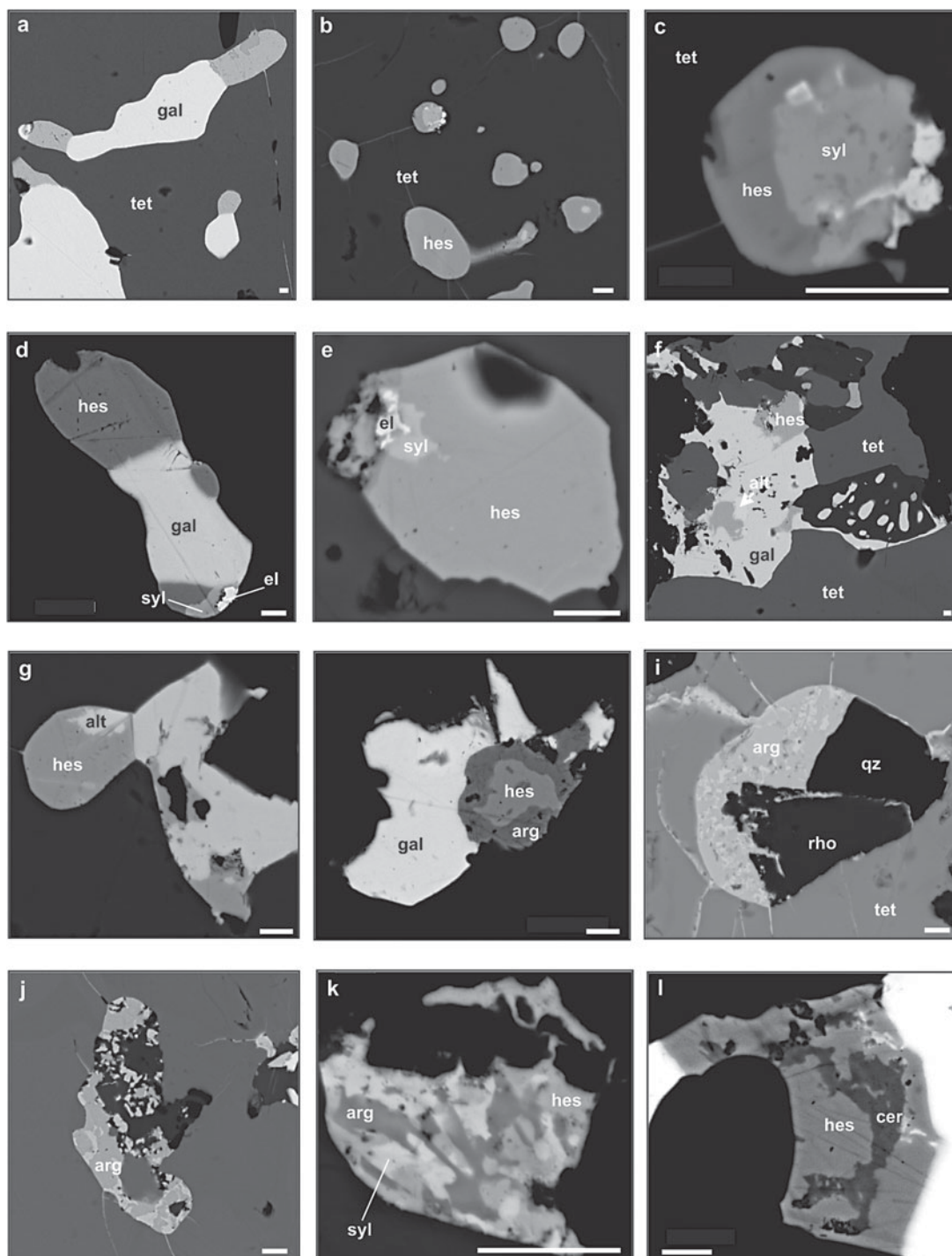


TABLE 1. SELECTED COMPOSITIONS OF SPHALERITE, ALABANDITE AND TETRAHEDRITE

No. Sample	Sphalerite			Alabandite			Tetrahedrite							
	11 LPC42112	34 RM611A	103 RM611A	10 LPC42112	12 LPC42112	7 LPC42112	48 LPC42112	100 LPC42112	109 LPC42112	42 RM611A	47 RM611A	50 RM611A	51 RM611A	56 RM611A
Cu wt.%	0.15	0.03	0.11	-	-	37.01	34.97	36.47	36.40	37.05	36.68	36.54	37.54	36.83
S	33.05	33.37	33.54	36.83	36.48	25.01	24.76	25.12	24.81	24.74	24.87	24.44	24.94	24.63
Fe	0.23	0.22	0.07	0.09	0.08	0.20	0.15	0.19	0.44	0.28	0.37	0.31	0.42	0.18
As	-	-	-	-	-	2.91	2.56	2.94	2.88	3.09	2.62	2.41	4.26	2.93
Zn	60.94	60.16	60.52	1.86	1.86	6.13	6.14	6.03	6.62	6.18	5.91	6.85	6.97	6.49
Pb	-	0.09	-	0.17	0.19	0.08	0.02	0.08	0.27	-	0.05	-	-	-
Ag	-	-	-	-	-	2.04	2.82	2.47	2.76	2.78	2.76	2.42	2.41	2.53
Cd	0.15	0.14	0.22	0.01	0.03	0.03	0.02	0.05	-	-	-	-	-	-
Mn	4.98	5.99	6.13	61.76	61.52	1.04	1.25	1.21	0.53	-	-	-	-	-
Sb	-	-	0.03	0.10	-	25.95	26.56	26.46	26.28	26.43	27.04	27.52	24.34	26.41
Total	99.49	100.00	100.62	100.80	100.15	100.41	99.24	101.03	100.98	100.54	100.30	100.50	100.86	100.00
Cu at.%	0.12	0.02	0.08	-	-	33.26	31.98	32.67	32.75	33.54	33.31	33.27	33.54	33.50
S	50.00	50.13	50.03	49.85	49.67	44.54	44.86	44.58	44.24	44.38	44.76	44.11	44.16	44.40
Fe	0.20	0.19	0.06	0.07	0.06	0.20	0.15	0.20	0.45	0.29	0.38	0.33	0.42	0.19
As	-	-	-	-	-	2.22	1.99	2.24	2.20	2.37	2.01	1.86	3.23	2.26
Zn	45.22	44.32	44.26	1.23	1.24	5.36	5.45	5.25	5.79	5.44	5.22	6.06	6.05	5.74
Pb	0.00	0.02	0.00	0.04	0.04	0.00	0.00	0.00	0.00	-	0.00	-	-	-
Ag	-	-	-	-	-	1.08	1.52	1.30	1.46	1.49	1.48	1.30	1.27	1.36
Cd	0.07	0.06	0.09	0.00	0.01	0.01	0.01	0.03	-	-	-	-	-	-
Mn	4.39	5.25	5.33	48.79	48.90	1.08	1.32	1.25	0.55	-	-	-	-	-
Sb	-	-	0.01	0.03	-	12.17	12.68	12.37	12.34	12.49	12.81	13.08	11.35	12.54

—: below detection limit.

galena and pyrite, as well as Au–Ag alloy (Benea *et al.* 2000). Hessite is also very common (Table 2) and is locally associated with cervelleite, with a chemical composition close to $\text{Ag}_3\text{TeCu}_{0.2}\text{S}$ (Fig. 5, photo 1; Table 2). Free grains of Au–Ag alloy (<5 μm in size) included in quartz are also observed. Petzite has been also identified by Ciobanu *et al.* (2004b) from similar samples.

DISCUSSION

Telluride paragenesis

Taking into account the morphology of the ore deposit, the gangue and ore mineralogy, the alteration assemblages, the zoning of the alteration and the geochemical association, Mârza *et al.* (1997) considered the Roşia Montană ore deposit as a typical low-sulfidation system. Tămaş & Bailly (1998, 1999) provided additional fluid-inclusion evidence to support this opinion (salinities from 0.7 to 7.85 wt% NaCl equiv. and temperatures in the range between 200 and 340°C).

Considering the ore-mineral assemblage dominated by sphalerite with a low FeS content, galena, tetrahedrite-tennantite and chalcopyrite associated with abundant Mn-bearing carbonates and silicates as gangue minerals, Roşia Montană is now considered an intermediate-sulfidation mineralized system (Sillitoe & Hedenquist 2003, Leary *et al.* 2004).

With two recent exceptions (Tămaş *et al.* 2004b, Ciobanu *et al.* 2004b), the previous mineralogical studies (Petrulian 1934, Cozubaş *et al.* 1986, Mârza *et al.* 1990, Tămaş 1995, 2002, Benea *et al.* 2000, Manske *et al.* 2004) were focused mainly on gold, alteration and gangue minerals. Gold was the primary target at Roşia Montană, and only Petrulian (1934) and Tămaş (2002) commented about Ag-minerals in restricted areas of the ore deposit. Using macro- and microscopic evidence, Petrulian (1934) proposed a sequence of ore deposition in which gold was entirely deposited before the appearance of sulfides and sulfosalts of Ag. Unfortunately, no mineralogical studies have been carried out yet on the so-called Filoanele de Argint ('Silver Veins') or their branches (Napoleon, Doica, Cârnicels vein,

among others), which were extremely rich in silver, with some gold.

The Silver veins like Cârnicel have discrete features. They are excessively Ag-rich (*ca.* 1,150 g/t), and have much lower Au grades (<5 g/t). In spite of the previously held perception that tellurides are absent in the Roşia Montană area, our studies give unequivocal evidence of the occurrence of several tellurides and Te–Ge sulfosalts: hessite, altaite, rare sylvanite, petzite and Te-bearing argyrodite. The occurrence of Bi tellurides, reported by Townsend *et al.* (2000), has not been confirmed in this work. Tellurides are closely associated with tetrahedrite, sphalerite, galena, chalcocopyrite, pyrite, rare alabandite and Au–Ag alloy. Hessite is by far the main carrier of Ag, accompanied by Ag-bearing tetrahedrite.

Telluride-bearing rhodochrosite–rhodonite veins hosted by Cetate breccia (Glamm) are less widespread than the Cârnicel vein system. Hessite and cervelleite,

and the absence of tetrahedrite and argyrodite, have been observed in these veins. The precious metals grades in selective vein material are 54 g/t Ag and 1.25 g/t Au. We note the lower Ag:Au ratio of these veins than in the Cârnicel vein.

At the ore-deposit scale, the bulk of the Au mineralization (Leary *et al.* 2004, Tămaş *et al.* 2004a) is given by the Au–Ag alloy. The Au grades as well as the dimensions of the telluride-bearing veins identified so far at Roşia Montană are low to very low compared to other orebodies (see below). In contrast with other telluride-bearing gold deposits, like for example Acupan (Baguio district, Philippines; Cooke *et al.* 1996), and given that Roşia Montană is a world-class epithermal gold deposit, these veins are very gold-poor, suggesting that the precious-metal-bearing assemblages (telluride-free) and the telluride-bearing veins may have been the product of distinct hydrothermal events. The assemblages encountered at Roşia Montană also contrast with

TABLE 2. SELECTED COMPOSITIONS OF TELLURIDES AND Au–Ag ALLOY

No. Sample	Hessite						Altaite			Cervelleite				Au–Ag		Syl
	17 LPC42112	21	87	91	106	112	30	12	14	88	89	90	93	4	9	
			RM95		RM611A		LPC42112				RM95			LPC42112		
Cu wt%	0.19	-	0.57	0.41	0.04	0.22	1.41	0.34	0.20	1.77	1.42	1.58	2.28	-	1.27	
S	0.07	0.09	0.30	0.23	0.57	0.44	0.23	0.08	0.11	5.99	4.23	6.11	6.60	-	0.07	
Fe	0.11	-	0.40	0.30	-	0.03	-	0.11	0.10	0.17	0.18	0.28	0.07	-	0.02	
Zn	-	0.09	0.05	-	0.02	-	0.21	-	0.00	-	-	-	-	0.01	0.04	
Pb	0.10	0.03	-	0.08	-	-	59.04	60.29	59.86	0.73	0.21	1.01	0.45	-	-	
Ag	63.76	61.70	63.06	64.19	62.44	63.42	0.91	0.75	0.59	65.97	64.79	67.39	64.96	14.29	12.64	
Cd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.08	
Au	0.12	-	0.02	-	0.61	0.08	-	-	-	0.12	-	-	0.01	85.45	25.55	
Mn	0.03	0.01	0.23	0.19	0.04	-	0.05	-	-	0.06	0.21	0.11	0.07	-	0.03	
Se	-	0.04	0.10	0.07	-	-	0.09	0.11	0.15	0.45	0.27	0.30	0.11	0.05	-	
Te	37.33	38.74	37.04	37.23	36.01	36.16	38.32	38.25	38.02	26.05	29.25	25.38	25.56	0.01	61.84	
Sb	0.17	0.10	0.22	0.16	0.12	0.19	0.61	0.20	0.12	0.03	-	-	0.02	0.53	0.54	
Total	101.87	100.80	101.99	102.86	99.86	100.52	100.87	100.14	99.14	101.33	100.56	102.16	100.11	100.34	102.07	
Cu at. %	0.33	-	0.99	0.70	0.07	0.39	3.50	0.89	0.52	2.67	2.24	2.36	3.42	-	2.63	
S	0.24	0.33	1.04	0.77	2.02	1.55	1.15	0.42	0.57	17.83	13.25	18.06	19.59	-	0.27	
Fe	0.21	-	0.79	0.59	-	0.05	-	0.33	0.29	0.30	0.33	0.48	0.11	-	0.04	
Zn	-	0.16	0.09	-	0.04	-	0.52	-	0.00	-	-	-	-	0.02	0.07	
Pb	0.05	0.02	-	0.04	-	-	44.94	47.62	47.83	0.34	0.10	0.46	0.21	-	-	
Ag	66.12	64.85	64.31	65.25	65.41	65.98	1.34	1.13	0.91	58.41	60.30	59.22	57.35	23.12	15.40	
Cd	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.09	
Au	0.07	-	0.01	-	0.35	0.04	-	-	-	0.06	-	-	0.00	75.71	17.04	
Mn	0.05	0.02	0.47	0.37	0.07	-	0.13	-	-	0.10	0.37	0.19	0.12	-	0.08	
Se	-	0.05	0.14	0.10	-	-	0.18	0.23	0.31	0.55	0.34	0.36	0.13	0.11	-	
Te	32.73	34.42	31.93	31.99	31.89	31.80	47.37	49.07	49.33	19.50	23.02	18.86	19.07	0.02	63.69	
Sb	0.16	0.09	0.20	0.15	0.11	0.17	0.79	0.27	0.16	0.02	-	-	0.02	0.76	0.58	

–: below detection limit. Symbols: Au–Ag: Au–Ag alloy, Syl: sylvanite.

TABLE 3. SELECTED COMPOSITIONS OF Te-BEARING ARGYRODITE

No.	14	15	16	19	32	42	43	94	104	105	110	4	5	6	8	9	11
Sample	LPC42112								RM611A								
Cu wt. %	0.43	0.54	-	0.11	0.76	-	0.08	0.01	0.02	-	0.43	0.35	0.63	0.49	0.22	0.87	0.32
S	9.69	9.39	9.50	9.52	9.14	9.67	9.06	9.76	9.87	9.74	9.73	9.14	8.89	8.52	7.50	7.72	8.46
Fe	0.04	-	0.10	0.09	0.25	0.03	0.16	0.25	-	0.01	-	0.24	0.10	0.61	0.50	0.20	0.14
Pb	0.04	0.07	-	0.13	0.05	0.12	0.47	0.15	-	-	-	-	-	0.20	0.19	-	0.26
Ag	65.69	65.78	65.18	65.24	65.36	66.22	63.65	66.70	66.85	66.95	65.19	65.03	65.15	63.62	64.62	63.97	65.95
Ge	5.13	4.89	4.96	5.18	4.57	5.16	4.58	4.66	4.93	5.12	4.94	5.37	5.05	4.89	4.47	4.62	5.38
Te	19.43	19.03	19.63	19.09	20.09	20.13	20.69	18.38	18.89	19.36	18.92	19.12	19.22	20.68	23.33	22.21	20.29
Total	100.43	99.69	99.36	99.36	100.22	101.32	98.70	99.91	100.57	101.17	99.21	99.26	99.03	99.02	100.82	99.58	100.79
Cu at. %	0.59	0.75	-	0.15	1.06	-	0.12	0.01	0.03	-	0.59	0.49	0.89	0.70	0.32	1.26	0.45
S	26.38	25.89	26.19	26.17	25.17	26.20	25.49	26.58	26.79	26.36	26.70	25.36	24.88	23.93	21.40	22.01	23.57
Fe	0.06	-	0.16	0.14	0.39	0.04	0.26	0.39	-	0.02	-	0.39	0.15	0.99	0.82	0.32	0.22
Pb	0.02	0.03	-	0.05	0.02	0.05	0.21	0.06	-	-	-	-	-	0.09	0.08	-	0.11
Ag	53.18	53.92	53.42	53.29	53.48	53.34	53.26	54.01	53.94	53.87	53.20	53.64	54.22	53.09	54.86	54.26	54.63
Ge	6.16	5.95	6.03	6.28	5.55	6.17	5.70	5.61	5.90	6.12	5.99	6.58	6.24	6.07	5.63	5.82	6.62
Te	13.30	13.19	13.60	13.18	13.90	13.70	14.63	12.58	12.89	13.17	13.05	13.33	13.52	14.59	16.74	15.92	14.21

—: below detection limit.

the mineralogical characteristics of other ore deposits of the South Apuseni Mountains (*e.g.*, Săcărâmb, Măgura) in which native gold is subordinate, and sylvanite [(Au,Ag)₂Te₄], nagyagite [Pb(Pb,Sb)S₂](Au,Te), krennerite (AuTe₂) and petzite (Ag₃AuTe₂) are the main carriers of gold (Giușcă 1936, Udubașa *et al.* 1992, Orlandea & Velcirov 1996).

Field observations provide evidence of a distinct sequence of emplacement of orebodies in the Cărnic ore field at Roșia Montană (Fig. 3). This separation is based upon the cross-cutting relationships between different mineralized structures. Furthermore, these hydrothermal episodes are characterized by different mineralogical assemblages and Au–Ag grades: 1) An initial event led to coarse, Ag-poor gold (free gold, Ag-sulfosalts) and quartz–“adularia” gangue, related to early phreatic brecciation (30–140 g/t Au and 20–70 g/t Ag); 2) gold- and silver-rich veins (free gold, Ag-sulfosalts) and quartz–“adularia” gangue (120 g/t Au and 150 g/t Ag); 3) silver–gold (Ag-sulfide and sulfosalts, free silver and free gold) and quartz–“adularia” gangue in re-brecciated phreatic–phreatomagmatic breccias (220 g/t Ag and 9 g/t Au); 4) extremely Ag-rich veins (Ag, Ag–Au–tellurides, altaite and Ag–Ge–Te–sulfosalts), gold-poor (free gold) and Mn-rich gangue minerals dominant, with minor quartz and “adularia” (1150 g/t Ag and 5 g/t Au).

Te-bearing argyrodite

The first mention of possible Ge minerals in Roșia Montană is attributed to Andronescu (1962). In 2002, Tămaș provided semiquantitative data to suggest the possible occurrence of argyrodite in samples from the Cărnic 2 breccia pipe body, Cărnic massif. The existence and the chemical composition of argyrodite are now clearly established in the present study; EPMA data suggest that one third of the sulfur in argyrodite is replaced by tellurium.

A solid solution exists between argyrodite (Ag₈GeS₆) and canfieldite (Ag₈SnS₆). According to Wang (1978), argyrodite and canfieldite are isostructural and crystallize in the orthorhombic space-group *Pna*2₁ or *Pnam*. Several investigators have reported the existence of Te-bearing canfieldite in the following localities: Revelstoke, Canada (Harris & Owens 1971), Belukhinskoye, Russia (Ontoyev *et al.* 1971), Tsumo, Kuga and Nakatatsu mines, Japan (Soeda *et al.* 1984, Kikuchi *et al.* 1980, Marioko 1981, respectively), Zlata Bana, Slovakia (Duda & Kristin 1978) and the Cirotan mine, Indonesia (Milési *et al.* 1994). On the basis of chemical and X-ray data, Harris & Owens (1971) proposed that Te replaces S in the structure of canfieldite, yielding an ideal formula of Ag₈Sn(S,Te)₆. To our knowledge, this is the first reported occurrence of Te-bearing argyrodite.

It is interesting to note that Te-bearing canfieldite and argyrodite share some optical characteristics, including the characteristic bluish tint (*cf.* Soeda *et al.* 1984, Wimmers 1985). They differ from Te-free argyrodite and canfieldite, which are characterized by a violet tint in reflected light.

There are several occurrences of Ge-minerals (germanite, argyrodite) related to Neogene hydrothermal ore deposits in the South Apuseni Mountains (Andrănescu 1962, Socolescu *et al.* 1963, Udubaşa *et al.* 1992, Cook & Ciobanu 2004). With the exception of Larga (Cook *et al.* 2004), Ge-minerals are associated with enargite at all the other occurrences (Bucium, Bucureşti-Rovina, Băiţa Crăciuneşti and Pârâul lui Avram), indicating merely a more or less local HS environment. By contrast, Te- and Ge-bearing minerals in the Roşia Montană ore deposit occur in orebodies with a mineral assemblage indicating an intermediate-sulfidation systems.

Ge-bearing minerals (germanite, briartite, renierite, Ge-rich colusite) are also reported in several deposits from the Upper Cretaceous Panagyurishte district of Bulgaria (Radka, Chelopech, Krassen). These are considered as high- or intermediate-sulfidation epithermal-type deposits (Tsonev *et al.* 2000, Popov *et al.* 2000). In Serbia, germanite and Ge-bearing enargite has been reported in the Tilva Ros orebody (Kozelj, pers. commun.). To our knowledge, argyrodite has only been reported in a single unequivocally low-sulfidation epithermal Au–Ag deposit (Wolyu, Korea, Yun *et al.* 1993). These occurrences and the findings of N.J. Cook (unpubl.) suggest that Ge-enrichment does seem to be limited to the high-sulfidation and intermediate-sulfidation deposits only. At the scale of the South Apuseni Mountains, the Ge-enrichment seems to be a common feature, being related to assemblages of high-sulfidation and intermediate-sulfidation minerals also.

Genetic significance

The documented presence of telluride minerals at Roşia Montană expands the number of telluride occurrences in Romania. Once again, it highlights the compositional differences between ore deposits from the Baia Mare region, dominated by sulfosalts, and those in the Metaliferi Mountains, which are telluride-bearing.

A compilation of the existing thermodynamic data for tellurides was established by Afifi *et al.* (1988). In the case of Roşia Montană, the use of $f(\text{Te}_2)$ – $f(\text{S}_2)$ – $f(\text{O}_2)$ diagrams is of little help to constrain the conditions of telluride deposition. Hessite and altaite are among the most common tellurides and are stable over a wide range of $f(\text{Te}_2)$ – $f(\text{S}_2)$ conditions. The absence of Ag_2S and native silver and of native tellurium in the samples studied can help to define the lower and upper limits of $f(\text{Te}_2)$, respectively, but only within the broad limits of most hydrothermal telluride-bearing deposits.

Two main hypotheses are proposed for the mechanism of Ge buildup in hydrothermal systems (Bernstein 1985): concentration in late igneous fluids by fractional crystallization, or leaching of the country rocks, particularly those containing organic material (*e.g.*, Barbanson & Geldron 1983). However, Ge may exhibit lithophile, siderophile, chalcophile, and organophile properties depending on the chemical environment (Bernstein 1985). Whereas some studies are available on the thermodynamic properties of aqueous Ge hydroxide complexes (*e.g.*, Pokrovski & Schott 1998), little is known about the behavior of Ge in S-bearing hydrothermal fluids. According to Bernstein (1985), two types of sulfide ore deposits may be distinguished: those where Ge is concentrated in sphalerite (up to 3000 ppm, *e.g.*, Barbanson & Geldron 1983) and those where Ge forms its own sulfide minerals or substitutes for metal atoms (mainly As and Sn) in sulfosalts. The behavior of Ge appears dependent on the sulfur activity. Ge enters ZnS in low to moderate sulfur activity environments and forms its own phases under higher fugacity of sulfur. In the samples studied from Roşia Montana, sphalerite and tetrahedrite are free of Ge (detection limit was about 400 ppm with the analytical conditions used), suggesting a relatively high activity of sulfur, also confirmed by the low FeS content of sphalerite, and Ge and Ag concentrations sufficiently high to allow the deposition of argyrodite.

The origin of Te as well as the origin of the hydrothermal fluids involved in such Te-rich ore deposits are still matters of debate. According to Giggenbach (1981), Te may be derived from deep-seated (> 5 km) magma bodies undergoing degassing. The input of magmatic volatiles is invoked to explain the ore mineralogy of Acupan (Cooke & Bloom 1990, Cooke *et al.* 1996, Cooke & McPhail 2001). In their studies of Au–Ag telluride-rich samples from the southern edge of Metaliferi Mountains (mainly Săcărâmb), Alderton & Fallick (2000) concluded that the hydrothermal fluids essentially consist of magmatic water. On the contrary, Shelton *et al.* (1990) concluded that the epithermal Au–Ag–Te of Tongyoung was largely dominated by meteoric water during all the stages of mineralization. Yun *et al.* (1993) suggested that the deposition of Au–Ag–Ge in the Wolyu mine, South Korea, can be correlated with an increase of the meteoric water component, introducing a progressive cooling and dilution of the ore fluids.

CONCLUSIONS

The dilemma concerning the presence or the lack of tellurides in the Roşia Montană ore deposit and their locations is now solved, adding to the Te-enriched character of the Metaliferi Mountains. Two occurrences of tellurides were identified at Roşia Montană: 1) the Cărnicele vein (Cărnicele massif) and rhodochrosite–rhodo-

nite veins from Glamm, part of Cetate breccia (Cetate massif). Several Te-bearing phases including altaite, hessite, sylvanite, cervelleite and petzite were confirmed by SEM and EPMA analyses. Te-bearing argyrodite was commonly encountered in the samples studied.

Concerning host phases for precious metals at Roşia Montană, it appears that gold occurs dominantly as Au–Ag alloy and native gold, and in rather negligible amounts, as tellurides (sylvanite, petzite). Silver occurs as native silver (>90%Ag), Au–Ag alloy, Ag sulfide and Ag sulfosalts in the beginning and median stages of the mineralizing process, and as tellurides and sulfosalts at the end of hydrothermal activity. The strong affinity of Te and Ge with silver is obvious, and they characteristically mark the final stage of economic epithermal deposition event at Roşia Montană. At the present level of knowledge, we may envisage that the Ge input is very poor at the third stage (Ag–Au in re-brecciated breccias) and more important at the last stage (tellurides veins), where Te-bearing argyrodite is an important component.

A transition from a Au-rich environment (early stages) to a Ag-rich environment (late stage) may be entertained for the Roşia Montană ore deposit. During this transition, a constant enrichment in Ag and accompanying depletion in Au from the early toward the waning stages of hydrothermal activity is very clear. Our data suggest that an input of tellurium and related Mn-gangue minerals took place toward the end of the metallogenic activity at Roşia Montană. Available fluid-inclusion data for the coxcomb quartz veins and the rhodochrosite–rhodonite veins from Glamm (Cetate massif) allowed Manske *et al.* (2004) to suggest a thermal rejuvenation of the system during the formation of the latest telluride-bearing carbonate veins. As compared to earlier hydrothermal stages (vein sets) with homogenization temperatures decreasing gradually from 245–250°C to 230–235°C, the fluid in the quartz from the last-stage carbonate veins from Cetate shows evidence of boiling at 280–290°C (Manske *et al.* 2004). The deposition of the telluride-bearing carbonate veins was clearly related to an increase in the temperature of the system. Fluid-inclusion data are lacking for the Câmicel vein, but a similar range of temperatures may be proposed. The $^{40}\text{Ar}/^{39}\text{Ar}$ data (Manske *et al.* 2004) suggest that the magmatic activity at Roşia Montană continued at least one million years after the bulk of alteration and Au–Ag mineralization in dacite domes. This indication, together with the widespread occurrence of multiple generation of phreatomagmatic breccias, suggest that the transition from an early low-sulfidation character (Au–Ag-dominated) to a final intermediate sulfidation character (Ag-dominated, Au subordinate, with Te and Ge) may be correlated with late magmatic pulses.

At least three major magmatic events (ophiolites at ~140 Ma, Late Cretaceous – Early Palaeogene or Banatite calc-alkaline magmatism at ~60 Ma and

Neogene activity at ~15–8 Ma) are superimposed on one another in the Apuseni Mountains (Pătraşcu *et al.* 1994, Udubaşa & Udubaşa 2004). As shown by Balintoni *et al.* (1997), Seghedi *et al.* (1998), Roşu *et al.* (2004) and Seghedi (2004), the Neogene calc-alkaline magmatism in the Apuseni Mountains has a clear subduction signature, but according to the geotectonic setting, there is no evidence of contemporaneous subduction. The Neogene magmatism from the Apuseni Mountains is explained in this context by decompressional melting of lithospheric mantle during translation and rotation of Tisia and Getia blocks in a transtensional tectonic regime in a non-subduction setting. Under these conditions, the mechanism of Neogene magma genesis and its subduction signature are considered to be related to the decompressional melting of a heterogeneous source (subcontinental mantle affected by metasomatic processes related to earlier subduction events or lower crust or both) (Balintoni *et al.* 1997, Seghedi *et al.* 1998, Roşu *et al.* 2004). The reworking of earlier banatite-related deposits, which have an “exotic” Au–Ag–Bi–Se–Te–Ga–Ge–In–Co–Ni–Sn–PGE signature (Cook *et al.* 2002), may have contributed to the Neogene metallogenic event, and this fact may explain the similarity of some of the associations of trace minerals.

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