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# GOLD-SILVER MINERALIZATIONS FROM NORTHERN PART OF ROȘIA MONTANĂ ORE DEPOSIT, APUSENI MOUNTAINS, ROMANIA

## EXTENDED ABSTRACT OF THE PhD THESIS

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## FOREWORD

The present work represents the extended abstract of the PhD thesis "*Gold-Silver Mineralizations from Northern Part of Roșia Montană Ore Deposit, Apuseni Mountains, Romania*" completed by PhD student Sergiu Drăgușanu under scientific supervision of Assoc. Prof. Călin Gabriel Tămaș, PhD, *Habil.*, at Department of Geology, Babeș-Bolyai University, Cluj-Napoca, Romania.

The PhD Thesis is drafted in Romanian and its structure is detailed further (see *Contents*). It comprises 10 chapters, as well as "*Conclusions*" and a reference list (238 titles). Part of the present abstract is taken from Drăgușanu and Tămaș (in print).

**Keywords:** Roșia Montană, hydrothermal ore deposits, phreatomagmatic breccia, hydrothermal breccia, low-sulphidation, gold-silver mineralizations, EPMA

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# 1. INTRODUCTION

The PhD thesis offers new data on the lithology, the hydrothermal alterations, the ore bodies, and the ore mineralogy from four mining fields located in the northern part of Roșia Montană ore deposit, *i.e*. Coș, Văidoaia, Țarina and Orlea.

Roşia Montană ore deposit is located in the Apuseni Mountains, west-central Romania, in a historical gold mining region known as Golden Quadrilateral (Udubașa et al., 2001). Manske et al. (2006) state that Roşia Montană is the largest gold deposit in Europe based on identified ore reserves of about 400 Mt averaging 1.3 g/t Au and 6 g/t Ag.

Roşia Montană ore deposit is hosted by a Neogene maar-diatreme structure (*vent breccia*) emplaced into Cretaceous sedimentary rocks (flysch type) and intruded by dacite domes (Leary et al., 2004; Manske et al., 2006; Tămaş, 2010) (Fig. 1). The deposit was interpreted by Mârza et al. (1997) as low sulphidation. Almost a decade later the deposit was considered as intermediate sulphidation by Manske et al. (2006), Tămaş et al. (2006) and Wallier et al. (2006). However, Tămaş (2010) stated that at the ore deposit scale there is a transition from an early low sulphidation character to a late intermediate sulphidation one.

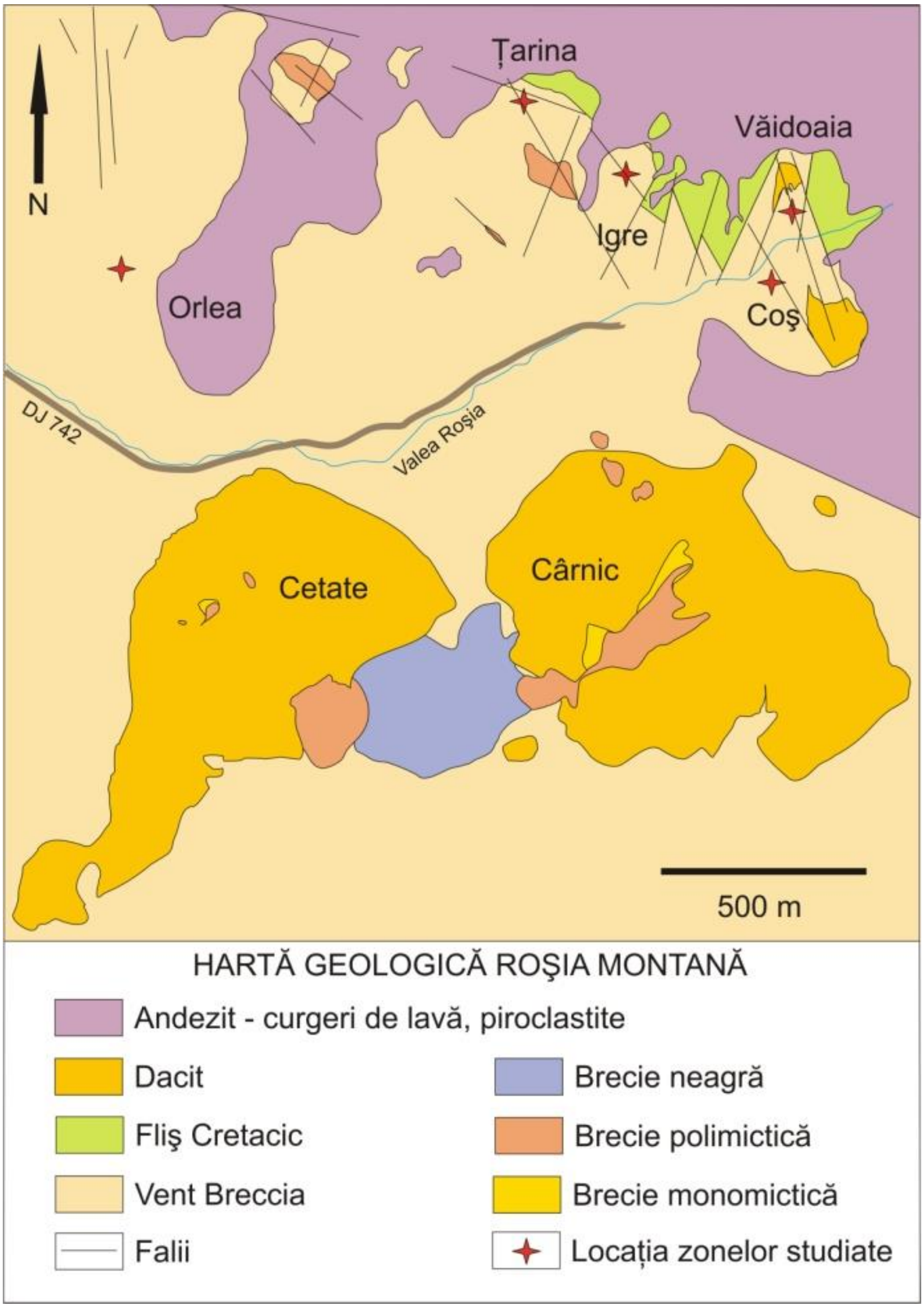


*Fig. 1. Geological map of Roşia Montană ore deposit with the main mining fields (RMGC courtesy); the position of the faults is given after Hewson et al., (2005).*

## 2. GEOLOGICAL SETTING

The Apuseni Mountains are situated in the eastern section of the Alpine – Balkan – Carpathian – Dinaride geodynamic province. They are located between the Transylvanian Basin and the Pannonian Basin. The basement of the region is composed of two lithospheric blocks, Tisia-Dacia in the South, where the Apuseni Mountains are located, and ALCAPA in the North (Balla, 1987; Csontos et al., 1992; Royden, 1993; Csontos, 1995; Fodor et al., 1999 etc.). These tectonic blocks experienced during Eocene to Early Miocene opposite-sense rotations, *i.e*. Tisia-Dacia block developed a clockwise rotation while ALCAPA block was affected by a counterclockwise rotation. These blocks rotations combined with the behavior of Mecsek-Villany area which was stopping the rotation (Seghedi et al., 2007) triggered the set-up of an extensional tectonic regime on the western border of the Apuseni Mountains (Royden, 1988; Săndulescu, 1988; Balintoni and Vlad, 1998). As a result three graben-like basins appeared within the Apuseni Mountains and focused the Neogene sedimentation and the magmatic activity (Seghedi et al., 2004) (Fig. 2).

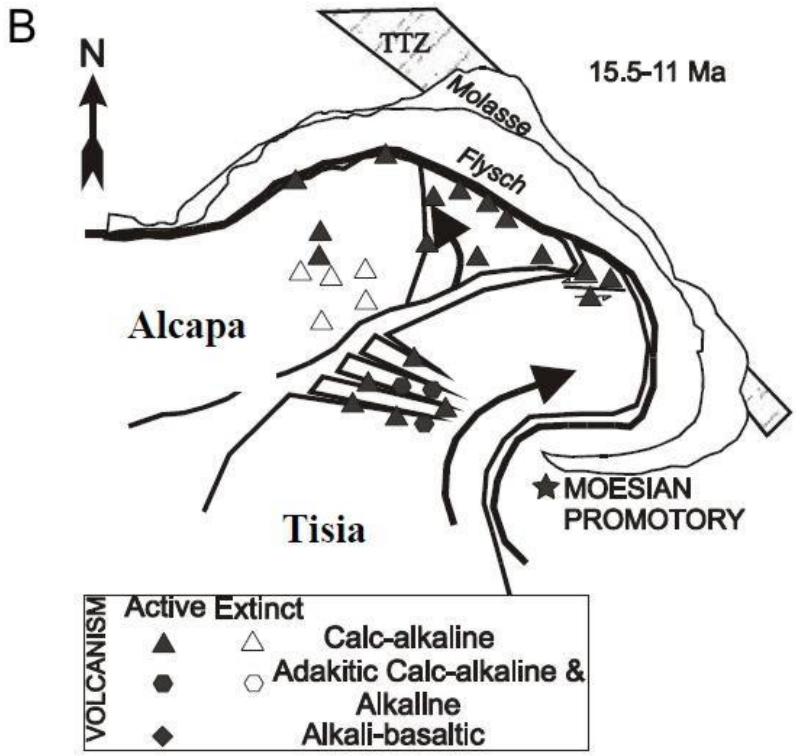


*Fig. 2. Geotectonic model relating the Neogene volcanism developed within Tisia block with the rotational movements of the Alcapa and Tisia tectonic blocks (Seghedi et al., 2004).*

# 3. ROȘIA MONTANĂ ORE DEPOSIT

Roșia Montană ore deposit is genetically controlled by 13.5 Ma dacite volcanic activity (Roșu et al., 1997 and 2004a). The basement of the perimeter consists of Cretaceous sedimentary rocks represented mainly by sandstones, shales, marls and conglomerates (flysch). These rocks are outcropping in the surrounding area of the deposit (Bordea et al., 1979).

The Cretaceous basement was pierced by phreatomagmatic eruptions which created the Roșia Montană maar-diatreme structure (Tămaș, 2010). The infilling of this large scale structure was previously interpreted by Borcoș and Mantea (1968) as a succession composed of "volcano-sedimentary formation", "grey marls horizon", and "marly-clayly schists horizon". Leary et al. (2004) considered the same rocks as "Vent breccia", Wallier et al. (2006) interpreted this lithological unit as volcaniclastic breccias, while Tămaș (2007) as intracraterial breccias. All these terms aimed in fact to give an idea of the genetic mechanism of formation, precisely phreatomagmatic eruptions, and to support the co-existence of sedimentary and volcanic sequences. According to Tămaș (2010), the vent breccia is the underground expression of Roșia Montană maar-diatreme structure being the first volcanic product of a hidrovolcanic activity which continued afterwards with the emplacement of Cetate dacite followed by other phreatomagmatic breccia pipe structures, *e.g.* Cetate, Corhuri and Corna breccias.

The vent breccia/Roșia Montană breccia was intruded by Cetate dacite bodies outcropping in Cetate and Cârnic hills (Fig. 1). These dacite plugs are today separated by a maar-diatreme breccia structure, known as Glamm formation (Mârza et al., 1990) or Black Breccia (Leary et al., 2004; Manske et al., 2006). The same structure was interpreted by Tămaș (2002, 2007, and 2010) as the fluidization channel of the Cetate breccia pipe. The phreatomagmatic brecciation including Cetate breccia and its fluidization channel passed through the Roșia Montană diatreme and brecciated the dacite already emplaced. At the end of the volcanic activity the phreatomagmatic brecciation was followed by the hydrothermal activity, *i.e.* hydrothermal alterations and formation of the bulk Au-Ag mineralization (Tămaș, 2002). The precious metals ore bodies are represented by disseminations, breccias, stockworks and veins hosted by dacite, diatreme breccias and Cretaceous flysch (Tămaș 2002).

The last volcanic pulse from Roșia Montană is the so-called Rotunda andesite. The andesite products occur in the northern part of the perimeter and are represented by a rooted body (Rotunda hill), lava flows and volcaniclastics (Bordea et al., 1979).

# 4. MATERIALS AND METHODS

The field work (geological mapping, observations, sampling) was carried out at the surface and in the underground of Coş, Văidoaia, Ţarina and Orlea mining fields (Fig. 3).

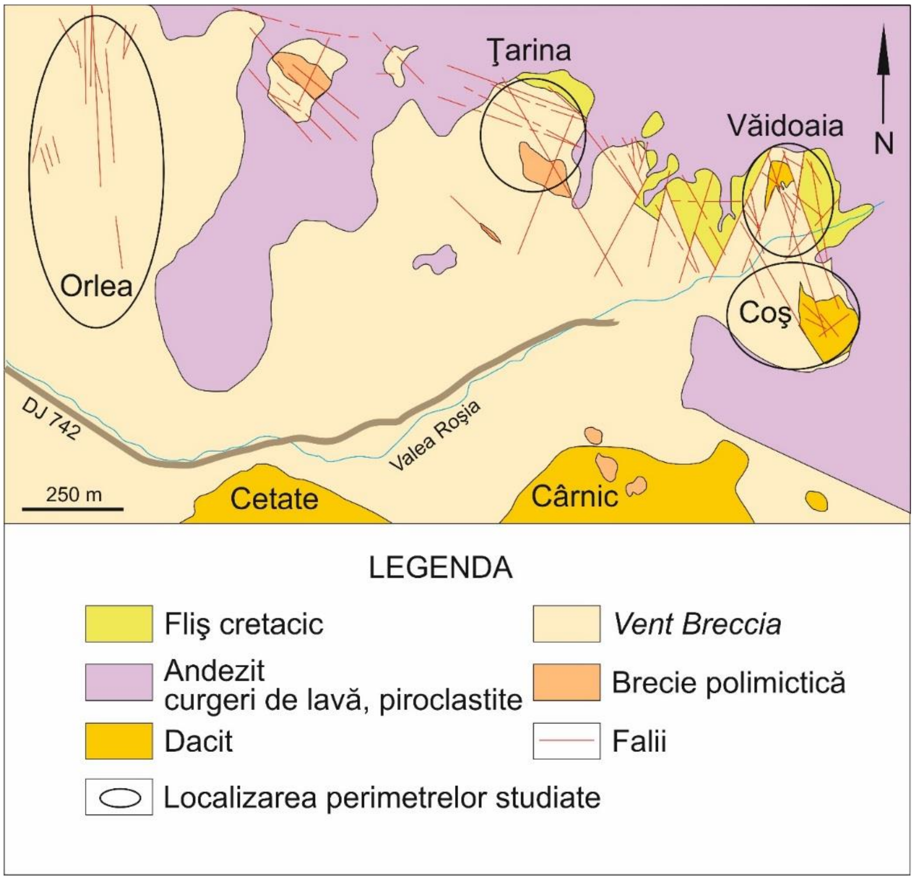


*Fig. 3. Geological map (RMGC courtesy) of the northern area of Roșia Montană ore deposit, with the location of the studied mining fields; the position of the faults is given after Hewson et al., (2005).*

During the field work have been collected 779 samples from the underground works and 90 samples from outcrops. The samples were later processed and 329 polished sections and 139 thin sections have been made.

Electron microscopy observations including semi-quantitative data were made using a JXA Superprobe 8600 scanning electron microprobe (SEM) at Paris Lodron University, Salzburg, Austria. Backscattered electron (BSE) images acquisition was also performed on two polished sections. Additional SEM data were acquired with a JEOL JSM-6360 electron microscope from GET Laboratory (*Géosciences Environnement Toulouse*), from Paul Sabatier University, Toulouse, France.

Chemical EPMA data were acquired on 4 polished sections with a CAMECA SX50 device at GET Laboratory, France.

Ore grade analysis has been performed on 5 samples at ALS Minerals Laboratory from Gura Roșiei, Alba County.

Table 1 shows a detailed description of the sampling carried out in the northern part of Roșia Montană ore deposit.

*Table 1. Number of samples within mining sectors and number of thin and polished sections manufactured and EMPA analysis*

| No. | Mining sector | Sample number | Location | Polished sections | Thin sections | EPMA |
|---|---|---|---|---|---|---|
| 1 | Coş | 50 | surface | 41 | 53 | |
| 2 | Coş | 368 | underground | 110 | 32 | 2 |
| 3 | Văidoaia | 20 | surface | 15 | 12 | |
| 4 | Văidoaia | 245 | underground | 85 | 12 | 1 |
| 5 | Ţarina | 11 | underground | 10 | 10 | |
| 6 | Orlea | 20 | surface | 20 | 10 | |
| 7 | Orlea | 175 | underground | 60 | 20 | 1 |
| Total | | 869 | | 329 | 139 | 4 |

Abbreviation names for minerals used in microphotographs description are according with Whitney and Evans (2010).

# 9. DISCUSSION

The research work made during the PhD was focused on the northern part of Roșia Montană ore deposit. The contact between vent breccia and Cretaceous flysch in this area represented a control factor for the set-up of phreatomagmatic and hydrothermal activity responsible for Au-Ag ore deposition. The field work was carried out on 4 mining fields, from east to west: Coș, Văidoaia, Țarina and Orlea. In this chapter are briefly presented some results, discussions and the interpretations proposed for each mining field.

## 9.1. COȘ MINING FIELD

Within Coș mining field the Cătălina Monulești coast adit crosscuts 2 stopes known by the local miners as *Coranda Mare* and *Coranda Mică*. Three types of lithologies were identified along the adit starting from the surface towards the underground stopes: vent breccia, Cretaceous shales and Cretaceous sandstones.

Within the stopes was noticed that in the hanging wall of Cretaceous shales there is a phreatomagmatic polymict breccia structure different from the vent breccia. The breccia is matrix dominated being mostly matrix supported but clast supported pockets also occur. The rock fragments within this breccia consist of dacite, sedimentary rocks, quartzite, and incarbonized wood fragments.

This breccia structure was emplaced along the contact between the vent breccia and the Cretaceous flysch (shales) and it was roofed by the Cretaceous sandstones. After the emplacement of the breccia structure started a hydrothermal activity with the mineralizing fluid flows focused along several lineaments which today are mineralized (Fig. 4). Some of them are representing breccia dyke structures formed by hydrothermal brecciation of the preexisting phreatomagmatic breccias. The most important breccia dyke structures are located at the C1, C2, and C5 sampling zones from *Coranda Mare* stope (Fig. 5A, C, D) and within C9 sampling area from *Coranda Mică* stope (Fig. 5B).

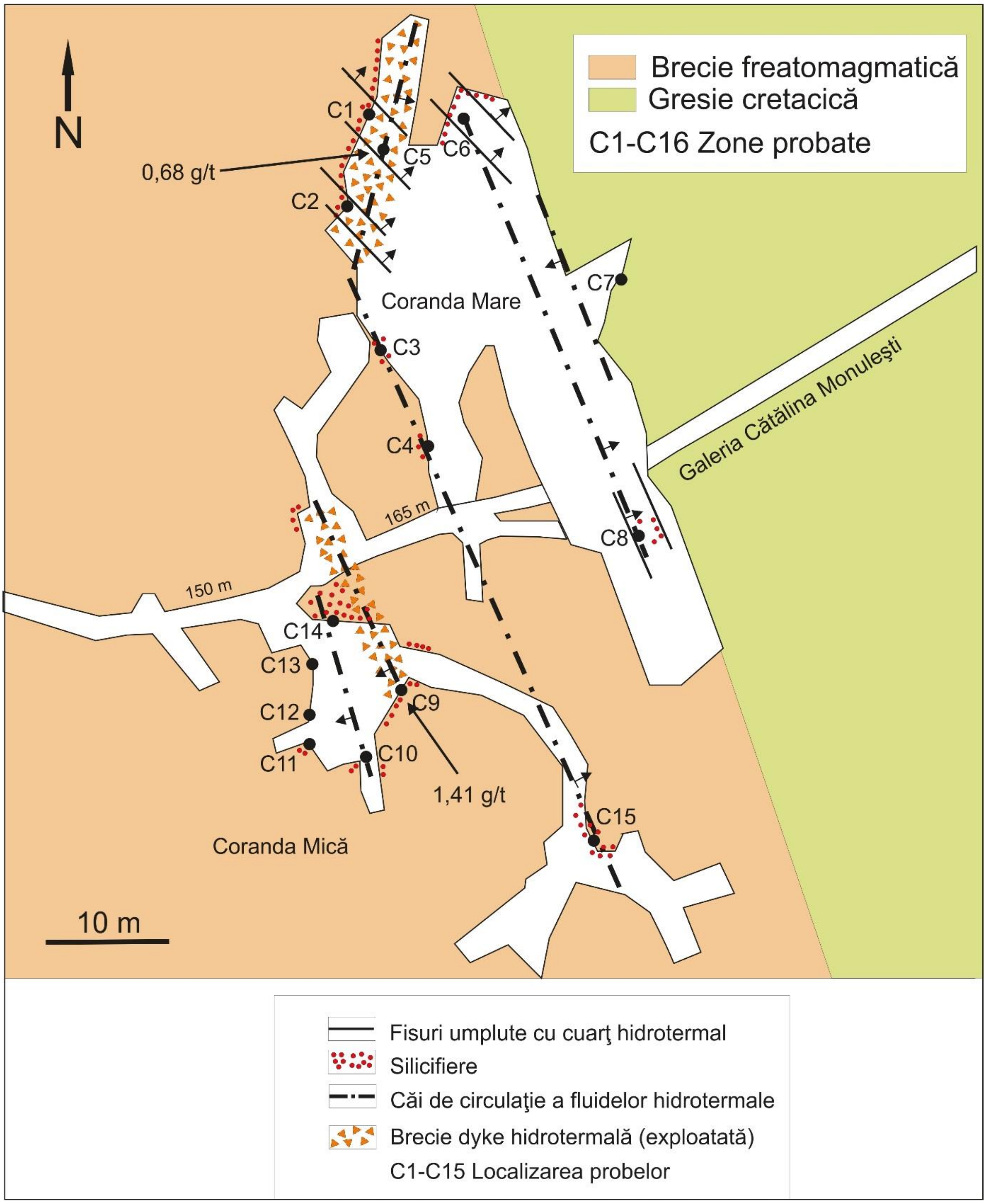


*Fig. 4. Underground mining works from Coș mining field (RMGC courtesy) with the location of the sampling zones. The geologic data comprise the lithologies, the hydrothermal fluids flow lineaments, the hydrothermal breccia dyke structures and the silicification accompanying the mineralized zones.*


*Fig. 5. Hydrothermal breccia dyke structures from Coş mining field: A) hydrothermal breccia dyke hosted by phreatomagmatic breccia structure mined out in Coranda Mare stope; B) hydrothermal breccia dyke mined in Coranda Mica stope; the square inset represents a detail photo showing the type of the hydrothermal breccia, precisely clast-supported breccia with open spaces; C) hydrothermal quartz veins which crosscut the hydrothermal breccia dyke open in Coranda Mare stope; D) detail image showing hydrothermal quartz veins which crosscut the hydrothermal breccia dyke in Coranda Mare stope.*

The hydrothermal breccia dyke structure from *Coranda Mare* stope is measuring 1.5 m width and 10 m long. It is heading north and possess a 50° dip to east. The breccia dyke structure was emplaced at the contact between the phreatomagmatic breccia structure and the Cretaceous black shales. The vent breccia is outcropping in the hanging wall of the hydrothermal breccia dyke structure. The hydrothermal breccia dyke structure is crosscut by several quartz veins. A hydrothermal breccia sample collected from C5 sample area is grading 0.68 g/t Au.

In *Coranda Mică* stope a clast-supported breccia with up to 5 cm sub-angular clasts and hydrothermal quartz cement is located along the contact between the phreatomagmatic breccia and the host Cretaceous shales (Fig. 5B). The host rocks (shales) have been silicified close to the breccia body. The ore grades of a sample from C9 area is 1.41 g/t Au.

Three ore deposition styles were identified within the ore bodies exploited in the two stopes from Coș mining field: 1) disseminations within breccia structures and the sedimentary host rocks; 2) high grade hydrothermal breccias (breccia pockets and breccia dykes) with ore cement accompanied by related quartz veins injected into and close to the phreatomagmatic breccia structure; 3) late quartz veins crosscutting the hydrothermal breccias. As interpreted from the remnant mining works, we concluded that in *Coranda Mare* stope were mined 4 different hydrothermal breccia dyke structures (Fig. 6).

*Fig. 6. Northern face of Coranda Mare stope and the position of hydrothermal breccia dyke structures (dot lines).*

The hydrothermal alteration of a rock is the evidence of the hydrothermal fluids flow through that rock by various paths, *i.e.* interconnected pores, cracks, fractures, contacts or brecciated zones. The field evidences strengthened by microscopically observations confirm the occurrence of silicification, potassic alteration (adularia), and phyllic alteration (sericite) in Coș mining field.

The silicification is affecting all types of rocks being associated with the quartz veins or the hydrothermal cement of the breccias (Fig 7A, B). The silicification is increasing the hardness of the rocks and is sealing the available pores. It affects the groundmass of dacite rocks and the matrix of breccia structures (Fig. 7C, D, F), as well as the clasts from breccia structures (Fig. 7I).

Two types of adularia have been observed, *i*) adularia I, formed by K-metasomatosis on the primary feldspar phenocrysts; and *ii*) adularia II, deposited in vugs and accompanied by hydrothermal quartz (Fig. 7B). Adularia I develops only on rock fragments from the vent breccia containing feldspars phenocrysts or clasts (dacite, breccias) (Fig. 7H), while adularia II occurs as open spaces filling or along quartz veinlets. Adularia II is deposited directly from the hydrothermal fluids and postdates the adularia I. It occurs frequently as euhedral crystals intimately associated with hydrothermal quartz.

Minor sericite was sometimes observed within adularised feldspar phenocrysts (Fig. 7H).

Minor calcite deposition was identified in *Coranda Mare* stope as narrow veinlets hosted by massive sandstones (Fig 7G).

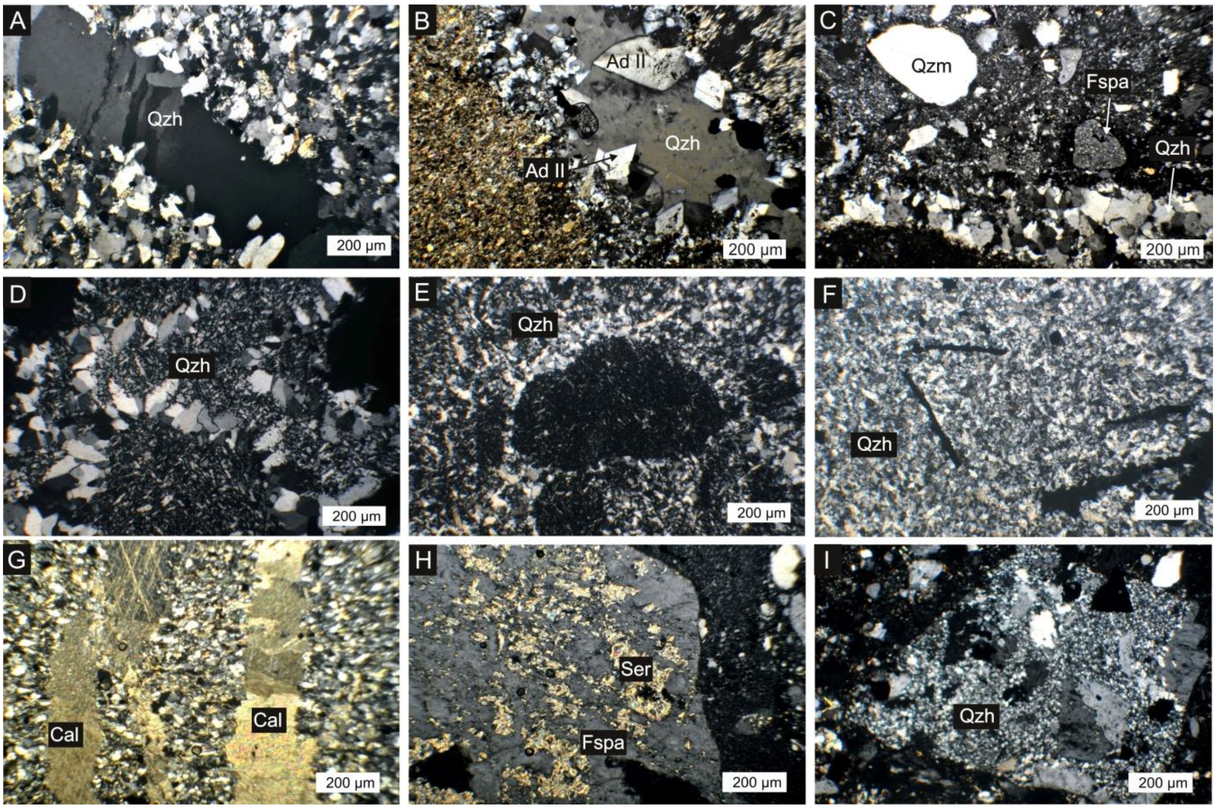


*Fig. 7. Microscopic views of the alterations from Coș mining field. A - hydrothermal quartz vein (Qzh) hosted by sandstone; B - adularia II (Ad II) associated with hydrothermal quartz (Qzh) in a vein hosted by shale; C - phreatomagmatic breccia composed of fragments of magmatic quartz phenocrysts (Qzm) and adularised feldspars (Fspa) in a rock-flour matrix crosscut by a hydrothermal quartz vein (Qzh); D: hydrothermal quartz (Qzh) deposited within vugs in breccia matrix; E - shale clast affected by silicification surrounded by hydrothermal quartz (Qzh); F - massive silicification (Qzh) related to the deposition of acicular opaque crystals; G: sandstone crosscut by calcite veins (Cal); H - Adularia I (Fspa) and sericite (Ser) developed onto a primary feldspar phenocryst; I - dacite clast with its groundmass affected by silicification (Qzh).*

The ore microscopy revealed a simple mineralogical association containing electrum, pyrite, chalcopyrite, sphalerite, tetrahedrite, pyrrhotite and galena.

The most common mineral is pyrite (Fig. 8A), being associated with all others minerals. The size of pyrite crystals varies from 10 to 250 µm, but most of them are ranging in size between 100 and 200 µm. Chalcopyrite is the second more common mineral identified under the microscope (Fig. 8F). Chalcopyrite grains have up to 300 µm. It appears also as small inclusions in sphalerite. Galena was crystalized in the open spaces from pyrite (Fig. 8D) or intimately related to it (Fig. 8E). The ranging size of galena crystal is from 10 to 300 µm. Tetrahedrite was identified as irregular grains up to 100 µm (Fig. 8B). Sphalerite was identified in association with pyrite, chalcopyrite and galena (Fig. 8E). It is also deposited into cracks and open spaces from pyrite or it is intimately related to chalcopyrite (Fig. 8C). Pyrrhotite has been deposited in association with small pyrite veins .

Abundant gold (electrum) grains were identified in association with pyrite (Fig. 8A). The size of gold grains is ranging between 10 and 20 µm.

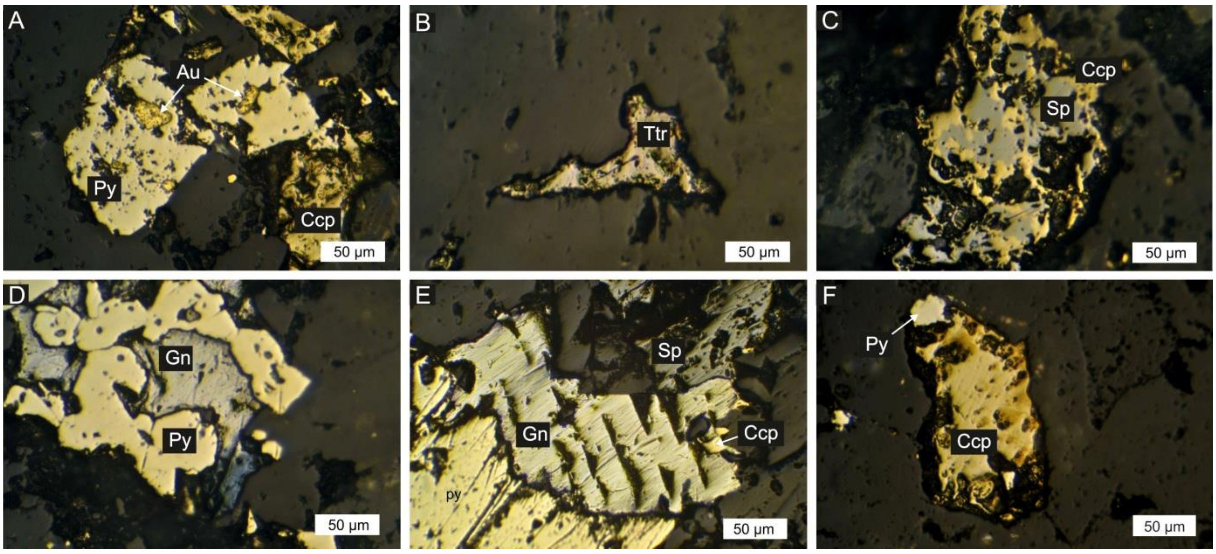


*Fig. 8. Microscopic views of ore minerals identified in Coș mining field. A - electrum in association with pyrite and chalcopyrite; B - tetrahedrite deposited in an open space; C - sphalerite in association with chalcopyrite; D - galena in association with pyrite; E - galena in association with pyrite, sphalerite and chalcopyrite; F - chalcopyrite in association with pyrite; Abbreviations: Au – electrum; ccp – chalcopyrite; gn – galena; py – pyrite; sp – sphalerite; ttr – tetrahedrite.*

Electron probe microanalyses (EPMA) were performed on nine electrum grains, one tetrahedrite crystal and one chalcopyrite grain. EPMA results confirmed that gold grains have a composition corresponding to a natural gold and silver alloy, largely known as electrum. According to Palache et al., (1944) and validated by IMA (*International Mineralogical Association*), electrum is not a mineralogical specimen, but a silver rich gold variety.

The electrum from Coș mining field is hosted by a hydrothermal breccia dyke structure from *Coranda Mare* stope. It is closely associated with pyrite (Fig. 9A, B, C, D, E, F). From 29 analyzed points, 13 exceed the error limits considered to be lower than 98 wt% and higher than 102 wt % respectively. The Ag content in electrum is ranging between 21.9 – 28.6 %, and the gold one is 68,43 - 75,27 % respectively. The mean calculated chemical formula of electrum from Coș mining field is $Au_{0,573}\,Ag_{0,396}$ .

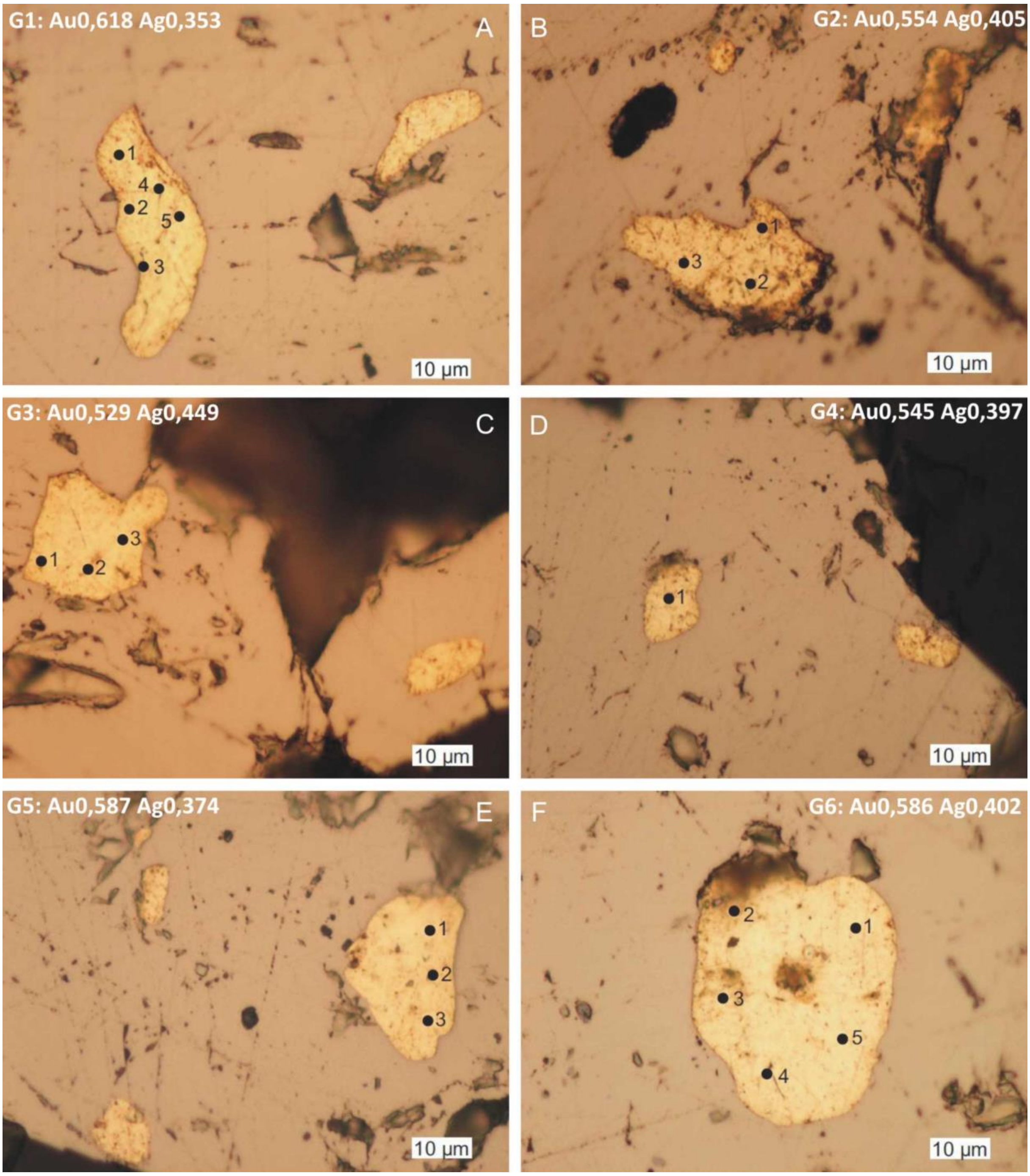


*Fig. 9. Microphotographs in reflected light (one polarizer) showing the electrum grains from Coș mining field analyzed by the means of EPMA; the points and their corresponding number shown in the microphotographs indicate the analyzed points; the mean calculated chemical formula corresponding to the analyzed grain is typed on the upper right corner of each image. All the electrum grains are hosted in pyrite.*

## 9.2. VĂIDOAIA MINING FIELD

Văidoaia mining field is located in the north-eastern part of Roșia Montană ore deposit at about 500 m from historical downtown of the locality.

Field work in Văidoaia including surveying, geological mapping, and sampling was carried out at surface and in the underground in an irregular large stope and an adit. The underground stope, known in the local miners slang under the common name *Coranda Văidoaia* is the result of the historical mining activity. It is located in vent breccia, close to the contact with the sedimentary rocks and the dacite body. It is partially backfilled and several vertical pillars are still in place ensuring thus the stability of this opening located in the vicinity of the surface. An adit heading west starting from the northern part of the stope is passing through the vent breccia approaching the Cretaceous flysch. At the surface several traces of surface mining along vein structures/breccia dykes are still well preserved west of the entrance in the underground stope.

The dacite from Văidoaia has a gray color with a bluish tint (Fig. 10) and posses the characteristics of a lava flow. The dacite is dominated by microcrystalline groundmass with some volcanic glass. The magmatic quartz and the feldspar phenocrysts are smaller as compared with the phenocrysts found in the dacites bodies from Cârnic and Cetate massifs. Moreover, the quartz phenocrysts are frequently broken/brecciated.

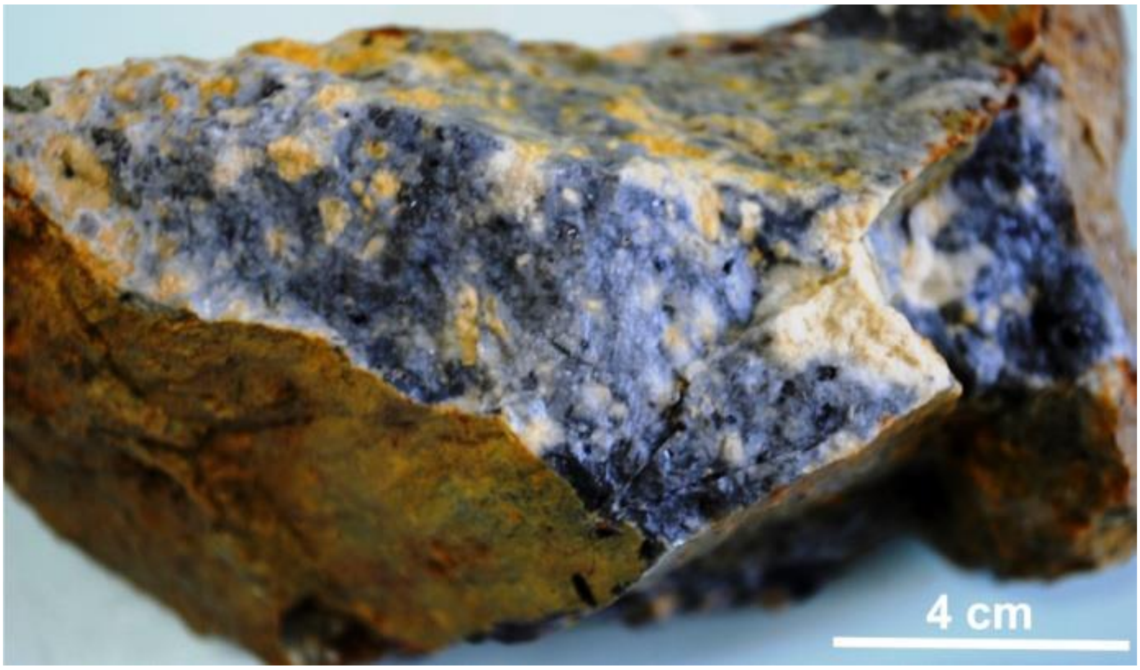


*Fig. 10. Hand specimen of porphyritic dacite from Văidoaia mining field, with dominant feldspar phenocrysts and a gray with a bluish tint groundmass. (Drăgușanu și Tămaș, in print)*

The mineralizations from Văidoaia mining field are hosted by vent breccia and are represented by disseminations, stockworks, veins and breccia dykes.

The disseminations were controlled by the porosity of the coarse matrix of the vent breccia. Pyrite is widespread within vent breccia and its exposure at surface generated an almost continuously yellowish brown blanket on the host rock. Pyrite disseminations were noticed also in dacite and in a lesser extent in Cretaceous rocks.

The stockworks are occurring in Cretaceous rocks, in vent breccia and along the eastern contact of the vent breccia with the Cretaceous sandstones. The stockwork fissures could be distributed roughly parallel or randomly in the host rocks (Fig. 11). The individual fissures are filled with hydrothermal quartz and pyrite. The stockwork zones were mined at the surface but also in the underground. The stockwork mineralizations along the fissures are accompanied by pyrite disseminations within the matrix of the host vent breccia. The stockwork zones are systematically intensely silicified.

*Fig. 11. Stockwork mineralization hosted by vent breccia from Văidoaia mining field (Drăgușanu and Tămaș, in print).*

The main mineralized structures from Văidoaia massif are represented by breccia dyke structures. The best developed breccia structure is exposed on the main face line of the old Văidoaia open pit (Fig. 12) and it is heading NNE and has a dip of about 70$^{o}$ towards WWN. This main breccia dyke structure is hosted by vent breccia and has up to 50 cm width. It was mined at the surface and then in the underground, with safety pillar preserved in Văidoaia stope. The breccia is clast supported with up to 10 cm sub-rounded to sub-angular clasts. The rock fragments within breccia are often covered by a hydrothermal quartz sequence. Among the clasts there are sometimes open spaces. A series of five parallel breccia dykes are also present having an overall NW strike and a dip of about 80$^{o}$ towards SW. The southernmost three breccia dyke structures from this parallel breccia dyke system were mined at the surface (Fig. 13), while the northern two are exposed only in underground. These breccia dykes reaches up to 1 m width. Each individual structure was tracked on over 10 m on strike within the old mining workings; however their initial length was certainly more important abutting probably towards SE and NW to the eastern and respectively the western contact vent breccia - Cretaceous rocks.

*Fig. 12. The main N-S Văidoaia breccia dyke exposed on the northern face line of the old open pit from Văidoaia massif; note that the exploitation followed the strike of this breccia body leading to the development of the underground Văidoaia stope (Drăgușanu and Tămaș, in print).*

The breccia dyke structures from Văidoaia massif seem to be the result of the interaction between a contrasting lithologies contact, the tectonic control and the hydrothermal activity. The parallel breccia dykes are the result of the hydrothermal fluids flow along several parallel take off planes formed by the subsidence of the vent breccia within the Roșia Montană maar-diatreme structure towards its inner part. The Văidoaia breccia dyke represents the southern extension of the contact Cretaceous basement - vent breccia. Moreover, the particular shape of the contacts between Cretaceous sandstones and the vent breccia within Văidoaia area suggests a tectonic relationships and a sinking of the vent breccia supporting the dacite remnant as compared with the Cretaceous shoulders located east and west of it. This sinking is also the reason which allowed the preservation of the dacite lava flow only in that particular area, while in the adjacent sides, due to their uplifted position both the dacite lava flows and the subjacent vent breccia were completed eroded down to the Cretaceous basement.

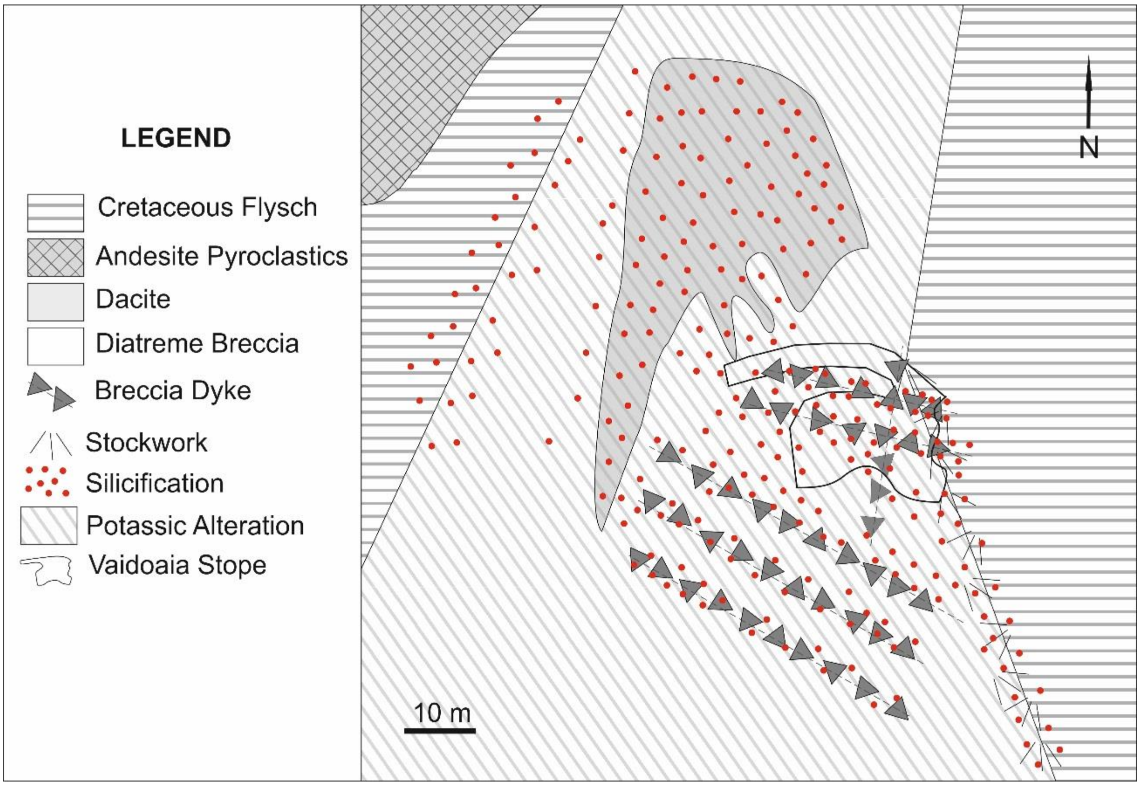


*Fig. 13. Surface geology of Văidoaia mining field, provided by Roșia Montană Gold Corporation. The map also shows the distribution of the hydrothermal alterations and the main mineralized structures (Drăgușanu and Tămaș, in print).*

The field evidences strengthened by microscopic observations confirm the occurrence of silicification, potassic alteration (adularia), and phyllic alteration (sericite) in Văidoaia mining field.

The silicification occurs within the groundmass of the dacite rocks and in the matrix of the vent breccia, being expressed by hydrothermal quartz veinlets and vugs infilling. The hydrothermal quartz is deposited also on the rock fragments within the breccia (dacite, shales, etc.). The intensity of the silicification is varying from high to moderate. The magmatic quartz phenocrysts are sometimes enveloped by hydrothermal quartz rims.

The K-alteration is represented by, *i*) adularia formed by K-metasomatosis upon magmatic feldspar phenocrysts; and *ii*) adularia deposited from the hydrothermal fluids in available open spaces and in this case it is accompanied by hydrothermal quartz. Adularia I is preserving the morphology of the magmatic feldspars phenocrysts, while adularia II is occurring as euhedral to subhedral crystals (Fig. 14A). Hydrothermal quartz is sometimes present within the pores formed during K-metasomatosis of the feldspar phenocrysts due to volume reduction.

The phyllic alteration (sericite) occurs mainly on the feldspar phenocrysts, preceding the K-metasomatosis and also into the matrix of vent breccia in association with massive silicification (Fig. 14B).

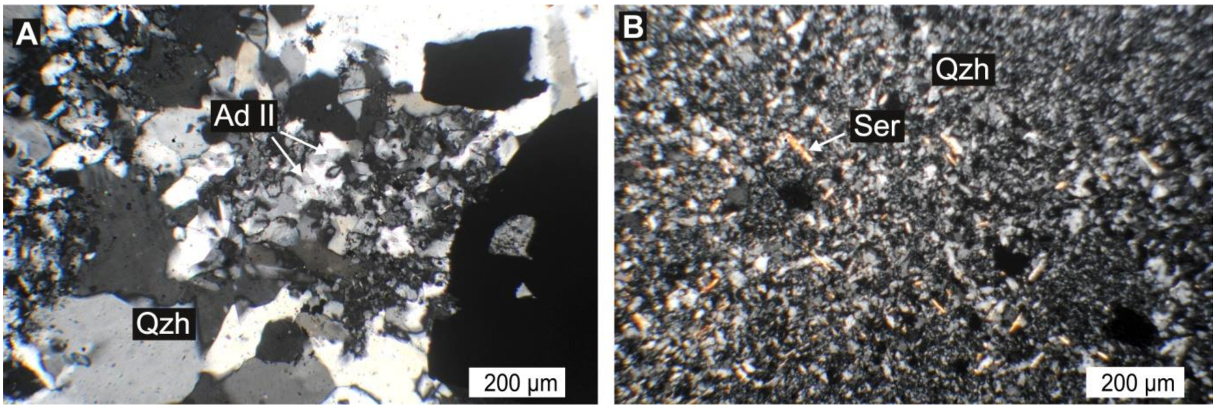


*Fig. 14. Microphotographs in polarized light (two polarizers). A - microscopic view of euhedral adularia II rhombus crystals (Ad II) accompanied by hydrothermal quartz veins (Qzh); B - microscopic view of an intense silicification (Qzh) of the vent breccia matrix associated with a minor phyllic alteration (Ser)(sericite flakes) (Drăgușanu and Tămaș, in print).*

The microscopic study of the ore samples using a transmitted light polarizing microscope revealed the ore mineralogy. Pyrite is the main mineral from the disseminations and stockworks, while chalcopyrite occurs subordinately. The pyrite reaches maximum 5 volumetric % in veins.

Gold was observed in veins and breccias. A quartz vein with adularia II and intense along vein silicification of the vent breccia host rock revealed the presence of gold hosted by pyrite (Fig. 15). Gold is deposited on euhedral pyrite crystals and in voids within pyrite reaching up to 60 micrometers length (Fig. 16).

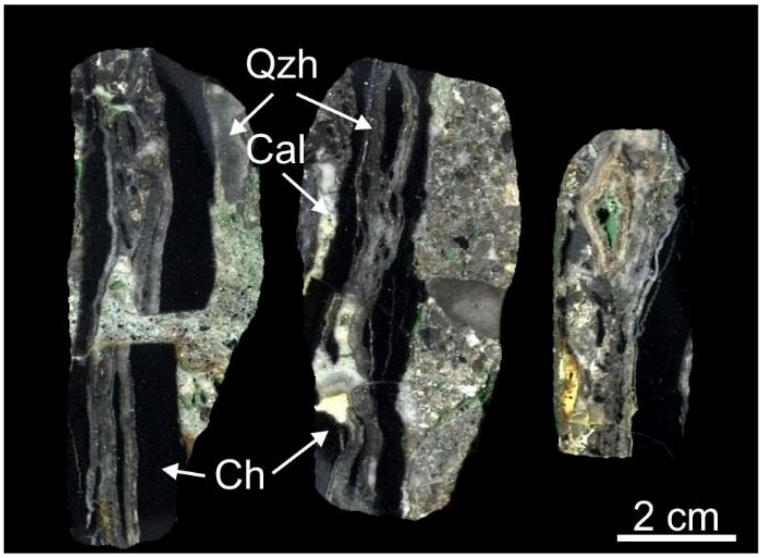


*Fig. 15. Detail of the late hydrothermal brecciation of chinga cement, consolidated with hydrothermal quartz and calcite. Abbreviations: Cal-calcite; Ch-"chinga" hydrothermal cement; Qzh-hydrothermal quartz. (Drăgușanu and Tămaș, in print)*

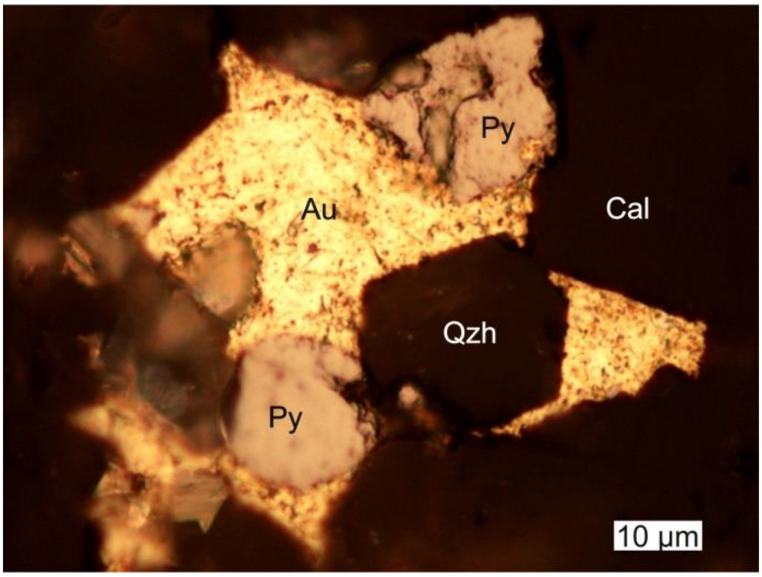


*Fig. 16. Microphotograph in reflected light (one polarizer) of electrum (Au) in association with pyrite (Py), calcite (Cal) and hydrothermal quartz (Qzh) (Drăgușanu și Tămaș, in print).*

According to EPMA analysis the gold content within electrum is 71 – 72 % and the silver content is 25 - 28 %. Average calculated chemical formula for the electrum from Văidoaia mining field is $\mathbf{Au_{0,59}\,Ag_{0,41}}$ . The ore grade of a hydrothermal breccia from Văidoaia mining field as indicated by a grade analysis is 5.19 ppm Au.

### 9.3 ȚARINA MINING FIELD

Țarina mining field is located at about 650 m north-west from Văidoaia mining field. At the surface outcrops vent breccia formation which covers the Cretaceous flysch. Both lithologies are covered towards north by andesitic lava flows and pyroclastics. The field work comprises essentially activities in the underground. The surface exposures are completely hidden by the dense vegetation. The access in the underground was possible by a small coast adit heading through north, named Arama adit. The adit intercepts along the first 10 m the vent breccia and then is passing into Cretaceous black shales.

The Cretaceous basement observed in Țarina mining filed is represented by black shales with sparse centimeters size sandstones fragments. The vent breccia exposed in Arama underground network is a polymict matrix-supported breccia with dacite, shales and sandstone clasts. The clasts are mainly subrounded to subangular and centimeters size. The vent breccia is silicified along cracks heading east-west with a 25° dip towards south.

At the contact between the vent breccia and the Cretaceous flysch was identified a polymict breccia dyke structure. The underground survey pointed out a breccia body measuring 2 m width and 7 m length. Within this breccia structure two types of breccias have been identified: an early phreatomagmatic breccia and a late hydrothermal breccia. Generally speaking, the phreatomagmatic breccia is the host rock of the ore body represented here by the hydrothermal breccia (Fig. 17A). The phreatomagmatic breccia structure is matrix supported with a rock-flour matrix, dominantly subrounded clasts and minor open spaces. The clasts are made from dacite, sedimentary rocks and quartzite (Fig. 17B). This early phreatomagmatic breccia was circulated later by hydrothermal fluids that triggered a hydrothermal brecciation. The most visible transformations of the early breccia consist in silicification and hydrothermal cement together with ore mineral deposition (Fig. 17C). A sample collected from the hydrothermal breccia structure contains 7.88 ppm (g/t) Au.

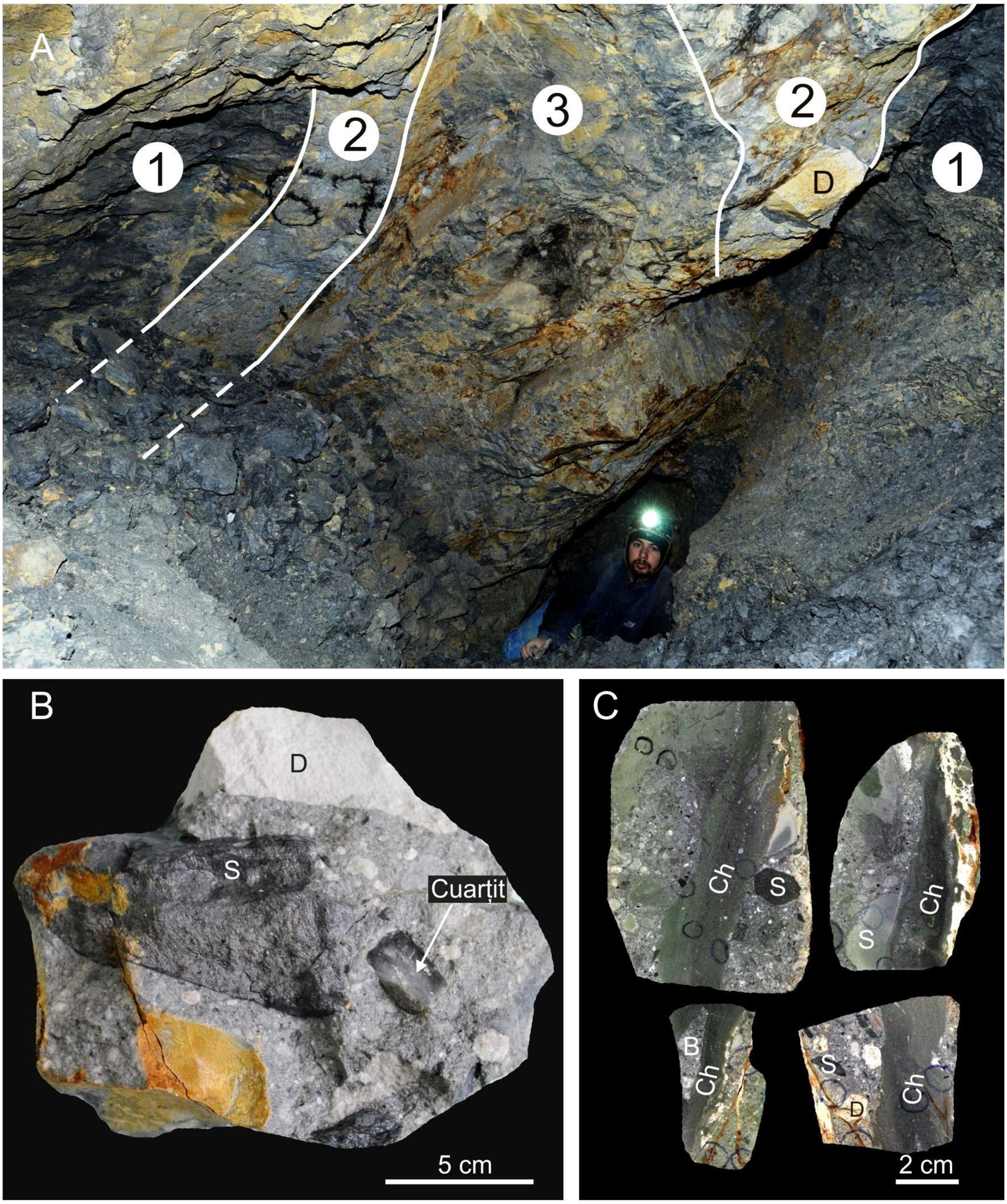


*Fig. 17. Phreatomagmatic - hydrothermal breccias relationships in Ţarina mining field. A - transversal cross-section into composite phreatomagmatic - hydrothermal breccia structure with 1) Cretaceous shales; 2) phreatomagmatic breccia; 3) hydrothermal breccia; B - fragment from phreatomagmatic breccia; C - samples from the hydrothermal breccia developed onto phreatomagmatic breccia. Abbreviations: B: breccia clasts; Ch - hydrothermal cement; D - dacite S - sedimentary rocks.*

## 9.4. ORLEA MINING FIELD

Orlea mining field is located in the north-western part of Roșia Montană ore deposit. The mining activity started in this area during the Roman times. According to the geological map, the ore bodies from Orlea mining field are located entirely into vent breccia which at its turn is partially covered by andesitic lava flows and pyroclastics.

The geological investigations carried out in the frame of the PhD thesis within Orlea mining field took place at the underground level +730. The access in the underground was possible through the inclined pathways deserving the Roman Adits Museum. From the underground works have been collected 145 samples from 3 different mineralized areas (Fig. 18), and have been prepared 48 thin sections and 20 polished sections.


*Fig. 18. Topographic map of the underground mining works from Orlea, +730 level, with the location of sampling areas (RMGC courtesy).*

The studied mineralizations are hosted by vent breccia and are represented by veins and breccia dyke structures. Three sampling zones (O1 to O3) with different ore deposit peculiarities have been investigated: (1) flat dipping vein with rhodochrosite gangue – O1 sampling area; (2) tectonic breccia dyke – O2 sampling area; (3) base metal vein – O3 sampling area.

**Flat dipping vein with rhodochrosite gangue – O1 sampling area**

The rhodochrosite vein is up to 5 cm thick and has a 10° dip towards south. In the underground mining works the flat dipping vein was followed on more than100 m², being exposed on vertical pillars (Fig. 19).

*Fig. 19. Flat dipping rhodochrosite vein hosted in vent breccia exposed on a vertical pillar. The image is showing the sampling zone of the sample used for grade analysis (101 g/t Au).*

The microscopic study (thin sections) revealed the presence of adularia II euhedral crystals in association with rhodochrosite.

The ore microscopy confirmed the occurrence of electrum, pyrite, chalcopyrite, sphalerite, and galena. Electrum was identified in association with pyrite (most often) and sphalerite. The electrum grains range in size from 20 to 150 µm (Fig. 20).

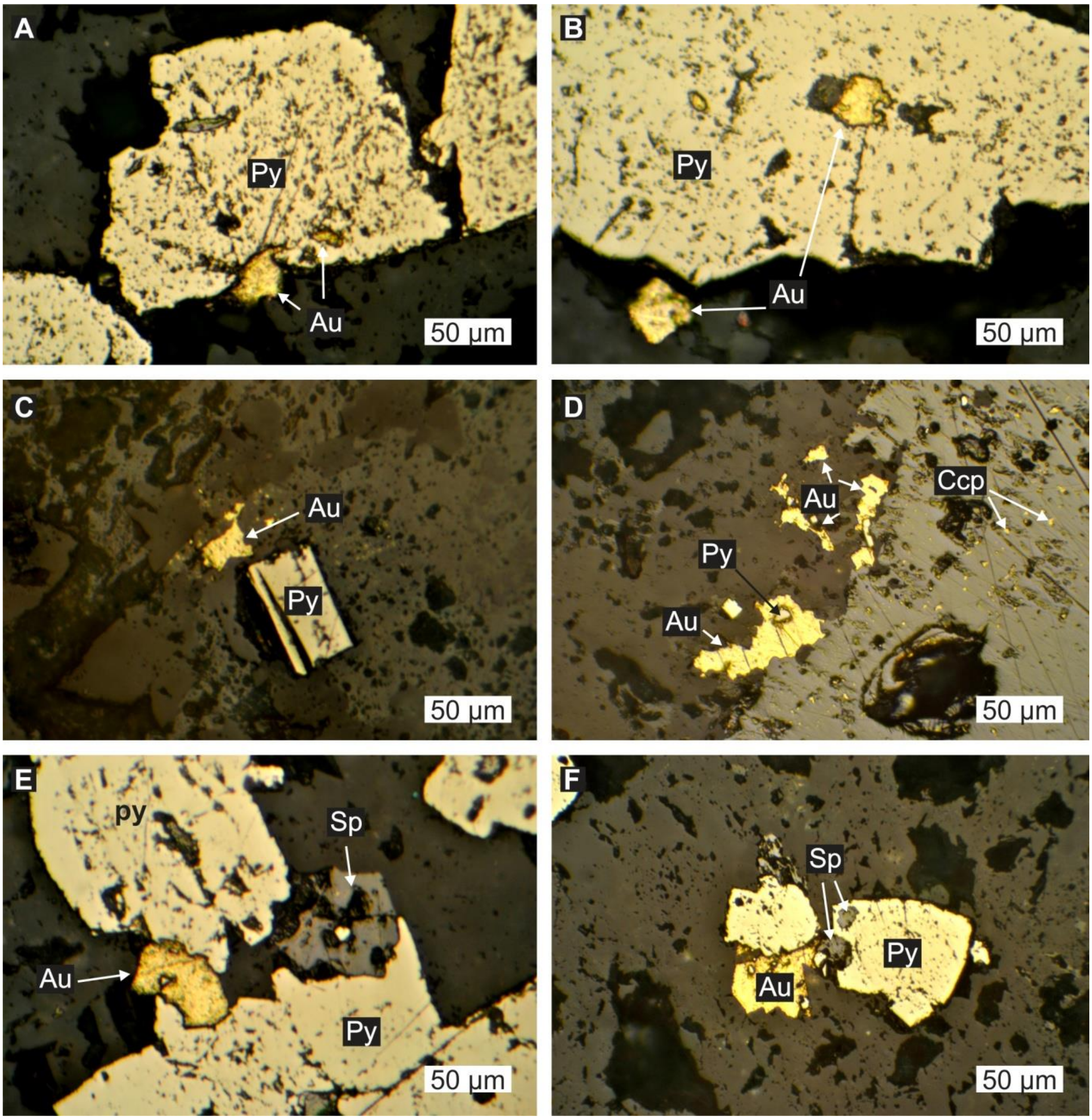


*Fig. 20. Reflected light microphotographs (one polarizer) presenting electrum mineral assemblage from the rhodochrosite vein from+730 level, Orlea mining field. Abbreviations: Au – electrum (gold), ccp – chalcopyrite, py – pyrite, sp – sphalerite.*

### Tectonic breccia dyke structure – O2 sampling area

An ore body represented by a tectonic breccia dyke struucture hosted by vent breccia formation was also investigated. This breccia dyke is 15 – 20 cm width (Fig. 21) and was followed on 25 m along strikee. It is heading N and is subvertical, being exposed in the ceiling of the drift.

*Fig. 21. Tectonic breccia dyke structure from +730 level, Orlea mining field.*

The regional tectonic regime was responsible for the creation of a N-S fault which was afterwards circulated by hydrothermal fluids. A banded quartz vein formed but this primary ore body was brecciated aganin with formation of angular ore fragments and a clast supported breccia suggesting a significant colapsing. Following the tectonic brecciation a new hydrothermal pulse was responsible for the deposition of a quartz sequence envelopping the fragments and their contact zones.

The ore microscopy study of this ore body allowed to identified the following mineral association: pyrite, chalcopyrite, galena, and pyrrhotite.

**Base metal vein – O3 sampling area**

A base metal vein with hydrothermal cement gangue heading north was studied in the O3 sampling area (Fig. 22A, B, C). This vein is about 10 cm thick and an accessible development along strike of 15 m.

The ore minerals association identified within the base metal vein is including pyrite, chalcopyrite, arsenopyrite, galena, and pyrrhotite. The ore minerals are accompanied by a minor hydrothermal quartz gangue.

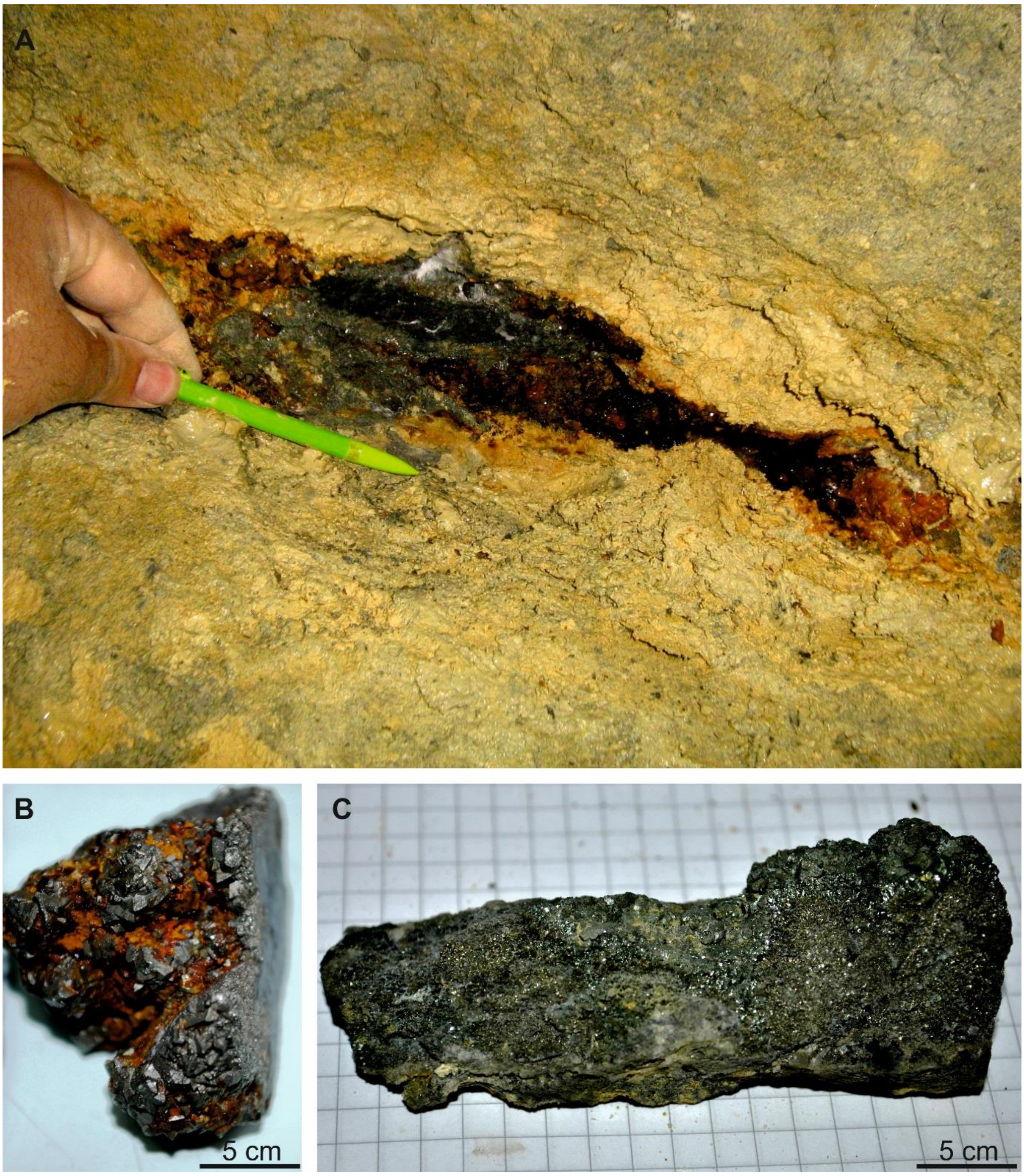


*Fig. 22. Base metal vein from +730 level, Orlea mining field.*

EPMA investigations revealed the chemical composition of electrum, galena pyrite grains from the rhodochrosite vein. The silver content of electrum is ranging between 26,42 and 30,93 % while the gold ones is comprise between 66,67 and 74,55 %. The calculated chemical formula of electrum from Orlea mining field is $\mathbf{Au_{0,564}\,Ag_{0,421}}$.

The ore grade analysis was performed on a sample collected from the rhodochrosite vein (Fig. 19) and confirmed the high grade character of this ore body, *i.e.* 101 ppm (g/t) Au.

# 10. MODEL OF THE NORTHERN PART OF ROȘIA MONTANĂ ORE DEPOSIT

Roșia Montană gold deposit is an epithermal deposit hosted by a maar-diatreme volcano emplaced in Cretaceous flysch. The PhD study focused on the northern part of Roșia Montană diatreme where the contact between the Cretaceous flysch basement and the filling of the diatreme, the so-called vent breccia played an important role in precious-metals ore deposition.

Roșia Montană diatreme has a circular footprint at the surface while in the underground it continues as an upside-down cone which go on deeper down as a pipe. Two tectonic controls have been delineated. The first is a regional scale one and it is responsible for the formation of N-S striking ore bodies. The second one has a local development and its origin has been deciphered.

Roșia Montana diatreme was a spot of significant phreatomagmatic activity responsible for the genesis of multiples phreatomagmatic breccia structures during at least 3 Ma (Tămaș, 2010). According to this author the phreatomagmatic activity started around 14 Ma and ended at about 11 Ma. The phreatomagmatic activity had a complex character being pre-, sin-, late- and post-mineral. During all this period, the Roșia Montana diatreme was subjected to repetitive eruptions/brecciations events. This phreatomagmatic activity comprised also eruptive pulses with significant expulsion of material from the diatreme that generated extracraterial sequences. The negative balance of material into the diatreme following these eruptions triggered an active subsidence towards the inner part of the diatreme. As such, ring shaped normal fault have been formed within the vent breccia filling of Roșia Montană diatreme. At the scale of the studied area the individual faults creating the ring faults structures have different orientations, *i.e.* north-west – south-east in Coș and Văidoaia mining field, east – west in Țarina mining field and north-east – south-west in Orlea mining field (Fig. 23).

Taking into account the above mentioned structural tectonic setting acting at regional and local scales it is possible to emphasis that the ore bodies formation and the ore deposition in the northern part of Roșia Montană ore deposit was controlled by:

- the contact zone between the Cretaceous flysch basement and Roșia Montana diatreme (vent breccia);
- the N-S faults within vent breccia which are tributary to the regional extensional tectonic setting from Roșia Montană - Bucium district;
- steep and flat dipping normal faults (listric faults) which are part of the ring faults structures dipping towards the center of the diatreme and which are formed due to

the subsidence of vent breccia as a reflex of prolonged phreatomagmatic activity within Roșia Montană diatreme;

- the contact between contrasting lithological sequences within Cretaceous basement rocks, *i.e*. shales and sandstones.

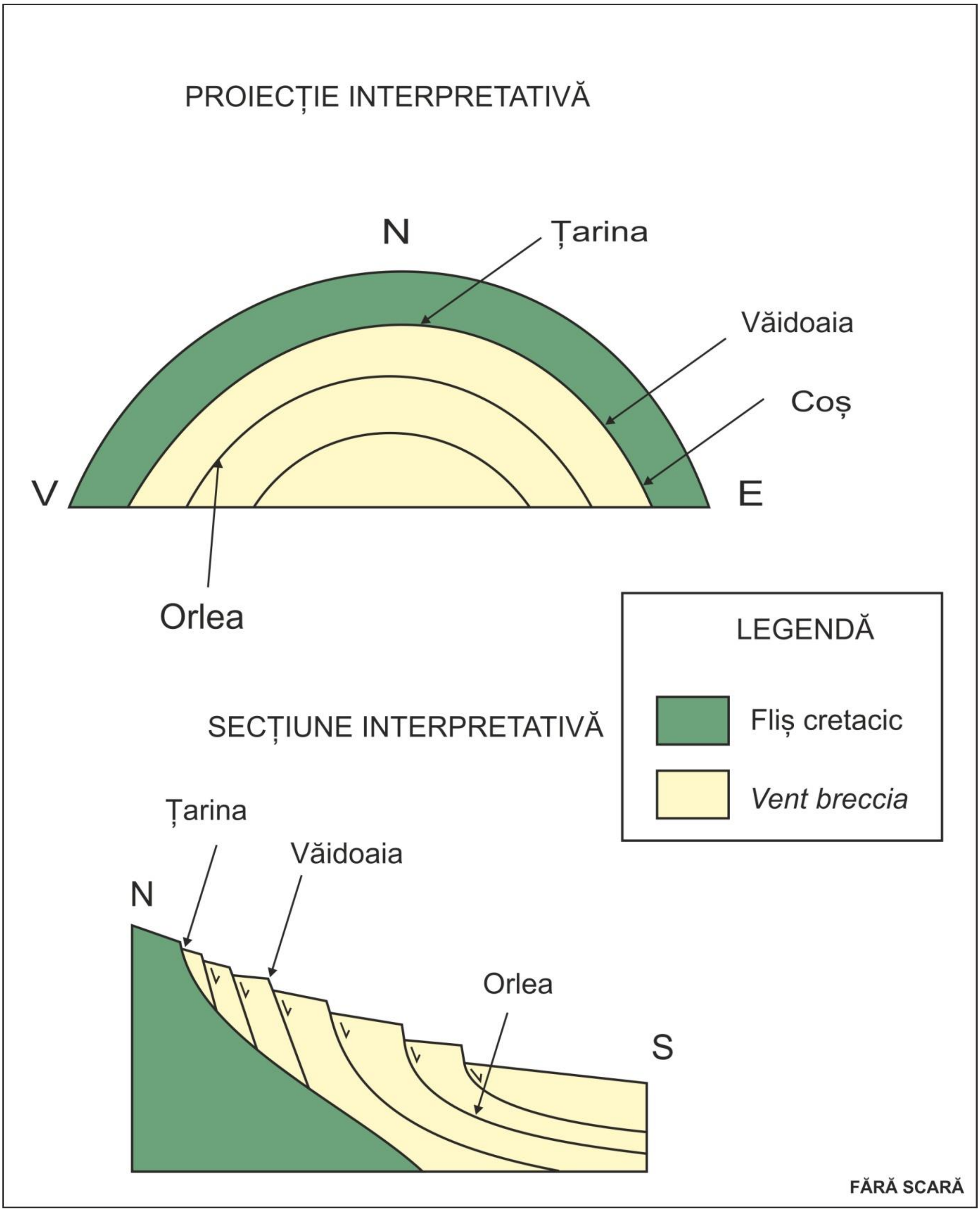


*Fig. 23. Interpretative horizontal projection (upper image) and cross section (lower image) of the northern part of Roșia Montană ore deposit, showing the contact between diatreme breccia (vent breccia) and Cretaceous flysch (basement), with the set up of subsidence towards the inner part of the diatreme partly controlled by ring shaped take-off planes similar to listric faults.*

The main ore bodies identified in the northern part of Roșia Montană ore deposit consist of hydrothermal breccia dyke structures and veins. While the breccia dykes are steep dipping, the veins are either steep or flat dipping (Fig. 24).

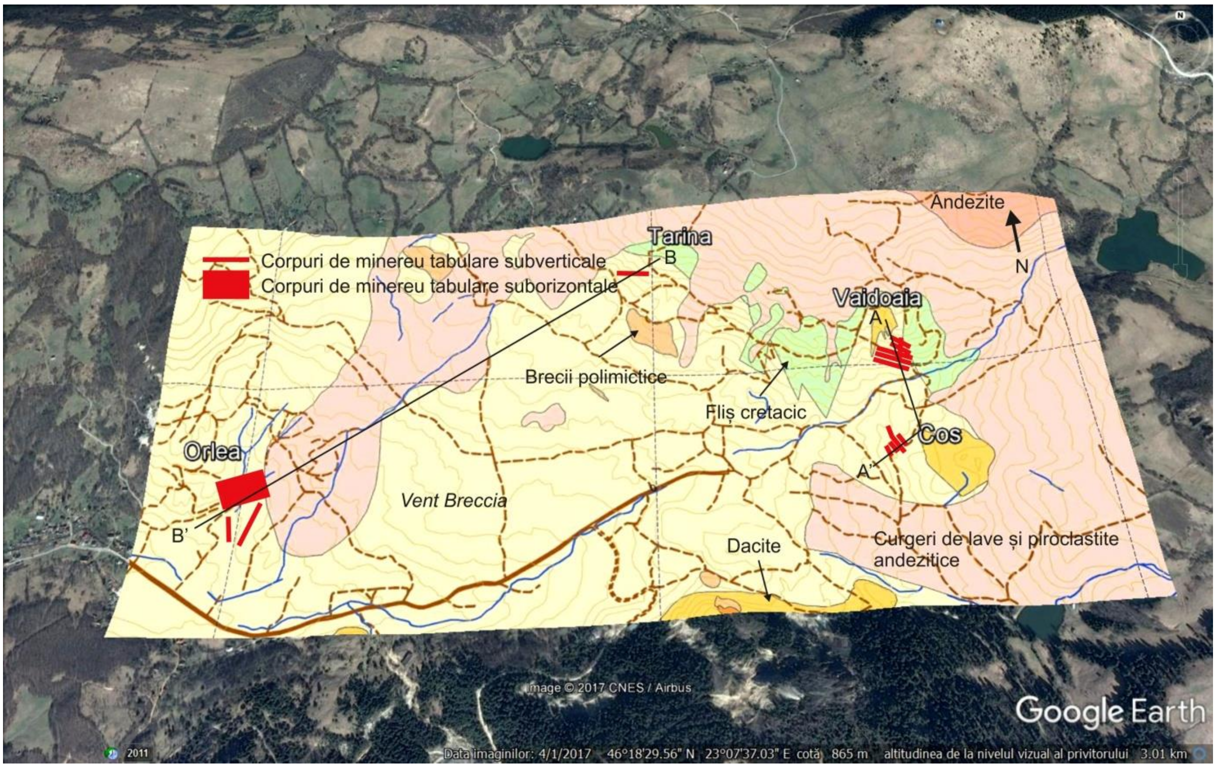


*Fig. 24. Georeferencing geological map (RMGC courtesy) in Google Earth of the northern part of Roșia Montană ore deposit with representation of the studied tabular ore bodies.*

Some differences concerning the characteristics of the ore deposition controls occur within the northern part of Roșia Montană ore deposits. These peculiarities are presented below for each mining field, from east to west.

The mineralization controls in Coş mining field are represented by a steep dipping take-off plane formed by the subsidence of vent breccia which was reinforced by a contact between the black shales and the massive sandstones from the Cretaceous basement. A phreatomagmatic breccia structure was first emplaced along the contact between Cretaceous shales and vent breccia and then a hydrothermal activity took place in the same area and created hydrothermal breccias and late quartz veins overprinting the hydrothermal breccia structures (Fig. 25).

The main control factors in Văidoaia mining field are represented by parallel steep dipping take-off planes formed by the subsidence of vent breccia close to the contact between vent breccia and Cretaceous flysch. The hydrothermal fluids rose towards the surface along these planes and triggered several hydrothermal brecciation events each one with its own hydrothermal cement (Fig. 25).

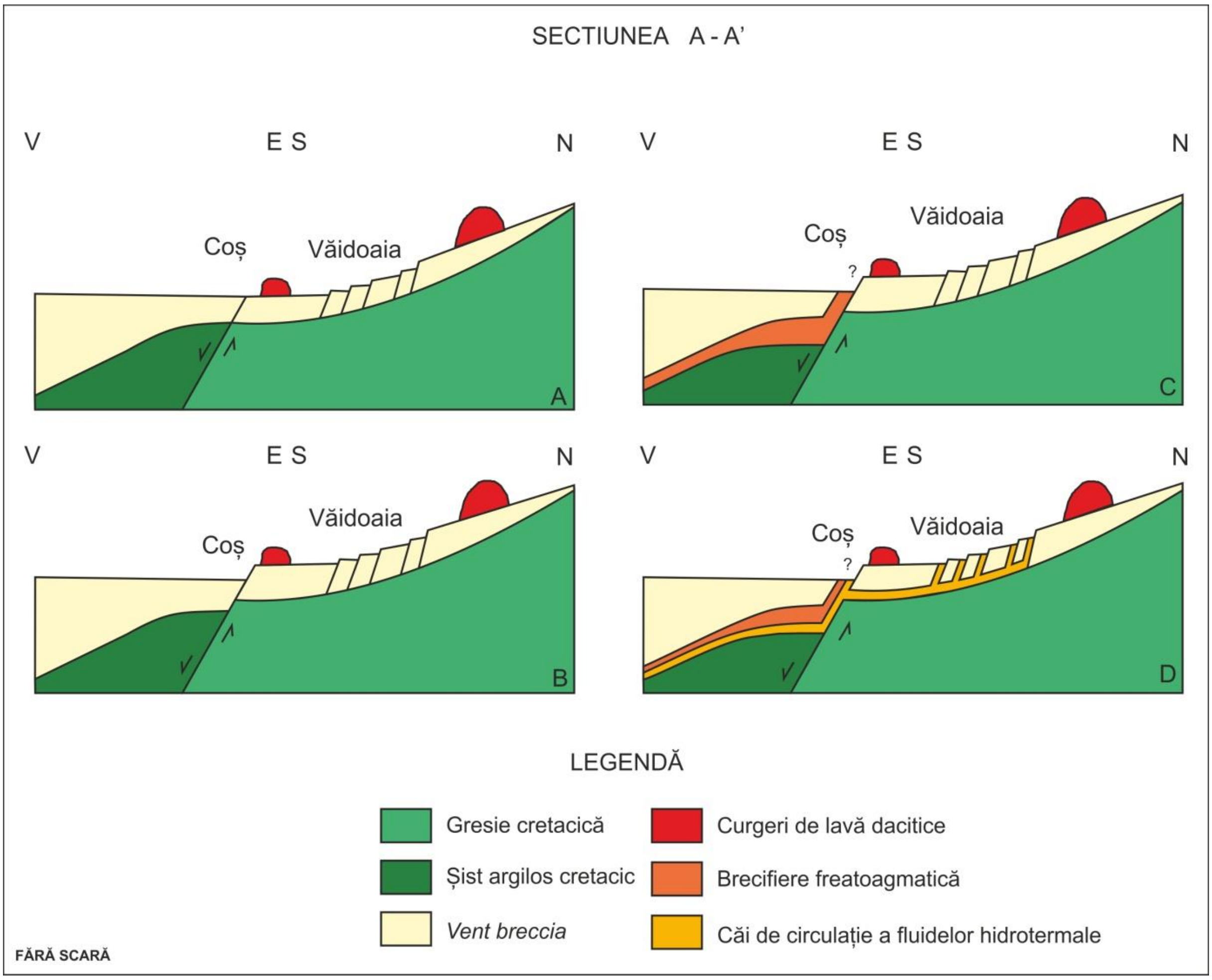


*Fig. 25. Ore deposit model for Coș and Văidoaia mining field: A - in the frame of a subsidence process listric faults formed within vent breccia; B - different charge on the black shales and sandstones sequences enhanced locally the tectonic control; C - phreatomagmatic activity took place along the contact between vent breccia and Cretaceous flysch; D - flow of the hydrothermal fluids focused along the contact surface Cretaceous basement - vent breccia filling and through already created discontinuities within vent breccia.*

As concerns Țarina mining field the contact between the Cretaceous shales and Roșia Montană diatreme breccia filling favored the emplacement of a phreatomagmatic breccia. The subsequent hydrothermal fluids passed through this breccia structure and triggered its hydrothermal brecciation. The ore bodies are represented by hydrothermal breccia dykes hosted in phreatomagmatic breccias located in Cretaceous shales in the proximity of the contact zone basement - vent breccia (Fig. 26).

The ore bodies from Orlea mining field are structurally controlled by the regional tectonic setting (N-S tabular ore bodies) and local tectonic constraints induced by the subsidence of the vent breccia. The field evidences suggest that the regional control was active earlier than the local tectonic control. The ore bodies are represented by steep dipping breccia dykes and veins and by flat dipping veins (Fig. 26).

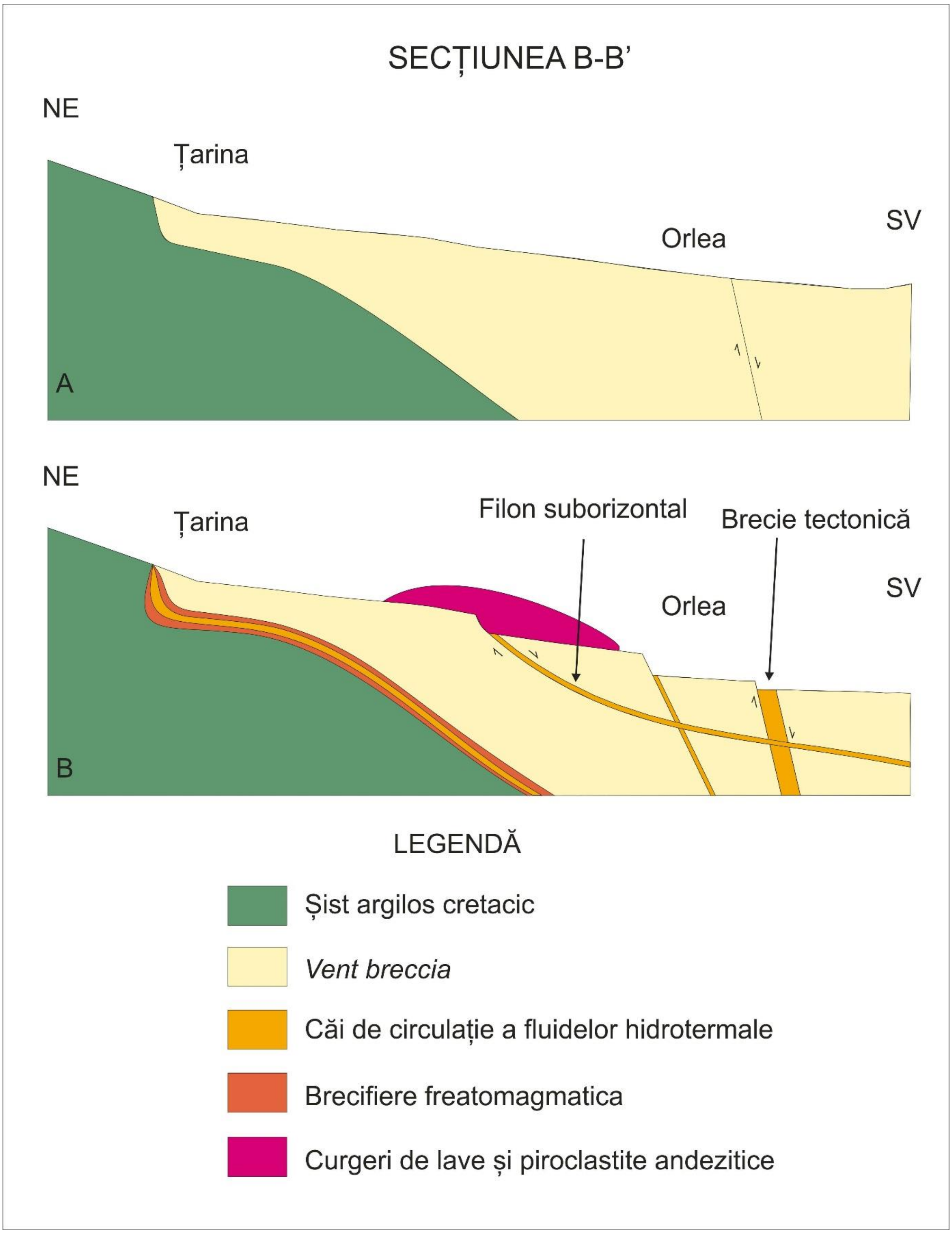


*Fig. 26. Simplified ore deposit model for Țarina and Orlea mining fields. A - The phreatomagmatic breccias were emplaced along the contact vent breccia - Cretaceous basement; B - Hydrothermal fluid flow and ore deposition took place along the above mentioned contact and through regionally and locally controlled faults.*

# CONCLUSIONS

The mineralizations from the northern area of Roșia Montană ore deposits have a clear low sulphidation character and consist of breccia dyke structures, veins, stockworks, and disseminations. The most important are the hydrothermal breccia dykes and the vein.

The ore bodies are controlled by, 1) the contact between Roșia Montană diatreme breccia (vent breccia) and Cretaceous flysch basement, 2) the regionally controlled N-S faults developed within vent breccia; 3) the locally controlled steep and flat dipping normal faults (listric faults) with a ring shape distribution created by the subsidence of the vent breccia as response to the continuous phreatomagmatic activity with Roșia Montană diatreme, and 4) the tectonic contact between the black shales and the massive sandstones from the Cretaceous flysch.

The hydrothermal alterations accompanying the ore and identified in the studied area comprise silicification, potassic alteration (adularia), and phyllic alteration (sericite). Two types of potassic alteration have been identified: *i)* adularia I formed by K-metasomatosis and developed only on magmatic feldspar phenocrysts, and *ii)* adularia II, which occurs as euhedral crystals in association with hydrothermal quartz.

The ore mineralogy was established by optical microscopy, electron microscopy (SEM), and microprobe data (EPMA) and comprises the following minerals: electrum, tetrahedrite, pyrite, chalcopyrite, galena, sphalerite, covellite, arsenopyrite and pyrrhotite. According to EPMA analysis, the electrum composition is dominated by gold (68 – 75 % weight) and contains silver 28%. Minor traces of Fe (max. 1,99 % wt), Cu (max. 0,11 % wt), As (max. 0,11 % wt), Bi (max. 0,27 wt), Sb (0,02 % wt) occur as impurities.

Ore grades analyses revealed that the rhodochrosite veins from Orlea mining field are the carrying the higher grades from the entire northern part of Roșia Montană ore deposit (101 g/t Au). Significant grades are hosted by hydrothermal breccia dyke from Țarina mining field (7.88 g/t Au), hydrothermal breccia with *chinga*, quartz and calcite from Văidoaia (5.19 g/t Au), and in a lesser extent by the hydrothermal breccia dyke from Coș (*Coranda Mică* stope, 1.41 g/t Au).

The PhD thesis generated many new results for an almost unknown part of Roșia Montană ore deposit. It also offers an innovative model for the northern part of Roșia Montană ore deposit.

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