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Neogene volcanics in the Apuseni Mts.: historical mining and gold deposits

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1. Geological introduction

1.1 The geology of Romania

The geological structure of Romania is controlled by three major units: (1) the Carpathian orogen, a region of significant crustal mobility which covers more than half of the territory, (2) its foreland which includes several platforms and the North Dobrogea Orogen and (3) the Pannonian + Transylvanian basins (Săndulescu, 1984, 1994).

1.2 The Carpathian orogen

The Carpathian orogen is a fold and thrust belt with an arc-like appearance. It is a segment of the Alpine range and represents the main montainous chain in Romania. In contrast, the adjacent units exhibit a platform character, constituting as a whole the "Fore-Carpathians" area. The Romanian Carpathians consist of three large folded zones: the Eastern Carpathians, the Southern Carpathians and the Apuseni Mountains. Besides the above-mentioned mountain range, the Neogene molasse-type foredeep is situated along the outer margin of the orogen and in intramountain (Transylvanian Basin) and internal (Pannonian Basin) basins. As a whole, the Carpathian range has a long geological evolution, from Proterozoic to Quaternary.

The *Eastern Carpathians* can be divided into three zones: (1) Early Ordovician metamorphic formations, covered by Late Palaeozoic to Mesozoic sediments, (2) the "Flysch zone" consisting of Upper Jurassic, Cretaceous, Palaeogene and Neogene sediments, and (3) Neogene volcanics, mainly andesites.

The main units of the *Southern Carpathians* are the Danubian nappe system and the Getic–Supragetic nappe system. The Severin nappe complex is located between these structures. Except for the Severin nappe complex, the above-mentioned units comprise Proterozoic and Palaeozoic metamorphic rocks with intrusions of granitic plutons. The cover consists of Palaeozoic–Mesozoic sediments.

The *Apuseni Mountains* will be discussed in details in the following section.

The *Carpathian Foredeep* has an intermediate position between the orogen and the foreland and is built up of Neogene molasse. This unit is divided into two parts: the inner (folded) part, which borders the "Flysch zone", and the external (unfolded) part, which represents an asymmetrical depression superimposed on the platform margin.

The *Transylvanian Basin* is a Neogene basin, located between the Eastern Carpathians, the Apuseni Mountains and the Southern Carpathians. The basement consists of metamorphics, Permo-Mesozoic sediments and island arc volcanics (Ciupagea, 1970; Săndulescu, 1984; Ionescu *et al.*, 2009a). The Neogene sediments consist of conglomerates, sandstones, claystones, limestones, sands and dacitic tuffs (Huismans *et al.*, 1997; Ciulavu *et al.*, 2002). The Neogene sediments from the northwestern part of the Transylvanian Basin continue towards west into the Pannonian Basin.

1.3 The Apuseni Mountains

General data

The Apuseni Mts. are located in the inner part of the Carpathian arc (Fig. 1). They consist of two main tectonic structures (Săndulescu, 1984): the Northern Apuseni Mts. (Inner Dacides) and Southern Apuseni Mts. (Transylvanides). The Northern Apuseni Mts. include the Highiş, Codru–Moma, Bihor, Gilău, Pădurea Craiului, Vlădeasa, Plopiş and the Meseş Mountains, whereas the Metaliferi, Trascău and Drocea Mts. belong to the Southern Apuseni Mts.

The basement of the Northern Apuseni Mts. consists of Proterozoic metamorphic rocks (mostly middle–grade metamorphic sequences) and associated granitoids (Late Cambrian ~502–490 Ma, Middle to Late Devonian ~372–364 Ma and Early Permian ~278–264 Ma). The pre-Permian orogenic formations and the Permian molasse with associated acid volcanics are overlain by a Mesozoic sedimentary and volcanic cover (Dallmeyer *et al.*, 1999; Pană *et al.*, 2002).

The Southern Apuseni Mts. are dominated by Jurassic ophiolites and Island Arc Volcanics. The Upper Cretaceous banatites and Neogene volcanics are distributed in both units. The Neogene volcanism (Badenian[1]–Pliocene) is present especially in the Metaliferi Mountains and in the north-western part of the Northern Apuseni Mts.

The complex nappe structure in the Apuseni Mts. is due to several Cretaceous orogenic events. The Mid-Cretaceous "Austrian" phase and the Late Cretaceous "Laramian" phase formed the Southern Apuseni Mts., while the intra-Turonian event is responsible for the nappe structure in the Northern Apuseni Mts. The latter consists of the deeper Codru nappe system built up predominantly of Paleozoic and Mesozoic formations, and the structurally higher Biharia nappe system containing predominantly Palaeozoic metamorphic rocks. Both overthrust the "Bihor Autochthonous Unit" formed of Palaeozoic metamorphic rocks and a Paleozoic–Mesozoic sedimentary cover (Fig. 2). The Northern Apuseni Alpine tectonic units, termed as Inner Dacides by Săndulescu (1984), are correlated with the Western Carpathians and Eastern Alps structures (Ianovici *et al.*, 1969, 1976; Săndulescu, 1984; Balintoni, 1994, 1997).

During Mesozoic, an ocean existed between the continental crust of the Northern Apuseni Mts. (Tisia continent) on one side and the continental crust of the Carpathians (Getic plate) on the other side (Săndulescu, 1984). The remnants of this ocean, which disappeared in the "Main Tethys Suture Zone" are the Middle Jurassic ophiolites in the Southern Apuseni Mts. including the island arc

[1] A Middle Miocene (~16.5–13.0 Ma) chronostratigraphic stage used in the Central Paratethys time-scale (Vass & Balogh, 1989).

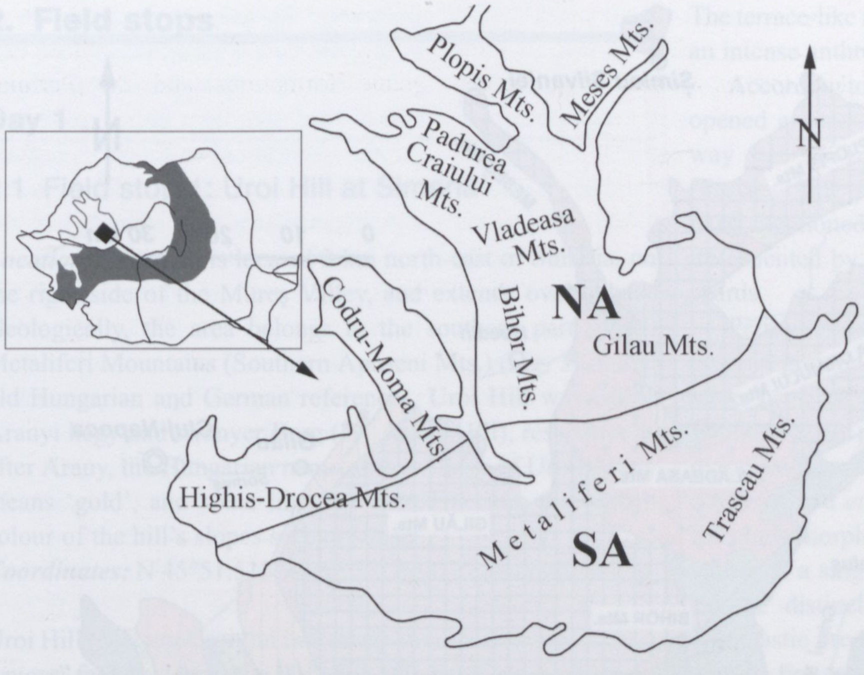

Fig. 1. General outline of the Apuseni Mountains showing the main geographical subdivisions and the geological division between the Northern Apuseni (NA) and the Southern Apuseni (SA) units (from Seghedi, 2004). The insert in upper left shows the position of the Apuseni Mts. in the Romanian territory (not to scale).

sequence (Bortolotti *et al.*, 2002) and their continuation beneath the Transylvanian Basin (Ionescu *et al.*, 2009a,b). The ophiolites consist of a plutonic sequence, a sheeted dyke complex and volcanics (Nicolae, 1995; Savu, 1996; Saccani *et al.*, 2001; Bortolotti *et al.*, 2002), overlain by Upper Jurassic calc-alkaline volcanics (Nicolae, 1995; Nicolae & Saccani, 2003) and Upper Jurassic platform limestones. During Cretaceous, flysch and wildflysch sediments (Lupu, 1976) were deposited.

Banatites

At the end of the Cretaceous, widespread intrusives, subvolcanic bodies, as well as volcanics, known as *banatites*, were formed. This magmatic event can be followed from the Northern Apuseni Mts. through the Southern Carpathians into the Srednogorie in Bulgaria (Ştefan *et al.*, 1988, 1992; Berza *et al.*, 1998). Von Cotta (1864) termed the volcanic and plutonic rocks displaying various compositions as "banatites", according to their occurrence in the Banat area, Romania. The most widespread notation for this belt today is "Banatitic magmatic and metallogenetic belt" (BMMB) according to Berza *et al.* (1998) or "Apuseni–Banat–Timok–Srednogorie Belt" (ABTS) according to Popov *et al.* (2003). The age range of the magmatic activity was estimated to last from 110 to 50 Ma by Ciobanu *et al.* (2002) based on various age dating radiometric methods. By contrast, Zimmerman *et al.* (2008) revealed only Late Cretaceous ages ranging from 92 to 72 Ma, based on Re-Os dating. For more details, see also Ilinca (2010) and Ionescu & Hoeck (2010).

Neogene volcanics

The latest magmatic event is the Cenozoic calc-alkaline to alkaline volcanism, widely exposed at the inner Carpathian arc from SE Austria, along the Western Carpathians, to the Eastern Carpathians in the Harghita Mountains (Romania). It also occurs in the central part of the Apuseni Mts. The Neogene magmatics range compositionally from basaltic andesites to dacites, with subordinate occurrences of alkaline rocks. Andesite is the most common and prevalent rock type. The famous Gold Quadrangle including the gold deposit of Roşia Montană, as well as the copper mine of Roşia Poieni are associated with the Neogene volcanism in the Apuseni Mts.

In the Eastern Carpathians, the magmatic event is related to the subduction of the Eastern European Platform beneath Tisia continent and the formation of a thrust and fault belt of the Carpathians followed by back-arc extension (Csontos, 1995). In the Apuseni Mts. (Tisia), the development of the Neogene volcanism is related to an extensional stage (Roşu *et al.*, 2004), as a consequence of the Neogene development of the Pannonian Basin (Fodor *et al.*, 1999) and the translational and rotational movements of the Tisia (Pătra?cu *et al.*, 1994; Csontos, 1995).

Radiometric ages of the Neogene magmatic rocks from the Southern Apuseni Mts. range from 14.7 to 7.4 Ma, with youngest age ~1.6 Ma (Uroi Hill). These data are in agreement with the magnetic polarity records and the biostratigraphic as well (Pécskay *et al.*, 1995; Roşu *et al.*, 1997, 2001).

Basaltic andesites are present as two small-scale occurrences in the Detunata hills, but also occur in the Zarand area (Savu *et al.*, 1993; Seghedi, 2004). Based on available K-Ar determinations, correlation of magnetic polarity data and petrological data, Roşu *et al.* (2004) separated, from north to south, four volcanic–intrusive areas: (1) Baia de Arieş, Roşia Montană–Bucium; (2) Zarand, Brad, Zlatna; (3) Băiţa–Săcărâmb and (4) Deva, including the occurrence at Uroi.

In the Banat area as well as in the southernmost part of the Eastern Carpathians (Perşani Mts.), Pliocene to Pleistocene alkali basaltic occurrences are encountered (Savu *et al.*, 1994a and Seghedi & Szakács, 1994; Seghedi *et al.*, 2004, respectively). The Banat occurrences were dated by Downes *et al.* (1995) at 2.5 to 2.6 Ma whereas the Perşani ages range from 2.2 to 0.35 Ma. The latter represent one of the youngest magmatic activities in Eastern Europe (Downes *et al.*, 1995). The volcanics in the Perşani Mts. consist of trachybasalts with abundant lherzolite xenoliths (Falus *et al.*, 2002, 2008).

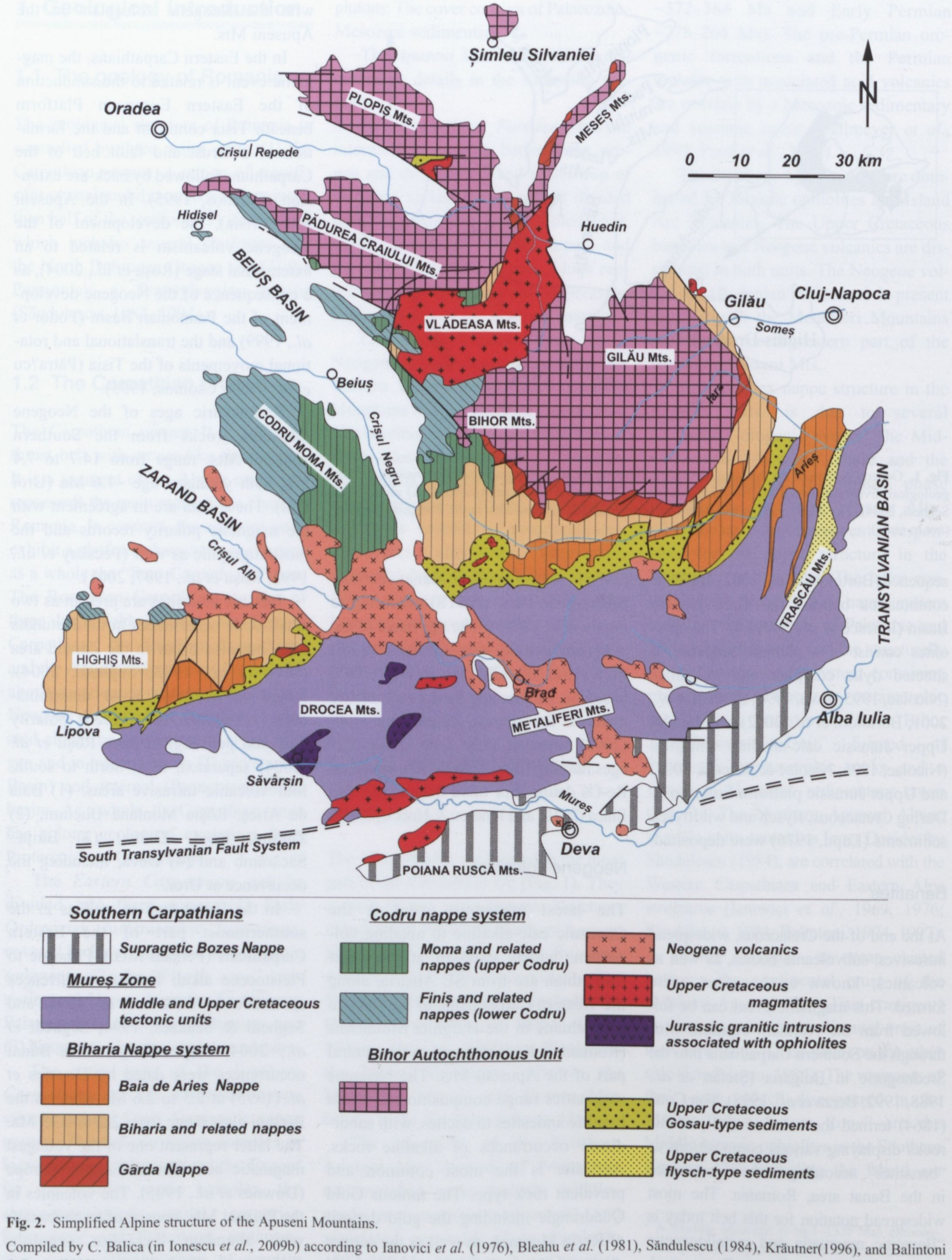

Fig. 2. Simplified Alpine structure of the Apuseni Mountains.

Compiled by C. Balica (in Ionescu *et al.*, 2009b) according to Ianovici *et al.* (1976), Bleahu *et al.* (1981), Săndulescu (1984), Kräutner(1996), and Balintoni & Pușteᅟ(2002).

2. Field stops

Day 1

2.1 Field stop 1: Uroi Hill at Simeria

Location: Uroi Hill is located 3 km north-east of Simeria, on the right side of the Mureș Valley, and extends over 1 km^2. Geologically, the area belongs to the southern part of the Metaliferi Mountains (Southern Apuseni Mts.) (Fig. 3). In the old Hungarian and German references, Uroi Hill was called Aranyi hegy and Aranyer Berg (*i.e.* Arany Hill), respectively, after Arany, the Hungarian name of the village of Uroi. Arany means 'gold', and some linguists derive it from the golden colour of the hill's slopes seen at sunset.

Coordinates: N 45°51.515' and E 23°2.581'; elevation: 300 m.

Uroi Hill (Măgura Uroiului in Romanian) represents the "*locus typicus*" for pseudobrookite $(Fe^{3+},Fe^{2+})_2(Ti,Fe^{2+})O_5$, with the theoretical formula of Fe_2TiO_5, and fluoro-magnesiohastingsite $(Na,K,Ca)Ca_2(Mg,Fe^{3+},Al,Ti)_5(Si,Al)_8O_{22}F_2$, having the IMA theoretical formula of $NaCa_2(Mg_4Fe^{3+})(Si_6Al_2)O_{22}F_2$). Pseudobrookite was identified for the first time in this occurrence in 1878 by Prof. Anton Koch, from the University of Cluj. Fluoro-magnesiohastingsite was identified and described as a new amphibole end-member in 2006 by Hans-Peter Bojar (Landesmuseum Joanneum, Graz) and Franz Walter (Institute of Earth Sciences, Graz).

Geology and mineralogy

Uroi Hill has a distinctive shape, a flat cone cut in half, with a steep southern slope and a gently sloping northern one (Fig. 4). The terrace-like morphologies on the south-eastern side indicate an intense anthropogenic activity.

According to Schafarzik (1909) the first quarry at Uroi was opened around 1866, when the construction of the first railway line in Transylvania started. However, other authors (Pascu, 1932; Pîrvu, 1964; Tudor, 1968; Wollmann, 1996) have mentioned several very old stone quarries in the area, documented by the presence of Dacian and Roman ceramics shards.

Petrographically, the Uroi Hill rocks display two rock types: a grey one, and a reddish, hematite-rich one. The rocks have been described as augite andesites (Koch, 1878), andesites with pseudobrookite (Lațiu, 1937), lava flows and pyroclastic rocks (Berbeleac, 1962), and finally as trachyandesites (Savu *et al.*, 1994b). Berbeleac (1962) found that the flat conic morphology of the hill does not represent the preservation of a single volcanic vent, but resulted from three successive distinct andesitic lava eruptions, accompanied by pyroclastic products (Fig. 5).

The first lava eruption, represented by grey andesites, covers the base of the hill and crops out in small quarries located in the close vicinity of the Mureș River and the Uroi–Rapoltu Mare village road (Fig. 3). The second lava generation is well preserved in outcrops and builds up the eastern, western and southern steep slopes of Uroi Hill. Mineralogically and petrographically, these rocks resemble the first lava generation, differing only by the crimson colour. The third lava level has a brownish red colour, an obvious flow texture and is more porous and softer than the second level. A thin level of pyroclastic rocks separates the second and the third main lava levels. In the northern part of the hill, where the third lava generation is almost entirely covered by soil, only a small outcrop is actually visible.

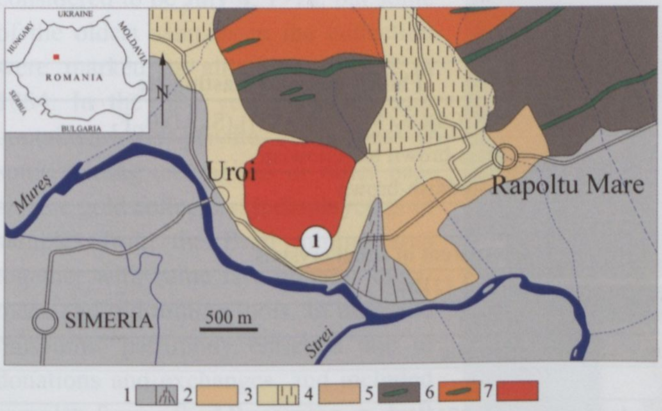

Fig. 3. Location of Field stop 1, Uroi Hill (white circle) on the geological map of Romania (redrawn from Bordea *et al.*, 1978). Legend: 1 – Holocene (actual alluvia and proluvium deposits – cone of dejection), 2 – Upper Pleistocene (fluvial deposits: gravel, sands), 3 – Quaternary (deluvial deposits and travertine), 4 – Middle Miocene (Badenian; marls, clays, limestones, sands), 5 – Lower Carboniferous (schists and sericitic-chloritic/sericitic-graphitic phyllites; metagabbros), 6 – Lower Carboniferous (metarhyolites; metagabbros), 7 – Pyroxene quartz-andesite with pseudobrookite. The top left inset shows the position of the area within Romania.

Fig. 4. The Uroi Hill (Photo Gh. Ilinca)

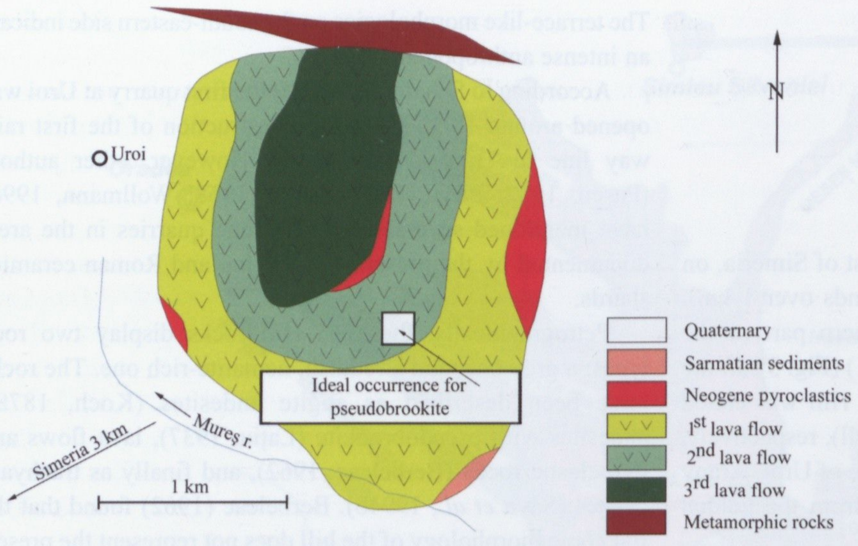

Fig. 5. Geological sketch of the Uroi Hill area (from König *et al.*, 2001, based on Berbeleac, 1962)

According to Roşu *et al.* (2004), pyroxene andesites at Uroi Hill have a pronounced shoshonitic character and represent the youngest (1.6 Ma) products of the alkaline magmatism in the Apuseni Mountains. A typical feature of andesites is the frequency of xenoliths consisting of gabbros, diorites and metamorphic rocks fragments. The xenoliths are surrounded by reaction coronas containing andraditic garnet, epidote, diopside, and hematite. The silica-rich xenoliths contain SiO_2 polymorphs, in particular tridymite.

The mineralogy of andesites includes plagioclase feldspar (andesine), clinopyroxene (augite), orthopyroxene ("hypersthene"), biotite, apatite, magnetite and hematite. "Hypersthene" forms small, elongated, reddish crystals (0.5–1 mm). It has been described first by Koch (1878) as szabóite, a new mineral species but Krenner soon proved that it is an oxidized variety of hypersthene (for a detailed research history see Papp, 2004). As "hypersthene" is no longer a valid species name according to the present internationally accepted nomenclature of pyroxenes and is included into Fe-rich enstatite or ferrosilite minerals (Morimoto, 1988), "szabóite" can be regarded as a partially weathered enstatite.

Pseudobrookite is present only in the reddish andesites (corresponding to the second level/generation of lava flows), both in the rock matrix and in the fissures. It forms black, elongated-tabular crystals, with a strong metallic lustre, up to 5 mm in length (Fig. 6). In almost all cases pseudobrookite associates with Fe-rich enstatite ("hypersthene") and hematite. Optical properties and the crystal structure of pseudobrookite were studied by Koch (1878), vom Rath (1880), Traube (1892) and Laţiu (1937), see Papp (2004) for details. The most important mineralogical features of pseudobrookite are listed in Table 1.

The new mineral fluoro-magnesiohastingsite, first described by Bojar & Walter (2006) forms small prismatic

Fig. 6. Pseudobrookite (black) and "hypersthene" (reddish) crystals; image width: 0.5 cm (from König *et al.*, 2001).

Table 1. The main mineralogical features of pseudobrookite (PDF card 41-1432, ICSD, 1998; Anthony *et al.*, 1997) and fluoro-magnesiohastingsite (from Bojar & Walter, 2006).

	Pseudobrookite	**Fluoro-magnesiohastingsite**
Chemical formula	Fe_2TiO_5 (theor.); $(Fe^{3+},Fe^{2+})_2(Ti,Fe^{2+})O_5$	$(Na,K,Ca)Ca_2(Mg,Fe^{3+},Al,Ti)_5(Si,Al)_8O_{22}F_2$
Colour	dark reddish-brown, brownish-black, black	reddish-brown to yellowish
Streak	reddish brown to ochre yellow	light reddish-brown
Lustre	metallic	vitreous
Transparency	opaque	transparent in small crystals
Cleavage	distinct {010}	perfect {110}
Fracture	conchoidal	no data
Crystal forms	prismatic to tabular, acicular in radial array	prismatic
Crystal system	orthorhombic monoclinic	
Cell parameters	a = 9.796 Å; b = 9.981 Å; c = 3.720 Å; Z = 4; V = 364.71 Å³	a = 9.871(1) Å; b = 18.006(2) Å; c = 5.314(1) Å; β = 105.37°; Z = 2; V = 910.7(2) Å³
Space group	*Bbmm*	*C2/m*
X-ray diffraction (I/I_0)	3.486 (1) 2.752 (1) 4.901 (4)	3.124 (100) 8.421 (61) 3.271 (61)
Mohs hardness	6–6.5	6
Density (g/cm³)	4.39	3.18
Appearance	as druses and fillings in voids of volcanic rocks	crystals in small cavities of xenoliths
Occurrences	Romania (Măgura Uroiului), Italy (Vesuvius, Etna)	Romania (Măgura Uroiului)

crystals (up to 3 mm in length) covering the walls of small cavities in altered xenoliths. It is accompanied by Ti-rich hematite, augite, phlogopite, enstatite, feldspar, tridymite, titanite, fluorapatite, ilmenite and pseudobrookite. The crystals have a reddish-brown to yellowish colour, light reddish-brown streak, vitreous lustre and a perfect {110} cleavage. The main mineralogical features of pseudobrookite and fluoro-magnesio-hastingsite are summarised in Table 1.

Day 2

2.2 Field stop 2: Gold Museum in Brad

Location: In the centre of Brad city (Hunedoara County), 40 km north of Deva (Fig. 8).
Coordinates: N 46°07.724' and E 22°47.444'; elevation: 270 m.

Brad represents the heart of the famous gold mining area, the "Gold Quadrangle", which had been an attraction for the local populations since Antiquity. The town hosts one of the oldest museums in Romania, the Gold Museum, the only collection of this type in Europe.

The foundation of the museum is considered to be July 4, 1912, but some of the oldest samples in the collection were marked as already collected in 1884. In the first years, the museum contained only private collections of some mining technicians or other passionate gold collectors. It displayed gold samples from the Brad mining area together with some rare mineral specimens and old mining tools. In time, the museums' patrimony enriched due to donations and exchanges, and included samples from other Romanian as well as from foreign mineral localities. Currently, the museum is managed by the Mining Company Barza–Brad (Bradmin Society, part of the National Company Minvest Deva).

The Gold museum hosts an invaluable heritage consisting of more than 2,500 mineral specimens originating from all over the world, of which about 1000 are gold samples. Mining-related archaeological materials are also displayed. The museum shows the types of gold mineralization in Romania, in particular from the Brad area. Outstanding specimens of minerals firstly described in Romania *e.g.* nagyágite, sylvanite, tellurium, pseudobrookite, as well as agates from Techereu (Trascău Mts. in the Apuseni Mts.), large crystals of pyrite and sphalerite from the Rodna ore deposit (Eastern Carpathians), and skarn minerals from Banat. Highlights of the collection are green fluorite octahedrons from Cavnic (Maramureş area), diamonds from South Africa, large cubic pyrite crystals with an edge length of 10 cm.

The main attraction of the museum is represented by the gold minerals of various sizes and shapes, collected from the mines of the Metaliferi Mountains. They consist of native gold, gold-containing minerals, associated with Ag and Pb tellurides. Some specimens are unique, *e.g.* large gold crystals, exceeding 1 cm. The mining works from Baia de Arieş, Săcărâmb, Almaş–Stănija, Hărţăgani, and Zlatna area are represented by samples of gold associated with base metal sulphides and carbonates (rhodochrosite). The native gold samples collected from the Barza gold mining area are shown in a separate room within the museum.

Spectacular native gold specimens resembling animals, flowers etc. but created during natural processes got names according to their shape (Figs. 7a–7d): "The Map of Romania", "The Cat", "Fram, the polar bear", "The Little Dog" (Fig. 7a), "The Cannon of Avram Iancu", "The Feather of Eminescu", "The Bird-Wing" (Fig. 7b). The gold dodecahedron (Fig. 7c) is considered to be a rarity. Two of the most beautiful and representative samples resemble "lizards". One of them (Fig. 7d) is 4.5 grams in weight and it was displayed at the Universal Exhibition in Paris, in 1937. These "lizard-like" samples formed in geodes, originally as a thin thread that was subsequently covered by multiple and very fine lamellae of gold.

Besides gold from the Apuseni Mountains, it is also worth to mention gold samples from the Baia Mare and Bozovici (Banat) areas, as well as gold specimens from abroad, such as the gold-bearing conglomerates from South Africa, the "golden viper" from Algeria and several specimens from North America.

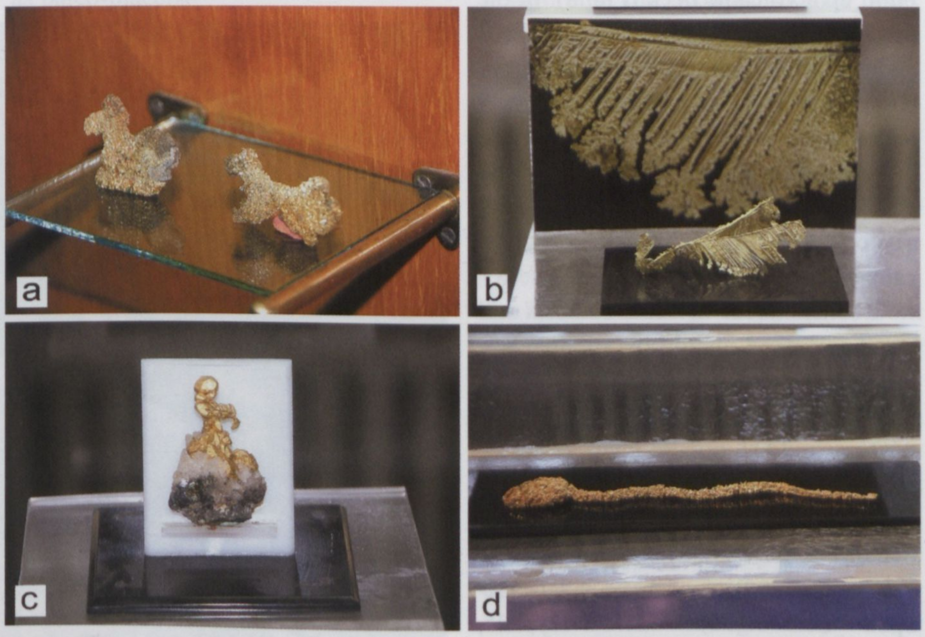

Fig. 7. Gold samples from Gold Museum in Brad: a – "The Little Dog", b – "The Butterfly", c – cubic and dodecahedral crystals, d – "The Lizard" (Photos: H. Bedelean and F. Forray).

2.3 Field stop 3: Arsului Valley quarry at Crişcior, near Brad

Location: 1.3 km south of the village of Crişcior, located 6 km east from Brad on the road to Abrud (Fig. 8). The Arsului Valley quarry (Fig. 9) is still active, being run by the PRODANDEZIT SRL Company. It produces crushed rock of various size and paving stone slabs.

Coordinates: N 46°6.831' and E 22°52.033'; elevation: 390 m.

In the Apuseni Mts. the Neogene magmatism is distinctive and took place in several phases in the Badenian to Pliocene interval. In the Metaliferi Mts. area three major Neogene igneous cycles were identified by Ianovici *et al.* (1976), each of it having a specific evolution of the geochemical features. Within each cycle, distinctive eruption phases or sequences evidenced by rock associations with similar geochemical features were defined.

In the eastern part of the Brad mining area, mineral associations typical for late hydrothermal events are hosted by Sarmatian–Pliocene andesitic rocks assigned to the second eruptive cycle.

The Valea Arsului quarry (Fig. 9) is mined for Sarmatian hornblende- and orthopyroxene-bearing andesites that build up a volcanic neck (Fig. 8). In the lower part of the quarry, a light coloured andesite crops out, while to the top, a darker one is present. The upper-level andesite is more fresh, massive and homogeneous and contains geodes and small fissures filled mainly by zeolites, associated with okenite, apophyllite, calcite, epidote, and chlorite.

Zeolites occur in veins or nests and are represented mainly by stilbite, laumontite and chabazite.

Stilbite $NaCa_4Al_9Si_{27}O_{72} \cdot 30H_2O$ forms white or reddish bundle-like rosettes of idiomorphic, transparent lamellar crystals. *Laumontite* $Ca_4Al_8Si_{16}O_{48} \cdot 16H_2O$ is one of the most frequent zeolite species in Romania. It occurs here as well developed (mm-sized) white crystals, grouped in nests. Exposed to the air, it dehydrates and turns into a microcrystalline powdery mass known as "caporcianite" (Bedelean & Nepodaca, 1975). *Chabazite* $(Ca_{0,5}Na,K)_4Al_4Si_8O_{24} \cdot 12H_2O$ forms pseudo-cubic, colourless crystals and is generally associated with calcite (Bedelean & Nepodaca, 1975).

In the andesite quarry, besides zeolites, a number of other minerals, such as okenite and apophyllite occur. *Okenite* $Ca_5Si_9O_{23} \cdot 9H_2O$ has a mixed, ino- to phyllosilicate structure. At Valea Arsului it occurs in veins or nests as spherical

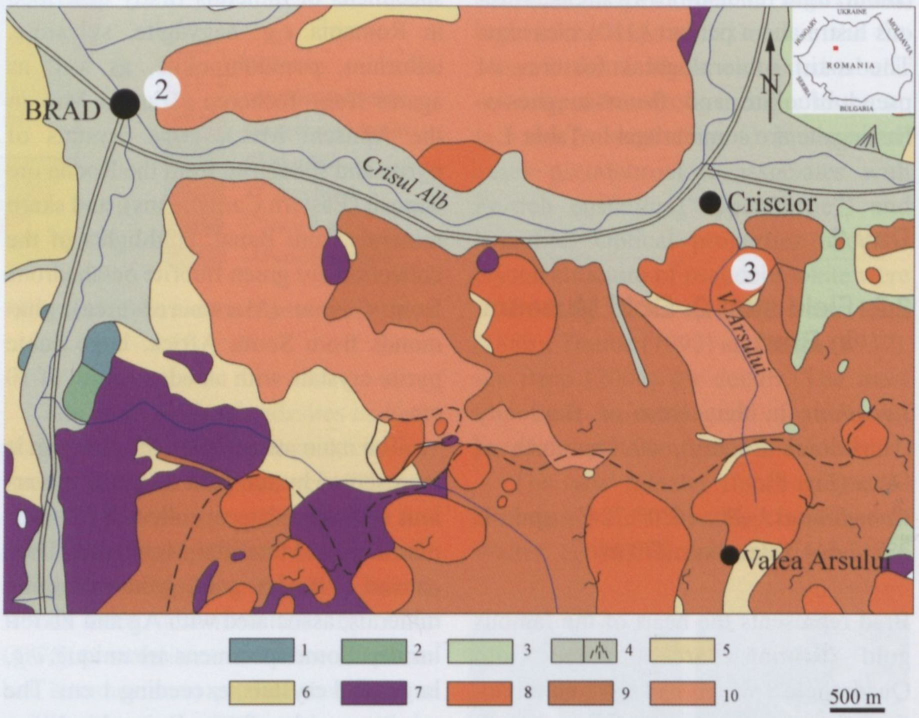

Fig. 8. Location of Field stops 2 and 3 on the geological map of Romania (from Bordea & Borcoş, 1972, modified). Legend: 1 – Tithonian; 2 – Upper Aptian; 3 – Upper Albian; 4 – Cenomanian-Vraconian; 5 – Badenian; 6 – Lower Sarmatian; 7 – Neogene basalts; 8 – Neogene pyroxene andesites (rooted bodies); 9 – Neogene pyroxene andesites (lava flows); 10 – Neogene pyroxene andesites (pyroclastites). The upper right inset shows the position of the area within Romania.

Fig. 9. View downhill to the Valea Arsului quarry (Photo H. Bedelean).

aggregates (up to 1–2 cm in diameter) consisting of white, fine, acicular crystals, often associated with stilbite or apophyllite (Istrate, 1980). *Apophyllite* $(K,Na)Ca_4Si_8O_{20}(OH,F)\cdot 8H_2O$ (mineral group: fluorapophyllite, hydroxyapophyllite, natroapophyllite) occurs as colourless or greenish, idiomorphous, short prismatic, crystals, up to 1 cm in size (Istrate & Udubaşa, 1981). The zeolites–okenite–apophyllite association occurs only at the upper level of the quarry.

2.4 Field stop 4: Mining Museum in Roşia Montană

Location: Roşia Montană is situated north-east of Abrud, ~7 km upstream in the Roşia valley. The Mining Museum from Roşia Montană is signalized by a tourist sign "Galeriile Romane Roşia Montană" (Roman galleries at Roşia Montană). Alburnus Maior is the Roman name of Roşia Montană.

Coordinates: N 46°18.388' and E 23°7.857'; elevation: 870 m.

Roşia Montană is a world class Au-Ag deposit (Manske *et al.*, 2006) hosted by volcanic (dacite) and volcaniclastic (vent breccia) rocks. It represents the north-western part of a NW–SE trending extensional basin (Roşia Montana–Bucium), which, together with Stănija–Zlatna and Brad–Săcărâmb basins, host the majority of Neogene volcanic rocks and the related Au-Ag and Cu ore deposits of the Southern Apuseni Mts.

The crystalline basement does not crop out in the Roşia Montană area (Fig. 10). The sedimentary rocks consist of a well developed Upper Cretaceous flysch and poorly developed Upper Badenian–Lower Sarmatian sequences (not shown on the map), interstratified with the volcaniclastics of the so-called Vent Breccia (Leary *et al.*, 2004). The volcanic rocks are represented by dacites (Cetate dacite) and andesites (Rotunda andesite), and their related volcaniclastics. Cetate dacite occurs in Cetate, Cârnic and Coş massifs, which represent remnants of two dacitic domes that pierced the Vent Breccia. Rotunda andesites and the related pyroclastic rocks cover the north and the north-eastern parts of the Roşia Montana perimeter (Fig. 10).

The volcanic activity from Roşia Montana started with the emplacement of Cetate dacite (13.5 ± 1.1 Ma) and continued with the Rotunda andesite (9.3 ± 0.47 Ma) (Pécskay *et al.*, 1995; Roşu *et al.*, 1997). An important phreatomagmatic activity (maar – diatreme) took place before, during and after the emplacement of Cetate dacite, being responsible among others by the formation of the Vent Breccia. The youngest phreatomagmatic breccia body known so far has an age of 11.0 ± 0.8 Ma (Manske *et al.*, 2004).

Roşu *et al.* (2004) obtained an age of 13.6 Ma for the altered and mineralised dacite from Cârnic massif, while the adularia associated with some quartz veins from Cetate massif indicated an age of 12.7–12.8 Ma (Manske *et al.*, 2004).

Roşia Montana is a low- to intermediate sulfidation deposit (Mârza *et al.*, 1997; Tămaş & Bailly 1998 and 1999; Sillitoe & Hedenquist, 2003; Leary *et al.*, 2004; Tămaş *et al.*, 2006). The ore bodies are represented by veins, breccias, impregnations, stockworks, as well as paleo-placers.

The brecciation at Roşia Montana is very complex. Several genetic types of mineralized breccias have been pointed out (Tămaş, 2002; Minuţ *et al.*, 2004; Tămaş, 2007): phreatomagmatic (Cetate Breccia, Black Breccia, Corhuri Breccia, Găuri Breccia, Piatra Corbului Breccia, Cănţălişte Breccia etc.), phreatic (many breccia bodies all around the deposit) and tectonic (Zeus Breccia from Cetate massif). Tămaş (2007) showed that many Roşia Montană breccia bodies, irrespective of their genetic type, were affected by later superimposed brecciation event(s), *i.e.* tectonic but especially phreatomagmatic and/or phreatic. Several examples will be discussed.

The Roşia Montană ore deposit was mined until recently (June 2006) by a state mining company (Minvest Deva), while a new mining project of a Canadian–Romanian mining company (Roşia Montană Gold Corporation) is currently under licensing process. The mining activity of the Romanian state company took place in the underground in several mining fields, *i.e.* Cetate, Cârnic, Ţarina, Orlea, Coş, Găuri, Carpeni, Jig-Văidoaia, Cârnicel, as well as at the surface (Cetate open pit). Part of these mining fields was developed from those mined as early as the Roman Age, *i.e.* Cetate, Cârnic, Coş, Găuri, Cârnicel, Orlea, Carpeni, with traces of different epochs of mining (Cauuet *et al.*, 2003).

Since 1999 a mining archaeological study of the Roşia Montana deposit has been in progress, conducted by French archaeologists from Toulouse II - Le Mirail University (France). Several years of studies allowed a better understanding of the Roman mining from Roşia Montana (Cauuet *et al.*, 2003; Tămaş & Cauuet, 2009), as well as the identification of the real extent of the underground network, of more than 5 km (cumulative length) of adits (Cauuet, unpublished reports).

The Cetate massif was famous for the "Curţile Romane" (Roman Courts), *i.e.* large open pits preserved since the Roman times. In the early 1970s the surface exploitation of the Cetate massif began and the Roman Courts were destroyed without previous archaeological research. Only a simplified surface plan and several cross sections (Fig. 11) are now available.

In the 1960s, Roman galleries partly filled with mud (Sîntimbrean, 1989) were found at the +725 m level of the Orlea mining field (Fig. 10). Later on, the Roman workings were isolated from the modern workings, cleaned and consolidated with concrete walls and reinforcements. Additional workings such as an inclined shaft, adits and enlargements, as well electric supply and drainage facilitate today the access. Since 1976 the Roman galleries are open to the public in the frame of the "Roşia Montană Mining Museum". The museum consists of two main sections, an open-air and an underground one.

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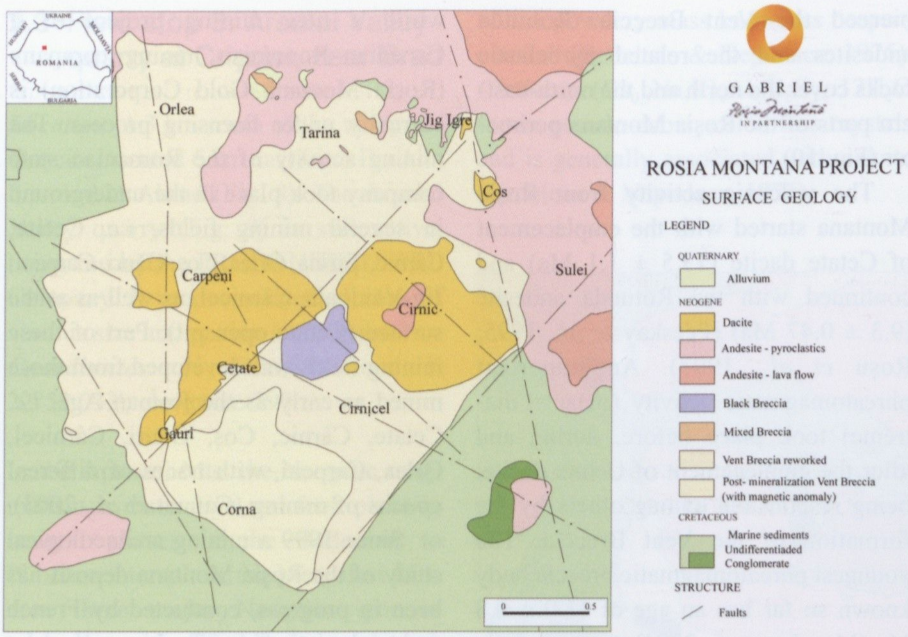

Fig. 10. Geology of the Roşia Montană ore deposit (data from Gabriel Resources – RMGC).

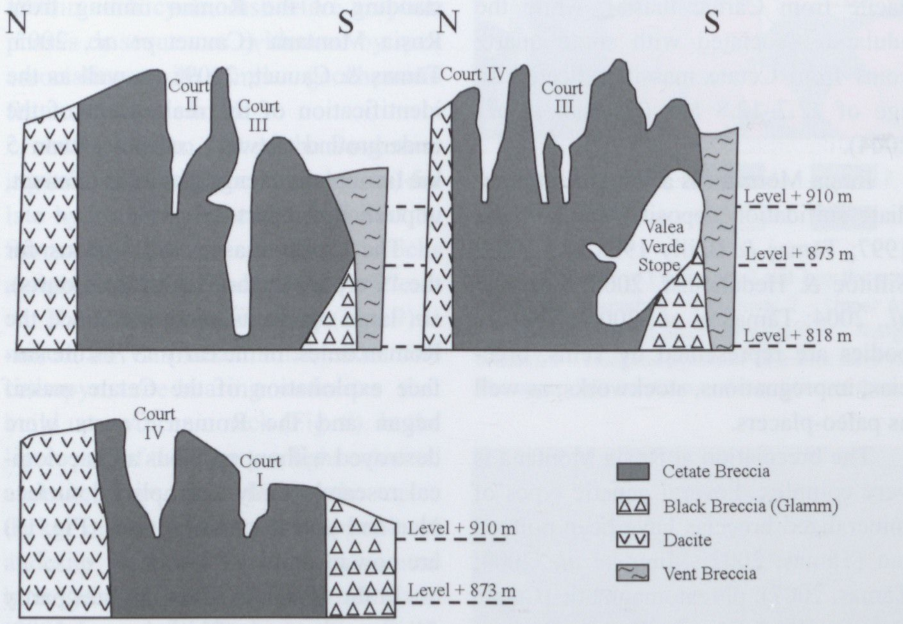

Fig. 11. Simplified cross-section of the Cetate Massif, with the Roman open pits, called "The Courts". Image before the begining of the open pit exploitation (from Sântimbrean & Wolmann, 1974, redrawn and updated); the huge underground unsupported stopes like Valea Verde are called "*coranda*" by the local miners (modern workings).

The open-air section displays a Roman *lapidarium* (Fig. 12) and a group of old and modern (from the beginning of the XXth century) equipment used for mining and ore processing. The *lapidarium* is composed of votive altars and funerary monuments discovered by chance or in 1983 during the only archaeological campaign held during the communism (Sîntimbrean, 1989). Some of the artifacts were recovered from old buildings of the village of Roşia Montană, where they were re-used as ashlars. The epigraphic artifacts together with the famous wooden tablets discovered in the underground workings during the XVIIIth and XIXth centuries, provide information about the Roman Dacia with a special emphasis on the Roşia Montană area: people movements, economy, mining activity, gods and beliefs, prices, contracts etc.

Apart from the modern access to the Roman galleries, an old, traditional entrance in the underground with its wooden propping, a wooden wagon and wooden rails were reconstructed. An old wooden stamp water mill used for ore-processing and more recent equipments, dating from the late XIXth – early XXth centuries, such as a Californian-type mill (Fraser & Chalmers Co., England) and the extraction engine from the former Cetate Shaft (Roşia Montană) are also displayed. A flotation chain composed of a ball mill with a holding capacity of 30 tons in 24 hours, which functioned at Baia de Arieş ore deposit (north of Roşia Montană), various bins, a belt conveyer, and flotation cells can be seen as well.

The underground section of the Mining Museum consists of almost 200 m of Roman workings. The access from the surface (Fig. 13) is possible through a 53-m long inclined shaft with 157 steps, which continues into a 42-m long adit before entering into the Roman workings (Fig. 14). The difference between the modern and the Roman workings is obvious: the first are sustained by concrete bricks, while the second are not supported at all. They still show signs of the use of iron tools (chisels and hammers). The shape is also completely different: the modern adits/inclined shafts have rounded ceiling while the Roman

Fig. 12. The *Lapidarium* from the open air section of the Roşia Montană Mining Museum (Photo C. Tămaş).

Fig. 13. The entrance into the underground section of the Mining Museum, Roşia Montană. Besides the entrance, the Latin text of the oldest wooden wax tablets discovered at Roşia Montană (dated on 6th February, 131) is engraved (Photo C. Ionescu).

ones have a trapezoidal cross section with flat ceiling (Fig. 15). In the southern part, the Roman adit has fairly constant dimensions, ranging from 1.7 to 1.8 m height, 0.87 to 1.05 m width at the ceiling and 1.2 to 1.4 m at the base. From place to place, the Roman adits show small notches used for lamps, as well as remnants of the face lines still preserved on the walls after slight changes of the digging direction by the Roman miners. The original drainage channel is now masked by a concrete channel. The northern extremity of the Roman workings area is crosscut by a modern ascending drift. In the upper part of this inclined shaft a steeply dipping banded quartz vein is crosscut by a rhodochrosite–rhodonite vein, both hosted in the Vent Breccia.

Day 3

2.5 Field stop 5: Roşia Montană: Găuri mining field

The Găuri mining field is among the smallest in Roşia Montană but it is well known due to its ancient mining vestiges. As concerns the geology, Găuri hill represents the south-westernmost dacite occurrence at Roşia Montană (Fig.10). Dacite underwent potassic and phyllic hydrothermal alteration and silicification additionally to a dense, stockwork-like fracturing. Dacite hosts a phreatomagmatic breccia pipe, for the first time mentioned by Tămaş *et al.* (2003), who named it *Găuri Breccia*.

The stop offers the possibility to see a fire setting stope (so called Găuri stope) located on the southern slope of the Găuri Hill (Fig. 16), and to observe the differences between the two Roman mining techniques: digging by hand tools and by fire setting. Găuri stope was previously mentioned by Sîntimbrean (1989). Later on, Cauuet *et al.* (2003) carried out mining archaeological research and assigned it to the Roman period (Cauuet, unpubl. report). Only two occurrences of fire setting workings are known at Roşia Montană: Piatra Corbului (Cârnic massif) and Găuri.

With the exception of the fire setting workings, the rest of the openings at the southern slope of the Găuri Hill are modern. The Roman stope consists of several levels similar to the modern sublevel mining. Each sub-level resulted from successive fire attack fronts that allow a gradual advancing into the country rock and the ore. The walls and the ceiling have rounded shape. The surface of the rock faces is smooth and there are no traces of tools. Nice cupolas are still preserved in the ceilings of different sublevels, either close to the surface, either deeper in the underground.

The Roman stope followed a dyke-like stockwork zone with black hydrothermal cement (so-called *chinga*) and thin quartz veins. Precious metal mineralization is hosted in the *chinga*, the quartz veins and the transition zone between them. The mineralized zone has a variable width ranging from few centimetres up to 1 m. The intense silicification increased the rock hardness considerably thus forcing the Roman workers to use the fire setting.

Whereas in the southern part of the stope the ore is hosted by a silicified dacite, in the northern part the host rock is represented by Găuri Breccia, easily

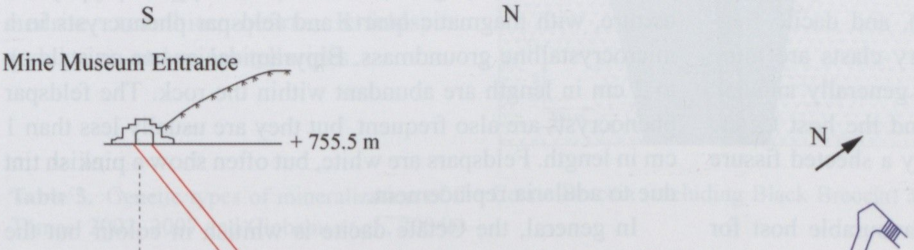

Fig. 14. Map of the Roşia Montană Underground Mining Museum. A–B (in red): vertical cross-section of the modern workings – the access from the surface; B–C (in green): plan view of the Roman workings (simplified from Sîntimbrean, 1989).

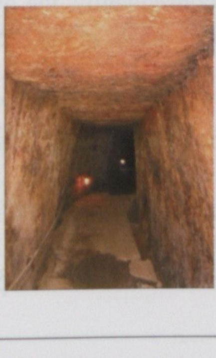

Fig. 15. Trapezoidal Roman adit from Roşia Montană Mining Museum (Photo C. Tămaş).

visible on the ceiling and the walls. This breccia occurs also in the modern workings of the Găuri mining field (+855 level), and crops out at the surface on the northern slope of the Găuri Hill. Based on surface and underground mapping, Tămaş *et al.* (2003) inferred a pipe-like shape of about 20-m diameter for the Găuri Breccia. The pipe is slightly tilted towards the south and was crosscut by the Roman fire setting exploitation in its southern part.

Fig. 16. The entrance in the Roman stope from Găuri mining field (Cetate massif). The stope shows typical rounded walls in the upper part while in the lower part it was re-shaped by the modern exploitation (traces of blast holes). The width of the stope is about 1.8 m at the bottom of the image (Photo C. Tămaş).

The Găuri Breccia is matrix-supported, with a fine-grained matrix prevailing over the clasts. The rock fragments have various lithologies that illustrate the basement and the host rocks *e.g.* metamorphic (garnet micaschists, gneisses), Cretaceous sediments (sandstones, shales), and dacite fragments. The crystalline and the sedimentary clasts are more rounded than the dacite clasts, which are generally angular. The contact between the Găuri Breccia and the host Cetate dacite is sharp and sometimes is marked by a sheeted fissure system within the latter.

The intensely silicified dacite was a favourable host for stockwork fracturing and deposition of the hydrothermal cement (*chinga*) and quartz veinlets. Precious metal mineralization is hosted in the *chinga*, quartz and the transition zone between them. By contrast, the fine-grained matrix of the Găuri Breccia did not allow the development of the mineralized structure, and consequently, the dyke-like shaped stockwork vanishes towards north, in the breccia body.

2.6 Field stop 6: Roşia Montană: Cetate open pit

The surface exploitation of the Cetate massif started in 1972 (Sîntimbrean, 1989) and lasted until 2006 when the Roşia Montană state mine was closed. The open pit was focused on the Cetate Breccia, the most important ore body of the deposit. During almost 35 years of continuous exploitation, the surface was lowered by ca. 130 m (Fig. 17), and the Roman open pits (*Roman Courts*) were completely destroyed. The Cetate massif is made mostly of the so-called Cetate dacite (Fig. 10). Several breccias (Vent Breccia, Cetate Breccia, Black Breccia) associated to the Cetate dacite, are cropping out in the open pit.

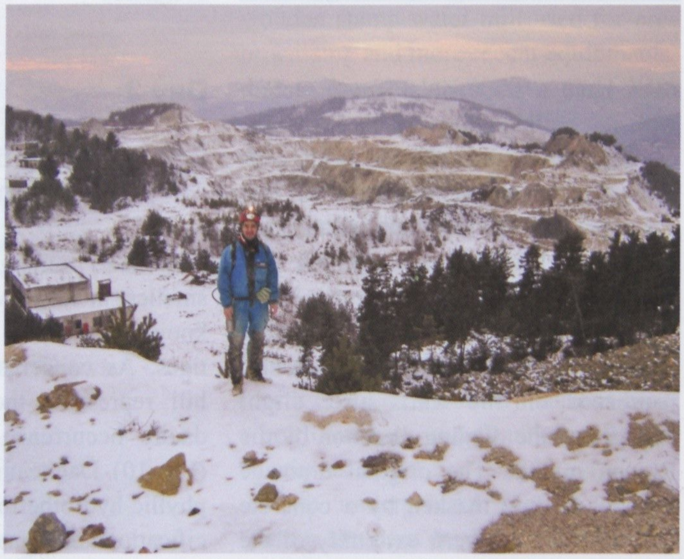

Fig. 17. The Cetate open pit seen from east (Cârnic western slope) six month after the closing (Photo D. Tănase).

Cetate dacite

The Cetate dacite crops out in the Cetate, Cârnic, Coş, and Văidoaia massifs (Fig. 10). The rock has typical porphyritic texture, with magmatic quartz and feldspar phenocrysts in a microcrystalline groundmass. Bipyramidal quartz crystals up to 2 cm in length are abundant within the rock. The feldspar phenocrysts are also frequent, but they are usually less than 1 cm in length. Feldspars are white, but often show a pinkish tint due to adularia replacement.

In general, the Cetate dacite is whitish in colour but the hues depend on the alteration. Dacite is heavy altered, showing a widespread adularia–sericite formation. X-ray diffraction and TEM electron microscopy confirmed that the most abundant clay mineral is illite, which is accompanied in a lesser extent by interlayered illite/montmorillonite and kaolinite, while carbonates occur only subordinately (Tămaş, 2002). The silicification is closely related to the ore bodies (veins, breccias, stockworks) and is responsible for the gray hues of the dacite host rock and the increase of the rock hardness.

Along the road towards the Cetate open pit, in the southwestern extremity of the Cârnic massif, the Cetate dacite will be observed. This place is known as "white rocks" due to the white color of the altered, highly friable rock. Well-developed bipyramidal quartz crystals can be easily collected.

Cetate Breccia

The road towards the Cetate open pit passes through the so-called Black Breccia (Leary *et al.*, 2004), formerly known as "Glamm Formation" (Mârza *et al.*, 1990, Tămaş, 2002). This breccia is regarded by Leary *et al.* (2004) as an independent structure, postdating the Cetate Breccia. Tămaş (2002) considered the Black Breccia as a particular facies of the Cetate Breccia, *i.e.* the fluidization channel of the Cetate phreatomagmatic breccia body (Fig. 18). The late mineral timing of brecciation for Black Breccia in respect with mineralization is proved by the presence of ore fragments and undisturbed vein swarm of Mn-bearing gangue minerals hosted in its central-western part. The close spatial relationship between rock fragments with different origin and their position in respect to the breccia body (*e.g.* metamorphic fragments from depths and wood fragments from the surface) indicates the setup of fluidization (*sensu* Lorenz, 1975) during the phreatomagmatic evolution of the pipe.

As concerns the relationships between the Black Breccia and the Cetate Breccia *s.s.*, there is no sharp or irregular contact between them, but a gradual transition marked by color change, matrix type, as well as rock fragments (frequency, size, shape, composition) and open spaces (frequency, size). The main features of the Cetate Breccia are summarized in Table 2.

Table 2. The main features of the Cetate Breccia (including the Black Breccia).

	Features
Morphology	Pipe-like
Clast *vs.* matrix	Matrix-dominated (50 to 90%); matrix-supported breccias
Clast lithology	Heterolithologic: dacite (different alterations), metamorphics (micaschist, gneiss, marble), sediments (sandstones, shales), ore fragments, breccia fragments (older breccias); wood and charcoal fragments
Matrix	Variable, from very fine-grained (Black Breccia) to coarse matrix (Cetate Breccia)
Open spaces	Very minor in the Black Breccia, abundant in the Cetate Breccia
Breccia/host rock contact	Sharp, sometimes irregular
Alteration	Almost absent in the Black Breccia matrix, but very intense in the Cetate Breccia; Potassic, phyllic and argillic alterations as well as silicification;
Mineralization	Electrum, acanthite, freibergite, Ag-rich tetrahedrite, common sulphides and tellurides
Brecciation mechanism	Reiterated phreatomagmatic eruptions with the setup of fluidization, overprinted by phreatic brecciation

Within the Cetate Breccia body and the dacite host rock several genetic types of mineralization and corresponding mineral assemblages were identified (Tămaş, 2002, 2007; Table 3). The mineralogy of the ore hosted by the Cetate Breccia is dominated by pyrite, electrum, chalcopyrite, galena, sphalerite, tetrahedrite, acanthite, quartz, K-feldspar (adularia), and minor tellurides.

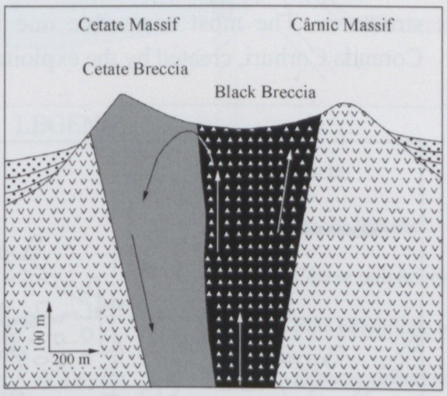

Fig. 18. Simplified model of the Cetate phreatomagmatic breccia pipe genesis with eccentric (non-central) position of the fluidization channel (Black Breccia), respectively the set up of a fluidization cell (from Tămaş, 2002). Legend: 1 – Cetate Breccia (*sensu stricto*, Leary *et al.*, 2004); 2 – Black Breccia; 3 – Cetate dacite; 4 – vent breccia; 5 – Transport direction within Cetate Breccia (*sensu lato*, Tămaş, 2002).

Table 3. Genetic types of mineralization of the Cetate Breccia (including Black Breccia) and their precious metals assemblages (based on Tămaş, 2002, 2007 and Ciobanu *et al.*, 2004a).

Genetic type	Electrum association	Overall mineralogy
Stockwork veining: quartz and K-feldspar (adularia) veinlets (dacite host rock)	pyrite–electrum sphalerite–electrum	quartz, adularia, pyrite, sphalerite, marcasite, chalcopyrite, galena, electrum, acanthite, Ag-bearing tetrahedrite–tennantite
Common sulphides and quartz veins (Cetate Breccia)	–	quartz, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, tennantite
Fissures and open spaces with quartz (Cetate Breccia)	pyrite–electrum quartz–electrum	quartz (amethyst), pyrite, electrum (gold)
Veins with Mn-gangue minerals (Cetate Breccia)	galena–chalcopyrite–electrum hessite–electrum–sphalerite quartz–electrum	quartz, rhodochrosite, rhodonite,sphalerite, galena, chalcopyrite, hessite, cervelleite, petzite, electrum
Clast-supported breccia (Cetate Breccia)	galena–electrum	calcite, pyrite, galena, sphalerite, electrum
Phreatic breccias (Cetate Breccia)	sphalerite–electrum	quartz, carbonates (calcite, siderite?), sphalerite, galena, pyrite, electrum

Rhodochrosite–rhodonite veins

Before the entry in the open pit, the road cuts through the Black Breccia containing a rhodochrosite–rhodonite vein swarm striking N–S (Fig. 19). The individual veins have a width ranging from a few millimetres up to 10 cm; the veins are 70° dipping westward. The veins are zoned (Fig. 20), with bands of adularia, intermingled rhodochrosite–rhodonite sequences, and a final axial quartz deposition sequence. Common sulphides (sphalerite, chalcopyrite, galena, pyrite) are present in these veins.
Recent studies (Ciobanu *et al.*, 2004a; Tămaş *et al.*, 2004, 2006) showed the presence of tellurides such as hessite, cervelleite and petzite in close relationships with the Mn-bearing gangue minerals (Table 5). Argyrodite and acanthite have been found as infilling of vugs within the Cetate Breccia (Ciobanu *et al.*, 2004a).

Fig. 19. Rhodochrosite–rhodonite parallel veins crosscutting the Black Breccia in the Cetate open pit, +886 m level (from Tămaş, 2007).

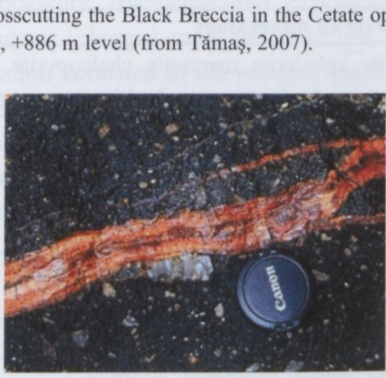

Fig. 20. Detail of a rhodochrosite–rhodonite vein from the Black Breccia, Cetate open pit, +886 m level (from Tămaş, 2007).

2.7 Field stop 7: Roşia Montană: Cârnic Massif (underground)

The Cârnic massif represents now, after the exploitation of the upper part of the Cetate Massif, the mining field with the largest ore reserves from Roşia Montană deposit (see also the introductory part to the Stop no. 4 Roşia Montana). The underground mining workings dating back from Roman times to XXth century were studied by a French–Romanian archaeological team (Cauuet *et al.*, unpublished reports) who identified almost 4 km of Roman mining workings, developed from the surface (max. +1081 m) to +921 m, the deepest Roman adit. Among the underground "attractions" in Cârnic massif are the so-called *coranda*, or unsupported large stopes, resulted by the exploitation of breccia structures. The most accessible one is Coranda Corhuri, created by the exploitation of a breccia body called by the local miners "Corhuri Breccia".

The modern +958 m mining level opened with a coast adit from the western slope of the Cârnic massif allows the access into the Corhuri area, situated at about 500 m from the entry. The large stope known as Coranda Corhuri (Fig. 21) resulted from the partial exploitation of the Corhuri Breccia in a traditional way, following irregular or pipe-like subvertical ore bodies. At its maximum extension, the cavity was ca. 200 m high and 35 x 45 m width and length, respectively. Presently, it is partly filled with waste and fallen blocks ranging up to 10 m. In the northern part of the Corhuri zone, an inclined stope resulted from the exploitation of a crosscutting vein is visible. The remnants of the ore are still preserved in several pillars.

Due to an accident happened in the early 1960s, the traditional mining method, in particular the unsupported large stopes changed to a more safely exploitation, with rooms and pillars (Fig. 21). This new extraction method was used for the exploitation of the rest

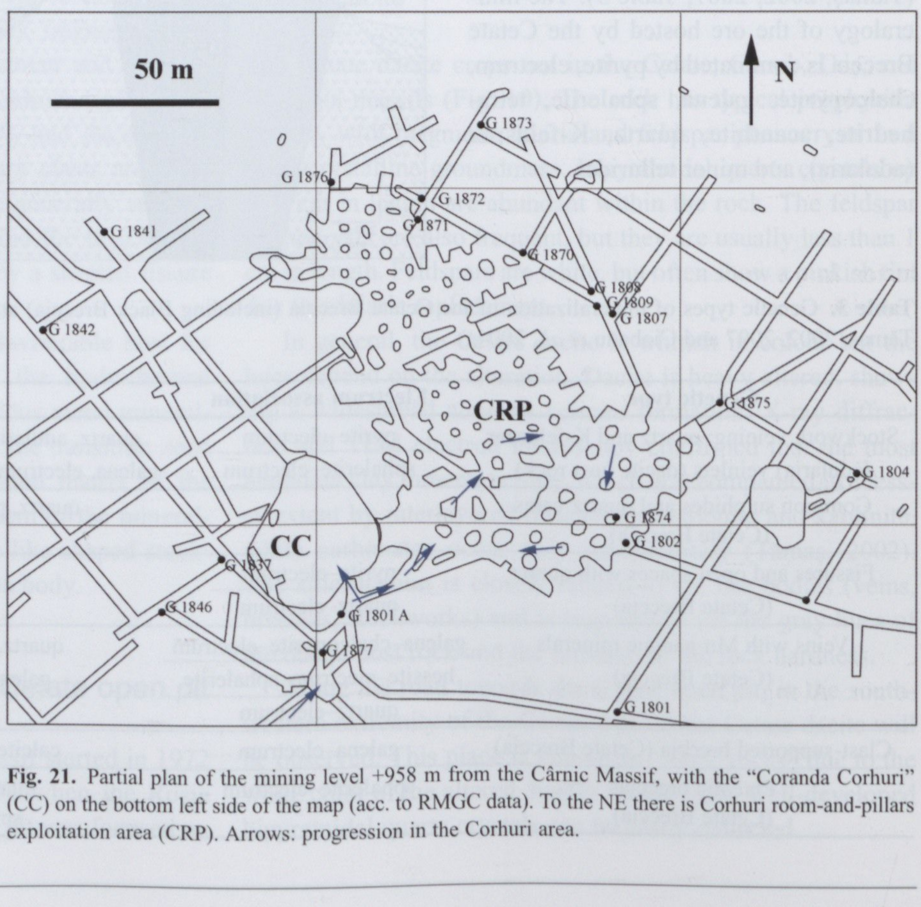

Fig. 21. Partial plan of the mining level +958 m from the Cârnic Massif, with the "Coranda Corhuri" (CC) on the bottom left side of the map (acc. to RMGC data). To the NE there is Corhuri room-and-pillars exploitation area (CRP). Arrows: progression in the Corhuri area.

of the Corhuri ore body (breccia pipe and related stockwork) and developed on 23 levels, from +860 level to +1023. The exploitation levels are vertically connected by rising shafts, some still accessible.

The ore bodies mined in Corhuri area are represented by a breccia pipe structure, the so-called Corhuri Breccia, and the related stockworks and crosscutting veins. The Corhuri Breccia is typical matrix-supported, with limited occurrence of clast-supported breccia. The breccia shows both sharp and gradational contacts to the dacite host rock. The clasts are mostly dacite, but metamorphic, sedimentary and older breccia fragments are also found. The metamorphic and the sedimentary rock fragments are more rounded and smaller than the dacite ones. The size of the clasts may range from a few millimetres to over 1 m, but most of them are in the range of a few centimetres to a few decimetres. Two types of matrix occur in the Corhuri breccia: (1) finely comminuted rock matrix (rock flour), and (2) hydrothermal cement. Corhuri Breccia pipe extends on over 650 m in high. The horizontal, elliptic cross-section measures 120×80 m.

The matrix and the clasts of the Corhuri Breccia show various hydrothermal alteration: potassic (adularia), phyllic (illite, illite/montmorillonite), argillic (kaolinite) and silicification (quartz). The mineralization consists of impregnation in the matrix, ore cement of the breccias, stockworks and crosscutting veins. The ore minerals are (Feier, 2005): electrum associated with hydrothermal quartz, and common sulphides (pyrite, galena, sphalerite, and chalcopyrite).

Lithologically, various types of breccias occur in the Corhuri Breccia: matrix-supported (dominant), clast-supported, mosaic breccias, fine-grained matrix breccias etc. Genetically, the Corhuri Breccia has a phreatomagmatic origin. Along its contact with dacite host rock, it was re-brecciated by later hydrothermal fluids thus forming phreatic breccias (Fig. 22). Hydrothermal quartz, electrum and base metal suphides, as well as the black *chinga* were deposited during this late, phreatic brecciation event. Overprinting veins and related breccia dykes are also in close connection to the post-phreatomagmatic hydrothermal activity. As seen in Fig. 22, the unsupported mining (*coranda* style) focused on phreatic re-brecciated contact zones of the Corhuri phreatomagmatic breccia (higher Au-Ag grades).

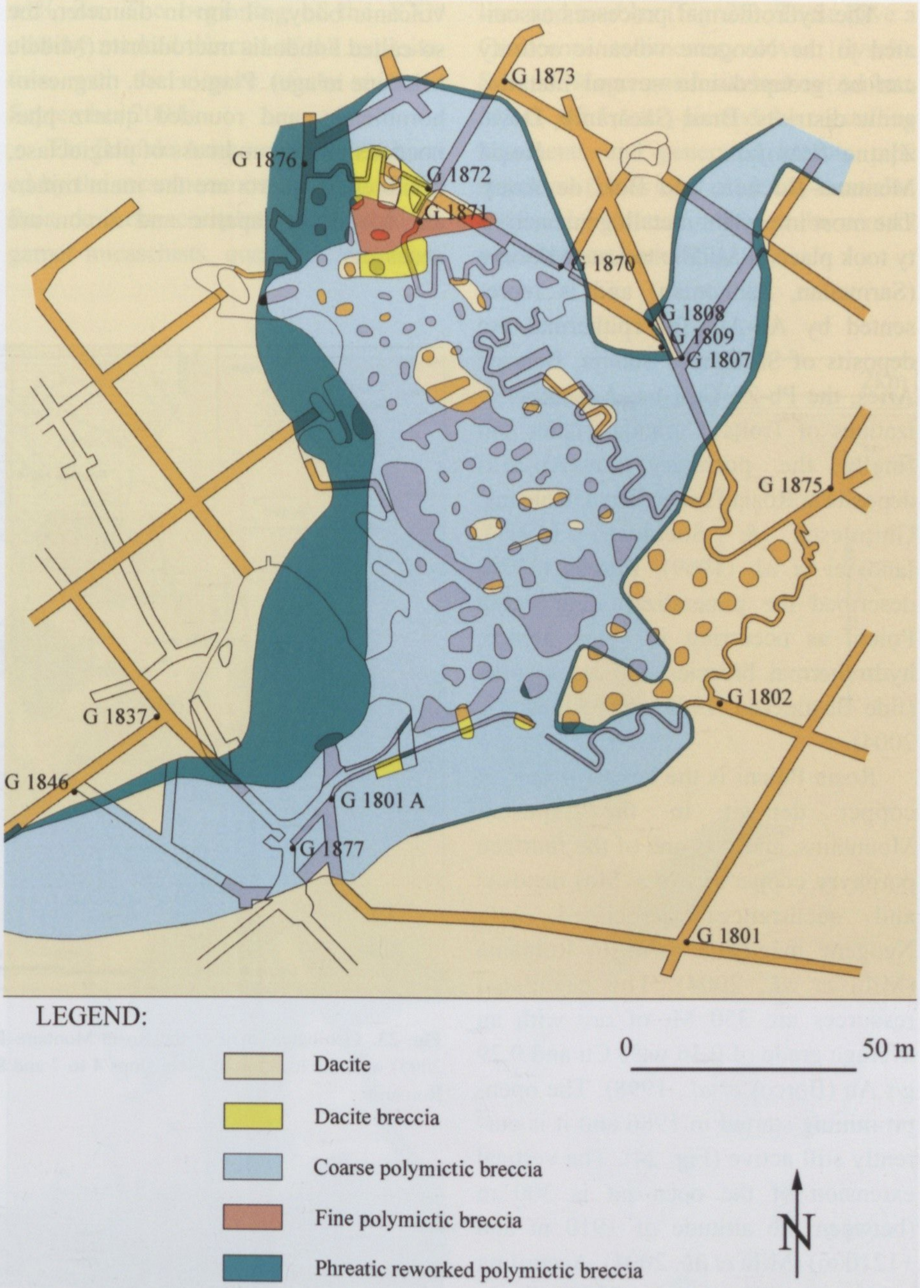

Fig. 22. Geological map of the Corhuri area (*coranda* = stope, rooms and pillars, and adjoining adits), at the level +958 m, Cârnic; dark colours – direct-mapped galeries; light colours – extrapolation (Feier, 2005).

Day 4

2.8. Field stop 8: Roşia Poieni porphyry copper ore deposit

Location: The Roşia Poieni deposit is located 4 km northeast of Roşia Montană, and 8 km southeast of Abrud (Fig. 23).
Coordinates: N 46°18.618' and E 23°9.796'; elevation: 920 m.

The hydrothermal processes associated to the Neogene volcanic activity can be grouped into several metallogenic districts: Brad–Săcărâmb, Deva, Zlatna–Stănija, Roşia Montană–Bucium, and Baia de Arieş. The most important metallogenic activity took place in Middle to Late Miocene (Sarmatian, Pannonian) and is represented by Au-Ag-(Te) epithermal ore deposits of Săcărâmb, Stănija, Baia de Arieş, the Pb-Zn-Cu-(Au, Ag) mineralizations of Troiţa, Coranda, Haneş and finally the porphyry Cu-(Au-Mo) deposits at Roşia Poieni, Deva, Bolcana. Ghiţulescu & Socolescu (1941), Ianovici *et al.* (1969), Borcoş (1976) described the mineralization at Roşia Poieni as occurring in veins, lenses, hydrothermal breccias and stockworks (fide Boştinescu, 1984 and Milu *et al.*, 2004).

Roşia Poieni is the largest porphyry copper deposit in the Apuseni Mountains, and it is one of the fourteen porphyry copper (± Au ± Mo) deposits and occurrences associated with Neogene magmatic rocks in Romania (Milu *et al.*, 2004). The calculated resources are 350 Mt of ore with an average grade of 0.36 wt% Cu and 0.29 g/t Au (Borcoş *et al.*, 1998). The open-pit mining started in 1986 and it is currently still active (Fig. 24). The vertical extension of the open pit is 300 m (between the altitude of +910 m and +1210 m) (Milu *et al.*, 2004). According to Kouzmanov *et al.* (2005) Roşia Poieni deposit is a porphyry copper system with a high-sulfidation epithermal overprint. Intensive research programs (geological, geochemical and geophysical), exploration galleries and drillings were carried out at Roşia Poieni starting with the 1960s.

According to Milu *et al.* (2004), the oldest Neogene igneous rocks are the Poieni andesites (described as diorite by Kouzmanov *et al.*, 2005). They consist of plagioclase, magnesiohornblende and quartz phenocrysts, in a groundmass of plagioclase and amphibole. Magnetite and apatite are accessory minerals. The Poieni andesites were intruded by a subvolcanic body, <1 km in diameter, the so-called Fundoaia microdiorite (Middle Miocene in age). Plagioclase, magnesiohornblende, and rounded quartz phenocrysts in a groundmass of plagioclase, hornblende, quartz are the main minerals. Magnetite, apatite and zircon are accessory.

The metallogenic activity developed within the Fundoaia intrusion and the surrounding rocks (Poieni andesite, Cretaceous sediments) has been accompanied by alteration. According to Ionescu *et al.* (1975) the neoformation minerals could be grouped in four alteration zones which develop successively:

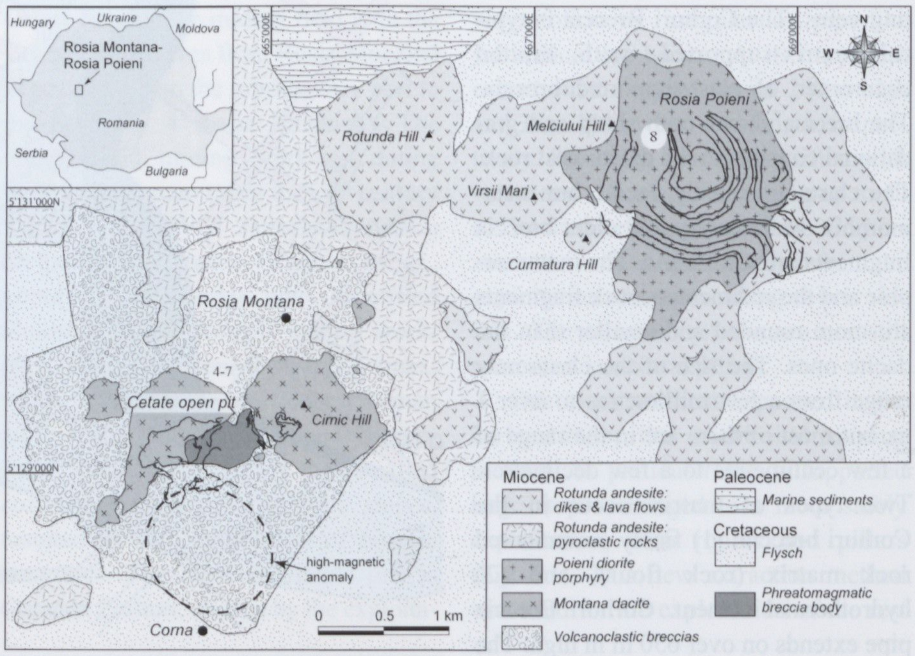

Fig. 23. Geological map of the Roşia Montana–Roşia Poieni area (modified after Kouzmanov *et al.*, 2005) with the location of Field stops 4 to 7 and 8. Top left inset shows the position of the area within Romania.

Fig. 24. Roşia Poieni open pit.

(1) biotitic zone, with biotite, orthoclase-microperthite, quartz; (2) sericitic zone, with sericite, clay minerals, quartz; (3) argillic zone, with clay minerals, quartz and (4) propylitic zone, with chlorite, calcite, epidote. The alteration zoning is accompanied by a mineralization zoning as well. Thus, chalcopyrite, magnetite, bornite and molybdenite are frequently found in the biotitic zone, pyrite, sphalerite, galena, enargite in the sericitic and argillic zones, and pyrite in the outer, propylitic zone. Later, Milu *et al.* (2004), separated four alteration types: potassic, propylitic, phyllic and advanced argillic. The zoning of the alteration is recognized in the deeper and central parts of the porphyritic intrusion towards shallower and outer parts, respectively. A close relationship between sulfide mineral assemblage and silicate alteration style was observed.

2.9. Field stop 9: Baia de Arieş waste dumps (hydrothermal Pb-Zn deposit)

Location: Baia de Arieş ore deposit is located close to Baia de Arieş (Alba county), 24 km east from Câmpeni and 60 km west from Turda (Fig. 25).

Coordinates: N 46°22.806' and E 23°16.818'; elevation: 480 m.

The Baia de Arieş ore deposit represents the northernmost occurrence of the Neogene volcanism and metallogenic activity in the Apuseni Mountains (Ghiţulescu & Socolescu, 1941). As the type locality for sylvanite (Udubaşa *et al.*, 1992; Papp, 2004; Tămaş *et al.*, 2006), this deposit is a well known reference point for telluride mineralogy. Furthermore, Baia de Arieş is a reference deposit for breccia pipe structures (Ghiţulescu *et al.*, 1979a,b; Laznicka, 1988; Tămaş, 2002) which represent favourable hosts for the ore deposition. Ghiţulescu & Socolescu (1941) published data on the ore grades exploited between 1920 and 1930: >2–8 g/t Au, 50–1500 g/t Ag, 2–30 wt% Pb, 3–15 wt% Zn. The beginning of the XXI[st] century marked the end of the exploitation, with the closure of the mine in September 2004.

The Baia de Arieş ore deposit is hosted by the mesometamorphic rocks of the Baia de Arieş complex, represented by garnet micaschists, quartzites, amphibolites and marbles (Fig. 25). These have a Cretaceous sedimentary cover (flysch). Several Neogene andesite bodies (Ambru, Mălai, Afiniş etc.) pierced the crystalline basements and generated breccia pipe structures (Ianovici *et al.*, 1969; Laznicka, 1988; etc.) located mostly at the contact with the host rocks (Fig. 26).

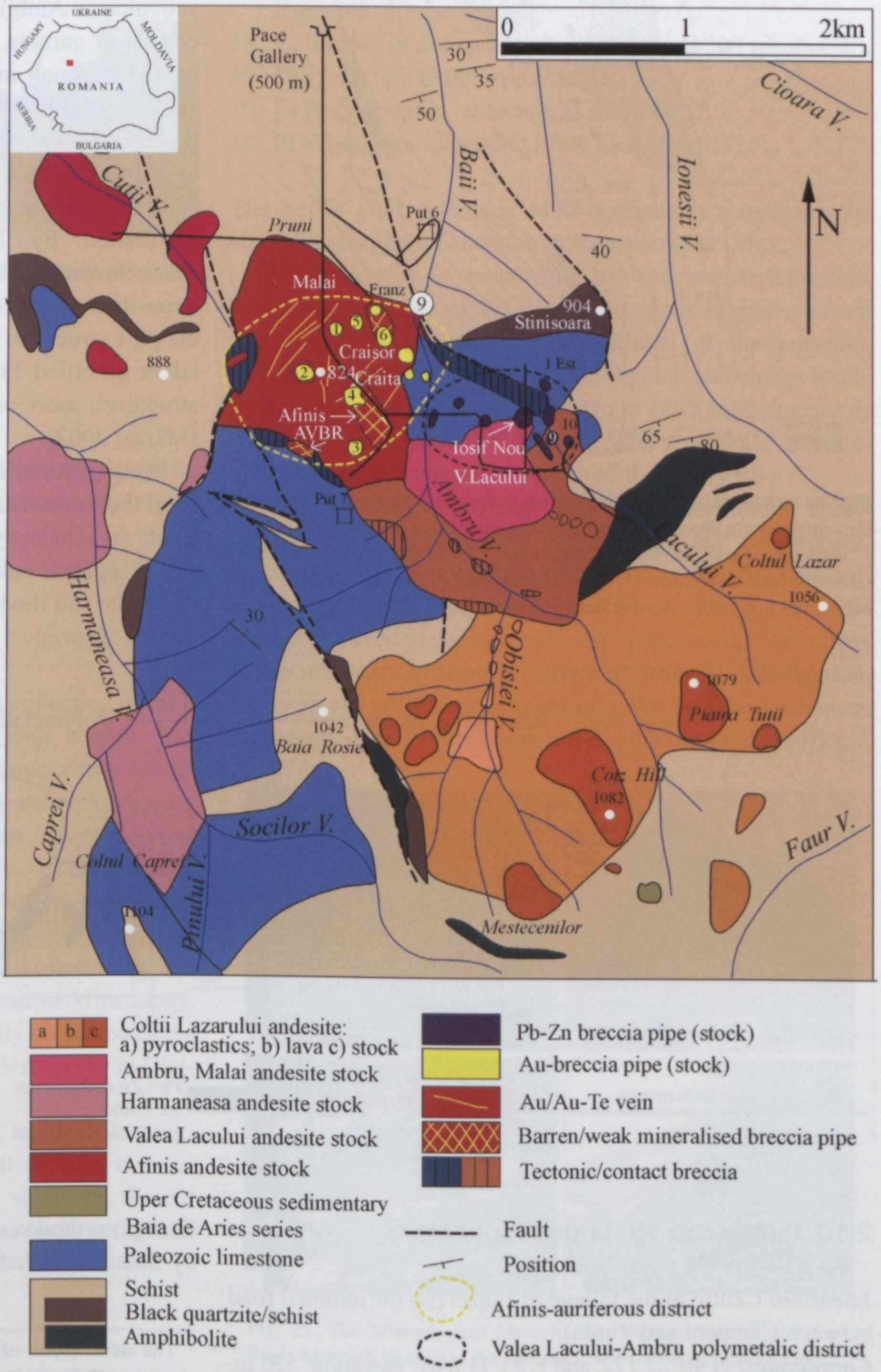

Fig. 25. Field stop 9 on the simplified geological map of the Baia de Arieş ore deposit (redrawn from Ciobanu *et al.*, 2004b). Top left inset shows the position of the area within Romania.

In the Baia de Arieş area the following types of mineralization were identified: skarn, replacement Pb-Zn ore bodies, large phreatomagmatic structures, Au-Ag collapse breccia

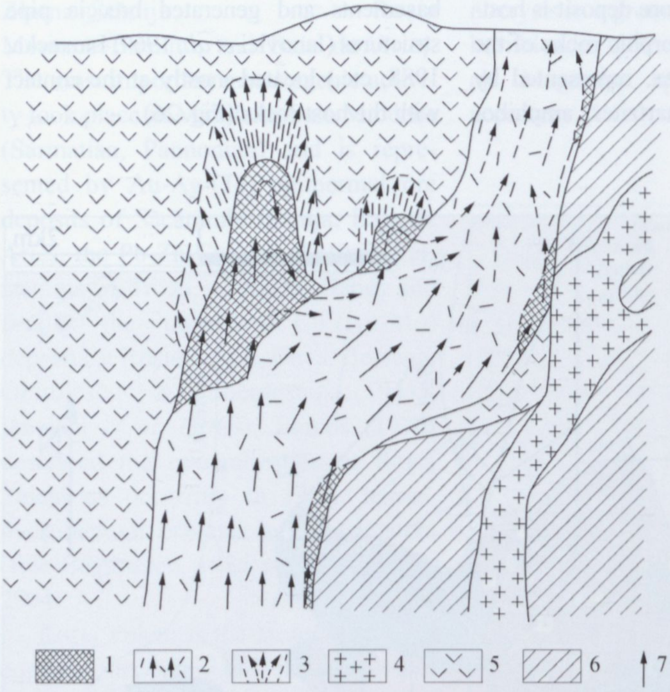

Fig. 26. Schematic cross section through a breccia-pipe structure from the Baia de Arieş ore deposit (by Ghiţulescu, in Ianovici *et al.*, 1969). Legend: 1 – "auriferous stock" (Au-bearing breccia pipe); 2 – breccia pipe; 3 – mineralization dispersion aureole; 4 – Mălai andesite; 5 – Ambru andesite; 6 – crystalline rocks; 7 – hydrothermal fluid flow direction.

(electrum and arsenopyrite rich), and telluride-bearing veins crosscutting breccia bodies (Ghiţulescu & Socolescu, 1941; Cioflica *et al.*, 1973; Mârza, 1982; Tămaş, 2002). A zoning inside the deposit, with the mostly Pb-Zn replacement bodies in the east and Au- and Ag-bearing breccias and veins in the west (Figs. 25 and 27) was outlined by Ciobanu *et al.* (2004b). Four main associations of precious metal were identified by Ghiţulescu *et al.* (1979a): Au + quartz, Au + arsenopyrite, Au +Te minerals and Au + pyrite.

The skarn occurrences formed at the very contact of the subvolcanic Ambru andesite with crystalline limestones, and consist of garnets, wollastonite, kotoite, szaibélyite accompanied by small magnetite and molybdenite bodies. On the same crystalline limestone background, large scale Pb-Zn replacement ore bodies have been formed. They include two ore-forming phases: an early phase, dominated by common sulfides and free of Mn-bearing minerals, and a late phase, dominated by Mn minerals (alabandite, rhodonite, rhodochrosite). The metallogenic activity ended with the deposition of precious metals, either dispersed within breccia pipe structures as impregnations, nests and veinlets hosted in silicified breccia matrix, either within related vein structures, more or less superimposed on breccia structures (Mârza, 2002).

Among the most frequent minerals that may be collected from the waste dumps in Baia de Arieş area, one can mention pyrite and chalcopyrite (isolated crystals or crystalline aggregates), galena, sphalerite, arsenopyrite, stibnite, alabandite, rhodonite and rhodochrosite, barite, calcite and quartz.

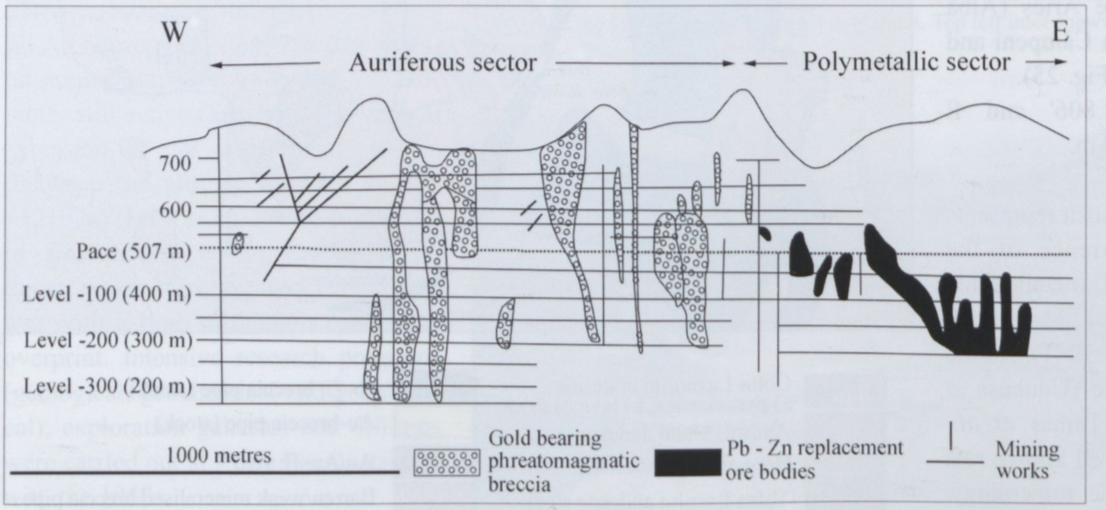

Fig. 27. Schematic cross section through the Baia de Arieş ore deposit with the simplified morphology of the breccia pipes and the mining levels (from Ciobanu *et al.*, 2004, based on unpublished papers from the archives of the Baia de Arieş Mining Co.).

2.10 Field stop 10: Lupşa Monastery

Location: Centre of the village of Lupşa (on the national road between Câmpeni and Turda).

Coordinates: N 46°22.172' and E 23°11.896'; elevation: 520 m.

In the centre of the Lupşa village, the newly rebuilt monastery includes the old, charming and small "Sf. Gheorghe" (St. George) orthodox church[2] (Figs. 28 a,b). It was built in 1421, by Stanislav (Vladislav), a squire from the Cândea de Lupşa

[2] The description of the Lupşa Monastery is based on http://www.crestinortodox.ro/mitropolia-clujului-albei-crisanei-si-maramuresului/68072-manastirea-lupsa; http://www.cimec.ro/scripts/monumente/seljuden.asp and http://www.karpatenwilli.com/apuseni/lupsa.htm.

family, above the ruins of another church. The church of the monastery is one of the oldest and best preserved wooden church in Transylvania. The bell turret was added in the 18th century (Figs. 28a,b). The monastery played an important role during the Middle Ages in preserving the Romanian orthodox faith and acted also as cultural centre. It hosted a school and a church painting workshop. The church walls are covered with three layers of painting, the oldest dated at the 15th century.

The monastery was closed in 1820 and re-opened in 1992 after the collapse of the communist regime.

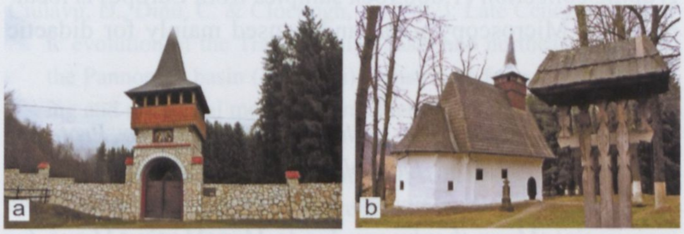

Fig. 28. a) The main entrance of the Lupşa monastery area, b) The Lupşa monastery church, renovated in 1993.

Day 5

2.11 Field stop 11: Cluj-Napoca: Mineralogical Museum of "Babeş–Bolyai" University[3]

Location: Centre of Cluj-Napoca, in the main building of the "Babeş-Bolyai" University.
Coordinates: N 46°46.048' and E 23°35.481'; elevation: 350 m.

The Mineralogical Museum contains a rich collection of mineral specimens, accumulated during its long history. The museum was established as purely academic collection in 1919, on the basis of the mineral and rock collection earlier jointly owned by the Transylvanian Museum Association and the Institute of Mineralogy and Geology of the "Ferenc József" University. Subsequently, the collections were reorganized, continuously and substantially enriched by donations, exchanges, acquisitions and samples collected by the professors and students in geology. The Chair of Mineralogy, Faculty of Biology and Geology scientifically co-ordinates the Mineralogical Museum of "Babeş–Bolyai" University in Cluj-Napoca (Ionescu & Tămaş, 2003).

Rare specimens (large crystals of pyrite, tetrahedrite, aragonite, halite, quartz and gypsum) as well as rare mineral species (native tellurium, tellurides, some silicates), the cut gemstones and the meteorites are among the main attractions in the museum.

[3] The text of the stop 11 is from Ionescu *et al.* (2009a) and Ionescu & Hoeck (2010).

The museum houses about 25,000 specimens, grouped in the following main collections:

11. Native gold collection (450 specimens);
12. Collection of meteorites (210 specimens);
13. Systematic collection (about 10,000 specimens);
14. Regional collection (about 1,500 specimens);
15. Cut gemstones (250 cut gems);
16. Collection of Romanian gemstones (about 3,500 specimens);
17. Collection of the minerals discovered for the first time in Romania (40 specimens);
18. Collection of radioactive minerals (about 200 specimens);
19. Ore minerals (5,000 specimens);
10. Crystallographic collection (1,500 items);
11. Petrographic collection (1,000 rock samples).

The *native gold collection* (450 specimens) constitutes the second largest gold collection in Romania (Fig. 29a).

The *collection of meteorites* (204 specimens) represents the single collection of this type in Romania. Fragments from five Romanian meteorites are exhibited in the museum, including the biggest, weighing 35.7 kg, which belongs to the Mociu meteorite shower. It fell down in 1882 at 40 km east of Cluj-Napoca (Fig. 29b). There are also fragments of meteorites found on 5 continents, some of them very rare.

The *systematic collection* contains about 10,000 specimens from the world's most important mineral occurrences, illustrating over 800 mineral species (Figs. 29c,d). This collection represents the greatest number of different minerals species gathered in a single museum, in Romania. The mineral specimens are ordered according to Strunz's classification. *The regional collection* consists of 1,500 mineral specimens illustrating over 70 Romanian mines, outcrops and quarries.

Fig. 29. The Mineralogical Museum: a) Dendritic gold crystal from Roşia Montană (length of the specimen = 2 cm, b) The Mocs (Mociu) chondritic meteorite (width of the specimen = 35 cm, c) Systematic exhibition of minerals, d) Bucium pyrite (length of the specimen = 66 cm). Images from Ionescu *et al.* (2009b).

The *cut gemstones collection* (250 cut gems), the richest and most complete collection of this type in Romania, is presented in an original cupboard from the XIXth century. It contains the main gems, such as diamond, corundum (with both ruby and sapphire varieties), beryl (emerald, aquamarine), garnets, tourmaline, quartz (amethyst, citrine, rock crystal, and agate), opals (precious opal, fire opal), spinels, zircon, turquoise, as well as pearls and corals. Synthetic counterparts of the main gemstones can also be seen.

The *collection of Romanian gemstones* is the richest and most complete collection of this type in Romania and consists of a total of 3,500 specimens, most of it cut in cabochon style. A number of 1,200 cabochon-cut gemstones, mainly silica varieties such as quartz, chalcedonies, agates, opals, jaspers, are displayed. This collection was set up in 1987, based on the samples collected by professors of the Geology Department from 90 occurrences.

The *collection of the minerals discovered for the first time in Romania* (40 specimens) contains 18 mineral species, *e.g.* native tellurium, sylvanite, nagyagite, krennerite, petzite, fizélyite, fülöppite, semseyite, andorite, tellurite. The *collection of radioactive minerals* (about 200 specimens) is not exhibited publicly and is used only for scientific purposes. The *ore minerals collection* contains about 5,000 specimens originating from Romania and foreign countries, genetically grouped in: orthomagmatic, pegmatitic, skarn, hydrothermal, metamorphic and sedimentary deposits. The *crystallographic collection* (about 1,500 items) consists of 750 natural crystals as well as casts, grouped on systematic criteria. *The petrographic collection* (1,000 rock samples from Europe) is located in the Microscopy room and is used mainly for didactic purposes.

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Appendix – Itinerary for IMA2010 RO3 Field trip

Monday, August 16, 2010 (Day 1): *Travel from Budapest to Deva*

08.00–14.00	Travel from Budapest to Deva
14.00–16.00	*Lunch break in Deva*
16.00–16.30	Travel to Uroi
16.30–18.00	**Field stop 1**: Uroi Hill: type locality of pseudobrookite and fluoro-magnesiohastingsite
18.00–18.30	Travel to Deva
19.00–21.00	*Dinner in Deva*
	Accommodation in Deva

Tuesday, August 17, 2010 (Day 2): *Travel from Deva to Roşia Montană*

08.00–08.45	Travel to Brad
08.45-10.30	**Field stop 2**: Brad: Gold Museum
10.30–11.00	Travel to Crişcior
11.00–13.00	**Field stop 3**: Valea Arsului Quarry: stilbite, chabasite, gyrolite, natrolite, okenite
13.00–14.00	*Lunch break at the entrance of the quarry*
14.00–15.30	Travel to Roşia Montană
15.30–18.00	**Field stop 4**: Mining Museum in Roşia Montană: open air museum with Roman artifacts and traditional machineries and underground Roman workings dug by hand; RMGC mining project presentation
18.00–18.30	Travel to Câmpeni
19.00–21.00	*Dinner in Câmpeni*
	Accommodation in Câmpeni

Wednesday, August 18, 2010 (Day 3): *Roşia Montană area*

08.00–08.30	Travel to Găuri
08.30–10.00	**Field stop 5**: Găuri mining field: Roman fire-setting stope (surface and underground), Găuri phreatomagmatic breccia, and silicified dacite
10.00–10.30	Travel to Cetate open pit
10.30–13.00	**Field stop 6**: Cetate open pit: Cetate dacite, Black Breccia, rhodochrosite–rhodonite veins, Cetate Breccia
13.00–14.00	*Lunch break in Cetate open pit*
14.00–14.15	Travel to Cârnic massif
14.15-18.00	**Field stop 7**: Cârnic massif (underground): huge stope, rooms-and-pillars chamber, breccias, crosscutting veins
18.00–19.00	Travel to Câmpeni
19.00–21.00	*Dinner in Câmpeni*
	Accommodation in Câmpeni

Thursday, August 19, 2010 (Day 4): *Travel from Câmpeni to Cluj-Napoca*

08.00–09.00	Travel to Muşca
09.00–11.30	**Field stop 8**: Roşia Poieni open pit: porphyry copper ore deposit
11.30–12.30	Travel to Baia de Arieş
12.30–13.30	**Field stop 9**: Baia de Arieş waste dumps (hydrothermal Pb-Zn deposit)
13.30–14.00	Travel to Lupşa
14.00–15.00	*Lunch break at Lupºa ("Casa Apuseanã" boarding house)*
15.00–16.00	**Field stop 10**: Lupşa Monastery: 15^{th} century Orthodox Church
16.00–17.30	Travel to Cluj-Napoca
18.00–20.00	*Dinner in Cluj-Napoca*
	Accommodation in Cluj-Napoca

Friday, August 20, 2010 (Day 5): *Travel from Cluj-Napoca to Budapest*

08.00–10.00	**Field stop 11**: Cluj-Napoca: Museum of Mineralogy of the Babeş–Bolyai University
10.00–12.00	City visit: Museum of Etnography, Medieval monuments etc.
12.00–13.00	*Lunch break*
13.00–19.00	Travel to Budapest

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