104 YEARS OF THE CARPATHIAN-BALKAN GEOLOGICAL ASSOCIATION



XXIII International Congress of the Carpathian-Balkan Geological Association CBGA

FIELD TRIPS GUIDE VOLUME

Sergiu Drăgușanu, George Pleș, Călin Gabriel Tămaș

(EDITORS)

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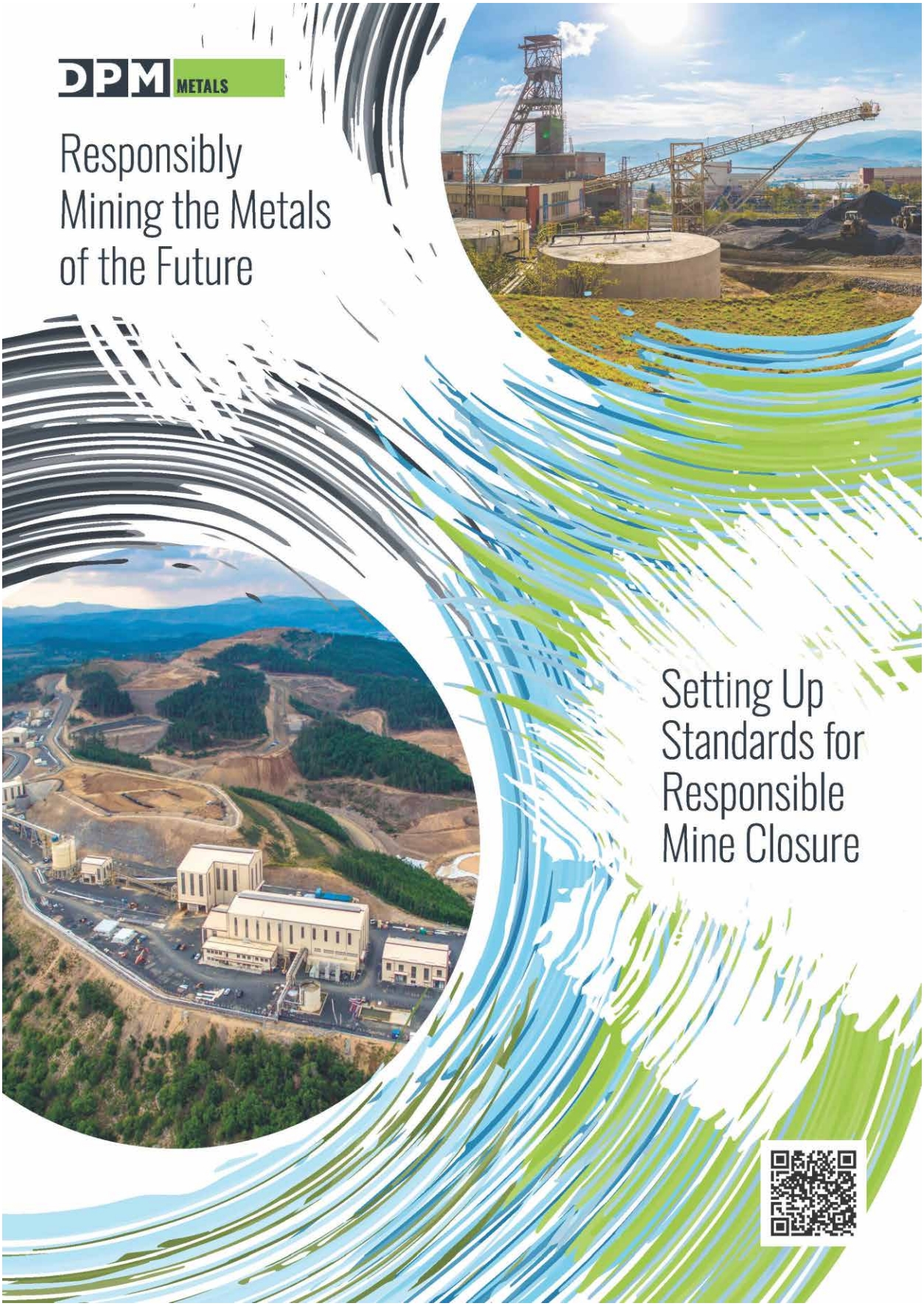

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FT1. Geological transect through the Apuseni Mts. – Banat – Timok: Late Cretaceous magmatism and metal endowment

István Márton[1], Kalin Kouzmanov[2], Nuțu Groza[1], Mladen Zdravkovic[1]

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INTRODUCTION AND FIELD TRIP ITINERARY

The Late Cretaceous Apuseni–Banat–Timok–Srednogorie (ABTS) belt is a major Cu–Au metallogenic province in southeastern Europe, developed during Neotethyan subduction, slab rollback, and upper-plate extension. Over the past 15 years, exceptional copper–gold discoveries have been made in relatively mature districts of the Serbian and Bulgarian segments of the belt, already totaling more than 20 Mt of Cu and 20 Moz of Au in new metal resources. Recent exploration reports suggest that these resource figures may soon double. The newly discovered deposits represent various parts of magmatic-hydrothermal systems, including porphyry Cu-Au (Čukaru Peki Lower Zone and Frasen in Serbia, and Brevene South Porphyry at Chelopech, Bulgaria), high-grade Au manto-skarn (Čoka Rakita, Serbia), skarn and carbonate-replacement Cu-Au-Ag-polymetallic (Dumitru Potok, Frasen, Rakita Deep, Malka Golaja in Serbia), high-sulfidation type epithermal Au-Cu (Čukaru Peki Upper Zone in Serbia, Wedge Deep Zone at Chelopech, Bulgaria) and distal sedimentary rock-hosted Au (Bigar Hill, Korkan, and Kraku Pešter in Serbia) mineralization. Historical resources and further exploration potential are particularly notable in the relatively underexplored Romanian segments of the Late Cretaceous belt, including the Apuseni Mts., Poiana Ruscă, and Banat district.

This field trip will provide an overview of the Late Cretaceous porphyry, epithermal, and skarn Cu-Au deposits from Romania and Serbia. The excursion will focus on three segments along the ABTS belt, each having significant metal endowment with past and present production, including the Apuseni Mts. and Banat regions in Romania and the emerging Timok ore district in Eastern Serbia. The trip will include site visits to the major active mine areas, and an overview of significant advanced exploration projects, together with an overview of the current understanding of the geological and geodynamic evolution of the belt and the conditions that led to the formation of this Cu-Au province. We will also review stratigraphic constraints, alteration vectors, specific petrological and geochemical features, and the associated challenges to exploration in this Late Cretaceous mineral province in Eastern Europe.

Visits to active exploration and mining projects are planned according to the following itinerary (Fig. 1):

- **Day 1** (September 12, 2026): Polymetallic skarn deposits of Mașca–Băișoara Metallogenic District and geology of the Apuseni Mountains, Romania (travel: Cluj – Băișoara– Brad – Lugoj).
- **Day 2** (September 13, 2026): Skarn and porphyry Cu-Au-polymetallic deposits): Skarn and porphyry Cu-Au-polymetallic deposits of Western Banat Metallogenic District, Romania (travel: Lugoj – Ocna de Fier – Ciclova Montană – Oravița – Orșova).
- **Day 3** (September 14, 2026): World-class porphyry and epithermal Cu-Au deposits of Timok East, Serbia (travel: Orșova – Iron Gates – Majdanpek porphyry Cu-Au deposit and Čukaru Peki epithermal & porphyry Au-Cu deposit – Bor).
- **Day 4** (September 15, 2026): Newly discovered Cu- and Au-rich alkaline porphyry, skarn and sedimentary rock-hosted deposits of Timok West, Serbia (travel: Bor – Čoka Rakita and Dumitru Potok Au-Cu-Ag skarn deposits and Frasen porphyry Au-Cu prospect – Bor).

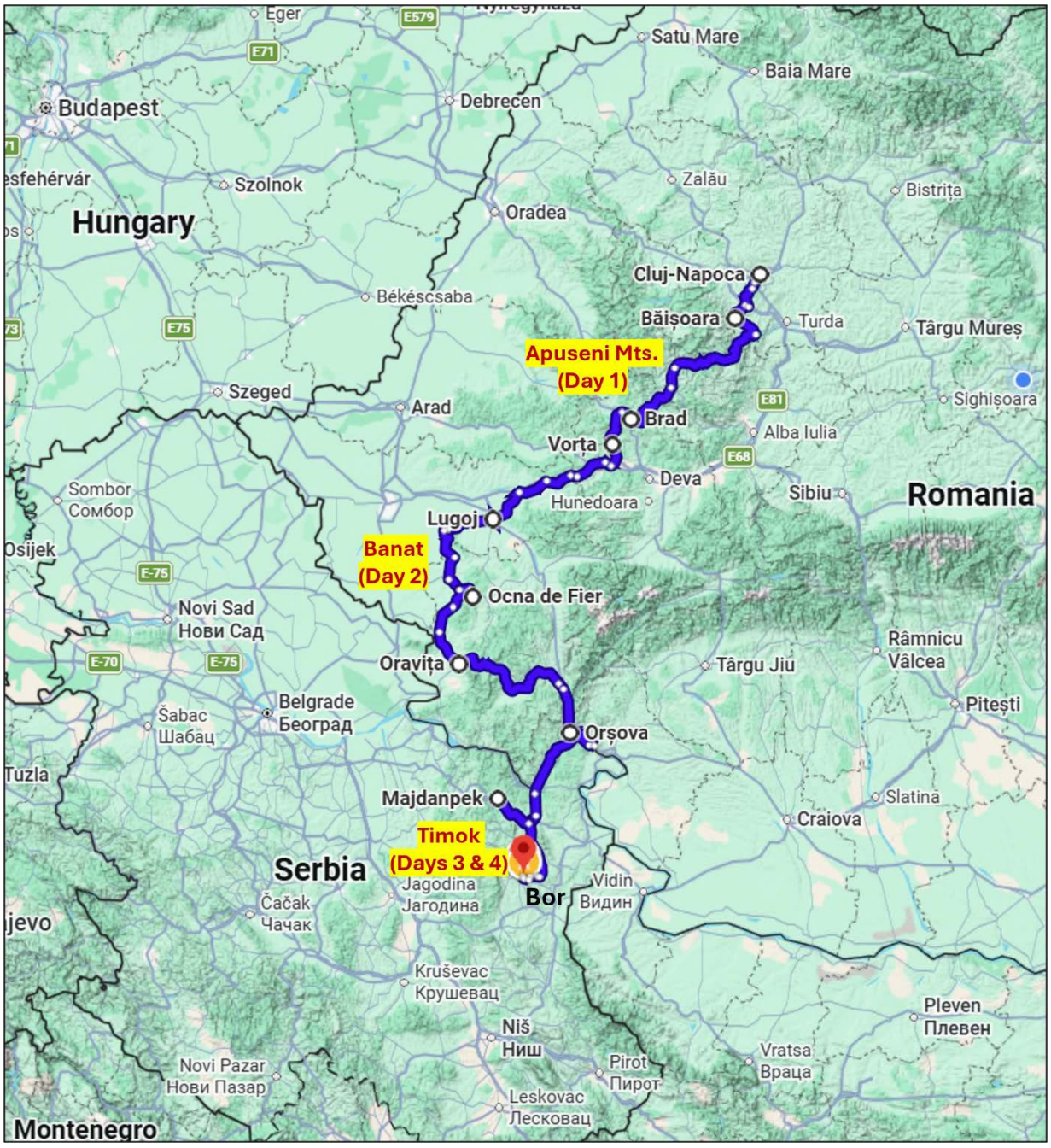


Fig. 1. Field trip itinerary and planned observation stops mapped on a Google Terrain base layer.

1. LATE CRETACEOUS MAGMATISM AND ORE DEPOSIT FORMATION IN ROMANIA AND SERBIA

The Late Cretaceous ABTS magmatic arc formed on the European margin during closure of the western branch of the Neotethys Ocean, and it was subsequently deformed into a complex orocline by continental collisions (Fig. 2).

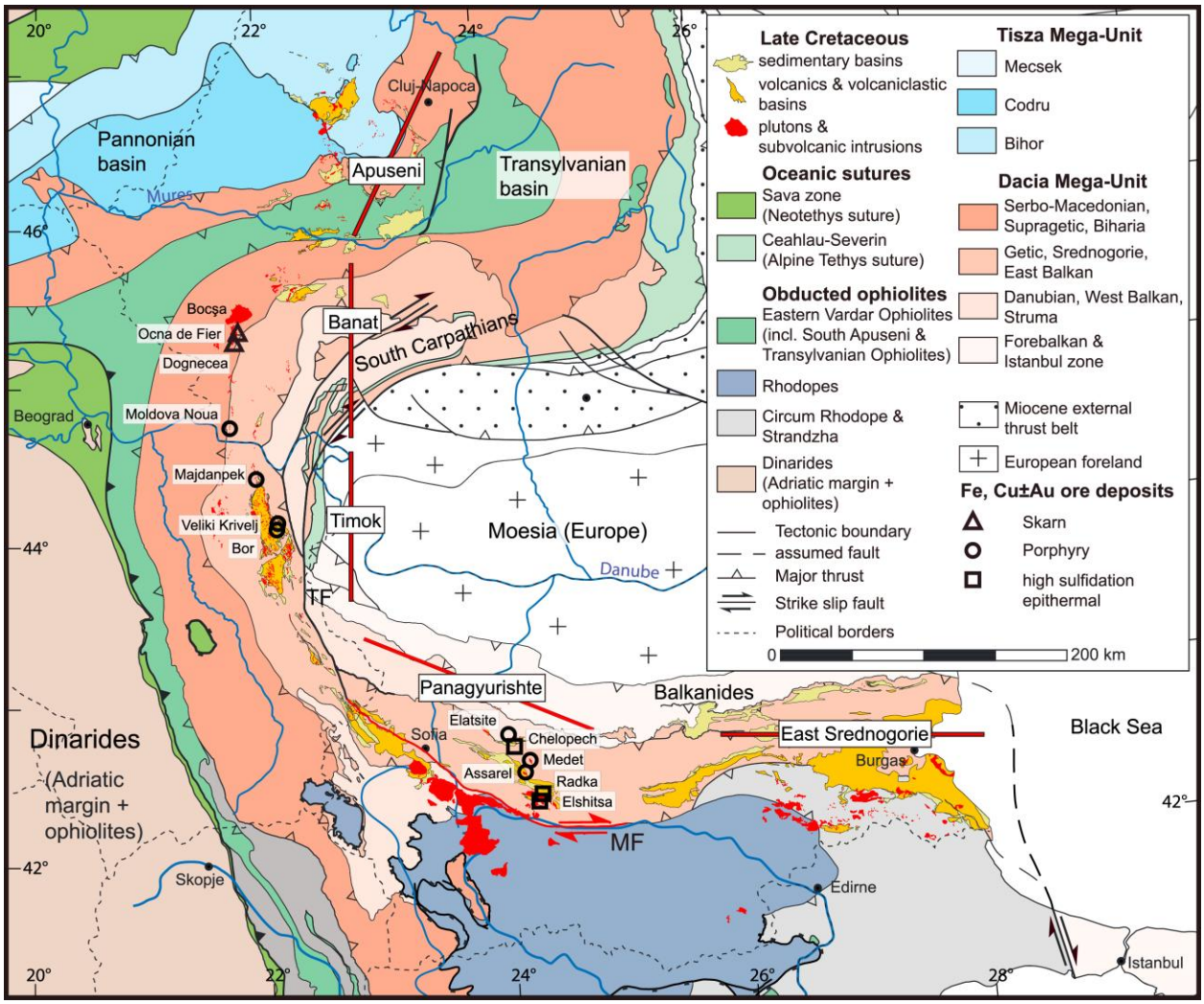


Fig. 2. Geological map of the Carpathian-Balkan orogen, modified from Schmid et al. (2008, 2011), showing major tectonic units and the occurrences of Late Cretaceous igneous rocks and sedimentary basins grouped into five segments of ABTS belt. These are, from NW to SE, the Apuseni, Banat, Timok, Panagyurishte, and Eastern Srednogorie segments. The red bars are reference lines approximating the present-day orientation of the arc front in each of the five segments, based on geochronological data derived in this and previous studies. MF = Maritsa fault system and TF = Timok fault are major transverse structures used to separate the segments (from Gallhofer et al., 2015).

The ABTS belt occupies a central position within the western Tethyan orogen, forming a major transition zone between the European continental margin to the north and the Pelagonian-Drama continental blocks to the south. Its current geometry reflects a long and complex geodynamic evolution since the Mesozoic. It has undergone successive phases of rifting, oceanic opening, subduction, collision, and post-collisional extensions (von Quadt et al., 2005; Schmid et al., 2008).

In the Middle to Upper Jurassic, the Vardar Ocean opened between the European and Pelagonian-Drama continental blocks, and the Nis-Trojan basin developed as a shallow intracontinental rift filled with sediments. With the intensification of convergence between the African and the Eurasian plates in the Cretaceous, these basins began to close (Fig. 3).

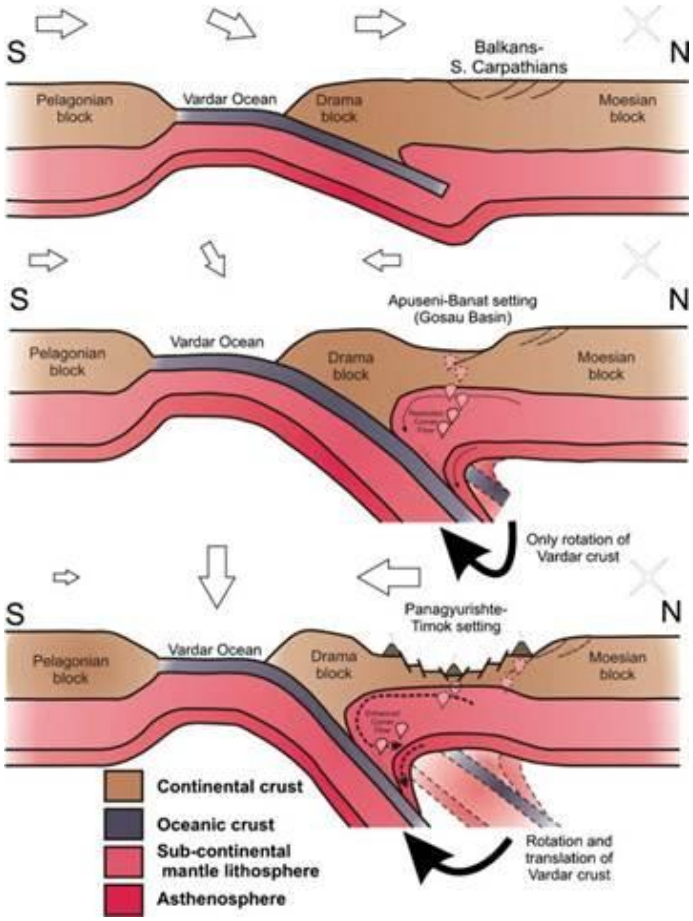


Fig. 3. Schematic cross-section through the Tethyan system during the Early Cretaceous. The arrows above tectonic units represent schematic direction and magnitude of motion towards the fixed Moesian block (Zimmerman et al., 2008).

According to Schmid et al. (2008), the Nis-Trojan basin closed first, then the Vardar oceanic lithosphere sank northward beneath the Drama block. First, the subduction of the Vardar plate was low-angle and hot, generating strong compression in the upper plate, inhibiting partial melting, and formed limited volcanism. Under these conditions, magmas probably stagnated at depth, forming coarse, hydrated plutons rather than volcanic arcs. At the same time, the tectonic coupling between the subducting plate and the overriding plate promoted uplift and crustal thickening of the South-Balkan Carpathian orogenic belt (Schmid et al., 2008; Royden & Faccenna, 2018).

During the Late Cretaceous, major reorganization of the plates occurred, significantly changing this system (Fig. 3). The Africa-Europe convergence slowed due to the reconfiguration of the Atlantic spreading system. Vertical gravitational forces took over from horizontal compression, and the Vardar plate tilted. It began to roll back, causing extensive faulting of the upper plate and the fusion by decompression in the mantle lithosphere. This led to the formation of high-K calc-alkaline magmatic-hydrothermal systems (Zimmerman et al., 2008). These processes are directly responsible for the porphyry and epithermal Cu-Au mineralization characteristic of the ABTS belt.

The extension induced by the rollback caused large structural differences along the belt. In the Panagyurishte and Timok regions, significant crustal relaxation and strong fracturing resulted in the formation of large, extensive basins. However, in the Apuseni and Banat regions, extension remained more localized (Matenco & Radivojević, 2012). The gradual southward migration of magmatism indicates a retreat of the subduction front (Royden & Faccenna, 2018). Then, as the rollback continued, the orogenic crust underwent a gravitational collapse that led to an asymmetric extension. This produced a crustal deformation gradient ranging from the Apuseni-Banat to Timok, where there was a moderate extension. Later, the area from the Panagyurishte district to the Black Sea suffered marked extension, representing the most advanced stage of an oceanic back-arc setting (Matenco & Radivojević, 2012).

Late Cretaceous magmatism along the ABTS belt can be best explained by slab rollback model, where slab roll-back towards the south leads to an across-arc age progression of calc-alkaline magmatism from north to south (Ciobanu et al., 2002; Zimmerman et al., 2008; Kolb et al., 2012; Gallhofer et al., 2015). Existing age data indicate that magmatism extended over at least 25 m.y., from about 90 to 65 Ma in each segment of the belt. Within the Apuseni Mountains and Banat, where magma emplacement was related to syn-collisional extension of the Carpathians, ore formation seems to have been restricted in time and constrained by a shared tectonic event (Ciobanu et al. 2002).

1.1. Romanian segment of ABTS (Apuseni Mts. and Banat)

Historically, the most important ore district within the Romanian Late Cretaceous belt was the eastern Banat Mountains along the N–S oriented Ocna de Fier–Dognecea–Oravița–Sasca Montană–Moldova Nouă lineament, which continues into the Serbian Ridanj-Krepoljin Zone (Figs. 2 and 4). Skarn is the most frequent mineralization style along this part of the belt. For instance, forsterite skarn hosting a magnetite-chalcopyrite-bornite ore assemblage with a characteristic Fe-Cu-Co-Bi–Ag-Sn-Te-Se-Au geochemical signature forms an inner Cu-Fe core at the Ocna de Fier prospect and a proximal Zn-Pb rich zone at the Dognecea prospect (Ciobanu et al. 2002). Further south, the Moldova Nouă district is economically the most interesting area but also the most enigmatic exploration and mining zone of Romania. Vlad (2011) described the district as a contact aureole of a deeply seated pluton, where the shallow apophyses were affected by alteration and mineralization. The magmatic fluid circulation promoted garnet skarn formation, as well as potassic, phyllic, argillic and propylitic alteration zones. Cu-Mo mineralization is spatially associated with the skarn and potassic alteration zones. In the north, at Corcana-Băieș, potassic alteration is prevalent and the skarn formation is restricted to minor occurrences. In addition, widespread and complete alteration and mineralization zoning characterize the central and southern parts of the district (Suvorov, Valea Mare and Gărâna-Varad prospects). The recently closed open pit operation at the southern part of the district, which exposes porphyry Cu-Mo-Au mineralization, might still enclose ca. 400 Mt of ore with 0.3% Cu and unknown Au and Mo grades (Vlad, 2011).

Close to Oravița, at the Cărbunari-Săpunari project, a somewhat atypical mineralization type was reported in the peripheral part of an intrusive complex, where gold-mineralized jasperoids ranging from 1 to 15 g/t Au grade occur as discrete boulder fields in calcareous and siliciclastic marine platform sediments (Carpathian Gold Inc., Press Release 2004). This type of mineralization was defined as “magmatic distal-disseminated Carlin-style” with characteristics that were later also described by Avala Resources also along the western part of the Timok Complex at their sedimentary rock-hosted gold deposits (van der Toorn et al, 2013).

The western Banat Mountains are a continuation of the Serbian Timok Magmatic Complex along a deep basement-related structure; however, no age data have yet constrained this relationship. Interestingly, no major modern exploration campaign has focused on this area until recently. Reservoir Minerals is currently undertaking reconnaissance work and compiling existing state data in the Bozovici area for the Gura Săliștei and Teiul projects. Initial results from the reconnaissance work identified robust Cu-in-soil anomalies of up to 0.78% Cu in mineralized quartz stockwork veins at Gura Salistei, up to 0.92% Cu in gossans and skarn from the Purcaru prospect, and 0.82% Cu and 1.57 ppm gold from skarn mineralization in the Nasovat prospect of the Teiul License (Reservoir Minerals, Press Release 2014).

The Gladna Montană area in the Poiana Ruscă Mountains (Fig. 4) hosts the Rozalia intrusion with a porphyry copper system in its apex and a zonation towards an epithermal environment represented by tiny veins of sphalerite-galena-pyrite crosscutting the Vingl Creek dacites. A limonite zone with high contents of Pb, Zn, As and Ag in the Băniţa Valley as well as a Pb-Zn mineralization in the Talianul Valley are also present (Tudor, 2012). Lundin Mining Corporation in association with Belevion Impex completed 6 drill holes on the Rozalia project between 2013 and 2014. The presence of porphyry Cu-Au mineralization has been confirmed, and the potential of the area is considered good by the prospectors; however, no further information is available so far.

The Băiţa Plai mine within the Băiţa Bihor district (Fig. 5) was operated until 2025 as a small-scale underground mining project in a joint venture of Vast Resources and SC Băiţa Bihor SA. This mine reveals the most diverse and economically important hydrothermal deposit related to the Late Cretaceous magmatism in the North Apuseni Mts. The mineralization is Cu- and locally Pb-Zn-dominated, but with

significant Mo, Bi, W, and B. It developed in calcic skarns conformable to nappe overthrusting planes or contacts between magmatic dykes and limestones, but mostly within a series of metasomatic "columns" (Baia Roșie, Antoniu, Hoanca Moţului, Bolfu-Tony). These cylindrical structures are hosted in Triassic dolomites and extend over 400 m in depth. The columns are enveloped by a thick layer of dolomitic marbles with abundant magnesian borates (kotoite, suanite, ludwigite, fluoborite, szaibélyite) grading inwards to a zone of formerly dolomitized carbonate rocks and further to diopside-andradite-wollastonite skarns. The outer shell of the skarn zone is rich in galena and sphalerite, whereas the central parts are enriched in chalcopyrite, Bi-sulfosalts, molybdenite and scheelite (Ilinca, 2010).

In the eastern part of the North Apuseni Mountains (Gilău Mts), the Mașca-Iara-Băișoara ore field shares many similarities with the Băița Bihor ore field (Fig. 5). Gabriel Resources earlier performed some exploration work in this area; however, their results were not publicly reported (Gabriel Resources Press Release, 2010).

Insight into these mineralized systems will be provided during days 1 and 2 of the field trip, while additional details are included in the Road Log section of this guide.

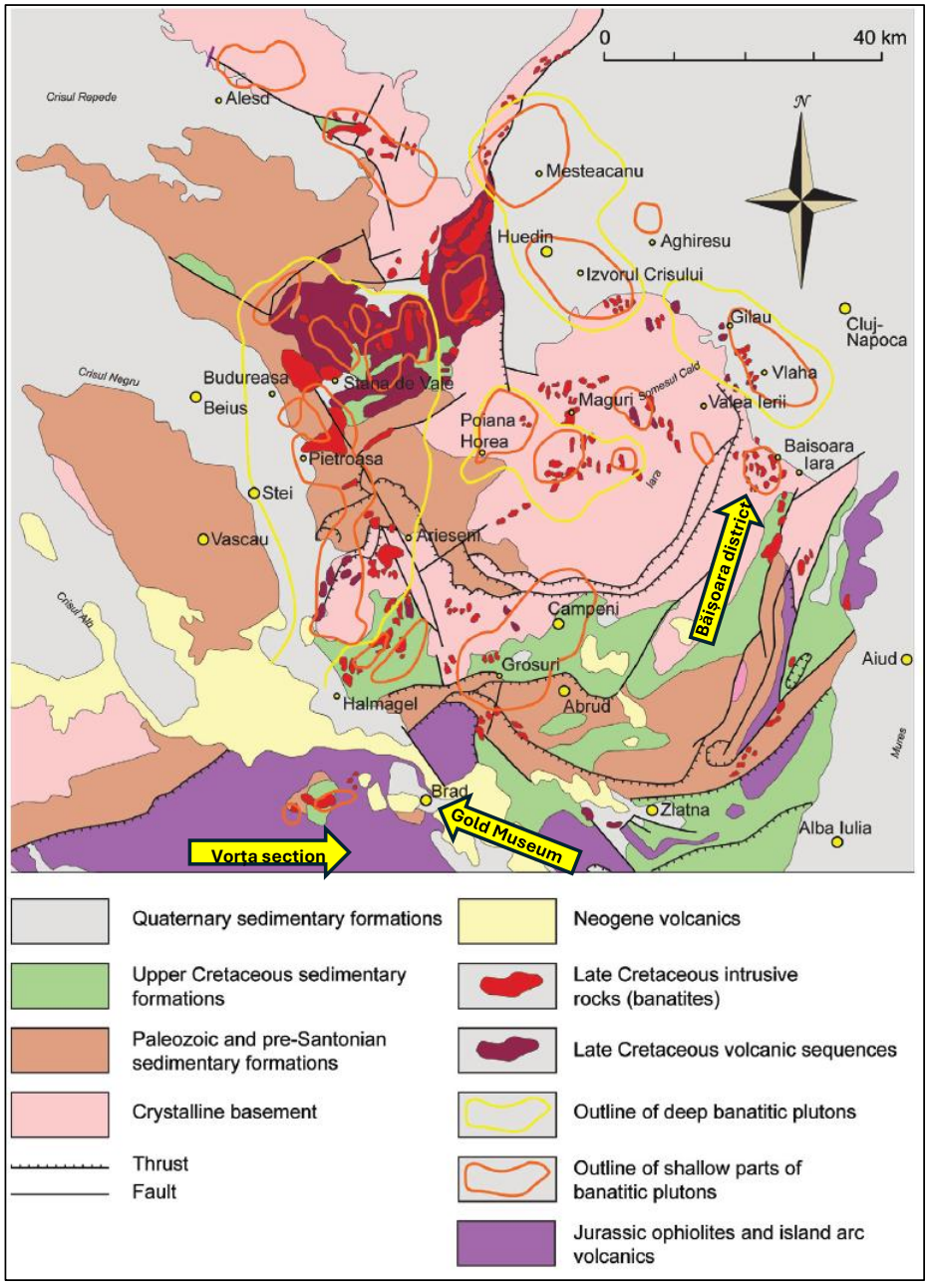


Fig. 4. Simplified map of the Apuseni Mts. with the in-depth development of Late Cretaceous banatitic plutons, interpreted from aeromagnetic and gravimetric data (Ilinca, 2010). Yellow arrows indicate the location of field stops of the first day.

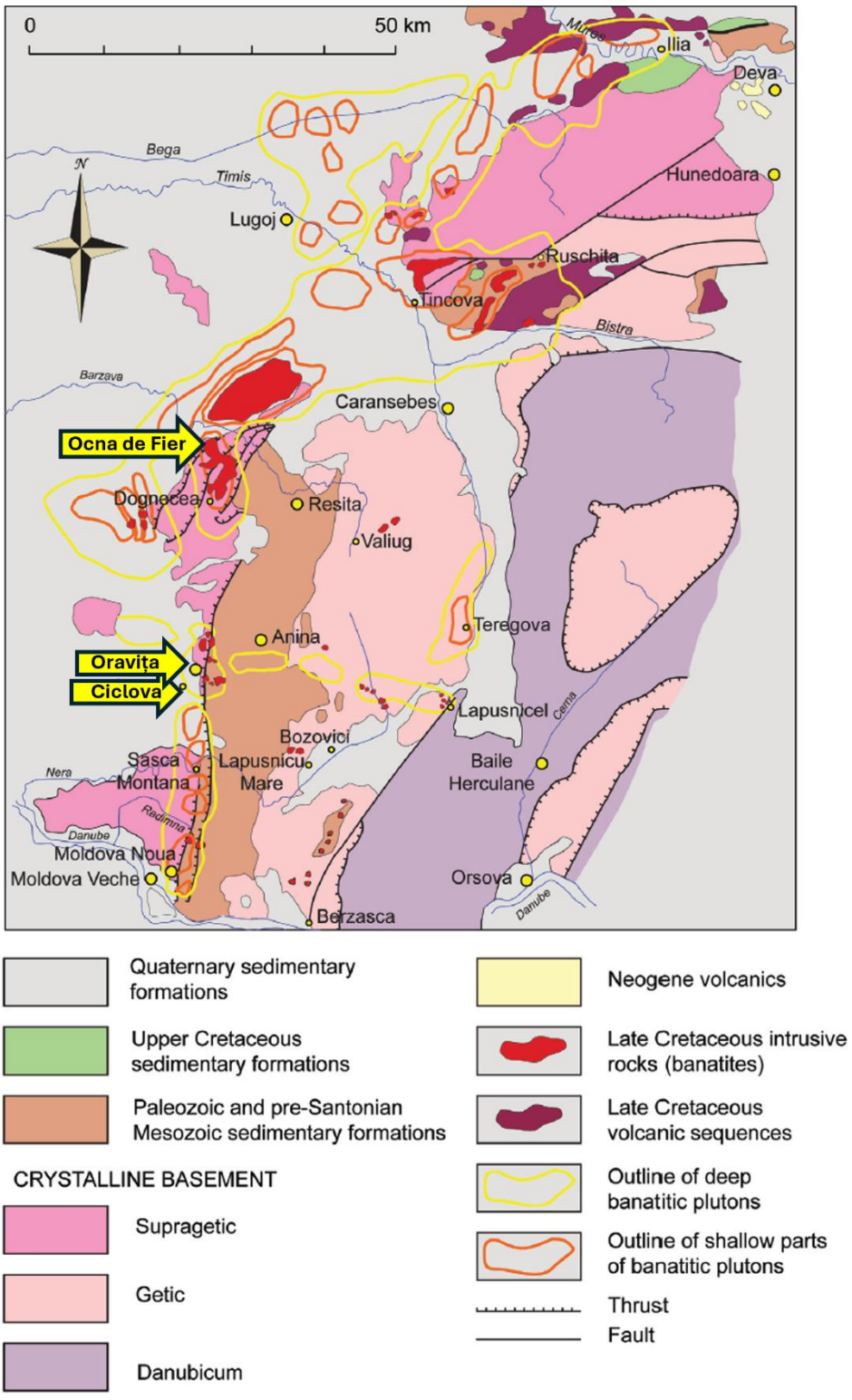


Fig. 5. Simplified map of the south-western part of the Southern Carpathians (Poiana Ruscă and Banat Mountains) showing the in-depth development of Late Cretaceous Banatitic plutons, interpreted from aeromagnetic and gravimetric data (Ilinca, 2010). Yellow arrows indicate the location of field stops on the second day.

1.2. Serbian segment of ABTS (Timok Magmatic Complex)

The Timok Magmatic Complex (TMC) is located within the Cretaceous magmatic arc in Eastern Serbia. It forms a critical, highly endowed segment of the continuous, 1,500 km long Late Cretaceous ABTS magmatic-metallogenic belt. The complex stands as one of the premier copper and gold provinces in Europe, hosting world-class porphyry and epithermal deposits.

The structural evolution was driven by associated alternating transpressive and transtensional episodes. These dynamic structural shifts opened localized conduit systems, tracking and focusing the ascent of magmas and mineralizing hydrothermal fluids (Banješević, 2010; Kolb et al., 2013; Gallhofer et al., 2015; Knaak et al., 2016; Kitanović et al, 2026). The present-day structural framework of the TMC is exceptionally complex. This complexity is highlighted by its distinct L-shaped geometry and a major clockwise rotation of approximately 30°. The L-shape and rotation reflect large-scale oroclinal bending. This deformation occurred during post-collision escape tectonics throughout the Tertiary period. Major transcurrent fault systems cut through the region, exhibiting an overall dextral displacement of more than 100 km.

Magmatic activity within the TMC was sustained over a 10 m.y. period during the Late Cretaceous, lasting from approximately 89 Ma to 79 Ma (Kolb et al., 2013; Gallhofer et al., 2015; Knaak et al., 2016; Zdravković et al., 2026). The geographic distribution of magmatism shows a general younging trend from east to west. The complex is subdivided into three distinct magmatic suites that track this westward migration. The Valja Strž composite monzonitic pluton is located along the westernmost margin of the TMC. It represents the final, most evolved magmatic pulse and is constrained as the youngest magmatic product of the complex, yielding an age of approximately 79 Ma.

The interplay between deep-seated Cretaceous magmatic plumbing systems and Tertiary structural re-activation resulted in exceptional metallogenic fertility. The economic endowment within the TMC spans four primary mineralization styles, representing one of Europe's most diverse copper-gold provinces (Fig. 6; Jelenković et al., 2016; Márton et al, 2026):

- 1. Porphyry Cu-Au Systems: These deep-seated, large-tonnage deposits are directly related to intermediate, calc-alkaline subvolcanic intrusions. They host extensive stockworks of chalcopyrite, bornite, and magnetite mineralization. Examples: Majdanpek, Veliki Krivelj, and the massive underground Borska Reka deposit.
- 2. High-Sulfidation Epithermal Cu-Au Deposits: Structurally controlled, shallow-crustal deposits characterized by massive to semi-massive sulfides. They feature dominant enargite, covellite, pyrite, and gold mineral assemblages hosted within intensely advanced argillic alteration zones. Examples: The historic Bor deposit area and the world-class, high-grade Čukaru Peki deposit (Upper Zone).
- 3. Skarn Au-Cu and carbonate-replacement polymetallic mineralization formed along the structural contact zones where fertile, subvolcanic diorite and granodiorite intrusives intersected highly reactive calcareous packages and carbonaceous sedimentary rocks. Hydrothermal fluids caused intense contact metamorphism, creating massive manto-like zones of gold-rich skarn mineralization. Examples: Čoka Rakita, which hosts high-grade underground gold reserves, alongside its neighboring high-grade discoveries at Frasen and Dumitru Potok.
- 4. Sediment-Hosted Disseminated Gold (SHDG) Deposits, relatively low-temperature, stratabound style of gold mineralization situated along the northwestern margin of the Timok Magmatic Complex (TMC). Mineralization is principally stratabound along unconformable contacts, where acidic hydrothermal fluids dissolved host-rock carbonate cement to create secondary porosity and deposit micron-scale gold. Examples: Bigar Hill (hosting over 1 million ounces of gold), alongside the stratigraphically linked Korkan and Kraku Pester deposits.

Insight into these mineralized systems will be provided during days 3 and 4 of the field trip, while additional details are included in the Road Log section of this guide.

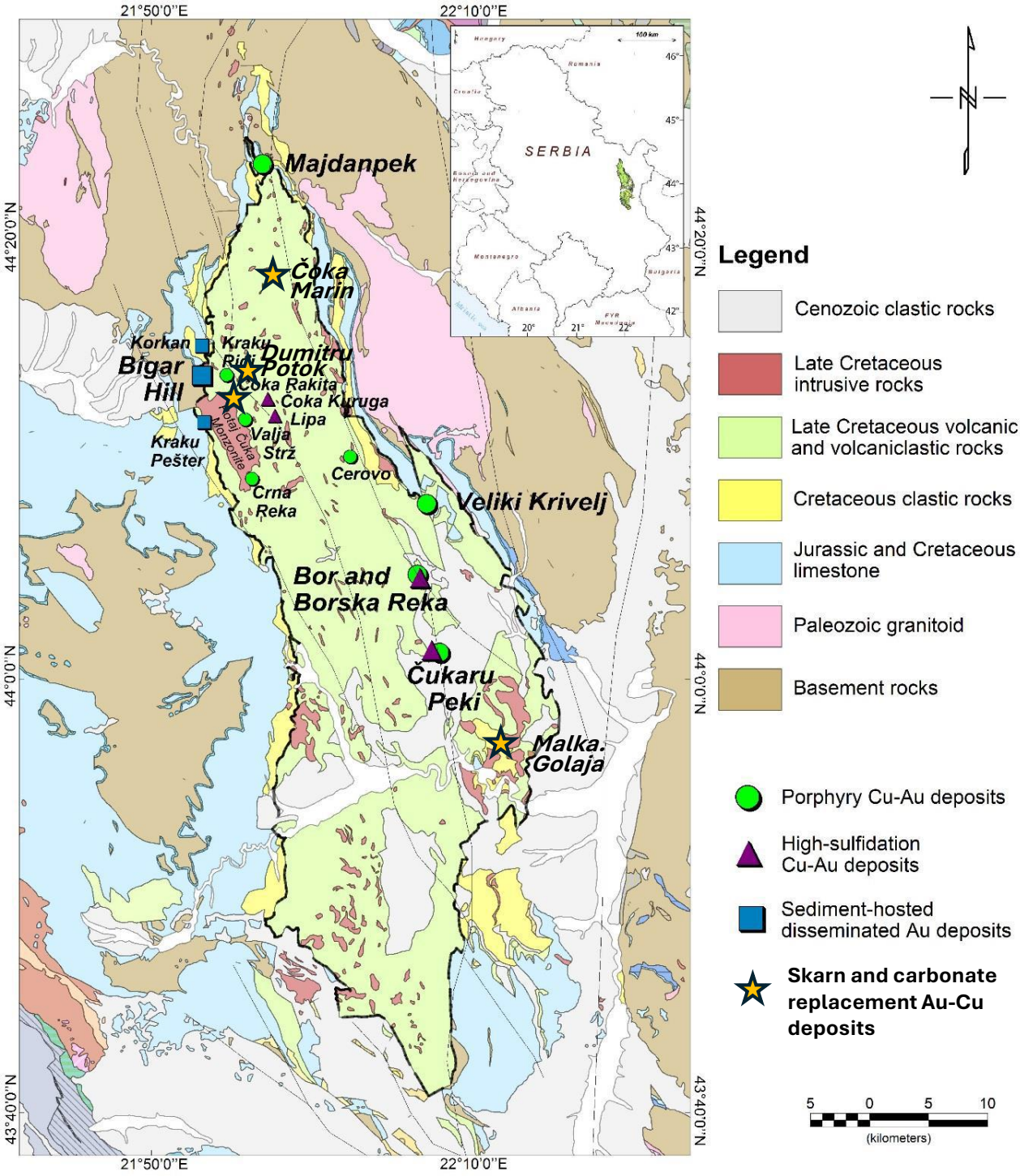


Fig. 6. Simplified geologic map of the Timok Magmatic Complex with the most significant ore deposits.

2. GEOLOGICAL FIELD LOG & NOTES

Day 1. Mașca–Băișoara Metallogenic District (Apuseni Mountains Province)

The Mașca–Băișoara District is located in the eastern part of the Gilău Mountains, encompassing the Băișoara Valley and its tributaries, near the localities of Iara, Cacova Ierii, and Băișoara (Cluj County).

Geologically the Mașca-Băișoara District belongs to the Gilău-Bihor zone within the Apuseni Mountains Province (Fig. 4). According to the current knowledge, this is a non-porphyry environment related to evolved granodioritic to granitic magmatism, featuring Fe-B and Pb-Zn skarn and replacement ore bodies at Mașca, Valea Litei, and Cacova (Figs. 7). Granodiorite apophyses originating from a deeply seated pluton, along with a related dike suite, are surrounded by a contact aureole. This has resulted in hornfels and skarn formation within the metamorphic host rocks of the Baia de Arieș Formation.

The district hosts Ca-Mg skarns affected by retrograde metasomatic assemblages. These are dominated by Fe-B ores (magnetite, ludwigite) with subordinate Pb-Zn mineralization (pyrite, chalcopyrite, cubanite, bornite, tetrahedrite, galena, and sphalerite) at Mașca, Cacova, and Valea Litei.

- **Cacova Ierii Deposit**: Mineralization consists of magnetite and hematite, with subordinate amounts of galena, sphalerite, pyrite, pyrrhotite, and chalcopyrite. It occurs as lenses and irregular bodies within marbles, or along the contact between marbles and schists. The main orebody ("Orebody #13") was investigated and mined between the -150 m and -400 m levels (Fig. 7).
- **Mașca Deposit**: An Fe-skarn type mineralization constitutes two subvertical main orebodies distributed in an en échelon pattern between the surface and the -470 m level (Fig. 7).
- **Valea Litei Prospect**: Consists of seven NE-SW-trending, irregular in shape skarn bodies ranging 25–150 m in length and 1–30 m in thickness, extending approximately 200 m along the plunge. Galena, sphalerite, pyrite, chalcopyrite, pyrrhotite, and marcasite occur as disseminations, ribbons, and pockets. Metal zoning is present, with Pb being more dominant in the upper zones and Zn increasing at depth.

<u>Exploration & Mining History:</u>

Historical Mining: Gold (Au) was exploited during the 18th century, followed later by Iron (Fe) extraction.

Exploration & Operations in 20th century: Exploration workings were conducted by Transgex but subsequently abandoned (under government decree HG 493/2000 Iara). Underground mining was restricted to Fe by Minvest and is now closed (under decrees HG 1864/2004 and HG 997/2010).

Recent exploration for Au was conducted by SC RomAur SRL (a subsidiary of Gabriel Resources Ltd). Historical resource estimates include:

- Mașca (Inferred): ~0.7 Mt @ 2% Pb, 1.5% Zn, 1.5% Cu;
- Lita (Indicated): ~2 Mt @ 0.3% Pb, 2.7% Zn;
- Lita (Inferred): ~0.5 Mt @ 0.3% Pb, 2% Zn.

The unexploited potential of the Valea Litei prospect remains highly attractive for future mining exploration and research.

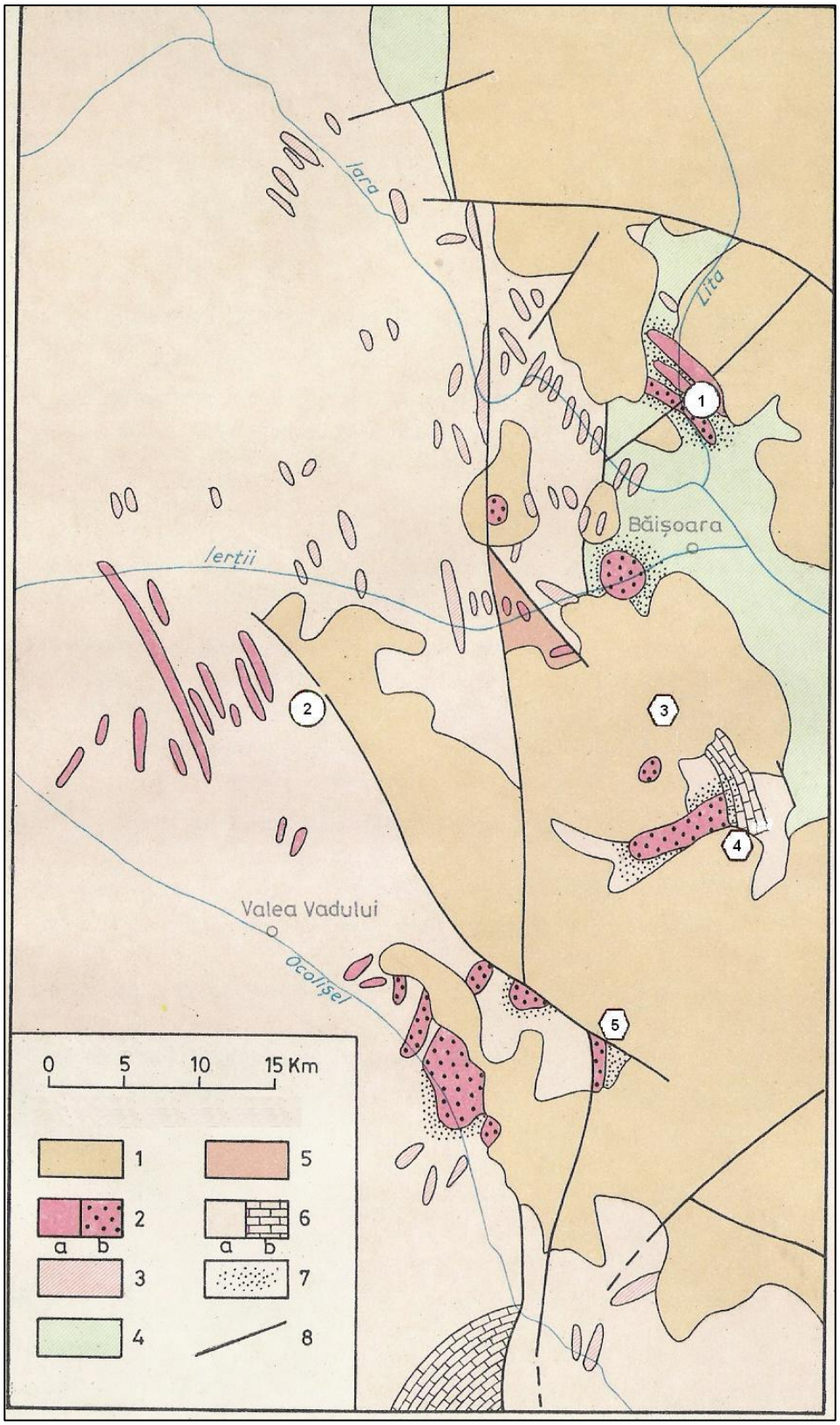


Fig. 7. Simplified geological map of the Mașca–Băișoara Metallogenic District (Lazăr and Intorsureanu, (1981). Legend: 1. Paleogene sedimentary rocks. 2. Banatites: a) dacite; b) granodiorite; 3. Banatites: andesite ± diorite; 4. Cretaceous sedimentary rocks; 5. Permian conglomerate; 6. Metamorphic rocks: a) Mica schists and quartzites, b) Marbleized dolomite; 7. Hornfels; 8. Fault. Deposits/Prospects: 1. Lita Cu, Zn, Pb ± Au, Ag skarns and metasomatic bodies; 2. Nyerges Au, Ag, Pb, Zn veins and impregnations; 3. Mașca Băișoara Fe ± B skarn bodies; 4. Mașca Fe ± B skarns; 5. Cacova Băișoara Fe ± Cu, Pb, Zn, Mn, B skarns and metasomatic bodies.

Mașca and Cacova Ierii (waste dumps of the mining district around Băișoara) field stop: granitoid rocks of the Baia de Arieș nappe, Late Cretaceous dykes, the hornfels contact aureole of the banatites and their ore minerals:

We will visit the remnants of the mining activity around Băișoara in the vicinity of Mașca and Cacova Ierii, where we will have the opportunity to observe the former mining operations and part of the waste dumps, which we hope will also be suitable for presenting the main mineral paragenesis of the mined ore. Geomorphologically, the area forms the eastern slopes of the Gilău Mountains, on the periphery of the Transylvanian Basin.

The geological structure of the area includes the metamorphic rocks of the Baia de Arieș Formation, Cretaceous–Neogene sedimentary rocks and Late Cretaceous magmatic intrusions (Fig. 8). The metamorphic basement is mainly characterized by garnet-bearing mica schists, quartzites, amphibolites and carbonate intercalations composed of dolomitic and calcitic marbles. Contact hornfels and skarn alteration occur between the Late Cretaceous ("Banatitic") intrusions and the carbonate sequences of the basement, as well as the overlying Cretaceous sedimentary rocks. Mineralization related to retrograde processes occurs as lenses and irregular bodies. The ore-mineral paragenesis includes magnetite, hematite, pyrrhotite, pyrite, marcasite, chalcopyrite, sphalerite, arsenopyrite, galena and molybdenite. Magnetite ores are primarily associated with garnet-bearing skarns, whereas sulfide mineralization is related to pyroxene-bearing skarns. As at the Băița Bihor district, characteristic magnesium borates, such as ludwigite and szaibelyite, are also present.

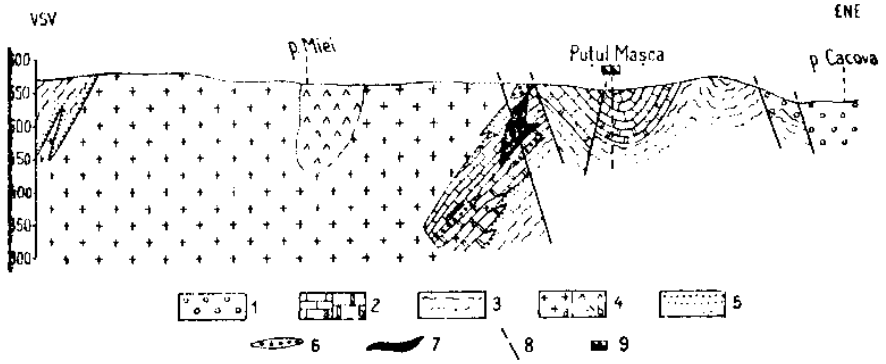


Fig. 8. Schematic geological section across the Mașca skarn mineralization, based on the work of Lazăr and Intorsureanu (1981): 1 – Late Cretaceous sedimentary rocks; 2 – Baia de Arieș Formation: 2a – crystalline limestone, 2b – crystalline dolomite, 3 – Crystalline schist (mica schist, gneiss); 4 – Late Cretaceous dioritic intrusions; 5 – Hornfels contact alteration; 6 – Skarn; 7 – Magnetite and sulfide mineralization; 8 – Fault; 9 – Shaft.

Surduc, Iara Valley field stop: garnet-bearing, amphibole-rich, carbonate, contact-type rocks of the Baia de Arieș Formation

We will stop on the left side of the Iara Valley, next to an abandoned dolomite quarry, 3 km from Surduc and 4 km from Buru.

In this area, limestone and dolomite lenses occur interlayered with the mica schists and garnet-bearing gneiss units of the Baia de Arieș Formation, which form the basement of the Trascău Mountains. Around Surduc, the state geological exploration company (IPEG) investigated two larger dolomitic bodies between 1970 and 1973, for which underground extraction was initially planned. At our stop, one of these dolomitic lenses is exposed, extending for approximately 180 m and developed over a thickness of several 10s m. The mostly whitish-grey dolomite, with a heteroblastic texture, consists of 97–99% dolomite, together with quartz, muscovite and chlorite. Locally, joints filled with calcite are also present.

The primary focus of this stop, however, are the few-metre-thick Late Cretaceous microdiorite dykes intruding the dolomites and the related skarn alteration. The microdiorite displays an intergranular texture,

with plagioclase, biotite and hornblende as the main rock-forming minerals. At the contact between the microdiorite and the dolomite host rock, a well-developed zoned Mg-type skarn alteration can be observed: within the microdiorite, garnet- and hornblende-bearing alteration is present, passing toward the margin into phlogopite- and tremolite-bearing alteration. At the contact with the dolomite, talc is the dominant mineral in a 1–3-metre-thick zone, although forsterite, phlogopite and diopside can also be observed. In the eastern part of the outcrop, extensive argillic alteration is visible, with halloysite and smectite alteration. Sulfide mineral assemblages may also be observed in nests or as vein infill within the skarn zone, mainly dominated by pyrite, pyrrhotite, bornite and covellite.

Visit to the Brad Gold Museum

Located in the center of Brad, the Gold Museum was founded more than 100 years ago and is regarded as a collection that is unique in Europe. The knowledge of how the collection was formed, as well as of the initiative to establish the museum, is incomplete. It was probably based on a private collection and on the collections of the mining companies at the time, including the Ruda 12 Apostles Mining Company and the Musariu Gold Mining Company. In Friedrich Schumacher's 1910–1911 report prepared for the Ruda 12 Apostles Mining Company, he already mentioned a collection comprising almost 200 specimens. The first entry in the guest book was made on July 4, 1912.

Despite changes in ownership of the mining company, the collection continued to exist and expanded further during the period of the "Mica" joint-stock company. Most of the gold specimens come from mines around Brad (80%) and from the mines of the Golden Quadrilateral in the Apuseni Mountains of Transylvania; minerals also arrived from other parts of the world through exchanges and donations. In addition, the collection includes archaeological findings from the area and objects related to gold mining and processing. At the time of nationalization in 1948, the inventory listed 992 native-gold-bearing specimens, 383 mineral specimens, 53 rock specimens, and numerous archaeological artifacts. In 1971, the museum moved to its current location—the former director's residence of the Mica joint-stock company—and it was inaugurated on August 23, 1972. From 2001, the museum building and collection came under the authority of "BradMin" (a branch institution of Minvest Deva) until it went bankrupt in 2007. The museum then closed and was reopened only on December 4, 2012, on Saint Barbara's Day, the patron saint of miners. The permanent exhibition presents the forms of occurrence of gold and its mineral associations thematically. Visitors can also admire minerals that were first described from the Apuseni Mountains of Transylvania, such as sylvanite, nagyágite, krennerite, native tellurium, alabandite, and others, along with numerous other mineral rarities, not only from Romania. The world-famous native-gold finds have been given many imaginative names, such as Ballerina, Salamander, Lizard, Wings, Eminescu's Pen, and others.

Field stop to examine the products of the Jurassic ophiolitic and calc-alkaline series along the road section between Țebea and Vorța

After leaving Țebea, we enter the area of the Mureș Zone, which appears as a complex nappe system (Bleahu et al., 1981; Balintoni, 2003). Its structure comprises an ophiolitic series forming the basement consisting of an island-arc-type calc-alkaline volcanic series (IAVs), and Late Jurassic–Cretaceous sedimentary successions (Ionescu and Hoeck, 2010). The ophiolitic series completely lacks the section characteristic of the upper mantle, namely dunite and harzburgite assemblages, and its lowermost part is composed of ultrabasic cumulates characteristic of the lower crust (Fig. 9). These are overlain by layered, coherent Fe–Ti-bearing gabbros. Cross-cutting gabbroic intrusions, with basaltic and basaltic-andesitic compositions, form a transition between the intrusive and volcanic assemblages. The volcanic assemblage consists of basaltic lava flows, basaltic pillow lavas, and breccias. Geochemically, they show a tholeiitic composition, with low SiO_2 (40–55 wt%) and Na_2O+K_2O (1–6 wt%) contents and high FeO_t and MgO contents (Ionescu et al., 2009).

In places, the ophiolitic series is overlain by a cherty succession, which is followed by a Late Jurassic island-arc-type volcanic assemblage. This calc-alkaline series is composed of lava flows of basaltic,

andesitic, and locally rhyolitic composition, or reworked pyroclastic deposits. In composition, these rocks are clearly distinct from the ophiolitic series; they generally have a porphyritic texture, with plagioclase, amphibole, and pyroxene occurring as phenocrysts. Geochemically, these rocks are characterized by relatively high SiO_2 (55–75 wt%) and Na_2O+K_2O (6–10 wt%) contents and lower FeOt and MgO contents (Ionescu et al., 2009).

The ophiolites are at several locations intruded by Upper Jurassic granites, granodiorites and diorites. They are interpreted by Bortolotti et al. (2002) as the plutonic equivalents of the calc-alkaline island arc sequence. Zircons from the intrusions were dated by Pană et al. (2002) with U-Pb as Oxfordian–Kimmeridgian in age (152–156 Ma). Zimmerman et al. (2008) published Re-Os ages on molybdenite from granitoids near Săvârșin and Cerbia with an age of 159.1 to 159.8 Ma. Thus, the ophiolites are older, which is in accordance with the biostratigraphic results by Lupu et al. (1995), who found a Callovian to Oxfordian age for radiolarites on top of the ophiolites. The biostratigraphic findings in limestone deposited on top of the IAVs indicate a Tithonian age for the beginning of the sedimentation (Săsăran, 2006).

During our excursion, we will examine two sections that are well exposed by the newly constructed paved road. The first section exposes andesitic lavas characteristic of the calc-alkaline series and a well-bedded, reworked volcaniclastic succession.

The second section exposes a textbook example of a succession of basaltic pillow lavas. These basalts have an aphanitic or, more rarely, porphyritic texture, and in places plagioclase or pyroxene can be observed as microphenocrysts. The primary glassy groundmass of the rock has been completely altered as a result of ocean-floor hydrothermal alteration and is now composed of chlorite, epidote, serpentinite, iron oxides, and clay minerals. Carbonates or zeolites are commonly observed in veins or cavity fillings.

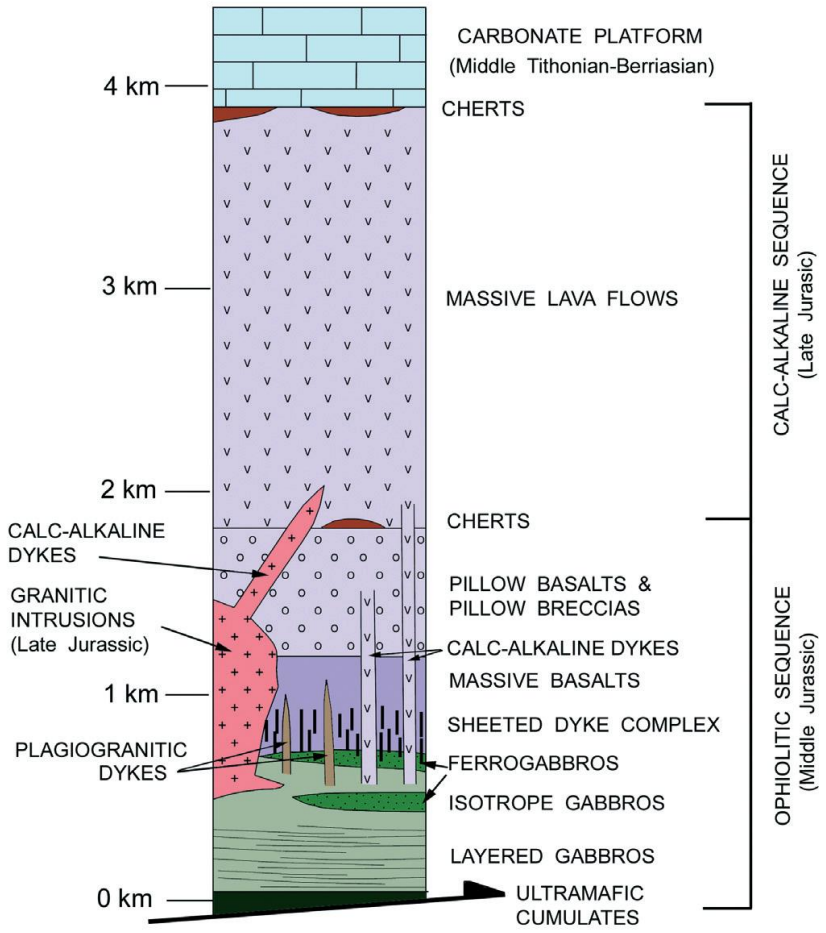


Fig. 9. Stratigraphic column of the Jurassic ophiolites and IAVs in the Southern Apuseni Mountains (modified from Bortolotti et al., 2002, 2004).

Day 2. Poiana Ruscă – Banat Province

Poiana Ruscă Metallogenic District: Ruşchiţa marble pit area field stop

The Ruşchiţa marble pit area is located in the southern part of the Poiana Ruscă Mountains, along the Padeş Valley, near the village of Ruşchiţa. The Poiana Ruscă metallogenic district is characterized by a marked base-metal association and may also reflect the presence of deeper-seated porphyry systems. Magmatism belongs to a relatively evolved granodioritic to granitic trend. Related Fe–Cu–Pb–Zn skarn mineralization occurs in distal to proximal peri-plutonic settings at Ruşchiţa, Ascuţita, Tincova, and Gladna.

At Ruşchiţa, metamorphic rocks of the Padeş Series, including the Ruşchiţa–Alun biotite–chlorite ± epidote greenschists, schists, and marbles, are intruded by Late Cretaceous ("banatitic") subvolcanic bodies. Both the metamorphic rocks and intrusive bodies are pervasively epidotized and are locally transformed into tectonized pyroxene-, garnet-, and epidote-bearing skarns. These skarns occur either as stratabound or as discordant bodies controlled by major tectonic zones and associated breccia structures.

A notable feature at Ruşchiţa is the preferential development of skarn alteration within greenschist host rocks, whereas the adjacent carbonate rocks are comparatively less affected. Superimposed Zn–Pb mineralization shows a broadly similar spatial distribution and occurs in two principal styles:

- **"Hanging-wall ore"**: infiltration-type skarns developed in epidotized rocks of the Ruşchiţa–Alun greenschist formation. These contain magnetite, hematite, galena, sphalerite, chalcopyrite, pyrite, bornite, and tetrahedrite, forming irregular stratabound bodies.
- **"Principal ore"**: a steeply dipping to subvertical massive ore body developed near the contact between relatively pure marble and chlorite–carbonate schists. This style is dominated by sphalerite and galena mineralization.

The bimodal style of mineralization, together with the contrasting character of the host rocks and the influence of Late Cretaceous brittle tectonics, suggests remobilization of an earlier protore during emplacement of the Banatitic magmatic system.

Exploration and mining history:

Ruşchiţa has a long history of mining. The former Minvest IM–Ruşchiţa mining operation was closed under Government Decisions HG 816/1998 and HG 997/2010. Formin also carried out exploration and mining-related work, including CET activities, which were subsequently closed under HG 720/1999. Most surface facilities have since been demolished.

Reported remnant resources include approximately 1 Mt grading 1.7% Pb and 1.7% Zn in the former Minvest area, and approximately 1 Mt grading 6% Pb and 2% Zn in the former Formin area.

Exploration potential:

Ore at higher levels has largely been mined out in the two principal ore sectors. In the "Principal orebody" target area, Pb–Zn sulfide mineralization was mined by Minvest down to the 500 m level. Below this, between the 450 m and 400 m horizons, Formin delineated approximately 1 Mt of mineralization grading about 8% combined Zn–Pb, with the orebody reaching a thickness of approximately 40 m.

Historic state drilling indicates that Pb–Zn mineralization may continue at depth within altered and brecciated host rocks. This deeper continuation remains an important exploration target.

Banat West Metallogenic District: Ocna de Fier – Dognecea field stop

The Ocna de Fier – Dognecea mineralized system, situated within the Banat region of southwestern Romania, represents a classic type-locality for zoned calc-alkaline skarn systems.

The ore district of Ocna de Fier and its 10 km southernmost extension Dognecea have been mined since pre-Roman and Roman times and were already described in the 19th century. The deposit of Ocna de Fier-Dognecea became famous because of a rich and complex paragenesis, with as many as 100 silicates and ore minerals and several unusual Bi-sulfosalts. The most famous mineral found in Ocna de Fier is perhaps the ludwigite $Mg_2Fe_3+[O_2BO_3]$ (Cook and Ciobanu, 2002).

Ocna de Fier mined out in 1993, while Dognecea closed in 1989. The deposit consists of 30 individual orebodies with a total tonnage of 15 Mt. Ocna de Fier accounts for 80% (13Mt) of the ore produced in the district: Fe-Cu ores (bornite-chalcopyrite-magnetite) are hosted by magnesian (forsterite and diopside) skarn and Fe-ores are hosted by calcic skarn. Dognecea produced 2Mt of the ore, comprising dominantly Zn-Pb ores hosted by Mn-hedenbergite (diopside-hedenbergite-johannsenite series) skarn or limestone. In Ocna de Fier the ore grades are 30-35% Fe, 0.5% Cu and minor grades of Zn-Pb, B; in Dognecea the grades are 3.69% Zn, 1.92% Pb and minor grades of Cu, Ag (Cook and Ciobanu, 2001; Ciobanu and Cook, 2004).

The orebodies lie within the contact aureole of the Ocna de Fier-Dognecea granodiorite intrusion and occur along the contact between an N-S trending body of Jurassic-Lower Cretaceous limestone and the Precambrian schists of the Bocșița-Drimoxa Formation. The limestone base is fragmented and rooted onto the granodiorite. In Ocna de Fier, ores occur as shoots and dominate over the calcic garnet pyroxene skarns. The skarn mass appears as limbs or forms scarce nodules within the ores or along the limestone-granodiorite contact (Fig. 10; Cook and Ciobanu 2001).

The orebodies have vertical extension between 200 and 350 m and stop at the base of the limestone at the contact with the crystalline schists. Although the following description is restricted to the approximately 50 m thick exoskarn, it should be noted that minor bodies of epidote, garnet and hematite endoskarn, hosted by granodiorite dykes, occur at several places across the area (Ciobanu and Cook 2004).

At Ocna de Fier, the orebodies have a concentric internal structure: massive ores (60 % oxides ± sulphides) form the core, enclosed by an outer zone containing more than 30 % ore minerals. In contrast, at Dognecea, the mineralisation is characterised by a lateral zonation in the skarn, and also by a vertical zonation. The vertical zonation is defined by Pb-Zn-rich chimneys in limestone at upper levels and by low-grade pyroxene-rich stocks at depth. On a regional scale, some workers reported a transitional trend with Fe-oxides to the North, sulphides and Fe-oxides in the middle, and sulphides to the South.

A key to explain the entire orefield zonation is given by the Simon Iuda orebody. Simon Iuda is the largest and deepest orebody situated in the central part of the Ocna de Fier-Dognecea district (Fig. 10). It extends from the surface to 350 m depth, and its high-grade supergene-enriched Cu ores were exploited in the 18th century. The ores are rooted in the granodiorite intrusion, where proximal high-temperature magnesian skarn hosts primary Cu-Fe ores (Cook and Ciobanu 2001).

The interpretation of these concentric zoning patterns (onion shapes) is based upon recognition of a source of fluids in the central and deepest part of the orefield, subjacent to the Simon Iuda body. The metasomatic column developed upwards and outwards from the source fluids emerging from the granodiorite. A metal distribution in three zones has resulted, i.e., Cu-Fe, Fe, and Zn-Pb, symmetrically centred on Simon Iuda.

The age of mineralisation, based on the Re-Os dating of molybdenite from Dognecea, has been estimated at 76.6 ± 0.3 Ma (Ciobanu and Cook, 2002). This data overlaps the age of 75.5 ± 1.6 obtained with U-Pb zircon of the granodiorite of Ocna de Fier-Dognecea (Nicolescu et al., 1999). The Re-Os data coupled with the U-Pb ages for the intrusion link skarn mineralisation with the granodiorite emplacement. These results substantiate the centered source model for the entire ore field (Ciobanu and Cook 2002).

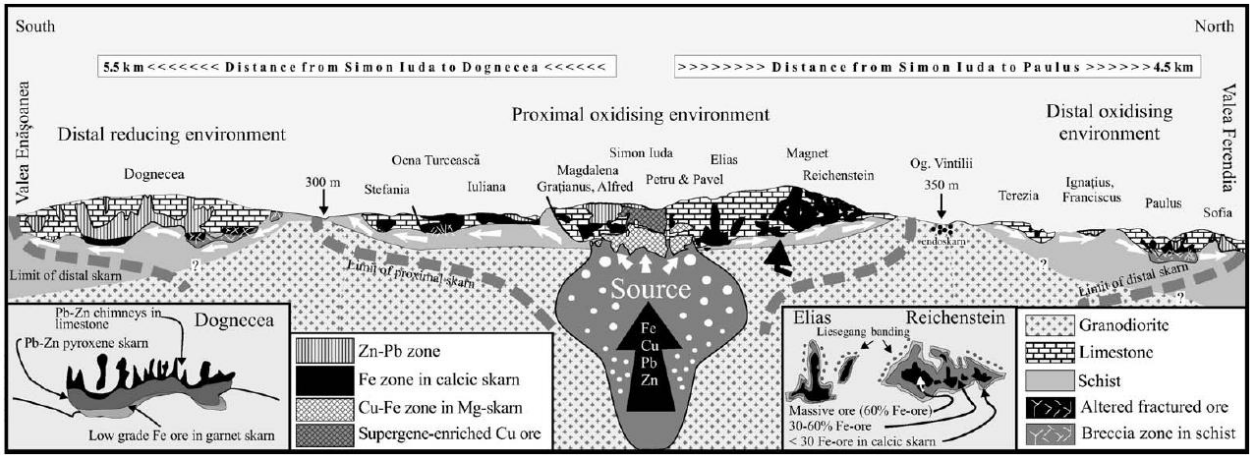


Fig. 10. N-S profile across the Ocna de Fier-Dognecea orefield showing the metal distribution and a schematic synthesis of the genetic model. The proximal part of the deposit, centred upon the fluid source beneath Simon Iuda and the Dognecea distal extremity of the orefield, are indicated. Onion-shapes characterize proximal bodies, with massive ore concentrated in the innermost shell. In contrast, distal ores have low-grade stocks at depth and high-grade chimneys at upper levels (Ciobanu and Cook 2004).

Banat West Metallogenic District: Ciclova Montană and Oravița field stops

The skarns of the Oravița–Ciclova area represent high-temperature calcic skarns, including gehlenite-bearing and vesuvianite-rich varieties, formed through contact metamorphism between Late Cretaceous, shallow-level magmatic intrusions and Mesozoic carbonate sequences composed mainly of limestones and marls. The most significant contact metamorphism occurs in the eastern part of the area, where banatites intruded a thick carbonate succession belonging to the sedimentary cover of the Getic unit (Figs. 5 and 11). Compared with the Ocna de Fier occurrence, the more diverse composition of the sedimentary paleosome—pure and cherty limestones, argillaceous limestones, and marls—was the primary control on skarn mineralogy, which includes abundant Al- and Mg-rich calc-silicates. Several major banatitic bodies crop out in the area, consisting of early diorites, monzodiorites, and isolated gabbros in the Oravița Valley and Ciclova areas, followed by porphyritic granodiorites at Maidan and Tâlva Mică, north of Oravița Valley. A later dyke-rock suite, including lamprophyres, andesites, syenites, alkali-granites, rhyolites, and dacites, is irregularly distributed throughout the main igneous bodies and sedimentary formations. The following mineralization styles are documented in the Oravița–Ciclova area: Cu-Mo porphyry-style mineralization within granodiorites; Cu-Bi-W mineralization in garnet-bearing skarns, granodiorites, and hornfels; Cu-pyrite mineralization in recrystallized limestones; Cu-Mo-W mineralization in garnet-vesuvianite-bearing skarns and monzodiorites; Cu-Co-As mineralization in propylitized skarns and monzodiorites; and Cu-Pb-Zn mineralization in monzodiorites.

More than 120 minerals have been described from the Oravița–Ciclova area, including minerals for which the area is considered, or has been proposed as, a type locality: hörnesite, a magnesium arsenate; csiklovaite, Bi2TeS2; and wollastonite. Although the scientific literature generally identifies Capo di Bove as the type locality for wollastonite, Papp (2002) suggested that Ciclova may be the actual original locality. The skarn deposits include remarkable occurrences of high-temperature skarn minerals, such as gehlenite, vesuvianite, diopside, wollastonite, garnet, and scheelite. These assemblages are overprinted by retrograde minerals including tremolite, epidote, and blue calcite, the latter being a characteristic feature of Ciclova.

Ore minerals include pyrite, bornite, arsenopyrite, tetradymite, chalcopyrite, sphalerite, scheelite, molybdenite, glaucodot, cobaltite, tetrahedrite, tennantite, and various Bi sulphosalts.

During the field trip, we will visit two skarn and banatite occurrences in the area: Ţiganilor Valley in Ciclova Montană and Ogașul Crișenilor in Oravița.

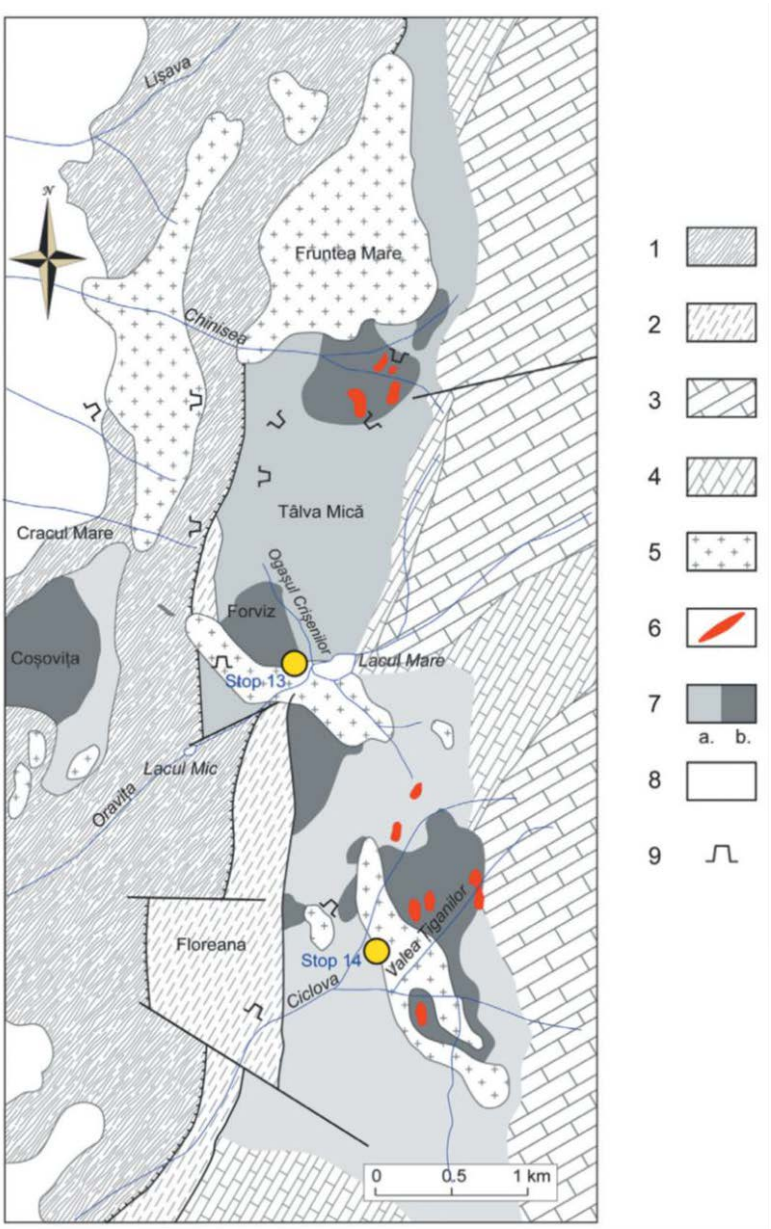


Fig. 11. Geological sketch of Oravița – Ciclova. 1) Precambrian (micaceous gneisses, chlorite-muscovite schists, amphibolites, quartzites, metagabbros); 2) Permian (sandstones, argillic schists); 3) Oxfordian-Tithonian (limestones, marls); 4) Berriasian-Aptian (limestones, marls, argillaceous limestones); 5) Upper Cretaceous – Paleocene: plutonic banatites (granodiorites, diorites, monzodiorites); 6) Dykes (andesites, syenites, alkali granites, rhyolites, dacites, lamprophyres); 7) a. Hornfels, recrystallized limestones, b. Skarns; 8) Pleistocene (alluvial deposits); 9) Old mining works.

Day 3. World-class porphyry and epithermal Cu-Au deposits of Timok East, Serbia

As part of the Apuseni-Banat-Timok-Srednogorie Belt, Timok East represents one of the most prospective zones for Cu-Au porphyry and high-sulfidation epithermal mineral systems in the region. It is genetically related to the formation of the Timok Magmatic Complex (TMC), which developed during three volcanic

phases: V1 (~90–84 Ma; easternmost TMC), V2 (~83–80 Ma; central part of the TMC), and V3 (82–78 Ma; westernmost TMC) (Banješević, 2010; Kolb et al., 2013; Gallhofer et al., 2015; Knaak et al. 2016; Jelenković et al., 2016; Zdravković et al., 2026). At Timok East, the V1 phase hosts the most significant ore mineralization and consists of hornblende-, hornblende-biotite-, and augite-bearing andesites and associated volcaniclastics, as well as hornblende-biotite dacite. These volcanic rocks are interlayered with marls, tuffs, and tuffisites and are intruded by quartz-diorite dykes associated with hydrothermal alteration. Large Cu-Au deposits are located along an NNW-trending lineament on the eastern margin of the Timok district (Fig. 6), including, from north to south, the Majdanpek porphyry Cu-Au and skarn deposit, the Čoka Marin carbonate-replacement polymetallic deposit, the Veliki Krivelj porphyry Cu-Au deposit, the Bor porphyry and high-sulfidation epithermal Cu-Au system, and the Čukaru Peki porphyry and high-sulfidation epithermal Cu-Au system. During the trip, we will visit two important deposits currently operated by Serbia Zijin Copper Mining Company: the Veliki Krivelj open pit and the Čukaru Peki mine.

Veliki Krivelj

Mining of the Veliki Krivelj deposit began in 1982 and is still ongoing; the open pit has now reached the +10 m level. The Veliki Krivelj porphyry copper deposit (Figs. 6 and 12) is situated approximately 3 km north of Bor. It is located within a zone composed predominantly of hydrothermally altered V1-phase andesitic rocks. The position of this zone is controlled by a NW-SE-trending longitudinal fault. The vertical mineralized interval exceeds 800 m, and exploration has not yet reached the lowest levels of ore mineralization. A significant characteristic of the deposit is that the copper grade does not decrease with depth. Hydrothermal alteration related to mineralization includes a) Si-K metasomatism accompanied by sericitization and silicification; b) sericitization accompanied by silicification and, locally, by biotitization and argillization; c) chloritization accompanied by carbonatization and, more rarely, epidotization and weak silicification; d) extensive pyritization; and e) zeolitization, mainly laumontite. These alteration assemblages are developed in all lithological units. Biotitization and silicification predominate near the quartz diorite porphyries, whereas argillization, sericitization, epidotization, chloritization, and calcitization occur farther away (Jelenković et al., 2000, 2002). Silicification commonly accompanies biotitization, sericitization, kaolinization, feldspathization, and propylitization. The mineral assemblage of the Veliki Krivelj deposit consists of magnetite (up to 2–3%), hematite, rutile, sphene, leucoxene, ilmenite, pyrrhotite, cubanite, valeriite, pyrite (up to 5%), marcasite, chalcopyrite, bornite, molybdenite (50–150 ppm Mo), sphalerite, galena, Au-Ag phases, enargite, tetrahedrite, siderite, covellite, chalcocite, malachite, azurite, and limonite. Gangue minerals are represented by quartz and minor calcite, barite, and siderite, with fluorite occurring only exceptionally.

The ore is characterized by very low gold contents; the mean value of 0.056 g/t is the lowest reported gold content among the porphyry deposits of the Bor metallogenic zone. Notably, the Veliki Krivelj deposit is situated only a few kilometers from the Bor copper-gold deposit, and both deposits are of the same or similar age and were likely related to the same, or a closely related, magmatic reservoir.

Above the -100 m elevation level, the mineral resources of the Veliki Krivelj deposit are estimated at >621 Mt of Cu ore grading 0.318% Cu and 0.056 g/t Au.

Note: *Serbia Zijin Copper Mining Company will provide an observation point on the rim of the open pit and a guide who will introduce participants to the main characteristics of the Veliki Krivelj deposit.*

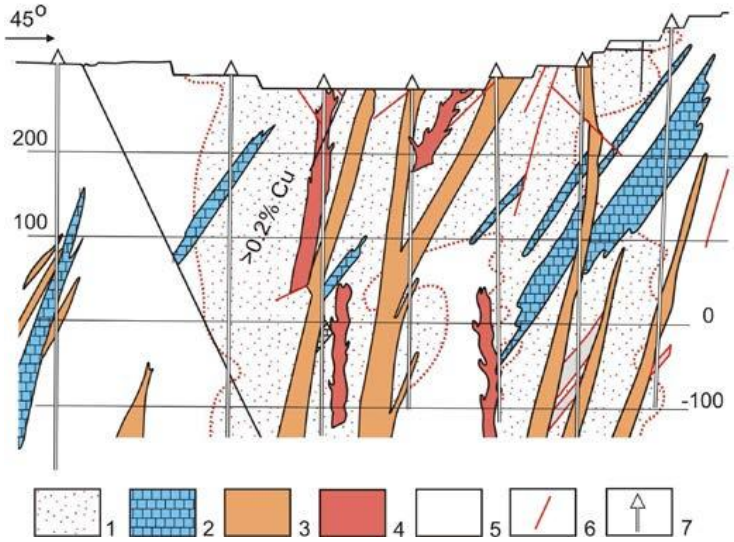


Fig. 12. Cross-section through the Veliki Krivelj porphyry copper deposit (Janković et al., 2003): 1) ore mineralization; 2) limestones and skarns; 3) andesites; 4) quartz diorite porphyry dykes; 5) hydrothermally altered andesites; 6) fault; 7) drill holes.

Čukaru Peki drill cores storage

Čukaru Peki is a recently discovered world-class epithermal-porphyry Cu-Au deposit (Koželj et al., 2014; Velojić et al., 2020). It is located about 6 km south of Bor. The Čukaru Peki deposit is covered by up to 250 m thick pile of Miocene sediments and a 200 m thick Upper Cretaceous post-mineralization volcano-sedimentary package. The Čukaru Peki deposit is composed of upper zone high-sulfidation epithermal orebodies (UZ-1, UZ-2) and lower zone porphyry orebodies (LZ-1). The UZ-1 and UZ-2 orebodies are distributed at an elevation of −400 to 0 m above sea level, while the LZ-1 orebody has a complex morphology and is mostly distributed at 550 m below sea level (Wang et al., 2025). The UZ is characterized by the presence of an epithermal high-sulfidation, massive-sulfide to semi-massive-sulfide, pyrite-covellite±enargite type of mineralization hosted by hydrothermally altered andesites and volcanoclastic rocks of the first volcanic phase. Dykes with dioritic composition were described at deep levels of the Bor porphyry deposit in early literature; one small, 1.5 m core interval was identified as a diorite dyke, syn-to post-mineral, in the upper part of the Borska Reka porphyry. Upper andesite at Čukaru Peki is texturally similar to the host rock at Bor; however, no lithology at Bor can be correlated to the lower andesite of Čukaru Peki, possibly due to faulting at Bor which juxtaposes conglomerate and Bor igneous rocks at depth (Fig. 13). The host rock, andesite, has experienced chlorite-sericite alteration with associated magnetite-chalcopyrite-quartz vein mineralization in the deep Borska Reka porphyry, which grades into a texture–destructive sericite-kaolinite alteration zone towards the shallow part of the Borska Reka porphyry, and is overlain by an anhydrite-kaolinite alteration zone with anhydrite-sulfide veins, referred to as Tilva Ros epithermal mineralization zone and surrounded by the massive sulfide lens-like orebodies, including recently mined-out T, T1 and historic Tilva Mika, Coka Dulkan, E, E 1 and others (Fig. 13; Klimentieva et al, 2020, 2022; Bosić et al,, 2025; Wang et al., 2025). Measured and indicated resources of the Bor deposit amount to 5.8 Mt Cu and 260 t Au, at a cut-off grade of 0.3% Cu. Čukaru Peki Lower Zone resource estimate amounts to 14.3 Mt Cu at 0.38% cut-off grade and 298.6 t Au. The total amount of Cu and Au extracted from Bor is difficult to estimate, as mining operations have been going on for more than a hundred years. Still, the approximate level of production + reserves reaches a total of 6.6–6.7 Mt with higher cut-off grades, namely at 0.6% Cu for the porphyry zone and 1.5% Cu for the epithermal zone, and a total of 290–302 t Au (Klimentieva et al., 2022).

Note: *The visit of Čukaru Peki will include: a tour through the Čukaru Peki mine infrastructure, an expert's introduction to the deposit, and the observation of drill cores that include: a) the volcanic-sedimentary package in the hanging wall of the mineralization in the UZ, b) the UZ epithermal mineralization, and c) the LZ porphyry mineralization.*

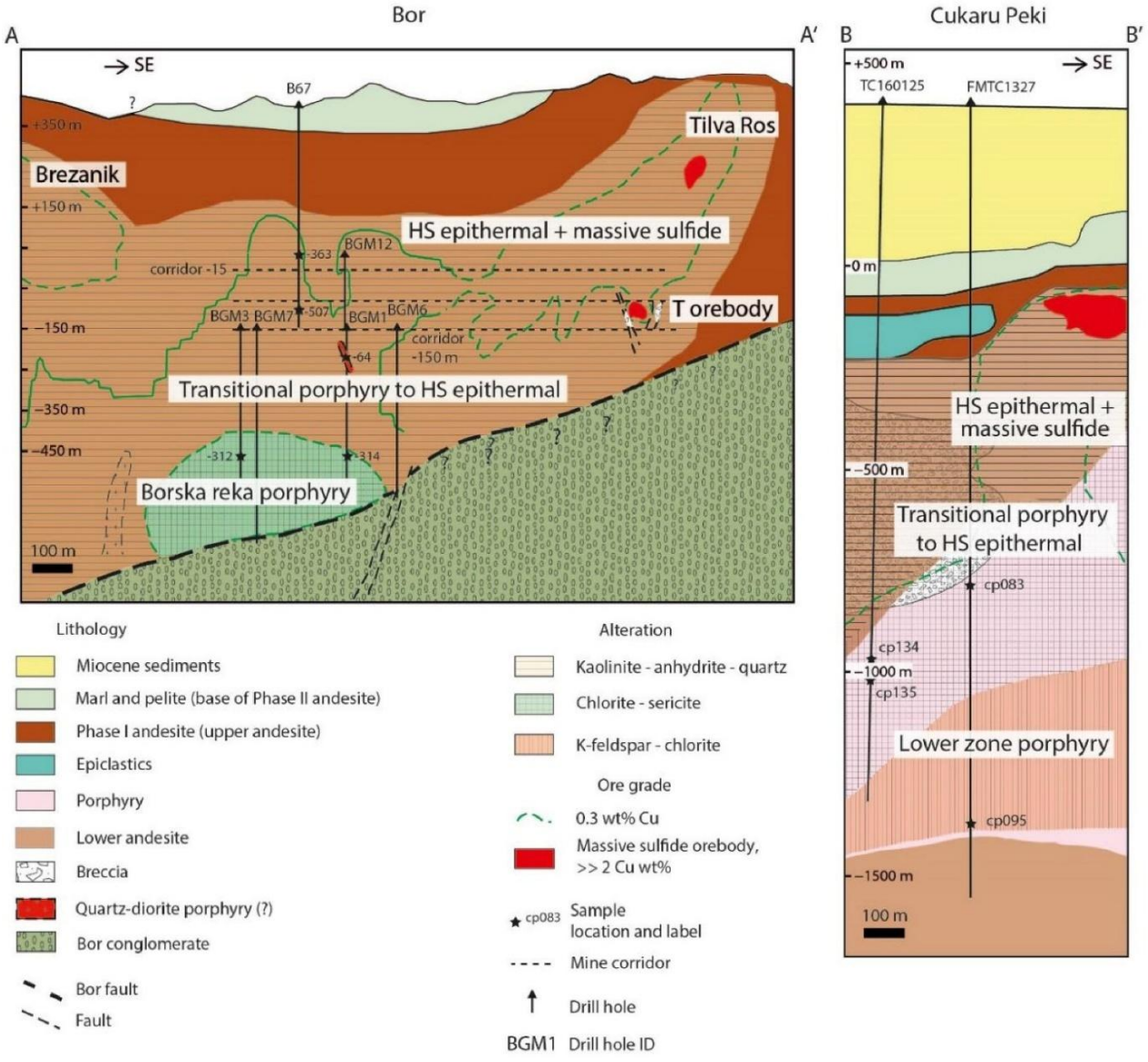


Fig. 13. Cross-sections of Bor and Čukaru Peki deposits (Klimentyeva, et al., 2022).

Day 4. Newly discovered Cu and Au-rich alkaline porphyry, skarn and sedimentary rock-hosted deposits of Timok West, Serbia

The western margin of the Timok Magmatic Complex (TMC) in eastern Serbia has transitioned into a world-class, district-scale mineral camp (Figs. 6 and 14). Exploration managed primarily by DPM Metals has discovered a highly diverse, interconnected gold and copper-gold system. The discovery story of the area evolved from the reveal of low-temperature, sedimentary rock-hosted Au deposits (Bigar Hill and Korkan deposits) into a major camp of high-grade Au-Cu skarn and porphyry mineralization (Coka Rakita Au skarn deposit, Dumitru Potok Cu-Au skarn deposit, Frasen porphyry Au-Cu prospect).

Modern gold exploration in the northwestern Timok Magmatic Complex (TMC) initiated between 2004 and 2009. Early campaigns utilized soil sampling, trenching, geophysical surveys, and limited diamond

drilling to target porphyry and high-sulfidation mineralization. From 2010 to 2013, Avala Resources Ltd. shifted exploration focus to carbonaceous sequences. Surface sampling and drilling successfully outlined sediment-hosted gold mineralization at the Bigar Hill, Korkan, and Kraku Pešter prospects (Van der Toorn et al., 2013; Knaak et al., 2016). Post-2016, exploration targeted shallow oxide mineralization, leading to the discovery of the Korkan West prospect. In 2020, Dundee Precious Metals (DPM) published a prefeasibility study and an updated mineral resource estimate for these sediment-hosted deposits, defining an Indicated Mineral Resource of 32.3 Mt grading 1.27 g/t Au (1.319 Moz contained gold), which included 8.2 Mt of oxide ore (DPM Prefeasibility study, 23/02/2021; de Weerdt et al., 2021).

In 2023, DPM announced the discovery of the high-grade Čoka Rakita gold skarn deposit along the southeastern portion of the mineralized trend. This high-grade gold mineralization is hosted within exoskarns that developed as massive, stratabound bodies. These bodies formed via the replacement of a calcareous, clastic sedimentary sequence situated in the hanging wall of a sill-like porphyritic diorite, positioned east of a major monzonitic intrusion (Ivascanu, 2024; Zdravković et al., 2024; Živanović et al., 2024). A feasibility study for Čoka Rakita was completed in 2025, establishing an updated Mineral Reserve estimate of 7.344 Mt grading 6.44 g/t Au (1.520 Moz contained gold; Major et al. 2025).

Concurrently, DPM reported the discovery of deep, marble-hosted, high-grade Cu-Au polymetallic skarn and carbonate replacement mineralization at the Dumitru Potok, Frasen, and Rakita North prospects (Milić et al., 2026). An initial Inferred Mineral Resource Estimate for these deep prospects defined a combined resource of 84.4 Mt grading 0.97 g/t Au and 1.02% Cu, containing approximately 2.6 Moz of gold and 1.9 billion pounds of copper (DPM Metals, 2026). At the Dumitru Potok contact skarn, located at a depth of approximately 1 km, a significant portion of the copper mineralization occurs as secondary copper sulfides (bornite, chalcocite, digenite) and native copper. This mineralization is hosted within strongly oxidized garnet skarn, where primary garnet has been partially to extensively replaced by a quartz-carbonate-goethite assemblage and subsequently overprinted by late-stage quartz-calcite with minor chalcocite (Milić et al., 2026; Segovia-More et al., 2026)

Our field trip aims to review representative drill core sections from these newly discovered deposits.

Geology of Northwestern Timok

The local stratigraphy comprises a Paleozoic basement of phyllite, meta-sandstone and meta-basalt, overlain by Jurassic and Cretaceous limestones dominantly recrystallized to marble. Above are clastic sediments, characterized by a general coarsening upward facies and an increased carbonate component (quartzite-dominated conglomerate to marl), followed by a debris-flow sequence with andesitic to basaltic components (Fig. 14). The Valja Strž composite monzonitic pluton, located along the westernmost margin of the TMC, has been constrained as the youngest magmatic product of the complex with an age of approximately 79 Ma. Numerous smaller intrusive bodies occur near the NE margin of the pluton, many of which are associated with zoned magmatic-hydrothermal systems that host important porphyry, skarn, and carbonate replacement-type Au-Cu-Ag-Pb-Zn-Mo mineralization within the Čoka Rakita - Dumitru Potok - Frasen ore field (Zdravković et al., 2024; DPM Metals press releases 2024-2026). Available age data from NW Timok gave age ranges from 75.8 ± 1.5 to 82.37 ± 0.98 Ma (zircon LA-ICP-MS) and from 79.402 ± 0.029 to 84.18 ± 0.11 Ma (zircon CA-ID-TIMS) and define three magmatic episodes (Zdravković et al., 2026).

At **Čoka Rakita,** the main economic mineralization is hosted by an exoskarn formed by the replacement of a calcareous clastic sedimentary sequence within a structural and stratigraphic trap bounded by the dioritic sill and monzonite intrusion (Fig. 15; Zeković et al., 2026). Mineralization is primarily lithologically controlled, occurring as massive stratabound bodies extending northwest-southeast and dipping approximately 40° eastward, with a secondary north-south structural control on the high-grade zone and the occurrence of subvertical brecciated zones. Mineralization also extends into the endoskarn of the

diorite, up to several meters from the intrusive contact. Prograde assemblage is dominated by garnet (andradite–grossular), with subordinate wollastonite and pyroxene, and the retrograde assemblage is primarily composed of chlorite, actinolite, epidote, and carbonate minerals. A typical feature of Čoka Rakita is the dominance of garnet over pyroxene and the occurrence of high-grade gold mineralization in sulfide-poor zones, which is consistent with an oxidized gold skarn deposit type (Kouzmanov et al., 2026). Abundant red-brown garnet above the diorite intrusions is interpreted to mark the main hydrothermal fluid pathway. Gold typically occurs within microfractures of garnet or in its intergranular spaces, although it may also be hosted by pyrite, chalcopyrite, epidote, quartz, calcite, and K-feldspar. Native gold aggregates may reach several millimeters in size.

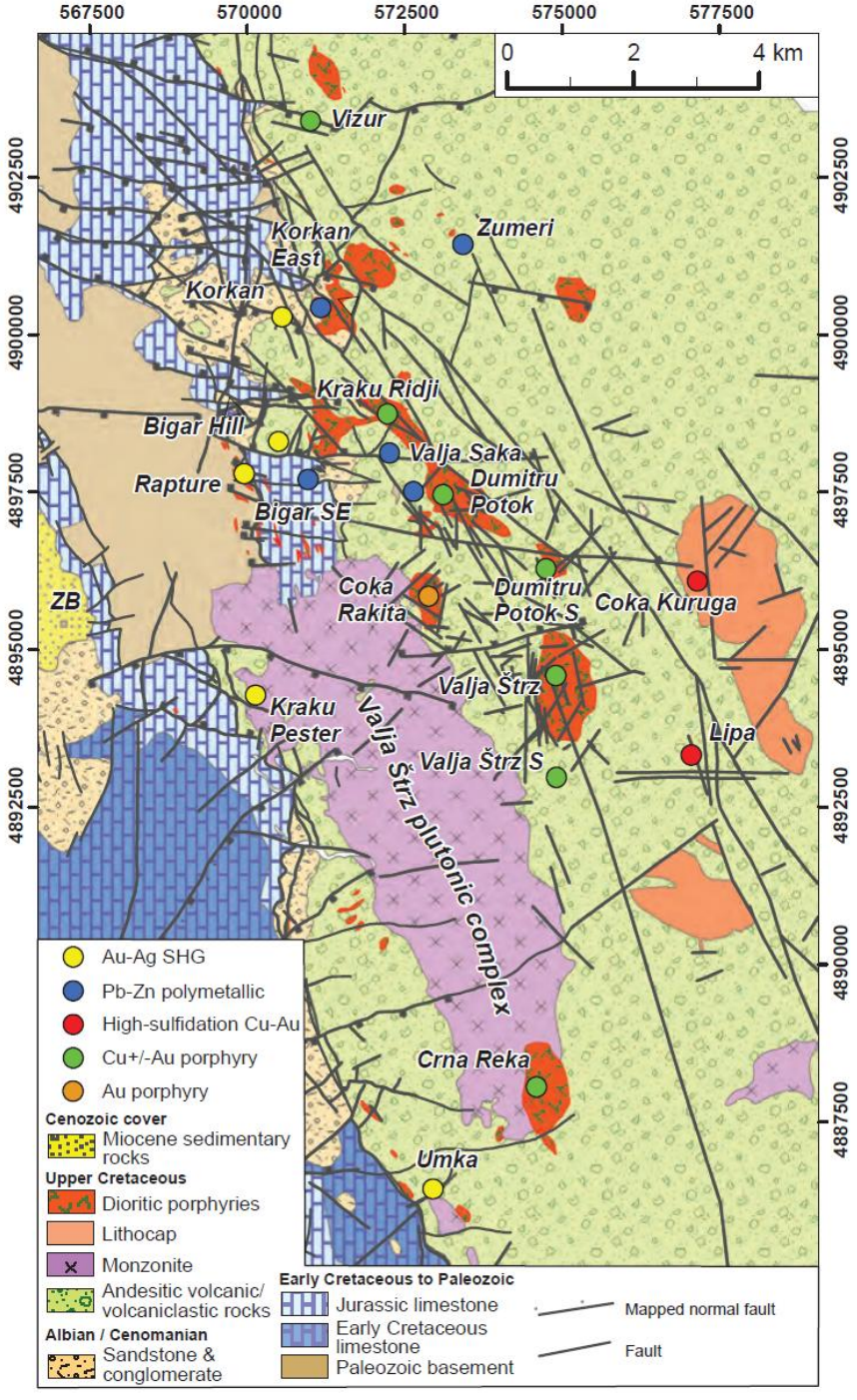


Fig. 14. Generalized geological map of the northwestern area of the Timok Magmatic Complex, eastern Serbia. UTM coordinates are WGS84 zone 34 (Knaak et al., 2016).

At **Čoka Rakita** the main skarn mineralization is closely spatially associated with several other mineralization types, including: porphyry Au-Cu-Mo mineralization hosted by potassic altered diorite, structurally controlled Au mineralization in epiclastic rocks, as well as stratabound Cu-Au mineralization occurring in deeper stratigraphic levels within the conglomerates and basal breccias and in skarn-altered marbles. The deeper stratabound Cu-Au mineralization in the marble and along its contact with the upper siliciclastic unit is mainly associated with garnet-dominated skarn alteration with Fe-oxide/hydroxide replacements in paleokarst zones, and an assemblage of chalcopyrite, bornite, and minor chalcocite.

The **Dumitru Potok–Frasen–Valja Saka** camp exhibits typical zonation of a potentially telescoped magmatic-hydrothermal system, from proximal porphyry and contact skarn through stratabound manto-type Cu-Au mineralization to distal polymetallic carbonate replacement, underscoring the camp as a multi-center magmatic-hydrothermal system with high exploration potential (Fig. 16; Suzić et al. 2026). At Dumitru Potok, marble-hosted Cu-Au skarn is the dominant mineralization style, developed as lens-shaped contact skarn bodies along the marble–quartz- monzodiorite contact and as stratabound manto-like bodies along the conglomerate- marble unconformity. The skarn assemblage comprises andradite–grossular garnet with secondary calcite, opaline silica, magnetite, hematite, and goethite, hosting chalcopyrite, bornite, chalcocite, digenite, and native copper mineralization. **Frasen porphyry Au–Cu mineralization** is related to several generations of quartz–magnetite–pyrite–chalcopyrite veins in potassic-altered quartz-monzodiorite. Distal, manto-like carbonate replacement bodies define an Au–Ag–Zn–Pb–Cu enriched zone hosted in marble, as well as near-surface “Chocolate Zone”, a strongly supergene oxidized residual deposit, containing gold associated with goethite–hematite pseudomorphing the pyrite. At Rakita North, marble-hosted Cu–Au–Ag mineralization is dominated by chalcopyrite with subordinate bornite, occurring as manto-like skarn bodies and stockwork veins. **Valja Saka is a geologically heterogeneous prospect** hosting diverse mineralization styles. Shallow garnet-altered marls carry Au mineralization analogous to that in Čoka Rakita. Gold occurs in oxidized skarn-altered marble with a low-sulfur assemblage and in association with pyrite-arsenopyrite-pyrrhotite. Distal polymetallic carbonate-replacement Ag–Zn–Pb ± Cu-Au mineralization occurs in limestone, marls, and sandstone.

The low-temperature, **sedimentary rock-hosted gold** (SRHG) deposits of the northwestern sector – comprising **the Bigar Hill, Korkan, Korkan West, and Kraku Pešter zones** – are spatially proximal to, yet invariably fault-bounded from, the polymetallic replacement, skarn, and porphyry Cu-Au prospects. Despite this structural compartmentalization, the frequent spatial association between these SRHG deposits and the zoned porphyry-polymetallic replacement systems, complemented by established exploration geochemical footprints, strongly suggests a genetic linkage across the entire hydrothermal system. At SRHG deposits, gold mineralization is predominantly stratabound and confined to two primary stratigraphic horizons (Fig. 17). The principal mineralized zone occurs at the contact between the S1 (comprising basal breccia, siltstone and dominantly sandy limestone, and calcareous sandstone) and S2 (Late Cretaceous volcanic detritus-rich, calcareous sandstone/conglomerate package) lithological units. A secondary, yet significant, mineralized corridor tracks the unconformable, breccia-like contact between the underlying limestone and the S1 unit. To a lesser degree, karstified limestones, faults, and fracture networks across all lithologies also host mineralization. Auriferous, acidic hydrothermal fluids preferentially exploited the primary permeability of preserved paleo-weathering crusts, brecciated zones, and unconformity-related karst features. These fluids subsequently enhanced ground preparation by dissolving

the host-rock carbonate cement to generate secondary porosity. While stratigraphic architecture heavily governed ore localization, regional structural frameworks and syn-mineralization fault reactivation were critical catalysts required to drive fluid migration into these favorable stratigraphic traps. Iron sulfidization represents the primary gold precipitation mechanism. The gold mineralization is sub-microscopic and hosted within fine-grained pyrite, arsenian pyrite, and minor marcasite. Although the primary sulfide mineralization is highly refractory, significant portions of the SRHG system have undergone supergene oxidation. Supergene and paleo-weathering events drove the oxidation of primary pyrite into secondary iron oxi-hydroxides. While a fraction of the gold remains encapsulated within these oxidized grains, gold previously concentrated within the As-rich rims of the primary pyrite has been liberated and redeposited as fine particles of native gold and gold-sulfides (Knaak et al., 2016; Magyar et al., 2026 – in press).

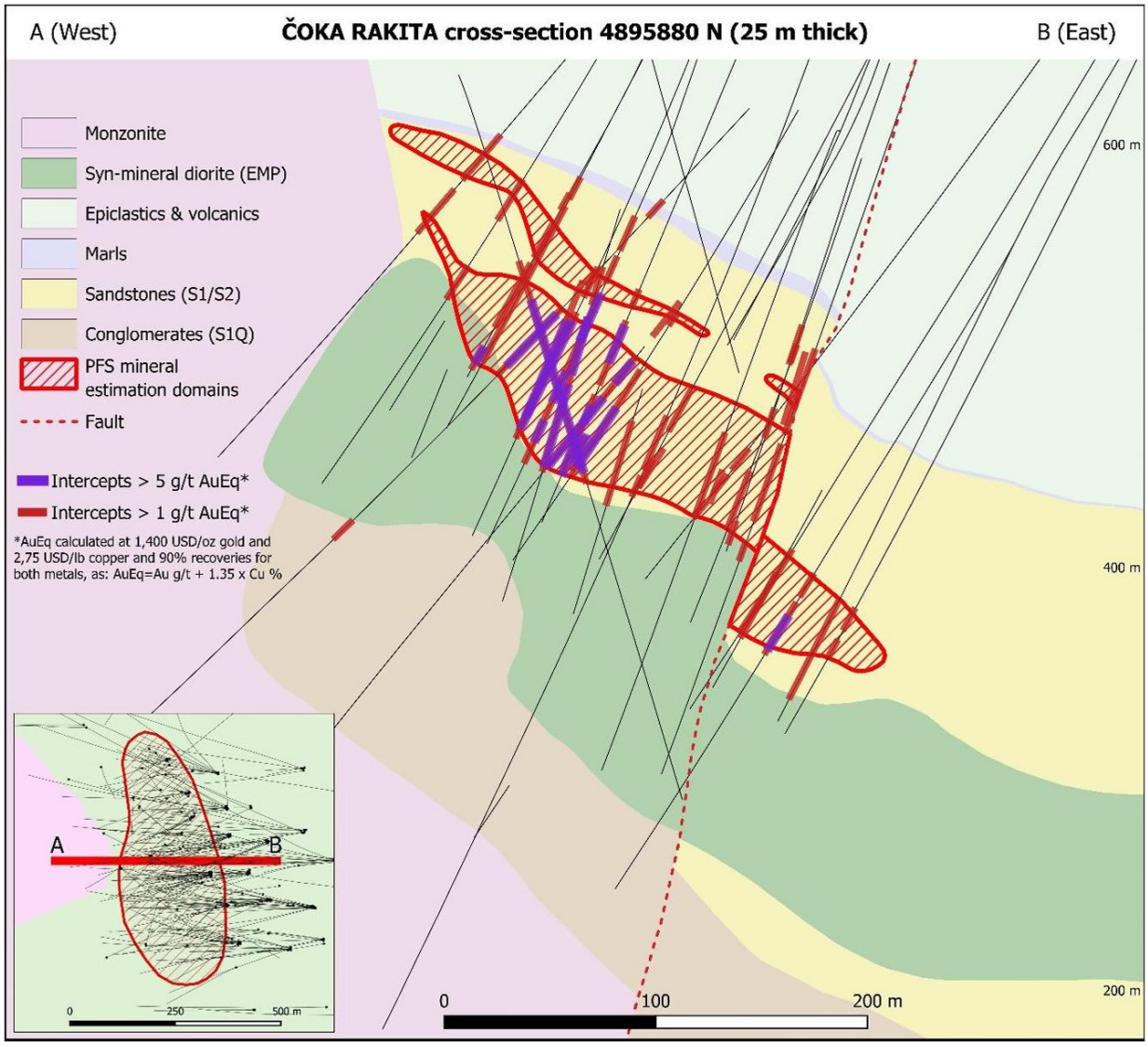


Fig. 15. Schematic cross section of the Čoka Rakita deposit, displaying drilling intercepts , geology and the PFS mineral estimation domains (Source: *DPM Metals 2026, Čoka Rakita Feasibility Study, https://dpmmetals.com/investors/investor-centre/#TechnicalReports).*

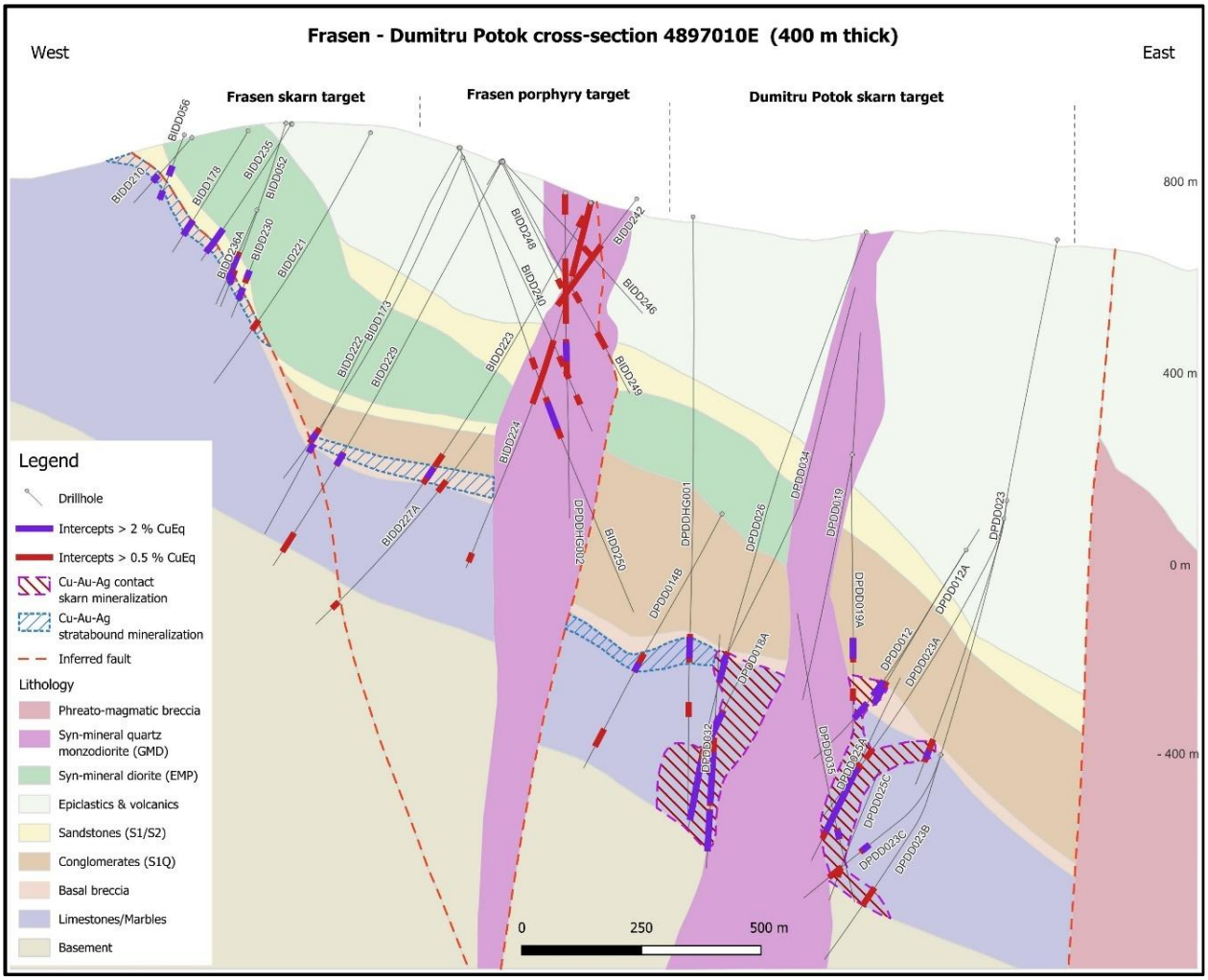


Fig. 16. Simplified section looking north, showing the interpretation of the geological setting and different mineralization styles in the Frasen-Dumitru Potok area. (Source: DPM Metals 2026, NI 43-101 Technical Report - Mineral Resource Estimate for Dumitru Potok, Frasen and Rakita North Prospects, Serbia, https://dpmmetals.com/investors/investor-centre/#TechnicalReports).

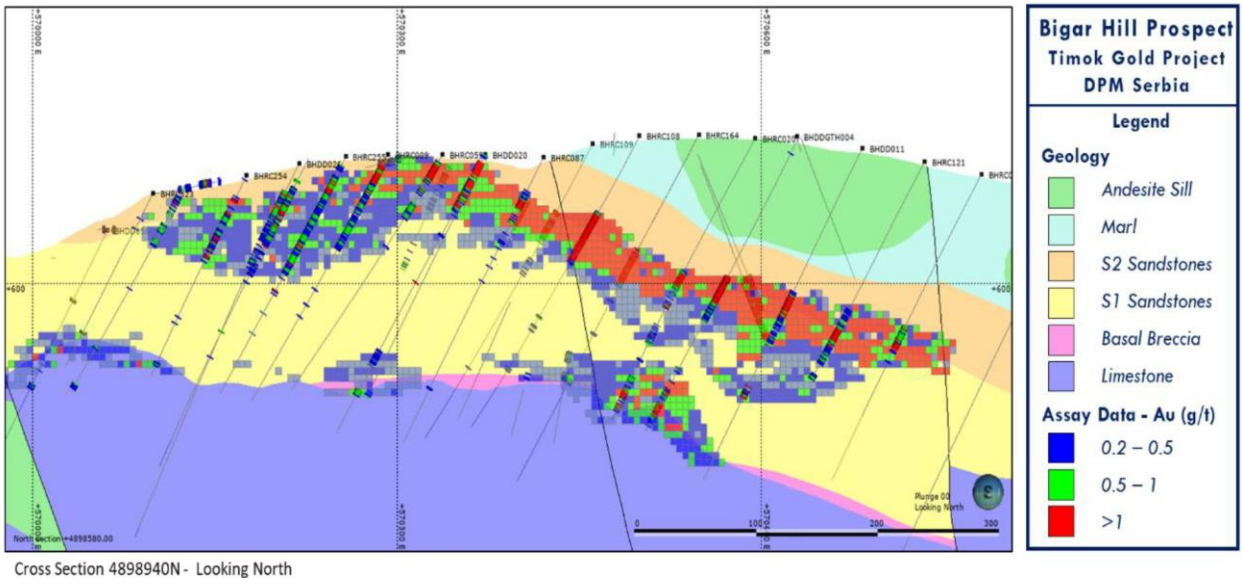


Fig. 17. Cross section of the Bigar Hill deposit (Source: DPM Metals 2021, NI 43-101 Technical Report Timok Project Pre-Feasibility Study, https://dpmmetals.com/investors/investor-centre/#TechnicalReports)

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REFERENCES

Balintoni, I., 2003. Towards an improved model of the Laramian Transylvanides. In: Ionescu, C., Hoeck, V. (Eds.), Proceedings and abstracts of the 6th International Symposium on Mineralogy, Cluj-Napoca 2003. Studia Universitatis Babeș-Bolyai, Cluj-Napoca, Special Issue, 13–20.

Banješević, M., 2010. Upper Cretaceous magmatic suites of the Timok Magmatic Complex. Annales Géologiques de la Péninsule Balkanique, 71, 13–22.

Bleahu, M., Lupu, M., Patrulius, D., Bordea, S., Stefan, A., Panin, S., 1981. The structure of the Apuseni Mountains. Carpatho-Balkan Geological Association, XIIth Congress, Guide to Excursion B3, Bucharest, 107 p.

Bortolotti, V., Marroni, M., Nicolae, I., Pandolfi, L., Principi, G., Saccani, E., 2002. Geodynamic implications of Jurassic ophiolites associated with Island-Arc Volcanics, South Apuseni Mountains, Western Romania. International Geology Review, 44, 938–955.

Bortolotti, V., Marroni, M., Nicolae, I., Pandolfi, L., Principi, G., Saccani, E., 2004. An update of the Jurassic ophiolites and associated calc-alkaline in the South Apuseni Mountains (Western Romania). Ofioliti, 29, 5–18.

Bosić, D., Cvetković, V., Pačevski, A., Banješević, M., Chen, S., Šarić, K., 2025. Petrological and geochronological characterization of the porphyry-epithermal system of Čukaru Peki, Bor Metallogenic Zone, East Serbia. Ore Geology Reviews, 186, 106910.

Ciobanu, C.L., Cook, N.J., 2004. Skarn textures and a case study: the Ocna de Fier-Dognecea orefield, Banat, Romania. Ore Geology Reviews, 24, 315–370.

Ciobanu, C., Cook, N., Stein, H., 2002. Regional setting and geochronology of the Late Cretaceous Banatitic Magmatic and Metallogenetic Belt. Mineralium Deposita, 37, 541–567.

Cook, N.J., Ciobanu, C.L., 2001. Paragenesis of Cu-Fe ores from Ocna de Fier-Dognecea (Romania), typifying fluid plume mineralization in a proximal skarn setting. Mineralogical Magazine, 65, 351–372.

de Weerdt, P., Ibrango, S., Gagnon, D., Bisaillon, C., Liskovych, V., Vasquez, L., Ritchie, D., Leahy, K., Overall, R., White, G., 2021. NI 43-101 Technical Report – Timok Project Pre-Feasibility Study, Zagubica, Serbia. DRA Americas Inc., Dundee Precious Metals, 532 pp.

Gallhofer, D., von Quadt, A., Peytcheva, I., Schmid, S.M., Heinrich, C.A., 2015. Tectonic, magmatic and metallogenic evolution of the Late Cretaceous Arc in the Carpathian–Balkan orogen. Tectonics, 34, 1445–1466.

Ilinca, G., 2010. Classic skarn localities of Romania: Contact metamorphism and mineralisation related to Late Cretaceous magmatism. IMA2010 Field Trip Guide RO5, 50 p.

Ionescu, C., Hoeck, V., Tomek, C., Koller, F., Balintoni, I., Bestutiu, L., 2009. New insights into the basement of the Transylvanian Depression (Romania). Lithos, 108, 172–191.

Ionescu, M., Hoeck, V., 2010. Mesozoic ophiolites and granitoids in the Apuseni Mts. IMA2010 Field Guide, Vol. RO2, Budapest, 44 p.

Ivascanu, P., 2024. Čoka Rakita: discovery & accelerated exploration of a new high-grade gold skarn deposit in Serbia. Proceedings of PDAC 2024 (Western Tethyan Session), Toronto, Canada.

Janković, S., Jelenković, R., Koželj, M., 2003. Borska metalogenetska zona: Geološki faktori lokalizacije orudnjenja bakra i zlata. Geološki anali Balkanskoga poluostrva, 65, 55–71.

Jelenković, R., Milovanović, D., Koželj, D., Banješević, M., 2016. The mineral resources of the Bor metallogenic zone: A review. Geologia Croatica, 69, 143–155.

Kitanović, V., Živanović, J., Zdravković, M., Strmbanović, I., Milošević, D., Milić, V., Suzić, I., Dukić-Mijucić, O., Sušić, D., Mitić, T., Zeković, A., Kotlajić, L., Kovačević, V., Šestak, A., Groza, N., Metodiev, S., Krumov, I., Márton, I., Kunchev, K., Ivascanu, P., 2026. Conjugate fracture systems as indicators of regional stress, Valja Saka prospect, Eastern Serbia. CBGA 2026 abstract book (in press).

Klimentyeva, D., Driesner, T., von Quadt, A., Tončić, T., Heinrich, C., 2020. Silicate-Replacive High Sulfidation Massive Sulfide Orebodies in a Porphyry Cu-Au System: Bor, Serbia. Mineralium Deposita, 56, 1423–1448.

Klimentyeva, D., Velojić, M., von Quadt, A., Hood, S., 2022. Interpretation of Trace Element Chemistry of Zircons from Bor and Čukaru Peki: Conventional Approach and Random Forest Classification. Geosciences, 12, 396.

Knaak, M., Marton, I., Tosdal, R., van der Toorn, J., Davidović, D., Strmanović, I., Zdravković, M., Živanović, J., Hasson, S., 2016. Geologic Setting and Tectonic Evolution of Porphyry Cu-Au, Polymetallic Replacement, and Sedimentary Rock-Hosted Au Deposits in the Northwestern Area of the Timok Magmatic Complex, Serbia. In: Richards, J.P. (Ed.), Tectonics and Metallogeny of the Tethyan Orogenic Belt. Society of Economic Geologists Special Publication 19, 1–28.

Kolb, M., von Quadt, A., Peytcheva, I., Heinrich, C.A., Fowler, S.J., Cvetkovic, V., 2013. Adakite-like and Normal Arc Magmas: Distinct Fractionation Paths in the East Serbian Segment of the Balkan-Carpathian Arc. Journal of Petrology, 54, 421–451.

Kouzmanov, K., Márton, I., Živanović, J., Zdravković, M., Zeković, A., Milić, V., Suzić, I., Groza, N., Krumov, I., Kunchev, K., Pačevski, A., Ivascanu, P., Metodiev, S., 2026. Architecture of an exceptionally high-grade Au skarn system at Čoka Rakita, eastern Serbia: Mineral and geochemical constraints. CBGA 2026 abstract book (in press).

Koželj, D., Canby, V.M., Naftali, L., 2014. The Čukaru Peki copper-gold deposit. Proceedings of the XX Congress of the Carpathian-Balkan Geological Association (CBGA 2014), Tirana, Albania, 1, p. 150.

Lazăr, C., Întorsureanu, I., 1981. Contribuții la cunoașterea zăcământului de fier de la Mașca-Băișoara. Dări de Seamă ale Ședințelor, Institutul de Geologie și Geofizică, 66, 45–60.

Magyar, L., Marton, I., Papp, R., Weiszburg, T., Harman-Toth, E., 2026. From invisible gold in arsenian pyrite to gold-rich brown “muds”: supergene Au–Ag remobilization in the Bigar Limestone area, Western Timok, Serbia. Bulletin of the Hungarian Geological Society (in press).

Major, I., Morrison, D., Gagnon, D., O’Connor, M., Leahy, K., Mounhir, K., Palmer, P., Dobr, M., Ahmed, I., Mandl, B., McBride, W.R., 2025. NI 43-101 Technical report, Feasibility Study, Čoka Rakita project, Eastern Serbia. Technical Report, 698 p.

Márton, I., Metodiev, S., Krumov, I., Kunchev, K., Živanović, J., Groza, N., Kouzmanov, K., Ivascanu, P., 2026. Unlocking an exceptional copper–gold endowment: New discoveries in the Late Cretaceous Timok–Srednogorie belt segment in Serbia and Bulgaria. CBGA 2026 abstract book (in press).

Matenco, L., Radivojević, D., 2012. On the formation and evolution of the Pannonian Basin: Constraints derived from the structure of the junction area between the Carpathians and Dinarides. Tectonics, 31(6), 2012TC003206.

Milić, V., Suzić, I., Živanović, J., Zdravković, M., Márton, I., Krumov, I., Groza, N., Milošević, D., Strmbanović, I., Kotlajić, L., Drobnjak, D., Zeković, A., Mitić, T., Dukić-Mijucić, O., Kitanović, V., Janjić, S., Sušić, D., Kovačević, V., Šestak, A., Metodiev, S., Kunchev, K., 2026. Dumitru Potok Cu-Au Porphyry-Skarn Mineralization System within the Timok Magmatic Complex, Eastern Serbia. 19th Congress of Geologists of Serbia, Serbian Geological Society, Belgrade (in press).

Nicolescu, S., Cornell, D.H., Bojar, A.V., 1999. Age and tectonic setting of Bocsa and Ocna de Fier-Dognecea granodiorites (southern Romania) and of associated skarn mineralisation. Mineralium Deposita, 34, 743–753.

Royden, L., Faccenna, C., 2018. Subduction Orogeny and the Late Cenozoic Evolution of the Mediterranean Arcs. Annual Review of Earth and Planetary Sciences, 46(1), 261–289.

Săsăran, E., 2006. Upper Jurassic–Lower Cretaceous Limestones from Trascău Mountains. Cluj University Press, Cluj-Napoca, 249 p.

Schmid, S.M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski, K., 2008. The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units. Swiss Journal of Geosciences, 101, 139–183.

Schmid, S.M., Bernoulli, D., Fügenschuh, B., Kounov, A., Oberhänsli, R., Schefer, S., van Hinsbergen, D.J.J., Ustaszewski, K., 2011. Similarities and differences between Alps, Carpathians, Dinarides-Hellenides and Anatolides-Taurides. Abstract #T43E-2425, 2011 AGU Fall Meeting, San Francisco.

Segovia-More, M., Kouzmanov, K., Tsay, A., Chiaradia, M., Stefanova, E., Živanović, J., Zdravković, M., Milić, V., Suzić, I., Krumov, I., Márton, I., Metodiev, S., 2026. Formation of native copper in a deep marble-hosted Cu–Au–Ag skarn system at Dumitru Potok, Serbia. SEG Conference 2026 (in press).

Suzić, I., Milić, V., Živanović, J., Zdravković, M., Milošević, D., Strmbanović, I., Zeković, A., Mitić, T., Dukić-Mijucić, O., Kitanović, V., Sušić, D., Kotlajić, L., Kovačević, V., Šestak, A., Groza, N., Márton, I., Krumov, I., Metodiev, S., Kunchev, K., Ivascanu, P., 2026. Dumitru Potok Cu-Au Skarn Mineralization within a Larger Porphyry-Skarn-Carbonate Replacement System, NW Timok Magmatic Complex, Serbia. CBGA 2026 abstract book (in press).

Tudor, G., 2012. Metallogenic considerations in NW Poiana Ruscă Mountains (Romania). Romanian Journal of Mineral Deposits, 85, 52–56.

van der Toorn, J., Davidovic, D., Hadijeva, N., Strmbanovic, I., Márton, I., Knaak, M., Tosdal, R.M., Davis, B., Hasson, S., 2013. A new sedimentary rock-hosted gold belt in eastern Serbia. 12th Biennial SGA Meeting (Mineral deposit research for a high-tech world), Uppsala, Sweden, Society of Geology Applied, Volume 2, 691–694.

Velojić, M., Jelenković, R., Cvetković, V., 2020. Fluid Evolution of the Čukaru Peki Cu-Au Porphyry System (East Serbia) Inferred from a Fluid Inclusion Study. Geologia Croatica, 73, 197–209.

Vlad, Ș.N., 1997. Calcic skarns and transversal zoning in the Banat mountains, Romania: indicators of an Andean-type setting. Mineralium Deposita, 32, 446–451.

Vlad, Ș.N., 2011. Perspective targeting CuAuMo porphyries of Romanian Carpathians: blind porphyry mineralization and its variable distal expression as vein and skarns. Central European Journal of Geosciences, 3, 318–335.

von Quadt, A., Moritz, R., Peytcheva, I., Heinrich, C.A., 2005. Geochronology and geodynamics of Late Cretaceous magmatism and Cu–Au mineralization in the Panagyurishte region of the Apuseni–Banat–Timok–Srednogorie belt, Bulgaria. Ore Geology Reviews, 27(1–4), 95–126.

Wang, Z., Yue, H., Wu, D., Rao, D., Xu, F., Sun, W., Lang, W., Yu, Z., Zhou, Y., Huang, W., et al., 2025. Age, Genesis, and Tectonic Setting of the Serbian Čukaru Peki Copper Deposit in Timok Ore Cluster Area, Eastern Europe: Constraints from Zircon U-Pb Dating, Pyrite Re-Os Dating, and Geochemical Data. Minerals, 15, 1178.

Zdravković, M., Davidović, D., Živanović, J., Strmbanović, I., Groza, N., Milošević, D., Dukić-Mijucić, O., Janjić, S., Šestak, A., Milić, V., Drobnjak, D., Kotlajić, B., Kitanović, V., Mihajlović, J., Novicić, N., Mitić, T., Suzić, I., Ivascanu, P., Kunchev, K., Metodiev, S., Krumov, I., Márton, I., 2024. New Genetic Type of Gold Deposit for Timok, Serbia: The High-Grade Gold Skarn Mineralization at Coka Rakita Project. Proceedings of Society of Economic Geologists Annual Conference (SEG 2024), Windhoek, Namibia.

Zdravković, M., Márton, I., Cvetković, V., Živanović, J., Strmbanović, I., Groza, N., Dukić-Mijucić, O., Milić, V., Kitanović, V., Mitić, T., Zeković, A., Suzić, I., Kunchev, K., Metodiev, S., Krumov, I., Peytcheva, I., Georgiev, S., Stefanova, E., Kalchev, R., Kouzmanov, K., Ovtcharova, M., 2026. New age constrains on the magmatic-hydrothermal systems at the Čoka Rakita - Dumitru Potok - Frasen ore field, NW Timok, Serbia. CBGA 2026 abstract book (in press).

Zeković, A., Živanović, J., Zdravković, M., Strmbanović, I., Milošević, D., Milić, V., Suzić, I., Kitanović, V., Dukić-Mijucić, O., Sušić, D., Mitić, T., Kotlajić, L., Kovačević, V., Šestak, A., Metodiev, S., Krumov, I., Marton, I., Kunchev, K., Groza, N., Kouzmanov, K., Ivascanu, P., 2026. Mineralization types in the Čoka Rakita deposit, Eastern Serbia. CBGA 2026 abstract book (in press).

Zimmerman, A., Stein, H.J., Hannah, J.L., Koželj, D., Bogdanov, K., Berza, T., 2008. Tectonic configuration of the Apuseni–Banat—Timok–Srednogorie belt, Balkans-South Carpathians, constrained by high precision Re–Os molybdenite ages. Mineralium Deposita, 43, 1–21.

FIELD TRIP 2

FT2. The Cenozoic stratigraphic and paleontological record of the Transylvanian Basin

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INTRODUCTION

The Transylvanian Basin is a relatively large (approx. 20,000 km²; Ciulavu, 1999), post-Cenomanian, Inner Carpathian sedimentary basin, bounded to the north, east, and south by tectonic units of the Carpathians, while to the west, the Apuseni Mountains separates it from the Pannonian Basin (see Fig. 1). Its basement is shared with that of the eastern part of the Pannonian Basin, and consists of folded-thrusted structures formed during the Early/Late Cretaceous (metamorphic units, magmatic and volcanic rocks of oceanic and island-arc origin, as well as Triassic to Cretaceous sedimentary units), collectively known as the Tisza-Dacia Terrane (see Csontos and Vörös, 2004). This basement is locally overlain by a more than 5 km thick sedimentary cover (Krézsek and Bally, 2006), consisting largely (but not exclusively) of terrigenous sediments deposited during the Late Cretaceous–Late Miocene (Huismans et al., 1997).

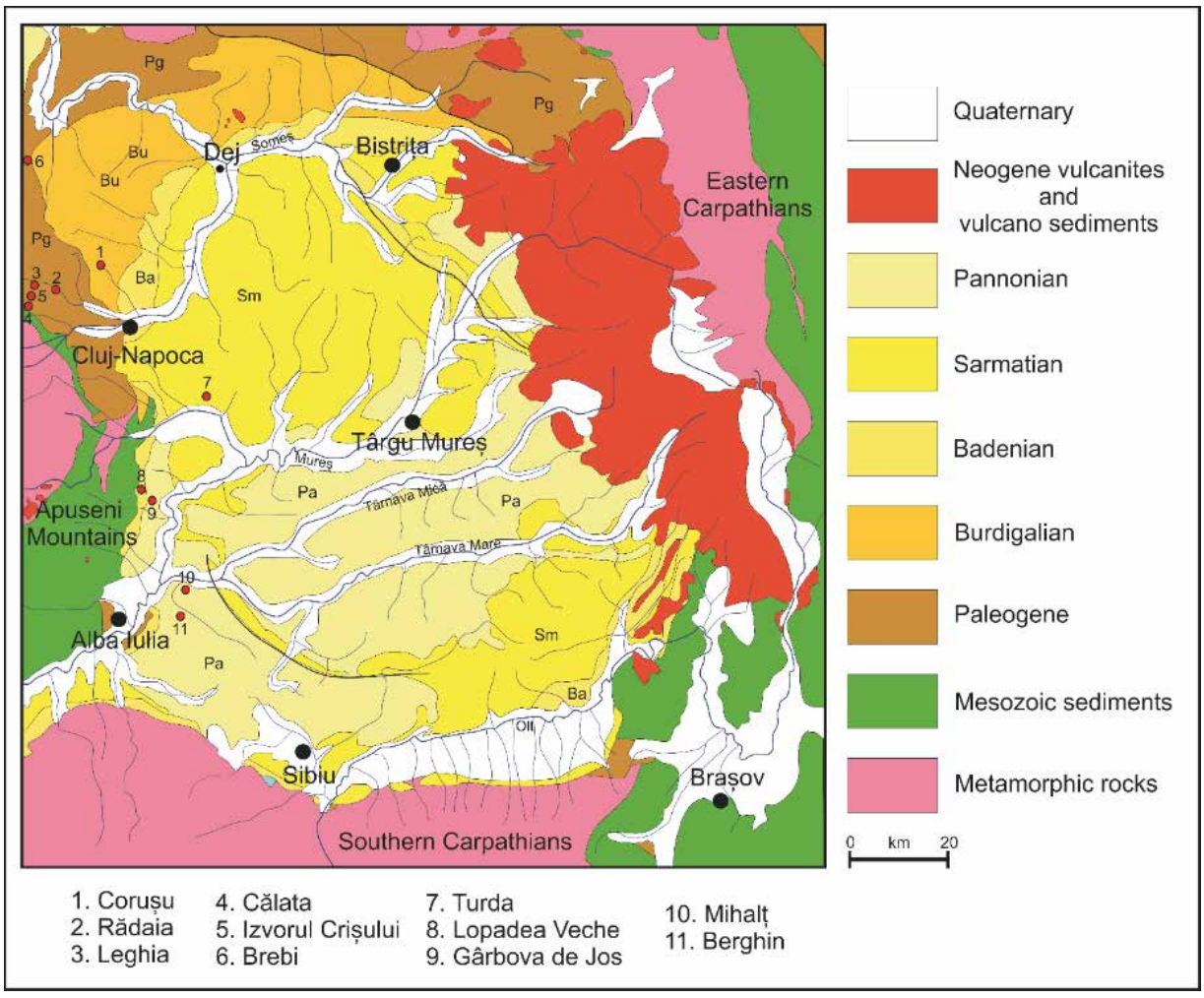


Fig. 1. Simplified geological map of the Transylvanian Basin. Modified after Filipescu (2011) and Kövecsi and Less (2019).

It is a well-known that the Transylvanian Basin exhibits certain distinctive geological and geophysical characteristics when compared to the Pannonian Basin or other inland Carpathian basins of similar age (see Visarion and Veliciu, 1981): a relatively thick continental crust (Răileanu et al., 1994; Visarion and Veliciu, 1981), very low surface heat flux—as low as 30 mWm^{-2} in the central-southern part of the basin and 60 mWm^{-2} at the margins (Demetrescu et al., 2001; Visarion and Veliciu, 1981), and a relatively high average elevation above sea level (Ciulavu, 1999).

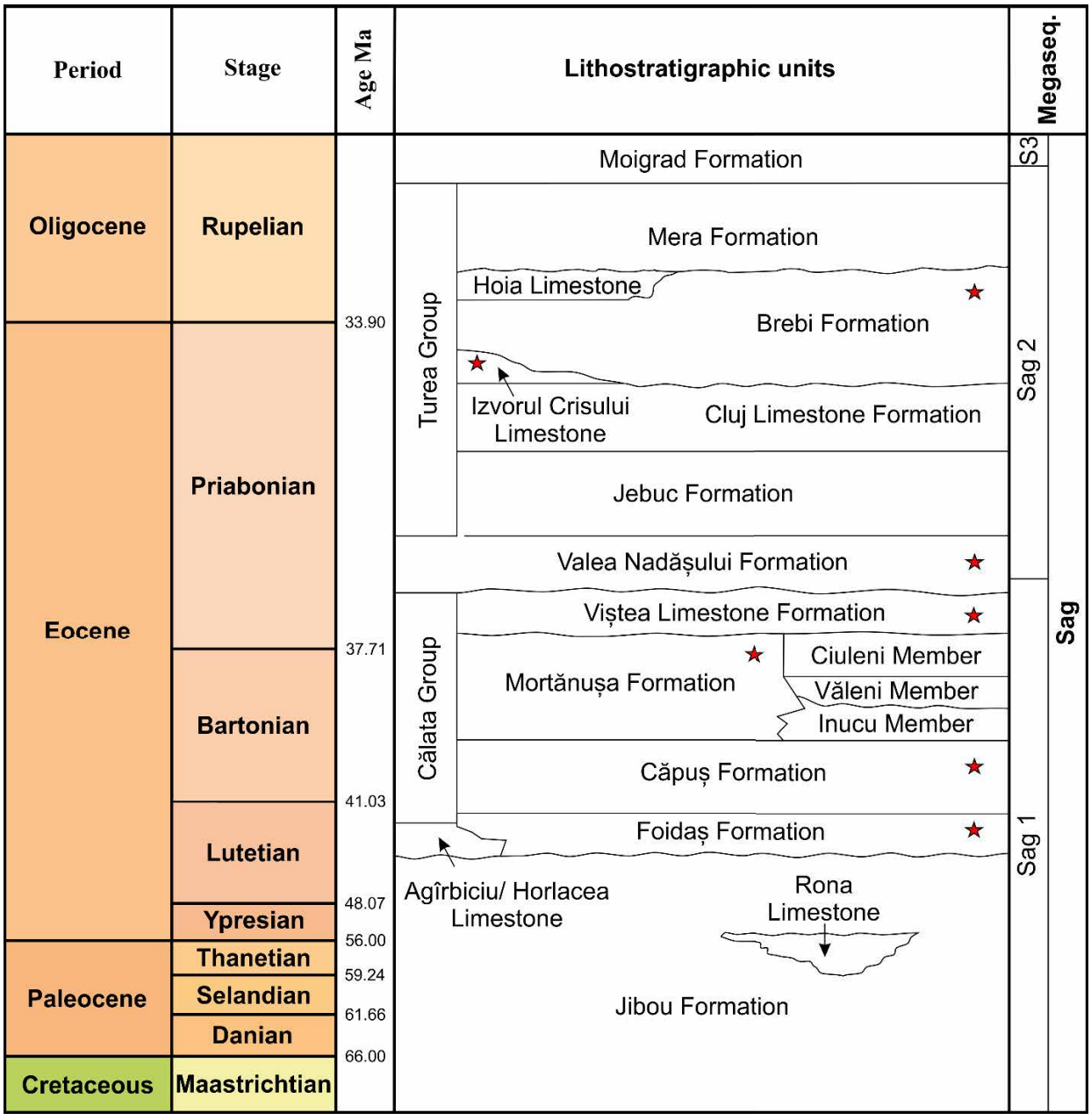


Fig. 2. Paleogene lithostratigraphic units of the northwestern part of the Transylvanian Basin based on Popescu (1984) and Filipescu (2011). The megasequences are based on Krészek and Bally (2006), while absolute ages are based on the International Chronostratigraphic Chart (https://stratigraphy.org/chart/).

At the same time, unlike many inner Carpathian basins, the Transylvanian Basin lacks any evidence of Miocene extension—except for some extensional structures associated with salt tectonics (Krézsek and Filipescu, 2005)—and possesses a significant salt tectonic feature set. The aforementioned characteristics of the Transylvanian Basin are because, while the Inner Carpathian basins typically developed as back-arc basins (characterized by significant extension during the synrift phase, which resulted in the thinning of their crust, while they underwent thermal subsidence during the post-rift phase), the Transylvanian Basin subsided significantly during the Middle and Late Miocene (Crânganu, 1986; Cranganu and Deming, 1996), and from the Late Miocene onward, it was characterized by significant tectonic uplift. At the same time, the Late Miocene history of the basin was significantly influenced by the uplift of the Carpathians and the associated gravitational salt tectonics, which were facilitated by volcanism (Szakács and Krézsek, 2006). This significant subsidence is also responsible for the very thick sedimentary cover of the Transylvanian Basin (Krézsek and Bally, 2006; Krézsek and Filipescu, 2005), which is divided into four major tectonostratigraphic megasequences: (1) Upper Cretaceous (rifting, gravitational subsidence), (2) Paleogene ("sag"), (3) Lower Miocene (flexure), and (4) Middle and Upper Miocene (sequence behind an arc dominated by gravitational tectonics); see Figs. 2 and 3.

This two-day geological field excursion traverses a diverse array of sedimentary formations across the Transylvanian Basin (Figs. 2 and 3), offering a rich glimpse into the region's stratigraphy, paleoenvironments, and paleontological record from the Eocene to the Upper Miocene.

Day 1 begins in Coruşu, showcasing the mollusks-rich Eggenburgian Coruş Formation, followed by Priabonian continental strata at the world-famous Rădaia section (Valea Nadăşului Formation) the type locality of *Prohyracodon orientale* Koch. The journey continues through Leghia's complex Lutetian-Priabonian stratigraphic record (Jebucu, Căpuşu, Mortănuşa, Viştea Limestone formations), then we will visit an impressive Bartonian nummulitic accumulation in Călata (Căpuş Formation). In the second part of the day, we will examine the building stones used in medieval and early modern times in Cluj, the Cluj Limestone, in Izvoru Crişului, and end our journey at the Eocene-Oligocene Transition in Brebi (Brebi Formation).

On Day 2, the focus shifts to the Miocene sedimentary record and the Miocene evolution of the Paratethys starting with the Badenian formations in Turda historical salt mine (Ocna Dejului Formation) and Lopadea Veche (Gârbova de Sus Formation), then progressing through fossil-rich Pannonian sequences in Gârbova de Jos (Lopadea Formation) and Mihalţ (Guşteriţa Formation). The trip concludes in Berghin, where Sarmatian sediments of the Dobârca Formation provide insights into the complexity of the Sarmatian sedimentary record. This itinerary highlights the diversity of the fossil record, the stratigraphic complexity and paleogeographic transitions of the Transylvanian Basin. The location of the deposits and related formations can be observed both on the geological map (Fig. 1) and on the lithostratigraphic schemes related to the Paleogene (Fig. 2) and Neogene (Fig. 3) of the Transylvanian Basin.

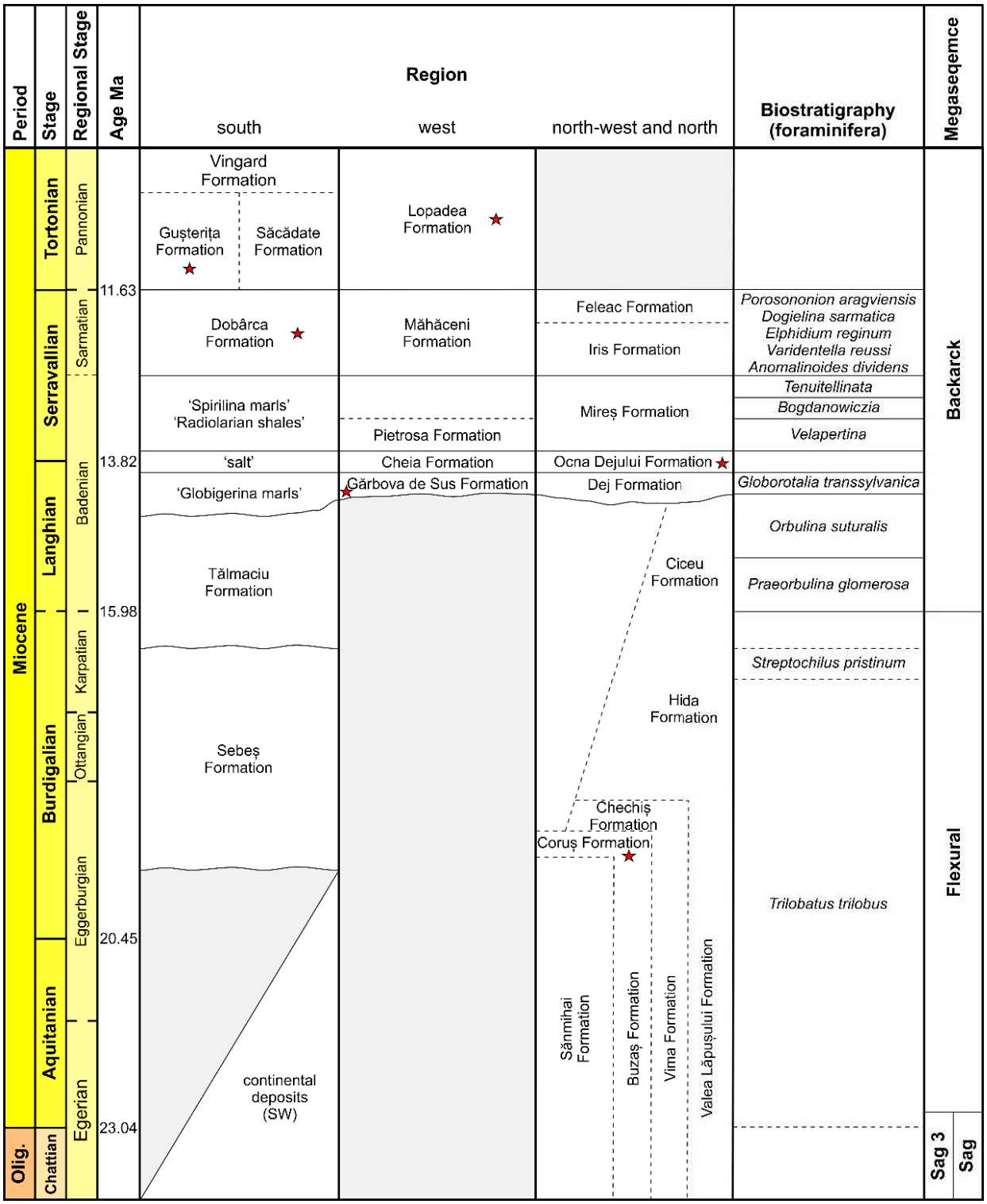


Fig. 3. Neogene lithostratigraphic units of the Transylvanian Basin based on Filipescu et al. (2025). The megasequences are from Krészek and Bally (2006), while absolute ages are based on the latest International Chronostratigraphic Chart (https://stratigraphy.org/chart/).

THE FIELD TRIP

Day 1.

Stop 1. Coruşu (former quarry)

Stratigraphy: Coruș Formation (Lower Miocene).
Location: the former quarry (Fig. 4) is located at the northern exit of Coruşu, near the DJ109V road.



Fig. 4. Overview picture of the former Coruşu quarry.

Description
The Coruș Formation (Hauer and Stache, 1863) is an Early Miocene transgressive marine unit, composed mainly of shoreface and inner shelf sediments. It records the progressive marine flooding of the Transylvanian Basin during the Early Miocene, due to the flexural deepening of the northern parts of the basin caused by the thrusting of the Pienide nappes (Krézsek and Bally, 2006).



Fig. 5. Channel fill with fossil plant remains in the former Coruşu quarry.

The base of the Coruș quarry exposes the continental Valea Almașului Formation and is marked by brown shales containing fossil plants, interpreted as marginal marsh deposits (Mészáros et al., 1976). Above this level, the succession is dominated by sandy deposits formed in beach and shallow storm-influenced paleoenvironments. The outcrop shows an overall fining-upward succession divided into three main intervals: lower interval with cross-bedded pebbly sandstones, coarse-grained laminated sandstones, and discontinuous gravel lags, locally associated with laminated shales and siltstones containing fossil plant fragments (Fig. 5); middle interval with massive to somewhat laminated sandstones alternating with shell-rich lumachelle beds with bivalves and gastropods (sublittoral setting above the storm wave base); upper interval consisting of fine-grained massive sandstones grading upward into horizontally and ripple-laminated siltstones, interpreted as tempestites accumulated below the storm wave base on a sand-rich inner shelf (Filipescu et al., 2009). Overall, the sedimentary succession records a progressive deepening-upward trend, from littoral to sublittoral and finally to inner shelf environments. The Coruș Formation is overlain elsewhere in the basin by the outer shelf marls of the Chechiș Formation (Fig. 3).

The Eggenburgian (Early Miocene) age assignment of the formation is based on the calcareous nannoplankton assemblages, which confirm the NN2 zone (Mészáros, 1991), foraminiferal assemblages, which correspond to the M2 planktonic zone of Berggren et al. (1995), and on the presence of *Oopecten gigas*, an abundant large Pectinidae (see fig. 6) occurring within the formation (Moisescu and Popescu, 1980; Rusu,1989). The locality is also well known for its abundant fossil flora, including *Daphnogene gracilis* and *Smilacophyllum oligocaenicum* (type-locality), and another ~60 additional fossil plant taxa (Givulescu, 1968; 1970). A coal layer identified in the quarry has been interpreted as marking the boundary between the Aquitanian and Burdigalian stages (Givulescu, 1968; 1970).



Fig. 6. Specimens of *Oopecten gigas* (Coruș Formation, Corușu).

Stop 2. Rădaia

Stratigraphy: Valea Nadășului Formation (Priabonian).
Location: on the left bank of the Nadășului River, Rădaia.

Description

This is one of the best-known, and perhaps most beautiful surface exposures of the Valea Nadășului Formation (Fig. 7). The alternation of striking reddish clays and grey sands characterizes the succession, which was first recognized as a stratigraphic unit by Antal Koch (Koch, 1894), but it was formally distinguished as a formation only in 1978 (Popescu, 1978). The maximum thickness of the Valea Nadășului Formation is approximately 55 meters, comprising two clearly separated units: a lower, ~25-meter-thick sandy/sandstone interval, and an overlying ~30-meter-thick reddish clay succession (Hosu, 1999). These two units are interpreted as deposits of a fluvial (primarily floodplain) and a coastal plain (tidal zone) environment (Proust and Hosu, 1996).



Fig. 7. Overview of the Valea Nadășului Formation at Rădaia.

Elek Pávay was the first to describe this site in 1871 (Pávay, 1871a), where he discovered the anterior (front) portion of a lower jaw. Based on his preliminary assessment, he identified it as belonging to an ancient perissodactyl (*Palaeotherium*? sp.) (Pávay, 1871b). The detailed study of this important fossil was carried out by Böckh and Matyasovski (Böckh, 1875), who described the remains as a new genus and species, *Brachydiastematherium transilvanicum*. Until recently, this genus and species were known only from Rădaia, although Koch (1894) also found some of its remains. More recently, a rib fragment and a partial molar were discovered at Morlaca, identified as ?*B. transilvanicum* (Mészáros et al. 2001; Fărcaș, 2011). *B. transilvanicum* is internationally significant: this endemic species belongs to the Brontotheriidae, an extinct family of rhinoceros-like perissodactyls (Mihlbachler, 2008) which became extinct during the Oligocene. Brontotheriids are known primarily from North America, with additional occurrences in Asia. Thus, *Brachydiastematherium* represents a biogeographic link between the Eocene and Oligocene faunas of America and Asia (Főzy and Szente, 2007).

The *Brachydiastematherium* remains discovered by Pávay motivated Antal Koch to begin research at this locality, which led to the first taphonomic observations and determined that the bone remains were deposited after transport, so they are allochthonous (Koch, 1875). Koch persisted, and according to museum inventory records, by 1876 he had found limb bones which, together with other finds (jaw fragments with teeth and limb bones), proved to belong to the partial skeleton of a previously unknown terrestrial vertebrate. Remarkably, 21 years after the description of *B. transilvanicum*, another new genus and species was described from Rădaia: *Prohyracodon orientale* (Koch, 1897). This small animal is one of the earliest known rhinocerotoids (Wood, 1929), likely living in open savanna environments (Codrea, 2000), and represents important evidence of paleobiogeographic connections between Europe and Asia during the Eocene (Uhlig, 2000). The holotype, along with other specimens collected by Koch, is housed in the Museum of Paleontology and Stratigraphy at Babeș–Bolyai University (Săsăran, 2016).

Given these outstanding fossil vertebrates, many researchers have searched for additional remains at the site. However, since Koch's work, only a single fragment of a *Trionyx clavatomarginatus* turtle carapace has been found (Fărcaș, 2011). Therefore, instead of searching for fossils, we turn our attention to the sedimentary features of the exposure, described in great detail by Hosu (1999) and Proust and Hosu (1996, 1997). The following summary is based on these three studies: in the lower half of the exposure, facies of an estuarine and tidal-zone environment can be observed. At the base of the succession, meter-thick, 10–20-meter-wide, medium-grained sandstone bodies with carbonate cement occur, showing large-scale trough and/or planar cross-bedding; however, our field observations suggest smaller-scale cross-lamination. These sandstone bodies represent channel fills, cutting erosively into floodplain deposits. They are covered by 5–10 cm thick sand layers alternating with dark clays, forming thinning-and-thickening layer pairs. The lower part of the succession ends with cyclic alternations of parallel-laminated clays and centimeter-thick medium-grained sands with ripple marks. These facies have been interpreted as a tidal flat dissected by smaller and larger distributary channels. The upper part of the exposure is located above an erosional surface that cuts almost exactly through the middle of the outcrop. It consists of trough-cross-bedded sands, overlain by decimeter-thick coarse-grained sandstones showing large-scale, low-angle parallel cross-bedding. Above these lie finer-grained, thinner sands, often bioturbated and showing hummocky cross-stratification. This succession represents former shoreface bars, beach ridges, and barriers, overlain by finely laminated red clays. Proust and Hosu (1996) argued that a sequence boundary can be placed between the sands and the overlying clays. Newer ongoing research focusing on heavy minerals suggests that these are diverse and can be correlated with distinct source areas (Obbágy et al., 2021).

Stop 3. Leghia

Stratigraphy: Foidaș (Lutetian), Căpuș (middle Bartonian), Mortănușa (late Bartonian-early Priabonian), Vișstea (early Priabonian) formations.

Location: this continuous Lutetian – early Priabonian succession can be studied along the left slope of Leghia valley, at Leghia, Cluj county, northwestern Romania.

Waypoint 1: Foidaș Formation.

Description

The Foidaș Formation represents the basal unit of the Călata Group (Rusu, 1995) and unconformably overlies the continental deposits of the Jibou Formation, dated from the late Maastrichtian to late Lutetian

(Fig. 2). Its upper boundary is considered heterochronous and is placed either above the *Anomia*-bearing dolomites or below the normal-marine, *Anomia*-bearing green marls (Popescu et al., 1978).

The Foidaș Formation displays considerable lithological variability, comprising grey-green clays, thin laminated dolomitic claystones, grey-bluish silty marly limestones, micritic dolomites, limestones, anhydrite, and gypsum beds of variable thickness, due to the facies variation, deposited within a restricted sabkha environment (Popescu et al., 1978).

Fossil assemblages are generally of low diversity and are dominated by small euryhaline mollusks, including *Anomia tenuistriata*, *Natica* sp., *Corbula gallica*, *Lucina bipartita*, *Venerella secunda*, and cardiids. Smaller benthic foraminifera (mainly nonionids and miliolids) are also present, together with rare ostracods and calcareous nannoplankton (Popescu et al., 1978; Mészáros et al., 1987; Rusu, 1995; Filipescu, 2011).

At Leghia outcrop, only the main evaporitic interval of the Foidaș Formation is exposed. The gypsum occurs predominantly as nodular masses and is extensively affected by karstification processes, producing characteristic dissolution features and irregular outcrop geometries (Fig. 8).



Fig. 8. Gypsiferous level at Leghia, with clear evidence of the effect of karstification.

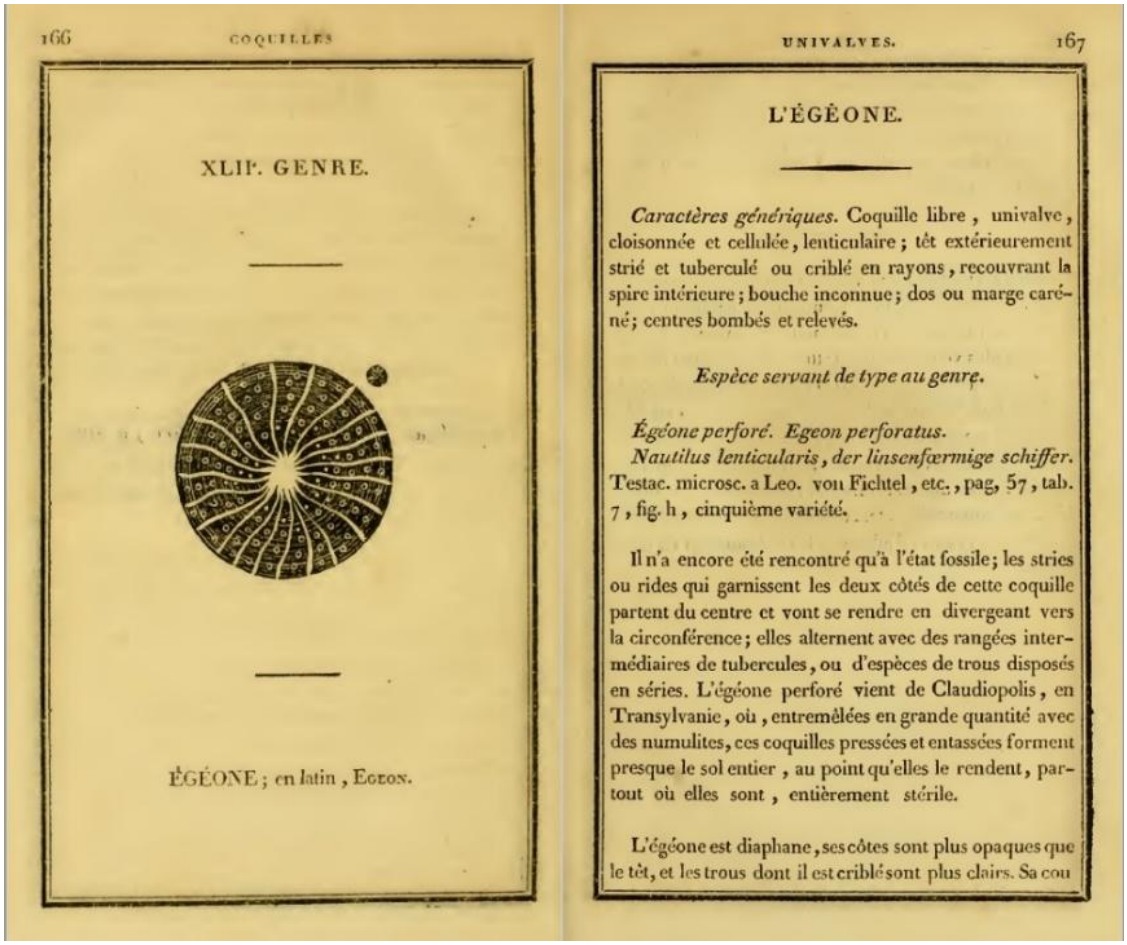
Waypoint 2: Căpuș Formation.

Description

On the right-hand side of the Leghia football field, a small outcrop exposes the Bartonian *Nummulites perforatus* accumulation (Fig. 9). This outcrop is regarded as the type locality of the species originally described by de Montfort (1808) under the name *Egeon perforatus (= Nummulites perforatus)* (Fig. 10). For a detailed description of the formation, see Stop 4.



Fig. 9. Leghia, type locality of the species *Nummulites perforatus* (de'Montfort, 1808).



166 COQUILLES

XLII^e. GENRE.

ÉGÉONE ; en latin, Egeon.

UNIVALVES. 167

L'ÉGÉONE.

Caractères génériques. Coquille libre, univalve, cloisonnée et cellulée, lenticulaire ; têt extérieurement strié et tuberculé ou criblé en rayons, recouvrant la spire intérieure ; bouche inconnue ; dos ou marge caréné ; centres bombés et relevés.

Espèce servant de type au genre.

Égéone perforé. Egeon perforatus.
Nautilus lenticularis, der linsenformige schiffer. Testac. microsc. a Leo. von Fichtel, etc., pag. 57, tab. 7, fig. h, cinquième variété.

Il n'a encore été rencontré qu'à l'état fossile ; les stries ou rides qui garnissent les deux côtés de cette coquille partent du centre et vont se rendre en divergeant vers la circonférence ; elles alternent avec des rangées intermédiaires de tubercules, ou d'espèces de trous disposés en séries. L'égéone perforé vient de Claudiopolis, en Transylvanie, où, entremêlées en grande quantité avec des numulites, ces coquilles pressées et entassées forment presque le sol entier, au point qu'elles le rendent, partout où elles sont, entièrement stérile.

L'égéone est diaphane, ses côtes sont plus opaques que le têt, et les trous dont il est criblé sont plus clairs. Sa cou

Fig. 10. The first description and illustration of the taxa known today as *Nummulites perforatus* (from the monograph of de'Montfort, 1808).

Waypoint 3: Mortănușa Formation.

Description

The Mortănușa Formation is a predominantly silty–pelitic succession situated between the Căpuș Formation and the Viștea Limestone Formation (Popescu, 1984; Rusu, 1995; Filipescu, 2011). Its thickness generally does not exceed 80 m (Popescu, 1978) and it is subdivided into three members: the Inucu, Văleni, and Ciuleni members (Rusu et al., 2004; Filipescu, 2011) (Fig. 2).

The Inucu Member consists mainly of fossiliferous marls containing diverse assemblages of foraminifera, mollusks, and echinoids. In its upper part, a distinctive *Ostrea bersonensis* horizon has been recognized and is regarded as an important regional marker bed (Rusu, 1987; Rusu et al., 2004). Sedimentological and palaeontological evidence indicates deposition in an open-marine shelf environment under normal marine salinity conditions (Rusu et al., 2004). Calcareous nannoplankton assemblages assigned to the NP16 Zone indicate a Bartonian age for this member (Gheța, 1984; Mészáros, 1992; Rusu et al., 2004).

The Văleni Limestone Member, formerly known as the "*Velates* Limestone", is a calcareous unit dominated by bioclastic and arenitic limestones. Its thickness is variable but rarely exceeds 8 m (Rusu, 1987). Fossil assemblages include benthic foraminifera, bivalves, gastropods, and echinoids, suggesting deposition in a shallow inner-shelf setting. Calcareous nannoplankton assemblages are characteristic of the NP16 Zone, thus indicating a Bartonian age (Rusu et al., 2004).



Fig. 11. General view of the deposits belonging to the Ciuleni member at Leghia.

The Ciuleni Member forms the uppermost subdivision of the Mortănușa Formation and reaches a maximum thickness of approximately 45 m. It consists mainly of greenish-grey clays and clay-marls that become progressively sandier towards the top of the succession (Rusu, 1995; Rusu et al., 2004). The member contains diverse fossil assemblages, including foraminifera, ostracods, and mollusks (Rusu, 1995; Rusu et al., 2004; Trif et al., 2022). A distinctive *Crassostrea orientalis* horizon occurs in its upper part and is considered a regionally significant marker bed (Rusu, 1995). From the uppermost Bartonian strata of the Ciuleni Member, Trif et al. (2022) described a diverse fossil fish fauna comprising 21 species belonging to

20 genera and 12 orders. Based on microfossil and fish-faunal evidence, the depositional environment is interpreted as a shallow tropical marine setting at water depths of approximately 40–60 m (Trif et al., 2022). Calcareous nannoplankton assemblages assigned to zones NP16–NP18 indicate a middle Bartonian to early Rupelian age for this member (Gheța, 1984; Mészáros et al., 1987; Rusu et al., 2004; Trif et al., 2022).

At Leghia, only the Ciuleni Member is exposed. The outcrop provides excellent exposures of the characteristic clay-marl succession, as well as the distinctive *Crassostrea orientalis* horizon (Fig. 11), allowing direct observation of one of the most important regional marker levels within the Mortănușa Formation.

Waypoint 4: Vișstea Limestone Formation (=Leghia Limestone)
Description

The Vișstea Limestone Formation (also referred to as the Leghia Limestone) constitutes the uppermost unit of the Călata Group (Fig. 2). It is represented by a carbonate succession composed of two bioclastic limestone intervals separated by a marly intercalation (Popescu et al., 1978; Popescu, 1984; Mészáros et al., 1987). The formation reaches a maximum thickness of approximately 8 m and was deposited in a shallow-marine environment (Rusu, 1995; Filipescu, 2011; Trif et al., 2024).

The fossil assemblages are diverse and include small and larger benthic foraminifera, coralline red algae, mollusks, echinoids, and balanid barnacles (Bombiță, 1984; Rusu, 1995; Filipescu, 2011). In addition, the formation has yielded significant vertebrate remains, including fish and crocodilian fossils (Sabău et al., 2021; Trif et al., 2024). The occurrence of larger benthic foraminifera such as *Nummulites fabianii* and *Alveolina elongata* indicates a Priabonian age for the formation (Bombiță, 1984).

The field stop is located within an abandoned limestone quarry at Leghia, where up to 2.5 m of bioclastic grainstones are exposed (Trif et al., 2024) (Fig. 12). The lower and middle parts of the succession are characterized by abundant benthic foraminifera, dominated by alveolinids and miliolids, together with rare rotaliids, echinoid plates and spines, bivalve fragments, and occasional coralline algae. These components form a well-developed bioclastic grainstone fabric.



Fig. 12. Leghia limestone, in the old abandoned quarry. Photo: Máriusz Kiss.

Up-section, the succession displays a clear coarsening-upward trend marked by an increasing abundance of bivalve shells and echinoid fragments. As a result, the carbonate deposits evolve from grainstone into grainstone–rudstone facies (Fig. 13). The uppermost part of the section contains less diverse and less abundant benthic foraminiferal assemblages, which are represented predominantly by miliolids (Trif et al., 2024).

Besides its rich invertebrate assemblages, the Leghia quarry is also notable for its vertebrate fossil record. Sabău et al. (2021) reported a pair of fused dentaries and a partial right mandibular fragment attributed to the extinct crocodilian genus *Diplocynodon*. Furthermore, Trif et al. (2024) documented a diverse fossil fish fauna including representatives of two orders of elasmobranchs (Lamniformes and Carcharhiniformes), one order of batoids (Myliobatiformes), and three orders of actinopterygians (Istiophoriformes, Perciformes, and Tetraodontiformes).

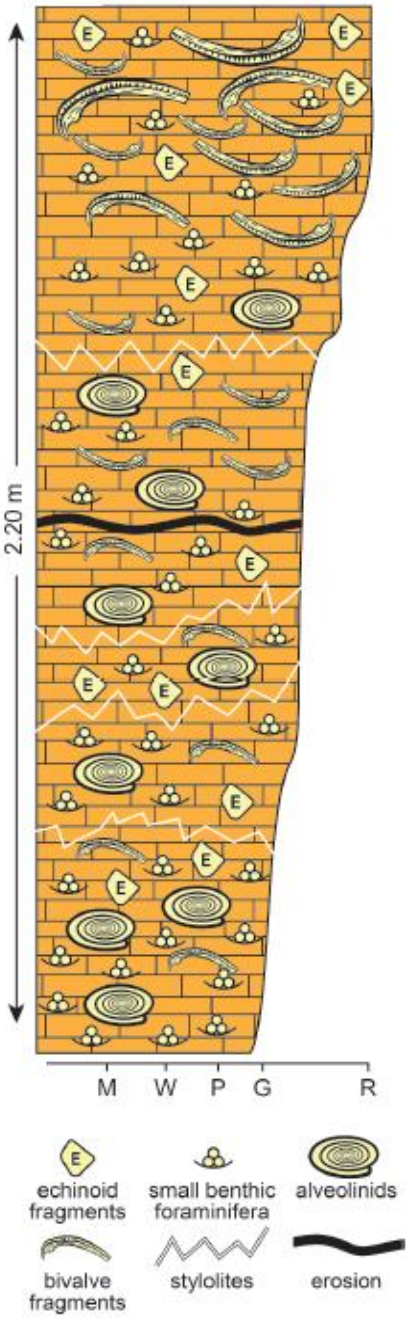


Fig. 13. Sedimentary log of the carbonate succession in the Leghia old abandoned quarry (taken from Trif et al., 2024).

Stop 4. Călata

Stratigraphy: Căpuș Formation (Bartonian).
Location: the studied lithological succession is exposed along the Călata River, between Călata and Călățele villages, in Cluj County, northwestern Romania.



Fig. 14. *Nummulites perforatus* accumulation at the left bank of the Călata River.

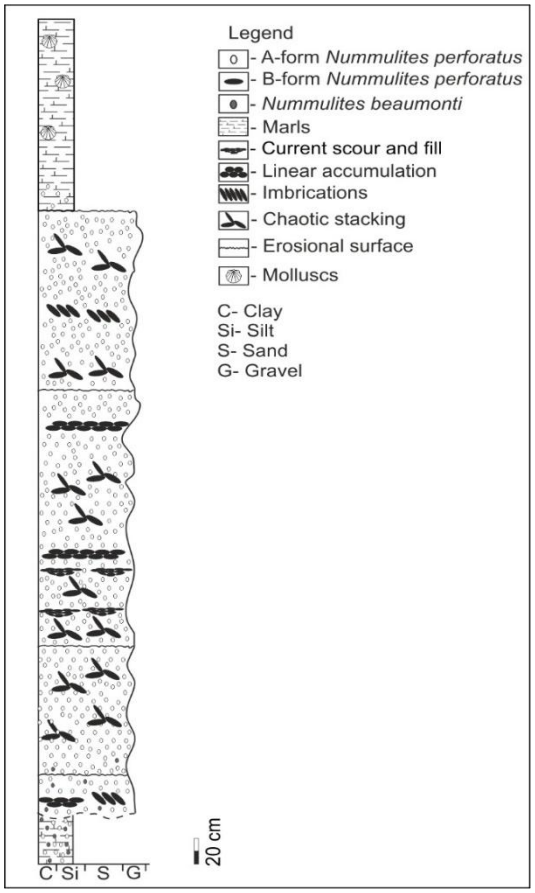


Fig. 15. Lithological log of the section from the Călata River (Szász-Csontos, 2023).

Description

The studied sedimentary succession is exposed in the northwestern Transylvanian Basin and belongs to the upper Lutetian-Bartonian Căpuș Formation (Figs. 14 and 15), a lithostratigraphic unit of the Paleogene Călata Group (Fig. 2) (Popescu, 1978; Popescu et al., 1987; Filipescu, 2011). The Căpuș Formation is approximately 25 m thick and consists predominantly of shallow-marine siliciclastic and carbonate deposits rich in benthic fossil assemblages (larger benthic foraminifera – *Nummulites*). Three main biohorizons have been recognized within the formation: the *Pycnodonte brongniarti* level, the *Sokolowia eszterhazyi* horizon, and the upper *Nummulites perforatus* accumulation. The latter, 2-10 m thick, is laterally extensive across the northwestern Transylvanian Basin and is dominated by *N. perforatus*, with rare *Nummulites beaumonti* (Rusu, 1987; Rusu et al., 2004) (Fig. 16). The nummulitic accumulations of the Transylvanian Basin consist of predominantly autochthonous to para-autochthonous *Nummulites* assemblages deposited on a low-gradient inner shelf between the fair-weather and storm wave bases (Kövecsi et al., 2016; Pleș et al., 2020; Kövecsi et al. 2022). Their development was controlled by the interaction of biotic factors, particularly the ecological preferences of *Nummulites* species, and abiotic factors, including relative sea-level changes, low siliciclastic input, and climatic conditions (Kövecsi et al., 2016, 2022). The distribution of monospecific and bispecific assemblages reflects environmental stability across the shelf: monospecific assemblages

characterize the most stable settings, while bispecific assemblages occur in shallower or deeper, less stable environments, where one species dominates according to its ecological adaptation.

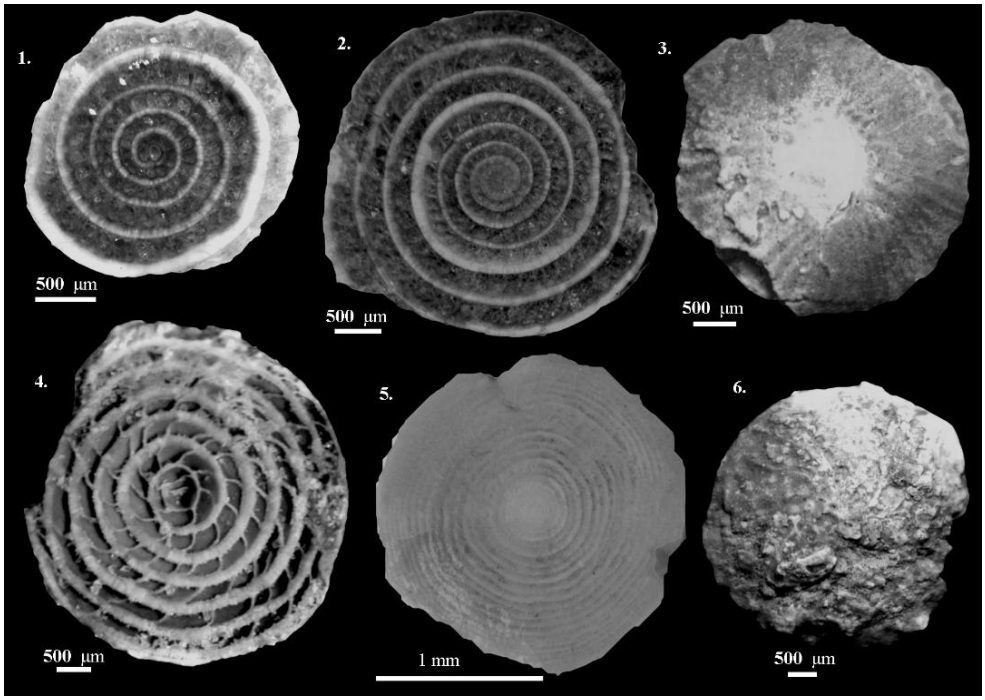


Fig. 16. Photomicrographs of the *Nummulites* specimens from the Căpuşu Formation (Szász-Csontos, 2023). 1. *Nummulites beaumonti* (de Archiac & Haime) A form; 2. *Nummulites beaumonti* (de Archiac & Haime) B form; 3. *Nummulites beaumonti* (de Archiac & Haime) B form; 4. *Nummulites perforatus* (de Montfort) A form; 5. *Nummulites perforatus* (de Montfort) B form; 6. *Nummulites perforatus* (de Montfort) A form.

In addition to the larger benthic foraminifera, the nummulitic accumulation contains diverse microfossil assemblages (Fig. 17) that provide valuable paleoenvironmental information (Bindiu-Haitonic et al., 2021): five calcareous nannoplankton assemblages (*Reticulofenestra dictyoda-R. umbilica*, *R. umbilica*, *R. minuta*, *Zygrablithus-Neococcolithes*, and *Blackites-Ericsonia*) and four benthic foraminiferal assemblages (*Pararotalia subinermis*, *P. byramensis*, *Cibicides*, and *Protelphidium-Nonion*). The nummulitic accumulation is Bartonian in age based on integrated biostratigraphic evidence (Kövecsi et al., 2016, 2022; Bindiu-Haitonic et al., 2021): the larger benthic foraminiferal assemblage correlates with Shallow Benthic Zone (SBZ) 17 of Serra-Kiel et al. (1998), the calcareous nannoplankton assemblages correspond to the regional *Reticulofenestra bisecta* Zone and the standard NP17/CP14 biozones (Martini, 1971; Okada and Bukry, 1980), and the smaller benthic foraminifera correlates with the *Pararotalia subinermis* Interval Zone (Rusu et al., 2004).

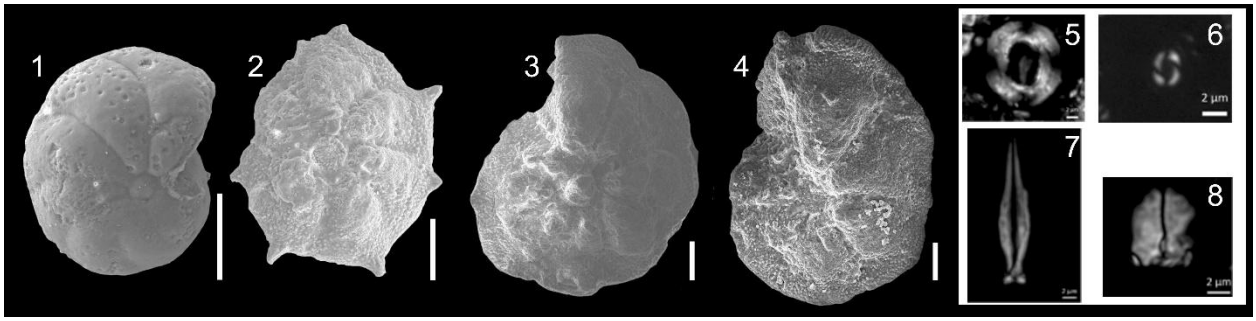


Fig. 17. Microfossils from the nummulitic accumulation (Bindiu-Haitonic et al., 2021). 1-4. Smaller benthic foraminifera (scale bar 200 µm). 1. *Lobatula lobatula*; 2. *Pararotalia byramensis*; 3. *Pararotalia subinermis*; 4. *Pararotalia inermis*; 5-8. Calcareous nannofossils (scale bar 2µm). 5. *Reticulofenestra dictyoda*; 6. *Reticulofenestra minuta*; 7. *Blackites inflatus*; 8. *Zygrablithus bijugatus*.

Stop 5. Izvorul Crișului

Stratigraphy: Izvorul Crișului Limestone (late Priabonian).
Location: southern part of Izvorul Crișului locality.

Description

The Izvorul Crișului Limestone is a lateral facies variant of the Cluj Limestone Formation and consists predominantly of skeletal wackestones to packstones containing a significant proportion of terrigenous material, mainly clay and quartz grains (Popescu et al., 1978). The unit was deposited in a carbonate ramp setting (Kovács, 2005) and occupies a stratigraphic position between the Jebucu Formation below and the Brebi Formation above (Fig. 2).

Several distinctive biohorizons have been recognized within the succession. Approximately 3–4 m above the lower boundary of the formation occurs the *Crassostrea transilvanica* horizon. Higher in the sequence, the *Vulsella*, *Campanile*, and echinoid biohorizons can be identified, while the upper boundary of the formation is marked by the *Nummulites fabianii* horizon (Popescu et al., 1978; Filipescu, 2011).

In the Izvorul Crișului area, Popescu et al. (1978) distinguished a reefal limestone unit termed the Izvorul Crișului Limestone, representing a lateral facies variation of the Cluj Limestone Formation. These facies consist mainly of calcarenites and calcirudites rich in corals, coralline algae, *Nummulites*, rotaliids, and rare molluscs. Toward the north, in a more basinward setting, these reefal limestones gradually pass laterally into deposits of the Brebi Formation (Popescu, 1984).

Calcareous nannoplankton assemblages described by Mészáros (1991) indicate an NP20 biozone age, while the *Nummulites fabianii* assemblage corresponds to the SBZ 20 Shallow Benthic Zone of Serra-Kiel et al. (1998). Together, these biostratigraphic data assign a late Priabonian (Late Eocene) age to the Cluj Limestone Formation.

The limestone succession around Izvorul Crișului hosts a well-developed karst system displaying a wide range of karstic landforms and processes. Numerous caves, dolines, and karst springs occur throughout the area. The two largest caves are Szala Stream Cave (Hungarian: Szala-pataka) and “Prist’s Hole” Cave (Hungarian: Pap-lyuka) (Fig. 18). The former has an explored length of approximately 550 m, whereas the latter reaches 210 m in total length (Mátyás and Imecs, 2008). A notable hydrogeological feature of the area is the spring of the Crișul Repede River, located southeast of Izvorul Crișului.



Fig. 18. Izvorul Crișului Limestone (Cluj Limestone Formation) at Izvorul Crișului, and the entrance of “Priest-Hole” cave.

Stop 6. Brebi

Stratigraphy: Brebi Formation (late Priabonian-early Rupelian).
Location: The exposure is located on the side of the DJ191C road, near Brebi locality (Sălaj county).



Fig. 19. Overview of the Brebi section.

Description

The succession (Fig. 19) belongs to the Brebi Formation, a 50-70 m thick marl-dominated unit deposited in offshore marine conditions during the second transgressive–regressive cycle of the Paleogene sag-basin evolution of the Transylvanian Basin (Popescu, 1984). The formation spans the late Priabonian-early Rupelian and records the Eocene-Oligocene Transition (Bombiță and Rusu, 1981; Krézsek and Bally, 2006). It consists predominantly of homogeneous marls with minor clayey limestone intercalations and an important interval rich in the large ostreid *Pycnodonte gigantica* in its upper part (Fig. 20) (Bombiță and Rusu, 1981; Popescu et al., 1978; Rusu et al., 1993).

Although the precise position of the Eocene-Oligocene boundary remains debated, integrated biostratigraphic studies based on planktonic foraminifera, calcareous nannoplankton, ostracods, dinoflagellates, and mollusks place the boundary within the formation (Iva and Rusu, 1982; Rusu et al., 1993; Kicsi et al., 2026). The succession also records major paleoenvironmental changes associated with the Eocene-Oligocene Transition, including cooling, enhanced terrigenous input, and a decrease in marine salinity, reflecting the regional response to global climatic and oceanographic changes. The most recent investigation of the Brebi section by Kicsi et al. (2026) integrates high-resolution benthic foraminiferal assemblages dominated by *Heterolepa eocaenica*, *Neoeponides schreibersii*, *Lobatula lobatula* and *Gyroidinoides soldanii* (Fig. 21), stable isotope geochemistry, cyclostratigraphy, and revised calcareous nannoplankton and planktonic foraminiferal biostratigraphy to refine the record of the Eocene-Oligocene Transition. Based on the aforementioned results, the Eocene-Oligocene boundary is placed at 15.3 meters within the section. The succession records approximately 1.7-2.1 Myr of deposition and is divided into three main phases, with Phase 2 representing the interval of greatest environmental perturbation around the boundary. The multiproxy dataset indicates that the Brebi section captures major paleoenvironmental changes associated with the Eocene-Oligocene Transition, including fluctuations in $\delta^{13}C$ and $\delta^{18}O$ isotope values, variations in sedimentation rate, and subtle but significant changes in benthic foraminiferal assemblages.



Fig. 20. The interval rich in the large ostreid *Pycnodonte gigantica* from the Brebi section.

Although no major taxonomic turnover was observed, multivariate analyses reveal shifts in community composition related to changes in oxygenation, nutrient availability, salinity, water depth, and temperature. These results demonstrate that the environmental evolution of the Transylvanian Basin during the Eocene-Oligocene Transition reflects the combined influence of global climatic changes and regional palaeoceanographic conditions within the semirestricted Central Paratethys.

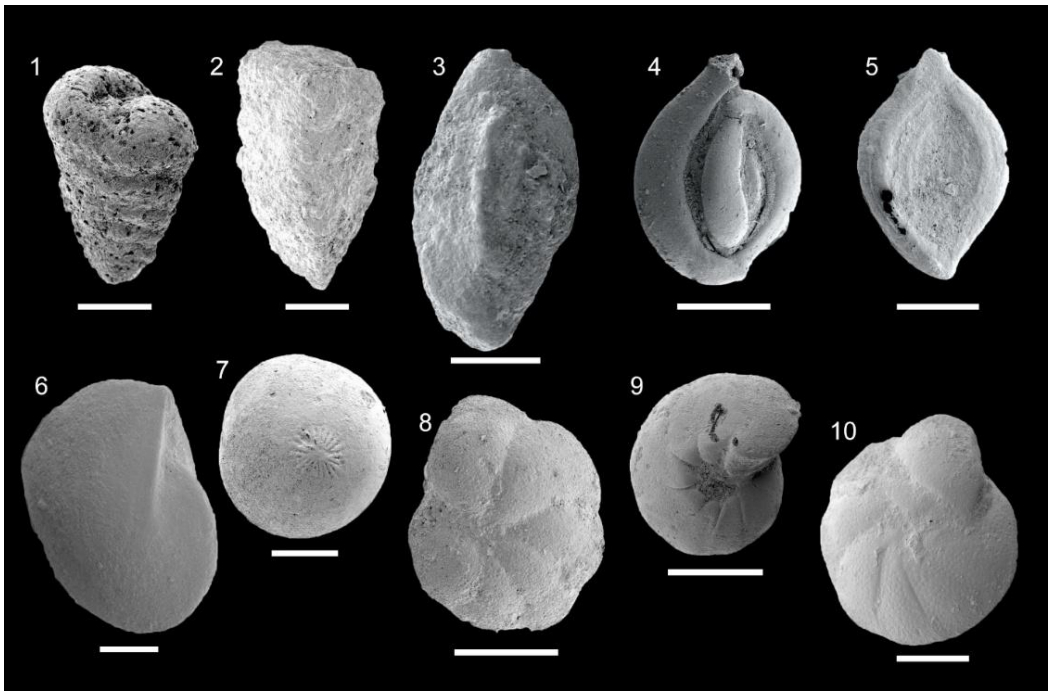


Fig. 21. Smaller benthic foraminifera from the Brebi Section (Kicsi et al., 2026) (scale bar 500 μm). 1. *Textularia agglutinans*; 2. *Pseudogaudryina schmitti*; 3. *Cycloforina* sp.; 4. *Quinqueloculina* sp.; 5. *Spiroloculina jarvisi*; 6. *Lenticulina inornata*; 7. *Globulina gibba*; 8. *Lobatula lobatula*; 9. *Gyroidinoides soldanii*; 10. *Heterolepa eocaena*.

Day 2.

Stop 1. Turda

Stratigraphy: Ocna Dejului Formation (Badenian).
Location: historical salt mine northern of Turda.

Description

The deposition of the salt in the Transylvanian Basin was related to a relative sea level fall by Krézsek and Filipescu (2005). According to them, the original thickness of the salt layer was about 300 m; however, its current thickness and distribution were controlled by post-depositional salt tectonics. The salt diapirs form two, roughly north–south oriented lineaments, one at the western and another one at the eastern borders of the Transylvanian Basin (Ciupagea et al., 1970). The western lineament was produced by the salt extrusions related to the late Mid-Miocene (late Sarmatian) to Pliocene thrust systems, whilst the eastern one by Pliocene gravitational gliding processes (Szakács and Krézsek, 2006). The evaporite observable in the mine is characterized by the alternation of white and dark, intensely folded evaporite layers and clay-rich beds. Locally, clay clasts occur in great number, indicating that the basin was periodically affected by turbiditic currents. The folding of the evaporite succession is associated with recurrent shear zones.

The existence of salt at Turda was known already by the Romans (hence the Latin name *Potaissa* of Turda), who mined it in open-pit and shallow-depth mines. However, the first mention of the salt mines at Turda appeared in the deed of gift "*Ultra silvam ad castrum, quod vocatur Turda, dedi tributum salinarum in loco, qui dicitur hungarice Aranas*", edited by the Hungarian king Géza I, in 1075. At least since then the salt was continuously mined until 1932, when, because of economic reasons, the mining activities were stopped (Bicsok, 2001). The main attractions of this salt mine are: 1) the 917 m long Franz Jozef transportation gallery, mainly excavated in 1853-1870; 2) the bell-shaped Theresia Mine (Fig. 22), built between 1690-1853; 3) the trapezoid-shaped, 40 m high, 80 m long Rudolf Mine; 4) the extraction well room, Rudolf Mine.



Fig. 22. The ceiling of the Theresia Mine. Please observe the folded white and dark salt layer couplets.

Stop 2. Lopadea Veche

Stratigraphy: Gârbova de Sus Formation (Badenian).
Location: south-west of Lopadea Veche along Buhii creek.

Description

Overlying mainly Jurassic substratum, the Badenian sedimentary record of the western edge of the Transylvanian Basin is represented by marine deposits. The early Badenian Leithakalk-like Gârbova de Sus Formation transgressively overlies the so-called ophiolitic complex of the Trascău Mountains. The Gârbova de Sus Formation is distributed over 40 km along the edge of the basin margin, and has a maximum thickness of 35–40 m. The sedimentation corresponds to a littoral algal-rich carbonate platform with coral build-ups and algal material, influenced by detrital contributions. These build-ups clearly underline a retrograding sequence. The coral assemblage is dominated by Faviidae and *Porites* colonies, and five different types of coral build-ups without any zonation can be distinguished. Their unusual extent and palaeogeographical position testify to the generalization of subtropical conditions and the complexity of the marine connections in the Paratethian area during the Badenian (Saint Martin et al., 2007).

The sedimentary record exposed at Lopadea Veche consists of mixed carbonate-siliciclastic sedimentary packages (Fig. 23) of about 30 m thick that transgressively overlie the Jurassic ophiolites of Trascău Mountains starting with a basal conglomerate. The exposure is highly fossiliferous e.g. red algae (Chelaru and Bucur, 2016), foraminiferal-assemblages (Filipescu and Gîrbacea, 1997), coral-buildups (Saint-Martin et al., 2007) or bryozoans (Zágoršek et al., 2010) are known from this locality, therefore the stratigraphy and paleoenvironmental of Gârbova de Sus Formation can be well constrained (Hosu and Filipescu, 1995; Filipescu, 1996).



Fig. 23. Details of the Gârbova de Sus Formation at Lopadea Veche.

Stop 3. Gârbova de Jos

Stratigraphy: Lopadea Formation (Pannonian).
Location: north-west of Gârbova de Jos, on the right bank of the Gârbova creek.

Description

The Gârbova de Jos outcrop exposes a coarse, gravity-flow–dominated succession composed of clast-supported conglomerates, massive to laminated sandstones, and shales with sharp lower boundaries. Conglomerates (up to 1 m thick) display erosional bases, fining-upward pebble–boulder packages, and locally chaotic textures with deformed shale and sandstone fragments, indicating debris-flow deposition and slumping. Beds are 1−50 cm thick. Poor normal grading and plane- to cross lamination can be observed. Clast size occasionally up to 50 cm in diameter, often covered by horizontally laminated, deformed mudstone layers. These units commonly grade into coarse, massive sandstones that fine upward into horizontal lamination, representing low-density turbidites. The overlying shales form abrupt, planar caps and record suspension fallout, not part of the turbidite flow sequence. Shallow-water mollusk fragments within sandstones and shales point to nearby sediment sources and reworking during transport (Kovács et al., 2016; Filipescu et al., 2009). These facies are products of sandy-silty and gravelly-sandy turbidity currents, and debris flows of a proximal submarine fan composed of stacked channels, interpreted as deep-water continuation of fan-deltas entering Lake Pannon. The abundance of erosional surfaces, channel forms, debris-flow textures, and slumps supports this high-energy interpretation.



Fig. 24. Lopadea Formation exposed at Gârbova de Jos.

Fossil assemblages along the Gârbova valley, including *Congeria banatica*, ostracods (*Amplocypris* sp., *Candona (Typhlocypris)* sp., *Candona (Propontoniella)* sp. and *Hemicytheria folliculosa*), gastropods, and bivalves, place the succession within the *Congeria banatica* Biozone (Lubenescu and Lubenescu, 1977) and *Hemicytheria tenustriata* Biozone (Kristić, 1985), hence Slavonian (Zone B). These taxa further indicate deep-water lake conditions, typically >50–100 m, consistent with the inferred fan-toe to basin-floor setting (Kovács et al., 2016).

Stop 4. Mihalț

Stratigraphy: Gușterița Formation (Pannonian).
Location: north of Mihalț, on the left bank of the Mureș River.
Description
The sedimentary record exposed at Mihalț consists of decimeter- to meter-thick massive or laminated gray colored marl or calcareous marlstone, with fossil mollusks (Fig. 25). The most common mollusks are various thin-shelled deep-water species like *Paradacna* cf. *lenzi*, *Congeria banatica*, *Congeria* sp., *Micromelania* sp, *Undulotheca nobilis,* and *Velutinopsis velutina* (Botka and Magyar, 2026; Kovács et al., 2016). The ostracods known from this site belong to different indeterminate species of Paratethyan Candoninae, and *Loxoconcha rhombovalis*, *Hemicytheria folliculosa,* and *Amnicythere miscere* reworked from the shallower (littoral or sub-littoral) settings (Kovács et al., 2016). The fauna places the exposed sedimentary record within the *Hemicytheria tenustriata* Biozone (Kristić, 1985), and indicates a deep-water environment. The profundal zone in Lake Pannon is supposed to have extended from 50-100 m down to the bottom of the lake.



Fig. 25. Gușterița Formation exposed at Mihalț.

Stop 5. Berghin

Stratigraphy: Dobârca Formation (Sarmatian).
Location: on the side DJ107 road, south-west of Berghin.

Description
The outcrop consists of an alternation of decimeter-thick beds of massive, planar; -and cross-laminated, weakly cemented, porous sandstone; matrix-supported, polymictic, poorly sorted, moderately rounded, inversely graded, and imbricated conglomerate, together with centimeter-thick thinly laminated claystone

layers (Fig. 26). Flame structures are observable within the claystone beds (Fig. 27). Based on these sedimentological characteristics, Krézsek et al. (2010) interpreted the facies observable at this location as the result of rapidly recurring depositional events in a shallow depositional environment.



Fig. 26. Overall view of the outcrop at Berghin.



Fig. 27. Details of the outcrop at Berghin. Note the flame structures "injected" into the conglomerate.

REFERENCES

Berggren, W.A., Kent, D.V., Swisher, C.C.I., Aubry, M.-P., 1995. A revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V., Aubry, M.-P., Hardenbol, J. (eds.) Geochronology, Time Scales and Global Stratigraphic Correlation: Unified Temporal Framework for an Historical Geology. SEPM Special Publications, v. 54, p. 129–212, Tulsa.

Bicsok, Z., 2001. Torda város története és statútuma, Csipkés Elek kézirata 1823-ból. Erdélyi Tudományos Füzetek 229, 1–71.

Bindiu-Haitonic, R., Bălc, R., Kövecsi, S.-A., Pleș, G., Silye, L., 2021. In the shadow of giants: Calcareous nannoplankton and smaller benthic foraminifera from an Eocene nummulitic accumulation (Transylvanian Basin, Romania). Marine Micropaleontology 165, art. no. 101988.

Böckh, J., 1875. *Brachydiastematherium transilvanicum* Bkh et Máty. Egy új Pachyderma-nem Erdély eocaen rétegeiből. A Magyar Királyi Földtani Intézet évkönyve 4, 2, 83–102.

Bombiță, G., 1984. Le Napocien, vingt ans après sa définition. Revue de Paléobiologie 3, 2, 209–217.

Bombiță, G., Rusu, A., 1981. New data on the Eocene/Oligocene boundary in the Romanian Carpathians. Palaeogeography, Palaeoclimatology, Palaeoecology 36, 3–4, 213–222.

Botka, D., Magyar, I., 2026. Deep-water lymnaeid gastropods (Hygrophila) of Lake Pannon (Late Miocene, Central Europe): taxonomy and biostratigraphic significance. ZooKeys 1282, 75–138.

Bucur, I.I., and Filipescu, S., 2011. Middle Miocene red algae from Lopadea Veche (Western border of the Transylvanian Basin). In: Calcareous algae from Romanian Carpathians, Field Trip Guidebook, 10th International Symposium on Fossil Algae, Cluj Napoca, Romania, p. 115-122, Cluj University Press.

Chelaru, R., and Bucur, I.I., 2016. The taxonomy of middle Miocene red algae from the Gârbova de Sus Formation (Transylvanian Basin, Romania). Carnets de Géologie 16, 11, 307–336.

Ciulavu, D., 1999. Tertiary tectonics of the Transylvanian Basin, PhD thesis, Vrije Universiteit, 152 pp.

Ciupagea, D., Paucă, M., and Ichim, T., 1970. Geologia Depresiunii Transilvaniei, Bucureşti, Editura Academiei RSR, 256 pp.

Codrea, V., 2000. Rinoceri și Tapiri Terțiari din România. Presa Universitară Clujeană, Cluj-Napoca, 174 pp.

Crânganu, C., 1986. L'estimation quantitative de la subsidence des bassins sédimentaires. Considérations sur le bassin de la Transylvanie. Revue Roumaine de Géologie, Géophysique et Géographie. Géophysique 30, 37–44.

Cranganu, C., and Deming, D., 1996. Heat flow and hydrocarbon generation in the Transylvanian Basin, Romania. AAPG Bulletin 80, 10, 1641–1653.

Csontos, L., and Vörös, A., 2004. Mesozoic plate tectonic reconstruction of the Carpathian region: Palaeogeography, Palaeoclimatology, Palaeoecology 210, 1, 1–56.

Demetrescu, C., Nielsen, S. B., Ene, M., Şerban, D. Z., Polonic, G., Andreescu, M., Pop, A., and Balling, N., 2001. Lithosphere thermal structure and evolution of the Transylvanian Depression — insights from new geothermal measurements and modelling results. Physics of the Earth and Planetary Interiors 126, 3-4, 249–267.

Fărcaş, C., 2011. Studiul formaţiunilor continentale eocen terminale şi oligocen timpurii din NV-ul Depresiunii Transilvaniei – biostratigrafie şi reconstituiri paleoambinetale, pe baza asociaţiilor de vertebrate continentale, PhD Thesis, Universitatea Babeş–Bolyai, Facultatea de Știința Mediului, Cluj-Napoca, 49 pp.

Filipescu, S., 1996. Stratigraphy of the Neogene from the western border of the Transylvanian Basin. Studia Universitatis Babeş-Bolyai, Geologia 41, 2, 3–78.

Filipescu, S., 2011. Cenozoic lithostratigraphic units in Transylvania. In: Bucur, I.I., Săsăran, E. (Eds.), Calcareous Algae from Romanian Carpathians. Presa Universitară Clujeană, Cluj-Napoca, pp. 37–48.

Filipescu, S., and Gîrbacea, R., 1997. Lower Badenian sea-level drop on the western border of the Transylvanian Basin: foraminiferal paleobathymetry and stratigraphy. Geologica Carpathica 48, 5, 325–334.

Filipescu, S., Krézsek, Cs., Săsăran, E., Silye, L., Wanek, F., Beldean, C., 2009. 3rd International Workshop Neogene of Central and South-Eastern Europe, Cluj-Napoca, May 20-24, 2009, Field Trip Guide, 35 pp.

Főzy, I., Szente, I., 2007. A Kárpát-medence ősmaradványai. Gondolat kiadó, Budapest, 456 pp.

Gheța, N., 1984. The Eocene of NW Transylvania. A new biochronostratigprahic zonation based on calcareous nannoplankton. Dări de Seamă ale Şedinţelor, Institutul de Geologie şi Geofizică, 69, 3, 95–106.

Givulescu, R., 1968. Ein neuer Beitrag zur Kenntnis der fosisilen Flora von Coruș bei Cluj (Rumänien). Geologie, 17, 5, 572–587.

Givulescu, R., 1970. Flora acvitaniană de la Coruș (Cluj) (IV). Contribuții botanice 337–343.

Hauer, F.R.v., Stache, G., 1863. Geologie Siebenbürgens. 636 pp., Verein für Siebenbürgische Landeskunde, W. Braumüller, Wien.

Hosu, A. 1999. Arhitectura sedimentaţiei depozitelor eocene din Nord-Vestul Depresiunii Transilvaniei. Editura Presa Universitară Clujeană, Cluj-Napoca, 224 pp.

Hosu, A., and Filipescu, S., 1995. Sequence stratigraphy on the Middle Miocene deposits from Gârbova de Sus Formation (Transylvanian Basin, Romania). Studii și comunicări, Muzeul Județean Bistrița 1, 87-97.

Huismans, R. S., Bertotti, G., Ciulavu, D., Sanders, C. A. E., Cloetingh, S., and Dinu, C., 1997. Structural evolution of the Transylvanian Basin (Romania): a sedimentary basin in the bend zone of the Carpathians. Tectonophysics 272, 2–4, 249–268.

Iva, M., and Rusu, A., 1981. La limite Eocène/Oligocène en Transylvanie précisée d'après les Foraminifères planctoniques. Dări de Seamă ale Şedinţelor, Institutul de Geologie şi Geofizică 66, 4, 157–180.

Kicsi, A., Silye, L., Ozsvárt, P., Vallner, Z., Bajnai, D., Zajzon, N., Pálfy, J., 2026. Benthic foraminiferal assemblage changes across the Eocene–Oligocene transition in an astronomically calibrated and isotopically characterized Paratethyan section. Marine Micropaleontology 204, art. 102569.

Koch, A., 1875. A *Brachydiastematherium* lelhelyén tett észleletek. Földtani Közlöny 5, 11–12, 273–279.

Koch, A. 1897. *Prohyracodon orientalis*, egy új ősemlős Erdély középeocän retegeiből. Természetrajzi füzetek 20, 4, 481–490.

Koch, A., 1894. Az erdélyrészi medencze harmadkori képződményei. I rész: Paleogén csoport. A Magyar Királyi Földtani Intézet Évkönyve 10, 6, 161–356.

Kovács, E., Magyar, I., Sztanó, O., and Pipík, R., 2016. Pannonian ostracods from the southwestern Transylvanian basin. Geologia Croatica 69, 2, 213–229.

Kovács, S., 2005. Depth gradient proxies: palaeoecology versus sedimentology. Case study from the Turea Group deposits of the Paleogene Transylvanian Basin. Acta Palaeontologica Romaniae 5, 259–276.

Kövecsi, S.A., and Less, G., 2019. Mi újság a szomszédban. In. Dulai, A. (Ed.), Eocén elővilág a Kárpát-medencében – Üvegház – 22 millió éven át. Magyar Természettudományi Múzeum, Budapest, pp. 279 –290.

Kövecsi, S.-A., Less, G., Pleș, G., Bindiu-Haitonic, R., Briguglio, A., Papazzoni, C.A., Silye, L., 2022. Nummulites assemblages, biofabrics and sedimentary structures: The anatomy and depositional model of an extended Eocene (Bartonian) nummulitic accumulation from the Transylvanian Basin (NW Romania). Palaeogeography, Palaeoclimatology, Palaeoecology 586, art. 1107

Kövecsi, S.-A., Silye, L., Less, G., Filipescu, S., 2016. Odd partnership among middle Eocene (Bartonian) Nummulites: Examples from the Transylvanian (Romania) and Dorog (Hungary) Basins. Marine Micropaleontology 127, 86–98.

Krézsek, C., and Filipescu, S., 2005. Middle to late Miocene sequence stratigraphy of the Transylvanian Basin (Romania). Tectonophysics 410, 1–4, 437–463.

Krézsek, C., and Bally, A.W., 2006. The Transylvanian Basin (Romania) and its relation to the Carpathian fold and thrust belt: Insights in gravitational salt tectonics. Marine and Petroleum Geology 23, 4, 405–442.

Krézsek, C., Filipescu, S., Silye, L., Maţenco, L., and Doust, H., 2010. Miocene facies associations and sedimentary evolution of the Southern Transylvanian Basin (Romania): Implications for hydrocarbon exploration. Marine and Petroleum Geology 27, 1, 191–214.

Kristić, N., 1985. Ostracoden im Pannonien der Umgebung von Belgrad. In: Papp, A. (ed.), M5 Pannonien (Slavonien und Serbien), Volume 7. Budapest, VEDA, 103–143.

Lubenescu, V., and Lubenescu, D., 1977. Observatii biostratigrafice asupra Pannonianului de la Lopadea Veche (Depresiunea Transilvaniei). Dări de Seamă ale Şedinţelor Institutului de Geologie şi Geofizică 58, 4, 57-64.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Farinacci, A. (ed.) Proceedings of the Second Planktonic Conference, Rome, 1970, p. 739–785, Tecnoscienza, Roma.

Mátyás, A., and Imecs, Z., 2008. A körösfői karsztfennsík. Karsztfejlődés 13, 167–185.

Mészáros, N., 1991. Nannoplankton Zones in the Miocene Deposits of the Transylvanian Basin. INA Newsletter 13, 2, Prague Abstracts, pp. 55-56, London.

Mészáros, N., 1992. Nannofossil zones in the Paleogene and Miocene deposits of the Transylvanian Basin. Knikovnička ZPN, 14b, 2, 87–92.

Mészáros, N., Clichici, O, Băluță, C., Dragoș, N., Dușa, A., Ferenczi, Ș., Florei, N., Fuchs, H., Gabos, L., Ghiurcă, V., Ianoliu, C., Marosi, P., Nagy, L., Nicorici, E., Petrescu, I., Șuraru, M., Șuraru, N., Tămaș, R, Țârlea, I., 1976. Pe poteci cu bănuței de piatră. Ghid geologic al zonei Cluj. Editura Sport-Turism București, 160 pp.

Mészáros, N., Codrea, V., Săsăran, E., & Săsăran, L., 2001. O succesiune reprezentativă a depozitelor Paleogene din aria Gilăului: zona Morlaca. Studii şi cercetări (Geologie şi Geografie), Muzeul Județean Bistrița 6, 69–72.

Mészáros, N., Moga, V., Ianoliu, C., 1987. Studying the various groups of fossil organisms of Leghia - Leghia Băi. In: Petrescu, I. (ed.) The Eocene from the Transylvanian Basin, Romania. Geological Formations of Transylvania, Romania 1, p. 143–150, Cluj-Napoca.

Mihlbachler, M.C., 2008. Species taxonomy, phylogeny, and biogeography of the Brontotheriidae (Mammalia: Perissodactyla). Bulletin of the American Museum of Natural History 311, 1–475.

Moisescu, V., and Popescu, G., 1980. Chattian - Badenian biochronology in Romania by means of molluscs. Anuarul Institutului Geologie și Geofizică 56, 205–224.

Obbágy, G., Dunkl, I., Józsa, S., Silye, L., Arató, R., Lünsdorf, N. K., and von Eynatten, H., 2021. Paleogeographic implications of a multi-parameter Paleogene provenance dataset (Transylvanian Basin, Romania). Journal of Sedimentary Research 91, 6, 551–570.

Okada, H., Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973;1975). Marine Micropaleontology 5, 321–325.

Pávay, E., 1871a. A Kolozsvár és Bánfy-Hunyad közti vasútvonal ingadozó talajának geologiai szerkezete. Földtani Közlöny 1, 7, 130–145.

Pávay, E., 1871b. Kolozsvár környékének földtani viszonyai, *A Magyar Királyi Földtani Intézet évkönyve*, 1, 327–462.

Pleș, G., Kövecsi, S.-A., Bindiu-Haitonic, R., Silye, L., 2020. Microfacies analysis and diagenetic features of the Eocene nummulitic accumulations from northwestern Transylvanian Basin (Romania). Facies 66, 3, art. 20.

Popescu, B., 1978. On the lithostratigraphic nomenclature of the NW Transylvanian Eocene. Revue Roumaine de Géologie, Géophysique et Géographie 22, 99–107.

Popescu, B., 1984. Lithostratigraphy of cyclic continental to marine eocene deposits in NW Transylvania, Romania. rchives des Sciences et Compte-rendu des séances de la Société 37, 1, 37–73.

Popescu, B., Bombiță, G., Rusu, A., Iva, M., Olteanu, R., Popescu, D., Tăutu, E., 1978. The Eocene of the Cluj-Huedin area. Dări de Seamă al Institutului de Geologie-Geofizică 64, 295–357.

Proust, J.-N., and Hosu, A., 1996. Sequence stratigraphy and Paleogene tectonic evolution of the Transylvanian Basin (Romania, Eastern Europe). Sedimentary Geology 105, 3–4, 117–140.

Proust, J.-N., and Hosu, A., 1997. Tectono-Stratigraphic Significance of the Paleogene Reds Beds in the Transylvania Basin (Romania). Studia Universitatis Babeș–Bolyai, Geologia, 39, 1–2, 33–60.

Răileanu, V., Diaconescu, C., and Rădulescu, F., 1994. Characteristics of Romanian lithosphere from deep seismic reflection profiling. Tectonophysics 239, 1–4, 165–185.

Rusu, A., 1987. Ostreina Biohorizons in the Eocene of the North-West Transylvania (Romania). In: Petrescu, I. (Ed.), The Eocene from the Transylvanian Basin, Romania. Geological Formations of Transylvania, Romania, 1, pp. 175–182. Cluj-Napoca.

Rusu, A., 1989. Problems of correlation and nomenclature concerning the Oligocene formations in NW Transylvania. In: Petrescu, I. (ed.) The Oligocene from the Transylvanian Basin, Romania, p. 67–78, Cluj-Napoca.

Rusu, A., 1995. Eocene formations in the Călata region (NW Transylvania): a critical review. Romanian Journal of Tectonics and Regional Geology 76, 59–72.

Rusu, A., Brotea, D., Ionescu, A., Nagymarosy, A., Wanek, F., 1993. Biostratigraphic study of the Eocene-Oligocene boundary in the type section of the Brebi Marls (Transylvania, Romania). Romanian Journal of Stratigraphy 75, 71–82.

Rusu, A., Brotea, D., Melinte, M.C., 2004. Biostratigraphy of the Bartonian deposits from Gilău area (NW Transylvania, Romania). Acta Palaeontologica Romaniae 4, 441–454.

Sabău, I., Venczel, M., Codrea, V.A., Bordeianu, M., 2021. *Diplocynodon*: a salt water Eocene crocodile from Transylvania. North-Western Journal of Zoology 17, 1, 117–121.

Saint Martin, J.-P., Merle, D., Cornée, J.-J., Filipescu, S., Saint Martin, S., and Bucur, I. I., 2007. The Badenian (Middle Miocene) coral build-ups of the western border of the Transylvanian Basin (Romania). Comptes Rendus Palevol 6, 1–2, 37–46.

Săsăran, L., 2016. Catalogue of type specimens housed in the Museum of Paleontology-Stratigraphy, Babeș-Bolyai University, Cluj-Napoca, Acta Palaeontologica Romaniae 12, 1, 3–23.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferrandez, C., Jauhri, A.K., Less, G., Pavlovec, R., Pignatti, J., Samso, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J., Zakrevskaya, E., 1998. Larger foraminifera biostratigraphy of the Tethyan Paleocene and Eocene. Bulletin de la Societé Geologique de France 169, 2, 281–299.

Szakács, A., and Krézsek, C., 2006. Volcano–basement interaction in the Eastern Carpathians: Explaining unusual tectonic features in the Eastern Transylvanian Basin, Romania. Journal of Volcanology and Geothermal Research 158, 1–2, 6–20.

Szász -Csontos, K., 2023. Asociații de foraminifere bentonice mici și mari din acumularea numulitică din zona Călata (Bazinul Transilvaniei). Bachelor's thesis. Department of Geology, Biology and Geology Faculty, Babeș-Bolyai University, 44 pp.

Trif, N., Arghiuș, V., Seitz, J.C., Codrea, V.A, Bălc, R., Bindiu-Haitonic, R., 2022. Integrated palaeontolgical investigation of a new mid-late Bartonian fish fauna from Călata area, Transylvanian Basin, Romania. Historical Biology 34, 9, 1788–1816.

Trif, N., Codrea, V.A., Pleș, G., Bordeianu, M., 2024. The Priabonian fish from Leghia (Transylvanian Basin, Romania). Historical Biology 36, 11, 2295–2308.

Uhlig, U., 2000. Paleobiogeography of some Paleogene rhinocerotoids (Mammalia) in Europe. Acta Palaeontologica Romaniae 2, 477–481.

Visarion, M., and Veliciu, S., 1981. Some geological and geophysical characteristics of the Transylvanian Basin. Earth Evolution Sciences 3–4, 212–217.

Wood, H.E. II, 1929. Prohyracodon orientale Koch, the oldest known true rhinoceros. American Museum Novitates 395, 1–8.

Zágoršek, K., Filipescu, S., and Holcová, K., 2010. New Middle Miocene Bryozoa from Gârbova de Sus (Romania) and their relationship to the sedimentary environment. Geologica Carpathica 61, 6, 495–512.

FIELD TRIP 3

FT3. Volcanism and associated hydrothermal activity in the Miocene Oaș-Gutâi volcanic zone

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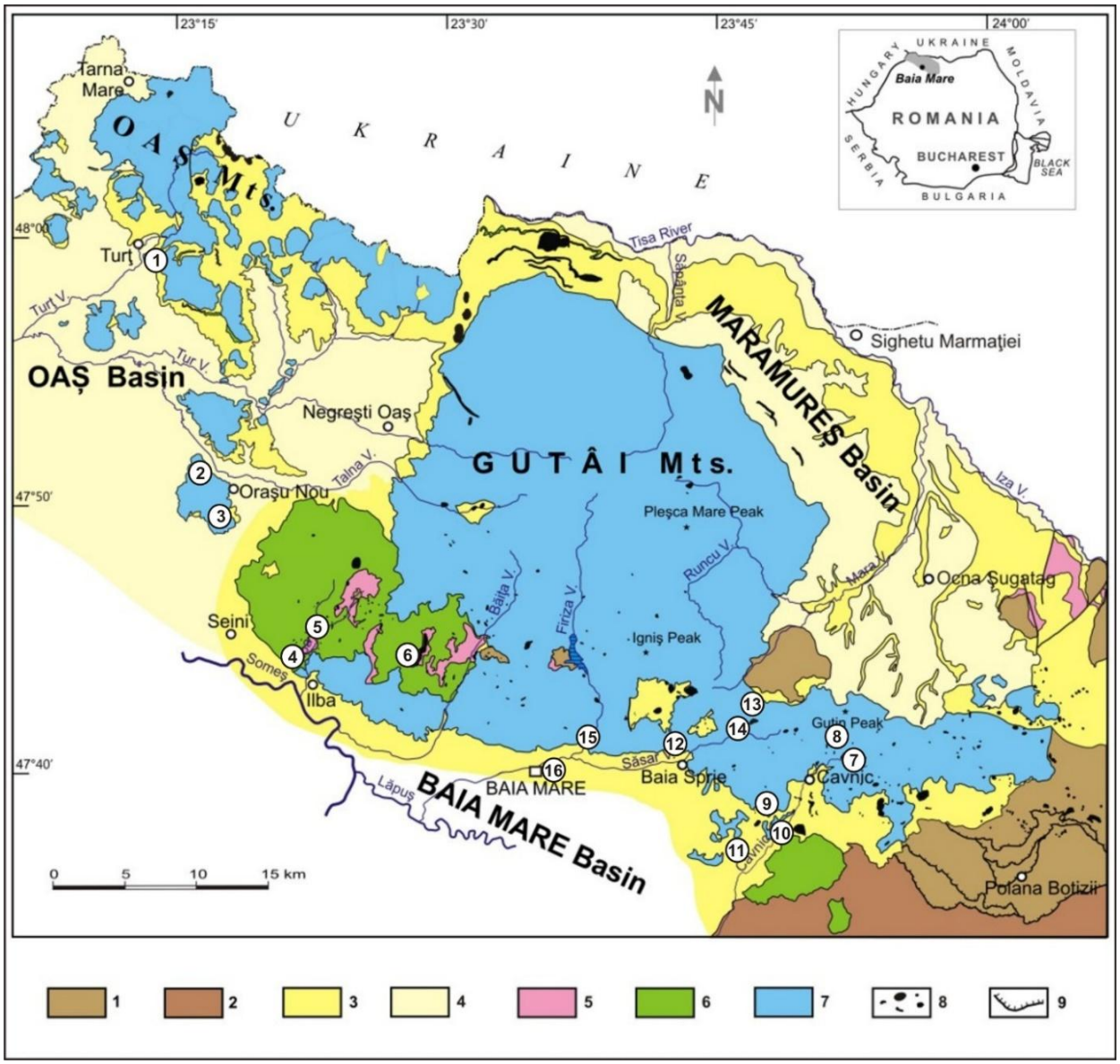


Fig. 1. Simplified geological map of the Oaș-Gutâi Volcanic Zone (OGVZ) with the Field trip stops. The inset shows the position of the OGVZ in Romania. Legend: 1. Paleogene sedimentary deposits; 2. Oligocene-Miocene sedimentary deposits; 3. Neogene (Badenian-Pannonian) sedimentary deposits; 4. Quaternary sedimentary deposits; 5. Silicic/ rhyolitic volcanic rocks (ignimbrites); 6. Intermediate/andesitic volcanic complexes - first stage; 7. Intermediate volcanic complexes - second, third, and fourth stages; 8. Intrusions; 9. Overthrusts.

1. GEOLOGICAL BACKGROUND

The Oaș-Gutâi Volcanic Zone (OGVZ) of East Carpathians in the northwestern part of Romania, belongs to the Neogene-Quaternary volcanic range of the Carpathian-Pannonian region in Central-Eastern Europe (Fig. 2). This volcanic range was built up during the Cenozoic geotectonic evolution of the broader Carpathian–Pannonian Region involving the subduction of the European Plate beneath two continental blocks/microplates, Alcapa and Tisza–Dacia (Csontos 1995; Seghedi et al. 1998).

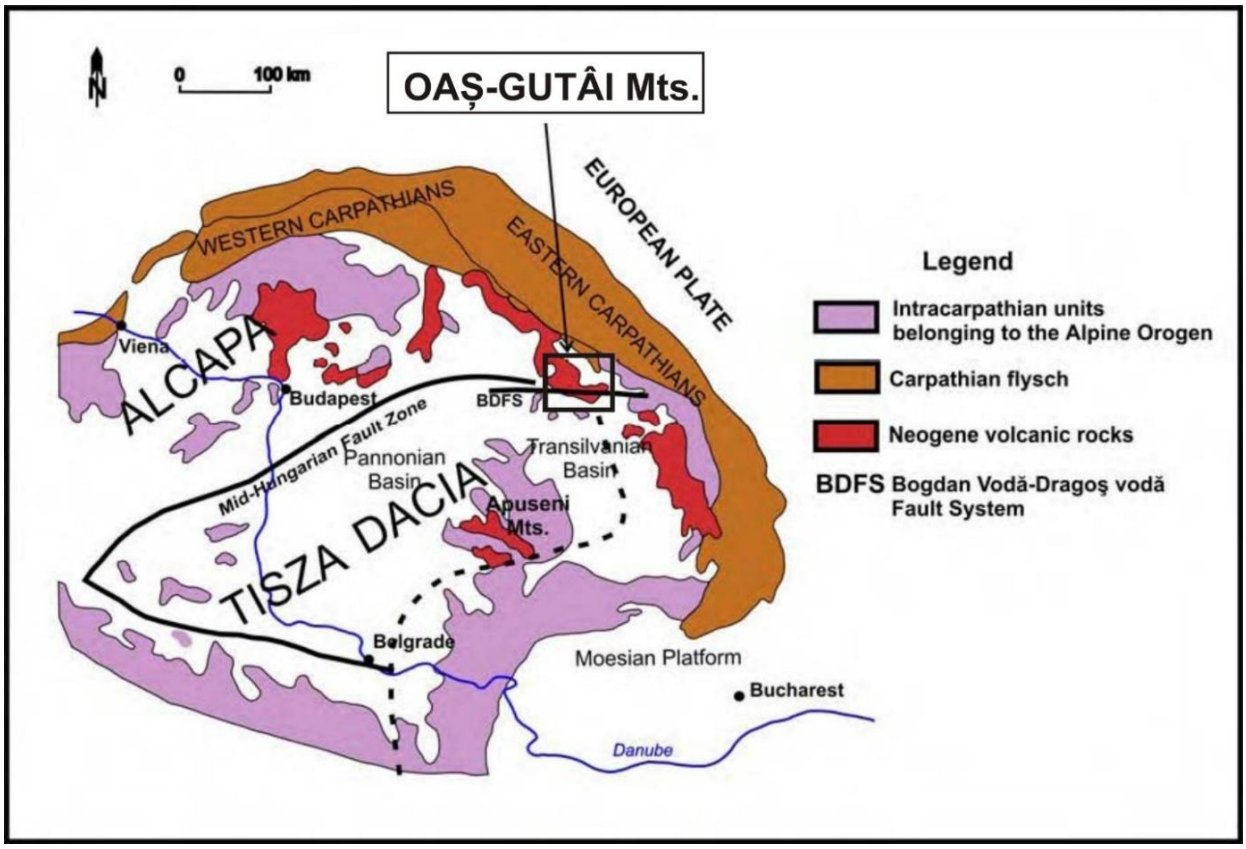


Fig. 2. Location of the Oaș-Gutâi Volcanic Zone within the Carpathian-Pannonian Region.

The pre-volcanic basement consists of the structural units of the Inner and Median Dacides and Piennides (Săndulescu 1984). The Dacides units are composed of Precambrian–Paleozoic metamorphic formations outcropping towards the south-eastern part of the OGVZ and are intersected underneath the Neogene volcanics by numerous boreholes. The Piennides consist of several overthrusted units composed of Paleogene flysch formations exposed extensively in the eastern part of the Gutâi Mts. and occur beneath the whole volcanic area, as intercepted by underground exploration and mining works. The "Pienniny Klippen Zone" (Jurassic–Upper Cretaceous in age) occurs in front of the Botiza Nappe, south-east of the volcanic zone in the Poiana Botizii area (Săndulescu 1984, Figs. 1 and 3).

The Neogene sedimentary deposits are composed of Badenian, Sarmatian and Pannonian rocks and, in general, are covered by the Neogene volcanics. The sediments crop out within several intra-volcanic basins and marginal basins surrounding the OGVZ (Fig. 1 and 3).

The volcanic activity in the OGVZ started with large-volume silicic (rhyolitic), caldera-related explosive eruptions around 15.4 Ma (Fülöp 2002, 2003), represented by ignimbrites and associated volcaniclastics, widespread in the southwestern part of the Gutâi Mts. The silicic volcanism displays a complex succession of ignimbrites and co-ignimbrite fallout tuffs, locally overlain by ignimbrite-related resedimented volcaniclastics interlayered with sedimentary deposits. Products of the silicic volcanism overlie the Paleogene sedimentary cover and are buried by younger andesitic products. Similar silicic volcanic products are found only in drill cores, at depths > 1000 m in the Oaş Mts (Fülöp and Crihan, 2002).

Post-collisional intermediate/andesitic volcanism developed during the 13.4-7.0 Ma time interval (Kovacs and Fülöp 2003, Pécskay et al., 2006) when a large variety of volcanic rocks were emplaced, ranging from basalts to rhyolites and dominated by andesites, which covers the entire area of the OGVZ. The intermediate/andesitic volcanic activity produced more than 90% of the volcanic rocks during multiphase activity with a climax between 11-9 Ma. The ~6 My long intermediate volcanism in the OGVZ

has been separated into four distinct stages based on the temporal, spatial, and compositional affinities of the different rock complexes (Figs. 3 and 4, Kovacs et al. 2017):

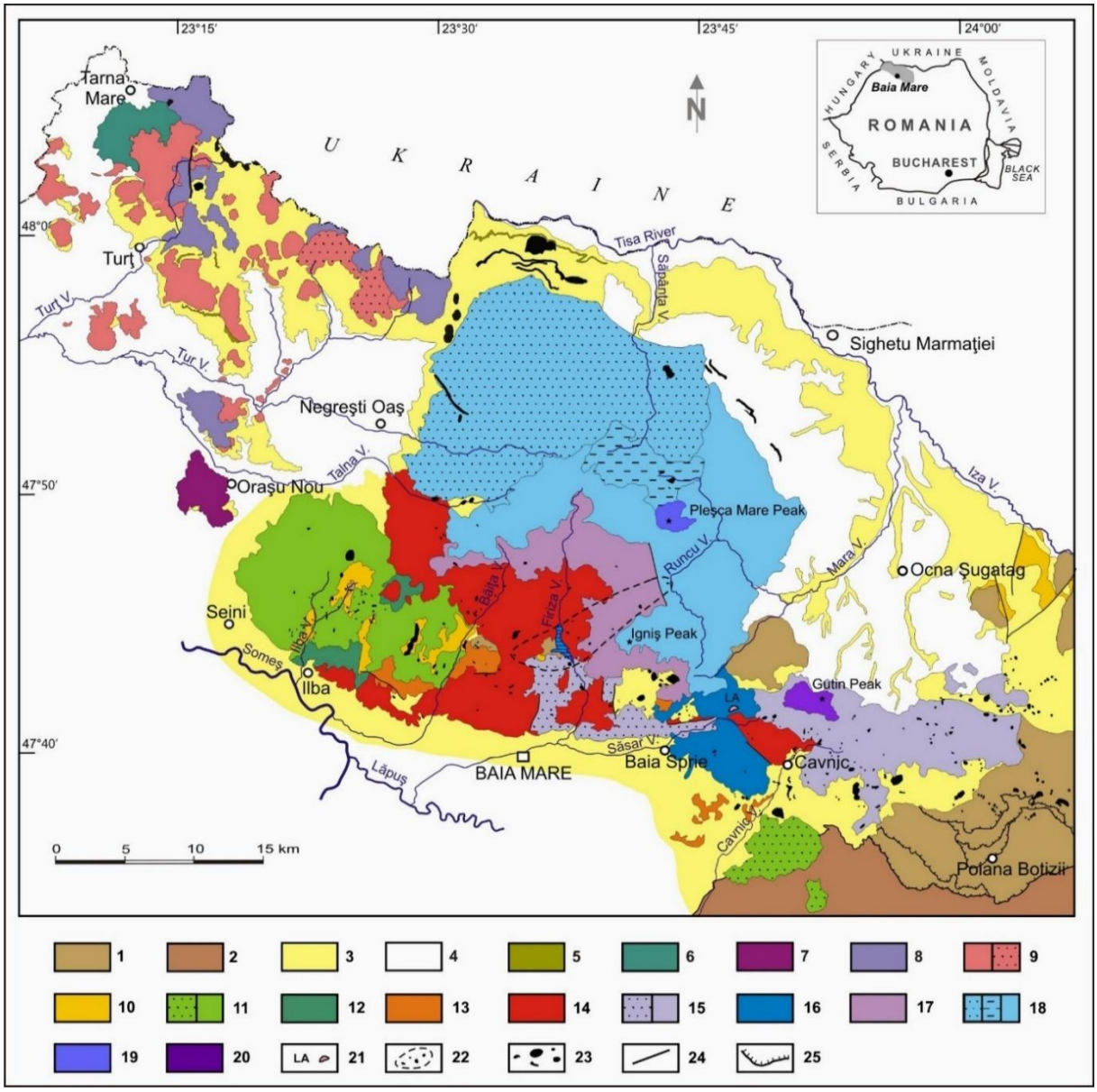


Fig. 3. Geological map of the Oaş-Gutâi Volcanic Zone (from Kovacs et al., 2017). The inset in upper right shows the position of the OGVZ in Romania. Legend: 1. Paleogene sedimentary deposits; 2. Oligocene-Miocene sedimentary deposits; 3. Neogene (Badenian-Pannonian) sedimentary deposits; 4. Quaternary sedimentary deposits; Oaș Mts.: 5. Călinești Tuff (O_1); 2. Socea andesitic complex (O_2); 7. Orașu Nou rhyolitic complex (O_3); 8. Dealul Negru-Huta andesitic complex (O_4); 9. Hatu Lung-Valea Custurii dacitic complex (O_5); Gutâi Mts.: 10. Silicic/rhyolitic volcanic rocks (ignimbrites, OG_F); Intermediate/andesitic volcanic rocks - Stage I: 11. Răchițele-Șatra and Seini-Nistru complexes ($G_{1,}$); Stage II: 12. Ilba andesitic complex (G_8); 13. Șindileu-Dănești dacitic-ryholitic complex (G_2); 14. Quartz-andesite complex (G_3); 15. Herja-Băiuţ andesitic complex (G_4); 16. Mogoșa andesitic complex (G_5); 17. Firiza andesitic complex (G_6); 18. Andesitic complexes from the northern part (G_7); 19. Pleșca Mare dacitic-andesitic composite dome (G_9); 20. Gutâi andesite extrusive dome (G_{10}); Stage III: 21. Laleaua Albă magmatic complex (G_{11}); Stage IV: 22. Firiza basaltic complex (G_{12}); 23. Intrusions; 24. Faults; 25. Overthrusts.

The first volcanic stage was generated during Badenian-Sarmatian times (13.4-12.0 Ma; Edelstein et al., 1992a; Pécskay et al., 1994), mainly in the southern part of the Gutâi Mts. The dominant rocks are pyroxene-bearing andesites. This stage is less represented in the Oaş Mts., where dacite tuffs and pyroclastic flows were emplaced at the end of the stage (Călinesti Tuff of 12.0±0.6 Ma age, Kovacs et al., 1997a).

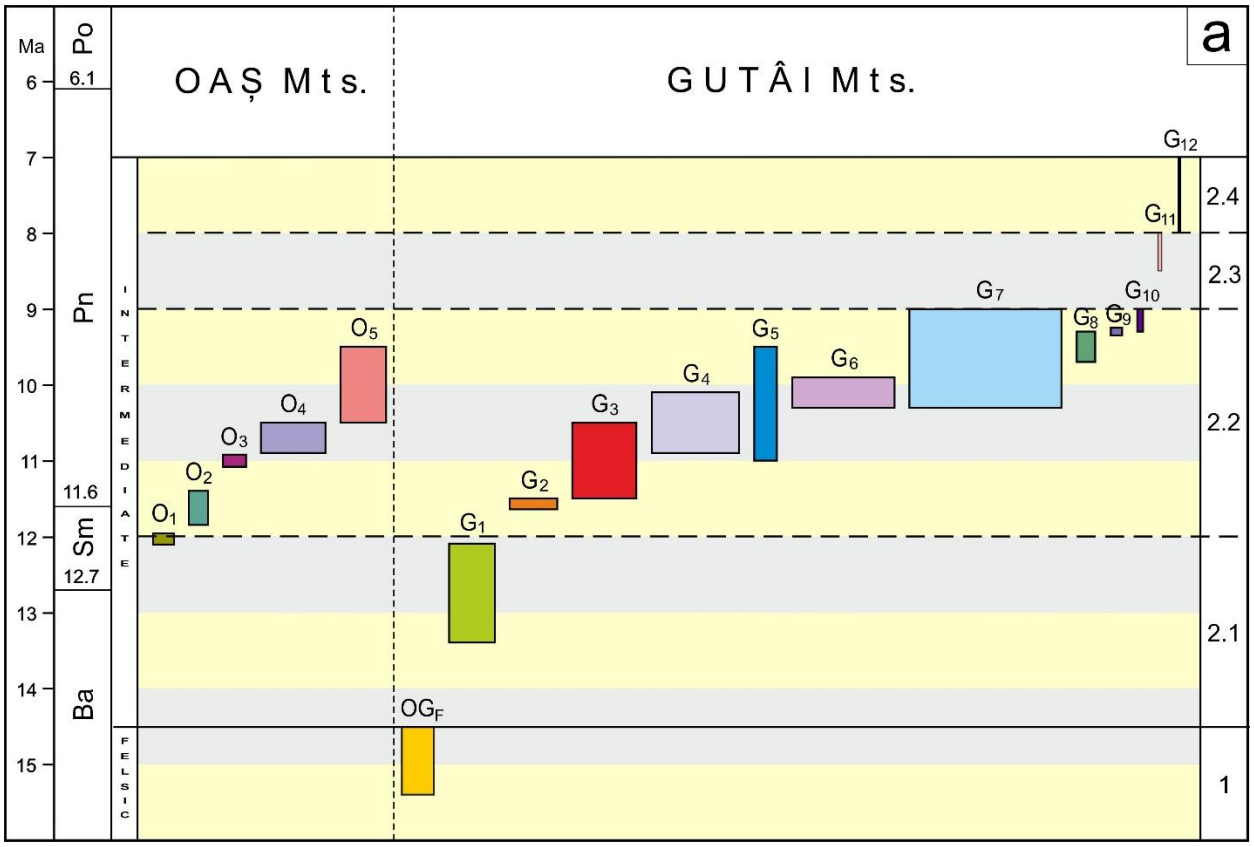


Fig. 4. Temporal evolution of the OGVZ volcanism (from Kovacs et al., 2017). Time distribution of the OGVZ refers to the volcanic complexes shown in **Fig. 3.** The width of the rectangles is proportional to the occurrence area of each complex. The height corresponds to the duration of each volcanic stage (labeled 2.1, 2.2, 2.3, and 2.4)_of the intermediate/andesitic volcanism. O_1 to O_5 are activity stages in the Oaș Mts., whereas G_1 to G_{12} are activity stages in the Gutâi Mts. OG_F refers to the early Oaș-Gutâi felsic volcanism. Stratigraphic ages: Ba-Badenian; Sm-Sarmatian; Pn-Pannonian; Po-Pontian (according to the chronostratigraphic scale for Central Paratethys from Harzhauser and Piller, 2007).

The second volcanic stage developed during Pannonian times (11.8-9.0 Ma, Pécskay et al., 2006; Kovacs et al., 2006). It comprises four volcanic complexes in the Oaș Mts. and nine volcanic complexes in the Gutâi Mts. (Figs. 3 and 4). This stage started in the Gutâi Mts. with a dome-building phase in the southern part of the volcanic area, with the large Dănești-Cetățele dacitic composite dome (11.6 Ma) followed by the emplacement of the andesitic complexes (11.6-9.9 Ma) in the central and southeastern part of the Gutâi Mts. The longest-lasting activity is related to the Mogoșa composite volcano (11.4-9.5 Ma) in the southern part of the volcanic area (Fig. 3 and 4). The second stage of the intermediate volcanism had its climax between 10.0-9.0 Ma, when a very large volume of volcanic products were emplaced in the northern part of the Gutâi Mts.

Several andesitic volcanoes (Rotundu, 9.8-9.7 Ma and Igniș, 9.5-9.0 Ma) and two large-sized dacitic (Plești Mare, 9.3 Ma) and andesitic (Gutâi, 9.3-9.0 Ma) extrusive domes were built up in this major volcanic phase. The much shorter-lasting volcanism in the Oaș Mts. (2.5 My, between 12.0-9.5 Ma), as compared to that in the Gutâi Mts., predominantly comprises dacitic extrusive domes. Numerous shallow subvolcanic intrusive bodies (dykes, sills, small laccoliths) of various compositions and textures, dated between 11.8-9.0 Ma (Kovacs et al., 2013), occur mainly in the southeastern part of Gutâi Mts. and are assigned to the second stage of the intermediate volcanism.

A small andesite-dacite composite intrusive structure, the Laleaua Albă magmatic complex (8.5-8.0 Ma, Kovacs, 2002) in the central-southern part of the Gutâi Mts., represents the third volcanic stage (Fig. 3 and 4). The fourth volcanic stage, the Firiza basaltic complex (8.1-7.0 Ma, Edelstein et al., 1993), consists of

several small intrusive bodies of calc-alkaline olivine-bearing basalts, developed exclusively in the central part of the Gutâi Mts. (Fig. 3 and 4).

The volcanic rocks of the OGVZ indicate subalkaline compositions and a medium to high-K character involving complex magmatic processes – assimilation-fractional crystallization (AFC) and magma-mingling and mixing – during their formation (Kovacs, 2002, Kovacs et al., 2017, Jurje et al., 2014). The magmatic source was an enriched lithospheric mantle, previously modified by a sediment subduction component (Kovacs et al., 2017). The petrogenesis of the volcanic rocks of the intermediate/andesitic volcanism was controlled by the architecture of the volcanic plumbing systems composed of multi-level, interconnected intra-crustal magmatic reservoirs connected with a deeper reservoir ("deep hot zone") that acted as a "MASH zone" at the crust–mantle boundary beneath the volcanic area (Kovacs et al., 2021).

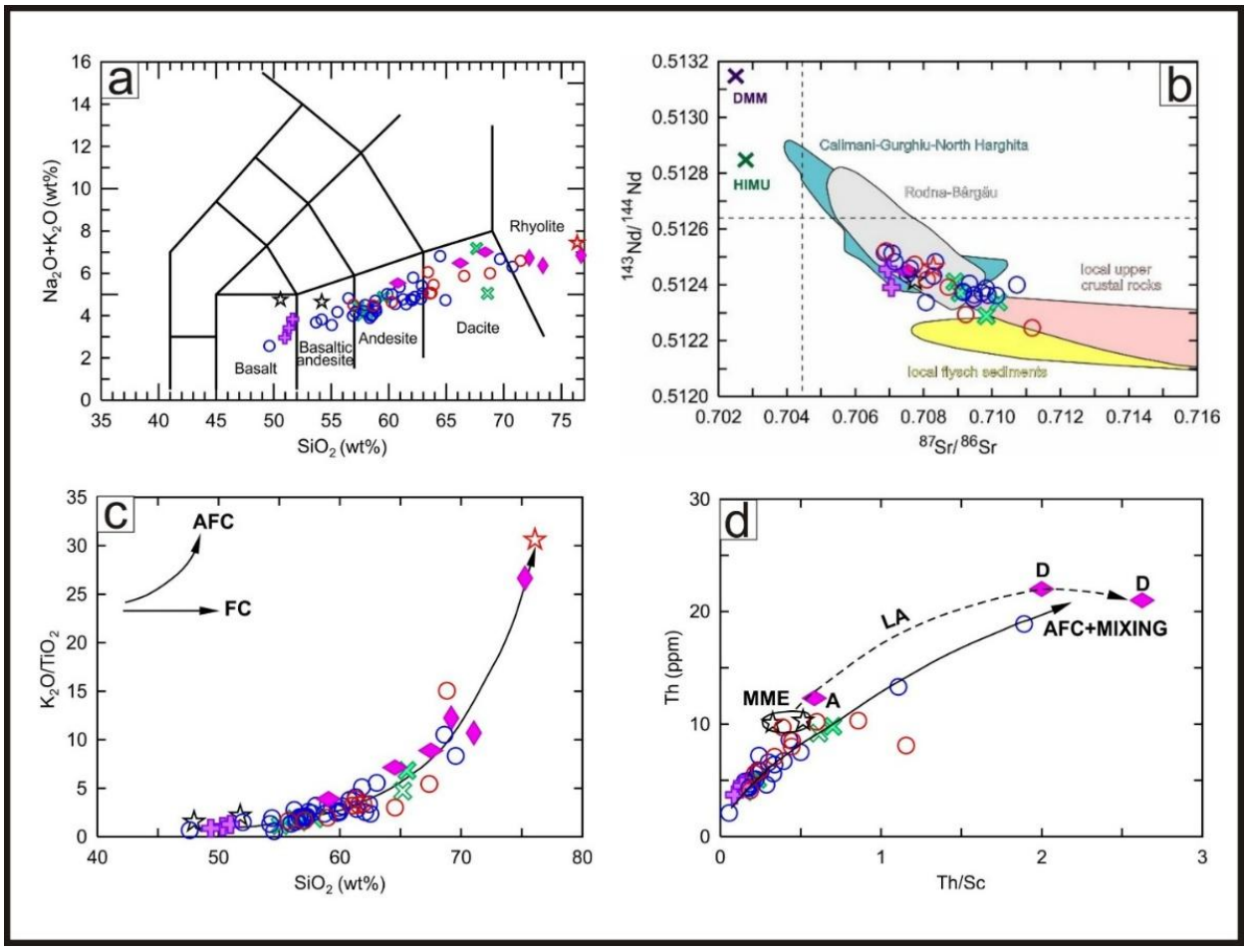


Fig. 5. Distribution of the OGVZ volcanic rocks in the TAS (a), 143Nd/144Nd vs. 87Sr/86Sr (b), K_2O/TiO_2 vs. SiO_2 (c) and Th vs. Th/Sc (d) diagrams (from Kovacs et al., 2017).

2. GENERAL VOLCANOLOGICAL FEATURES

Volcanic activity in the Oaş-Gutâi Volcanic Zone took place simultaneously with major tectonic events and was influenced by the local paleogeography dominated by intra-volcanic and marginal sedimentary basins. The dominantly effusive volcanic products were emplaced in both subaerial and subaqueous conditions.

Large-scale caldera-related explosive silicic/rhyolitic volcanism released a complex succession of ignimbrites and co-ignimbrite fallout tuffs in the southwestern part of the Gutâi Mts, locally overlain by ignimbrite-related resedimented volcaniclastics interlayered with sedimentary deposits (Fülöp 2002, 2003; Fülöp and Kovacs, 2003, 2007, Fig. 6).

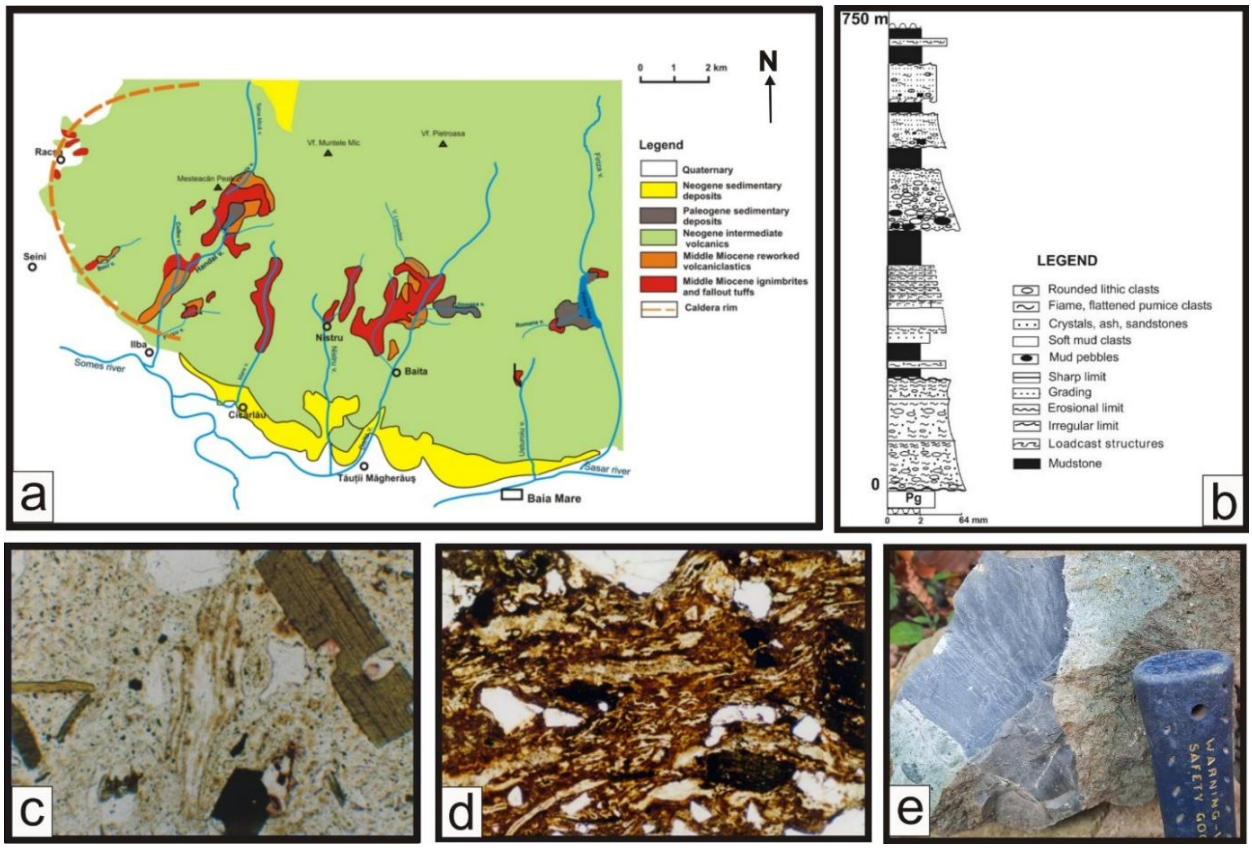


Fig. 6. Silicic volcanism from the Gutâi Mts. (acc. to Fülöp 2002, 2003). a) Surface occurrence areas of the rhyolitic ignimbrites with the location of the inferred caldera rim; b) Synthetic lithological column of the rhyolitic ignimbrite formation in the Racșa-Seini-Ilba zone (SW Gutâi Mts.; c) Biotite, quartz and flattened pumice clast as the main petrographic components of the ignimbrites as seen under microscope ; d) Welded ignimbrite under microscope; e) Thermal contact features of an engulfed clay lithoclast testifying for high emplacement temperatures of the enclosing pyroclastic rock/ignimbrite. Photo: Alexandrina Fülöp (c, d), Marinel Kovacs (e).

The intermediate/andesitic volcanism displays specific features in the two areas where it took place. In the Oaş Mts., dome-building phases developed mainly in a submarine environment. Extrusive domes, dome-coulées and dome complexes are composed by coherent dacites and andesites. Volcaniclastic products – in situ and resedimented hyaloclastites, primary and reworked pyroclastic flow deposits, often interbedded with sedimentary deposits – are associated to some of the domes (Kovacs and Fülöp, 2002, Szakács and Kovacs 2022, Fig. 7).

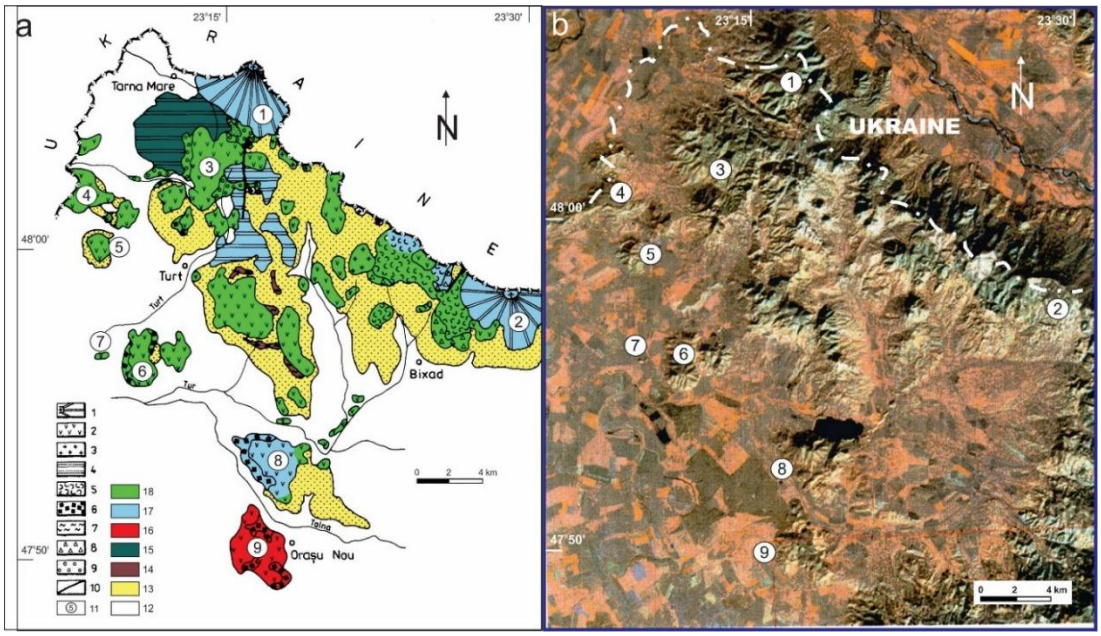


Fig. 7. a) Volcanological map (according to Kovacs and Fülöp, 2002), and b) geomorphological map/Landsat image of the Oaș Mts. Legend: 1. Composite volcanoes; 2. Extrusive domes; 3. Intrusions; 4. Volcano-tectonic depressions filled with lavas and volcaniclastics; 5. Lava flows (unknown centers); 6. Hyaloclastic deposits; 7. Pyroclastic flows; 8. Coarse volcaniclastics; 9. Fine volcaniclastics; 10. Faults; 11. The volcanic structures: A. Composite volcanoes: 1. Dealul Negru; 2. Poiana Şesu-Huta; B. Extrusive domes: 3. Batarci; 4. Hatu Lung; 5. Pleşcuţa; 6. Pusta Heghii; 7. Turulung; 8. Jeleznic; 9. Oraşu Nou; The color legend represents the sedimentary deposits and the main volcanic phases (according to their temporal evolution): 12. Quaternary sedimentary deposits; 13. Neogene sedimentary deposits; 14. Călineşti Tuff complex; 15. Socea andesitic complex; 16. Oraşu Nou rhyolitic lava-dome; 17. Volcanic rocks of the main andesitic phase (10.9 - 10.5 Ma); 18. Volcanic rocks of the main dacitic dome-building phase (10.5 - 9.5 Ma) (from Szakács and Kovacs, 2022).

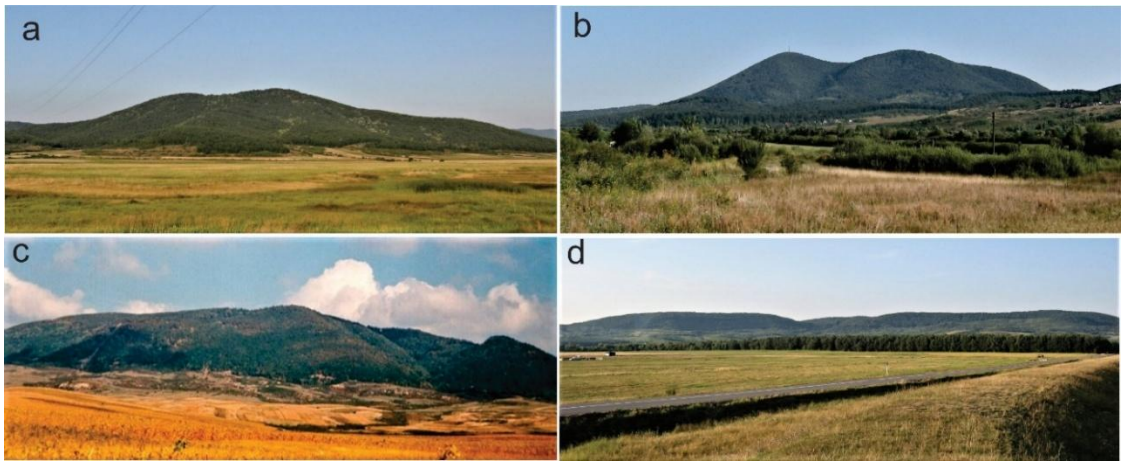


Fig. 8. Extrusive domes in the Oaș Mts. (from Szakács and Kovacs, 2022). a) The rounded shape Pleşcuţa dome (quartz, biotite-bearing andesite) with low-angle slopes; b) the steep cone-shaped Jeleznic dome (pyroxene andesite); c) the large-sized flat-topped Oraşu Nou lava dome (rhyolite); d) the Hatu Lung dome-coulée (pyroxene hyaloandesite) with a flat top. Photo: Marinel Kovacs (a, b, d); Alexandrina Fülöp (c).

One of the most significant features of the Gutâi Mts. consists in the overlapping of the volcanic products belonging to different stages and/or to different coeval volcanic structures, hindering identification and reconstruction of individual edifices. Thus, only a few composite volcanic structures were readily identified, as well as the volcanic products of several extrusive domes, located within the main volcanic area, inter-fingering with those of the neighboring composite volcanic structures. The most specific volcanic landforms are associated with composite volcanoes, extrusive domes, lava plateaus, and exhumed

intrusive bodies. The composite volcanoes geomorphologically represent residual volcanic landforms resulting from intense erosional modeling of the original edifices. Their current morphology is a result of both constructional and destructional processes, including collapse events and erosional lowering and denudation processes related to the evolution of the hydrographic systems after the edifice construction (Szakács and Kovacs, 2022). The most voluminous volcanic activity developed in the central and northern parts of the Gutâi Mts., where composite volcanoes (Mogoşa, Igniş, Muntele Mic, Pietroasa, Rotundu, Muntele Bradului), large-sized extrusive domes (Breze, Pleşca Mare, Gutâi) and extended lava plateaus were formed (Fig. 9 and 10).

In the Gutâi Mts, multiphase intermediate volcanism took place simultaneously with extensive tectonic events: a thick pile of volcanic products fills a series of volcano-tectonic depressions/grabens controlled by the major E-W-trending Bogdan-Dragoş-Vodă fault system in the southern part of the volcanic area, such as the Baia Sprie graben with a ca. 700 m thick pile of volcanic products.

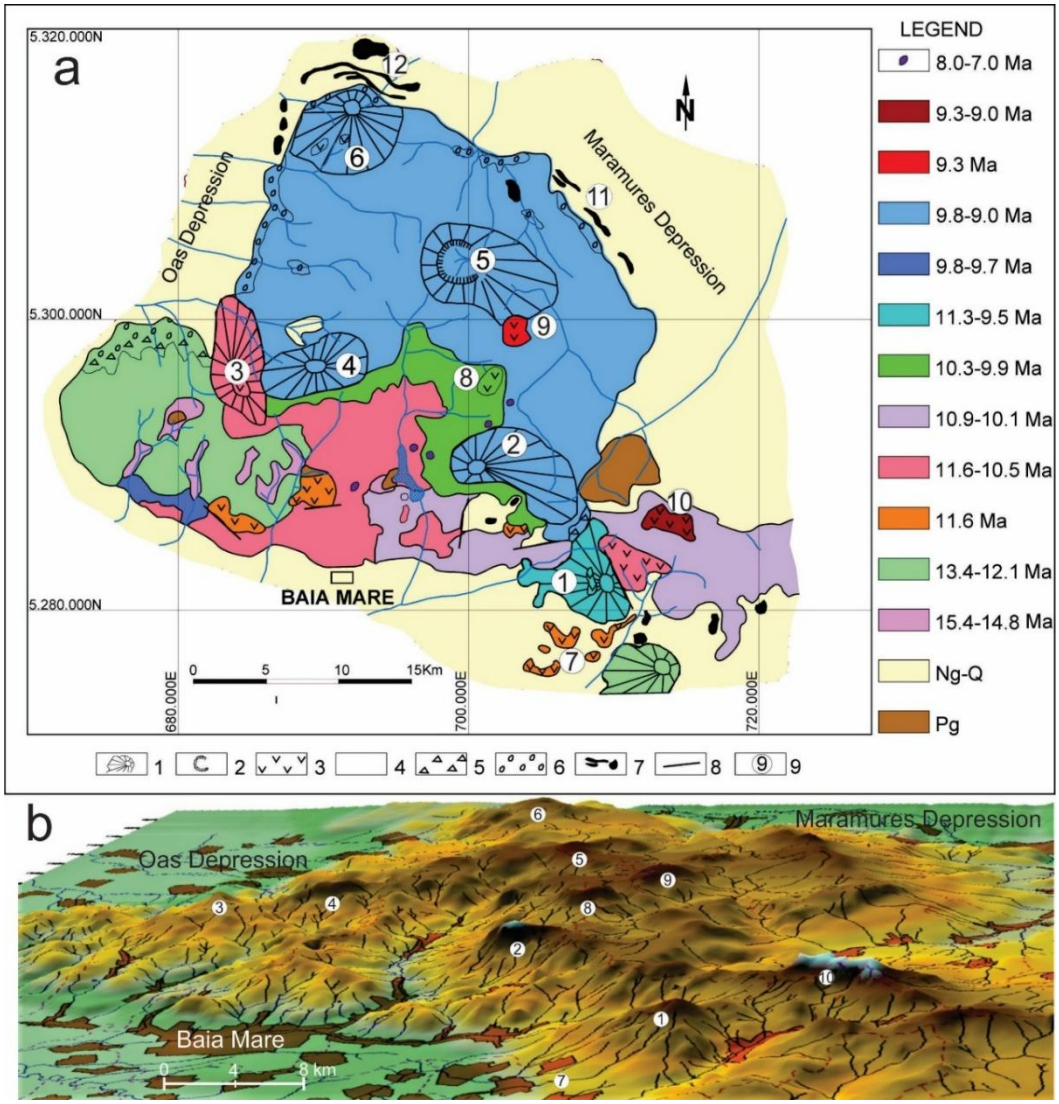


Fig. 9. a) Volcanological sketch map (updated after Kovacs et al., 2006) and b) digital terrain map of the Gutâi Mts. Legend: 1. Composite volcanoes; 2. Crater; 3. Extrusive domes; 4. Lava flows (prevalent) and volcaniclastics; 5. Volcaniclastic rocks (hyaloclastites, pyroclastic rocks); 6. Reworked volcaniclastics (epiclastic rocks); 7. Intrusions; 8. Faults; 9. The volcanic structures listed in the text: Composite volcanoes: 1. Mogoşa; 2. Igniş; 3. Muntele Mic; 4. Pietroasa; 5. Rotundu; 6. Muntele Bradului; Extrusive domes: 7. Dăneşti-Cetăţele; 8. Breze; 9. Pleşca Mare; 10. Gutâi; Intrusive bodies: 11. Agriş sills; 12. Cherec sills. The color legend represents the volcanic rocks (as temporal evolution/geochronological ages) and the sedimentary deposits (Pg - Paleogene; Ng-Q – Neogene-Quaternary) of the Gutâi Mts. (from Szakács and Kovacs, 2022).

In the northern part of the Gutâi Mts., a more than 1000 m thick volcanic complex is likely also related to a volcano-tectonic depression. Lava flows of basaltic andesite and andesite composition represent the most voluminous volcanic products in the Gutâi Mts, in places forming extended lava plateaus (e.g., in the northern part of the volcanic zone, Fig. 10d). Autoclastic breccias formed in the front of the subaerial lava flows, whereas hyaloclastite deposits formed as subaerial lava flows entered a subaqueous environment. Scarce phreatomagmatic deposits with accretionary lapilli are related to explosive volcanic phases. Widespread occurrence of mass flow-type volcaniclastics, mainly by reworking of primary volcanic products, suggests erosional/denudation processes during and following volcanic activity.

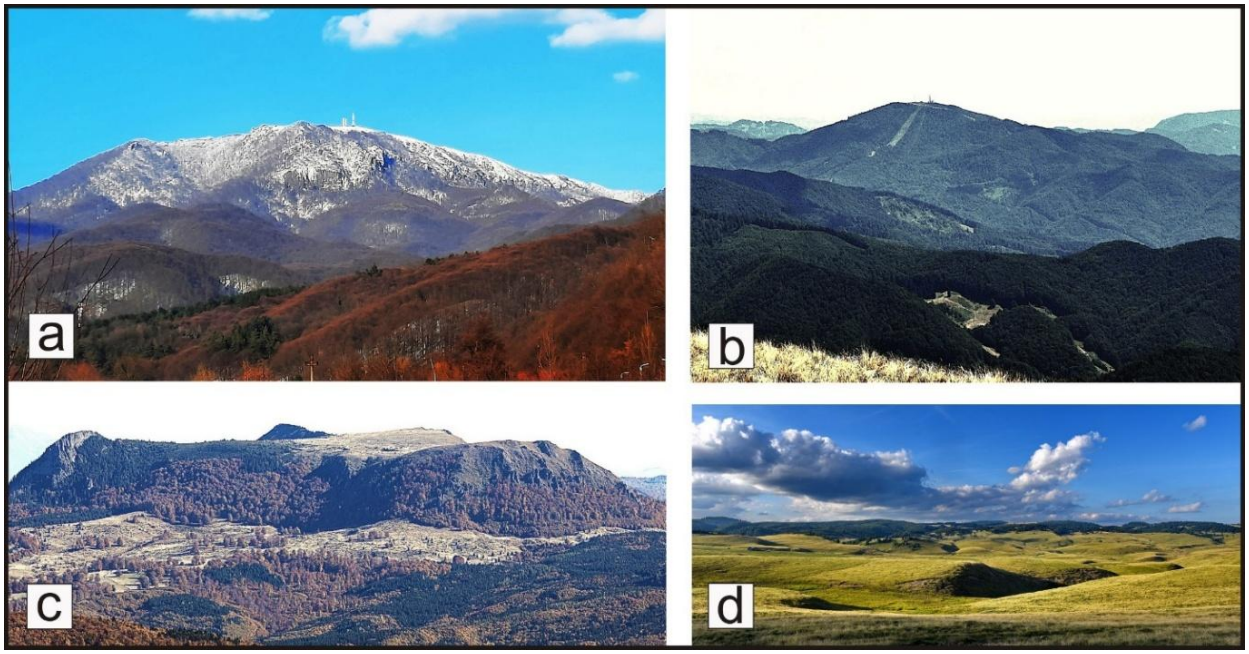


Fig. 10. a) Igniș and b) Mogoșa composite volcanoes; c) The large-sized Gutâi dome; d) Extended lava plateau in the Northern half of the Gutâi Mts. Photo: Marinel Kovacs (a), Péter Lengyel (b, d), Benone Cristian (c).

3. HYDROTHERMAL ACTIVITY AND METALLOGENY

Large-scale hydrothermal and metallogenetic activity, resulting in typical epithermal mineralization (polymetallic and gold-silver), took place mainly in the southern part of Gutâi Mts. (11.5-7.9 Ma, Lang et al., 1994) in connection with the intermediate/andesitic volcanism. The mineralization is of typical low-sulfidation type and mainly consists of polymetallic and gold–rich veins, and less breccia pipes/dykes and stockworks, respectively. More than 20 ore deposits developed in three main metallogenetic fields (Fig. 11). The Ilba – Nistru field is composed of base metal deposits, connected with the Sarmatian magmatism developed in the south-western part of the Gutâi Mts. The Săsar-Dealul Crucii field consists of a typical gold epithermal system located in the southern-central part of the mountains (north of Baia Mare city). The Herja-Băiuţ field of base metal-gold ore composition includes some of the most important deposits at Baia Sprie and Cavnic. The mineralization in the latter two metallogenetic fields is connected to the Pannonian magmatism.

The hydrothermal and metallogenetic activity in the Baia Mare district was controlled by both tectonics and magmatism. The most important tectonic control was played by the major W–E trending transcrustal Bogdan Vodă–Dragoş Vodă fault system (Săndulescu et al., 1993; Tischler et al., 2007) located in the southern part of the Gutâi Mts. (Fig. 2). The main epithermal ore deposits are located either along this transcrustal fault system or controlled by several NE–SW or NW–SE oriented, satellite tectonic structures

(mostly tensional fractures). Most of the epithermal mineralisations in the Baia Mare metallogenetic district are connected genetically with intrusions, thus being classified as "intrusion–related" epithermal systems.

The mineralization is hosted by volcanic and intrusive rocks, or by sedimentary deposits. The Baia Sprie ore deposit is an example of a mineralization located within a thick sequence composed of andesite lavas and volcaniclastics filling a volcanic–tectonic depression/graben connected to the Bogdan Vodă –Dragoş Vodă fault system. Other examples are the Cavnic ore deposit hosted by both volcanic and intrusive rocks and the Herja ore deposit hosted by intrusions in an uplifted basement zone consisting of Paleogene sedimentary deposits covered by Neogene (Pannonian) sedimentary deposits.

The lengths of the veins range from hundreds of meters to up to 5 km (e.g., the Principal Vein of the Baia Sprie ore deposit). The thickness of the veins ranges between 0.3 m and 10 m, and the whole height of the mineralised level is between 300 and 1000 m.

The ore-related hydrothermal alterations are predominantly of adularia–sericite type, developed in particular in the Ilba–Nistru and Săsar–Dealul Crucii metallogenetic fields. The mineralogy of the hydrothermal alteration zones is typical for the neutral pH alteration style of the low–sulfidation epithermal systems with adularia, quartz, illite and smectite as dominant mineral phases and chlorite, calcite and kaolinite as subordinate minerals. Quartz–adularia is the common paragenesis of alteration zones that occur near the veins. Adularia, the most significant hydrothermal mineral of the area, usually appears in rhombic/pseudorhombic, twinned or pseudozoned crystals, as a vug–filling phase within the veins (quartz–adularia–sulfides) or in their close vicinity (quartz–adularia). Common alteration zoning showing silicic, adularia, phylic (illite – smectite) and propylitic alterations was recorded outward from the veins for the great bulk of the epithermal ore deposits. Locally, the alteration zones are overprinted on each other both laterally and in depth (Stanciu, 1984)

Acid–sulfate alterations are locally developed in the eastern part of the Gutâi Mts. (Cavnic–Jereapăn–Băiuţ). Advanced argillic alteration, kaolinite±pyrophyllite±alunite and vuggy silica occur in restricted areas in the upper part of the Cavnic epithermal system (Mariaş, 1996, 2005). In the central part of the Cavnic base metal–gold ore deposit, in the Bolduţ mine, the assemblage composed of quartz–illite–kaolinite ± pyrophyllite suggests the transition from the high sulfidation to the low–sulfidation type of alteration (Mariaş, 2005).

Well–displayed vertical zonality, with Au–Ag on top, Pb–Zn in the middle part and Cu at the bottom, is typical for some of the main ore deposits of the Baia Mare district (e.g., Baia Sprie ore deposit).

A wide variety of textures were identified in the epithermal ore deposits in the Baia Mare district. Cavity-filling veins with sharp boundaries, typical for low–sulfidation systems, are the prevalent features. Different magmatic, phreato–magmatic and hydrothermal breccias host most of the ore deposits, e.g., breccia pipes in Cavnic, Şuior, Baia Sprie, Săsar, and breccia dykes in Cavnic and Baia Sprie (Genna et al., 1994; Mariaş, 1996, 2005). Stockworks (e.g., Borzaş gold mineralisation in the Săsar ore deposit) and disseminated textures occur only within the gold-rich upper part of some ore deposits (e.g., Ilba, Nistru, Băiţa and Baia Sprie–Mine Hill open pit). Banded and drusy textures are common in most of the veins. Collomorph and finely banded quartz–chalcedony textures developed in the Au-Ag and in the upper part of the polymetallic ore deposits.

The hydrothermal activity in the Baia Mare metallogenetic district spanned the Pannonian time, i.e., between 11.5–7.9 Ma, according to radiometric data: K–Ar on adularia and illite and Ar–Ar dating on adularia by Lang et al. (1994) and Kovacs et al. (1997b), respectively. Two main metallogenetic phases have been separated: a Lower Pannonian phase (11.5 –10.0 Ma), responsible for the Ilba–Nistru base metal and Săsar–Dealul Crucii Au-Ag metallogenetic fields, and an Upper Pannonian phase (9.4 –7.9 Ma), for the Herja–Băiuţ base metal–gold mineralization (Kovacs et al., 1997b).

The field observations and the radiometric dating altogether allow understanding some of the temporal relationships between the mineralization and their host magmatic rocks. Thereby, the youngest hydrothermal processes, of 7.9 Ma Ar–Ar age on adularia from the Principal Vein in the Baia Sprie ore

deposit (Lang et al., 1994) are younger than the youngest magmatic rocks, excepting the basalts which ended the magmatism in the region at 8.1–7.0 Ma ago (Edelstein et al., 1993, Fig. 11). None of the mineralized structures contain magmatic rocks younger than the hydrothermal mineralization. There is a gap of 0.5–1.5 Ma between the main magmatic phases and the associated hydrothermal processes, similar the other occurrences in the arc-related magmatic provinces (Lang et al., 1994; Kovacs et al., 1997b).

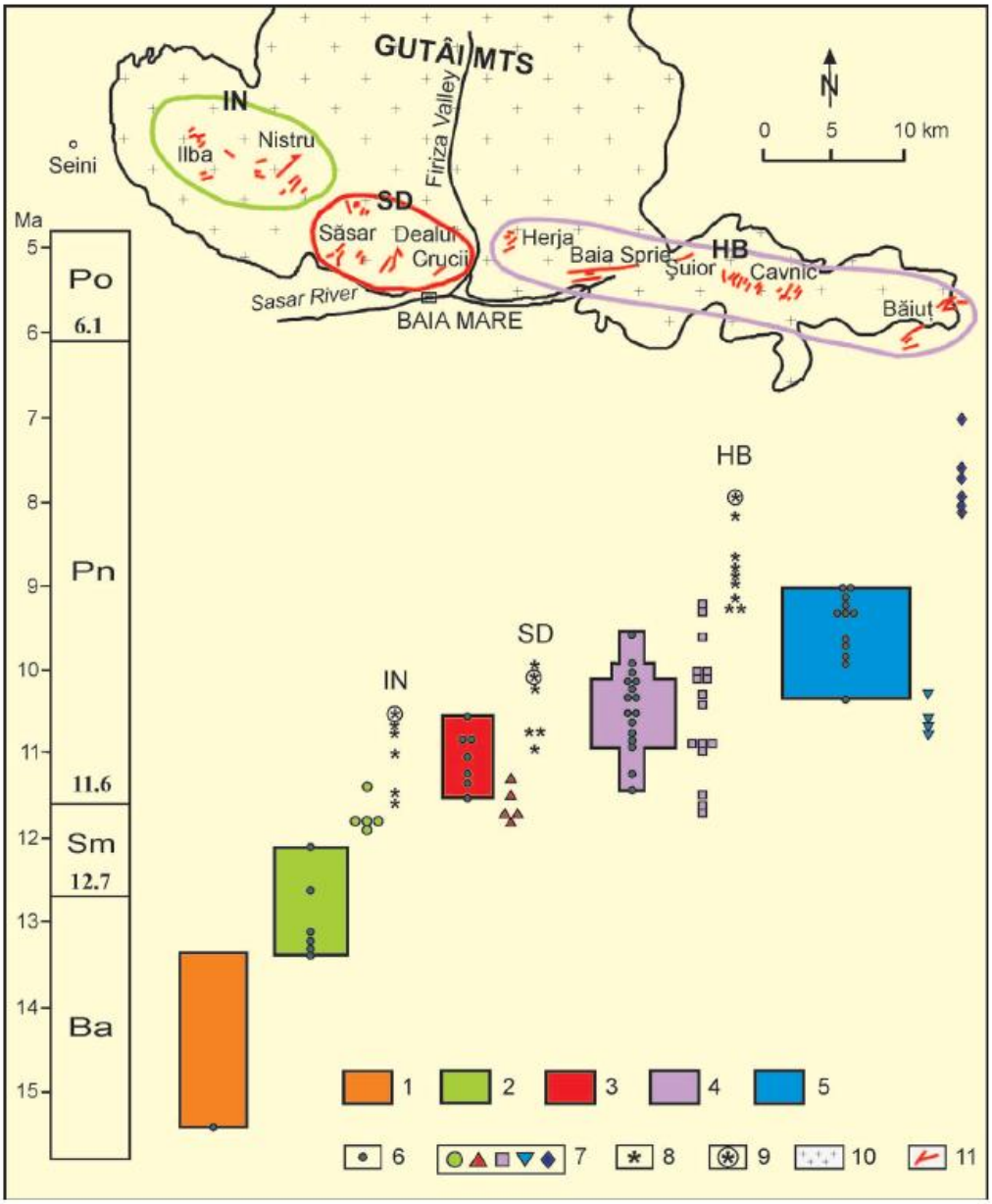


Fig. 11. Comparative K-Ar and Ar-Ar ages of the hydrothermal mineralization, intrusions, and lava flows in the Gutâi Mts. (from Kovacs et al., 2013). The time intervals defined by the K-Ar dating of the volcanic complexes are illustrated on the Y axis. The different volcanic complexes are illustrated according to their relative sizes. Legend: 1 – Badenian silicic volcaniclastic rocks; 2 – Badenian-Sarmatian lava flows (pyroxene andesites); 3 – Pannonian quartz andesite volcanic complex; 4 – Pannonian volcanic complexes in the central-southeastern part of the Gutâi Mts; 5 – Pannonian volcanic complexes in the northern part of the Gutâi Mts; 6 – K-Ar ages of the lava flows; 7 – K-Ar ages of the intrusive rocks; 8 – K-Ar ages of adularia and illite from hydrothermal mineralization; 9 – Ar-Ar ages of adularia; 10 – Neogene volcanic rocks in the Gutâi Mts; 11 – Hydrothermal veins. IN – Ilba-Nistru base metal metallogenetic field, SD – Săsar-Dealul Crucii gold-silver metallogenetic field, HB – Herja-Băiuț base metal + gold metallogenetic field (Herja, Baia Sprie, Șuior, Cavnic, Băiuț ore deposits).

The complex mineralogical assemblages were attributed to ore–forming fluids spanning across different ranges of temperature and salinity. An overall range of 150–320°C is characteristic for the mineralization of the Baia Mare metallogenetic district, as Borcoş et al. (1974), Manilici and Kalmar (1973), Nedelcu and Pintea (1993), Bailly et al. (1998), Grancea et al. (2002) and Mariaş (2005) reported based on homogenization temperatures of the fluid inclusions in quartz, calcite, fluorite and sphalerite.

The cupriferous mineralization of the base metal ore deposits formed at higher temperatures: e.g., 250°–320°C in the Nistru Pb–Zn–Cu ore deposit (Borcoş et al., 1974) and 265°–340°C in the Băiuţ Cu–Pb–Zn ore deposit (Manilici and Kalmar, 1973). Decreasing temperatures, from 315°C and 324°C respectively in the early mineralizing event, to ~ 200°C in the late events, were reported in the Cavnic ore deposit by Grancea et al. (2002) and Mariaş (2005). Lower temperatures are typically determined for the gold–silver mineralization, 170°–210°C in the Săsar ore deposit, according to Bailly et al. (1998). Similar temperatures were determined for the gold-rich mineralization occurring in the upper part of some base metal ore deposits (e.g., in the Baia Sprie ore deposit): 160°–250°C for fluid inclusions in quartz and sphalerite from the veinlets of the Dealul Minei/Mine Hill open pit (Grancea et al., 2002).

The ore–forming fluids in the Baia Mare metallogenetic district had higher overall salinity than those of the typical low–sulfidation epithermal ore deposits, in the range from 1 to 21 wt.% NaCl equiv. (e.g., 1–14 wt.% NaCl equiv. in the Cavnic ore deposit (Piantone et al., 1999), 3.6 – 19.9 wt.% NaCl equiv. in the Baia Sprie ore deposit (Nedelcu and Pintea, 1993) and 5 – 15.2 wt.% NaCl equiv. in the Dealul Minei open pit, the upper part of the Baia Sprie ore deposit (Grancea et al., 2002). Besides the variable salinity of the ore fluids, the main ore deposits of the Baia Mare district also show highly variable homogenization temperatures, suggesting the complex evolution of the hydrothermal systems, mainly as open systems involving mixing of magmatic fluids with meteoric waters and boiling processes.

The lead isotope compositions determined in the ore deposits of the Baia Mare district are well clustered within the radiogenic values: $^{206}Pb/^{204}Pb$ ratios from 18.752 to 18.876, and $^{208}Pb/^{204}Pb$ ratios from 38.841 to 38.981 (Marcoux et al., 2002). The similarity between isotopic compositions of the ore deposits and the volcanic rocks is in agreement with the genetic link between the volcanism and the epithermal activity, i.e., a common crust-contaminated magmatic source (Kovacs, 2001; Marcoux et al., 2002; Tămaș et al., 2024)

4. FIELD STOPS

Day 1. Dome-building volcanism in the Oaș Mts. and volcanism in the south-western part of the Gutâi Mts.

A major dome-building volcanism, generating isolated extrusive domes, lava-domes, dome-coulées and dome complexes, developed in the Oaș Mountains (Kovacs and Fülöp, 2002; Kovacs et al., 2014). With one single exception – the Orașu Nou rhyolitic lava-dome - they are of dacite and high-silica andesite composition.

Stop 1. Turț Quarry (small-sized extrusive dacite dome)

Raw material rocks of a small-sized dacitic extrusive dome have been extracted in a quarry for decades in Turț village (Fig. 12a). It is worthy to observe the internal structure of this volcanic structure following the development of the quarry. About 30 years ago, at the quarry front, one could observe columnar jointing of coherent dacite lavas. Ten years later, in the middle part of the quarry front, brecciation zones were exposed, suggesting the presence of tuffisite formation processes within the dome body. In 2015, in approximately the same area, at the new quarry front, the contact zone between the dacitic dome rocks and adjacent soft sedimentary deposits is visible (Fig. 12b). Today, this contact zone is much narrower than earlier (Fig. 12c).

Different aspects of peperites and tuffisites can actually be observed in the quarry as well as cooling textures (even radially oriented columnar jointing) in parts of the new extraction front. The dacitic rocks are glassy, black-grayish colored, and often present prominent fluidal textures. Their K-Ar radiometric age is 9.9 ±0.4 Ma (Kovacs et al., 1997a).

Stop 2. Mujdeni quarry – perlites and bentonites in the Orașu Nou rhyolitic dome

The large-sized Oraşu Nou rhyolitic lava-dome represents the most relevant volcanic structure in the southernmost part of the Oaș Mts. (Figs. 7 and 8c). The flat-topped and ca. 5 km across lava dome is an isolated volcanic structure that represents one of the oldest volcanic domes (11.3–11.0 Ma, Kovacs et al., 1997a) in the Oaș Mts. It exposes the unique perlite occurrence in Romania.

The Mujdeni quarry is located about 3.5 km from Orașu Nou village, in the northern part of the rhyolitic lava dome. Fluidal and vacuolar textured rhyolites occur in the upper level of the quarry (Figs. 13a, b). Underneath, a massive quasi-homogeneous level of perlites is exposed, mainly consisting of macro perlites (Figs. 13a, c). In the lower level of the quarry, the perlites pass into bentonites exploited nowadays. The bentonite has variable colors, from yellow-white to greenish or pinkish. The main mineral in the composition of the bentonite is Ca-montmorillonite.

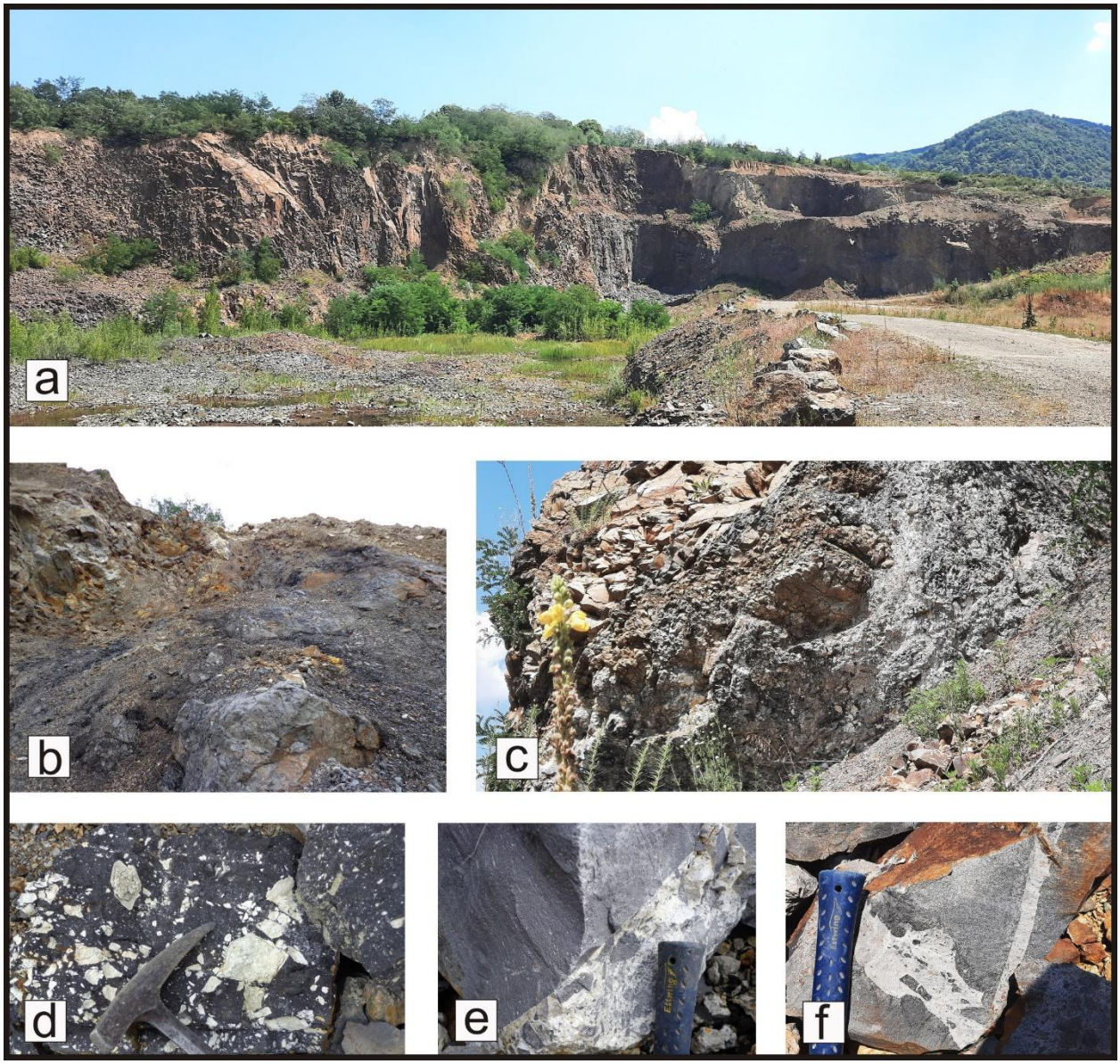


Fig. 12. a) General view of the Turț quarry; b) Soft sedimentary deposits in front of the quarry in 2015 with peperites near the contact with the volcanic rocks of the extrusive dome; c) Contact between the dome dacite (upper left) and sedimentary rocks in the present front of the quarry; d) Detail in peperites at the dome rock-sedimentary rock contact; e, f) Tuffisite veins cutting through the dome dacite. Photo: Marinel Kovacs

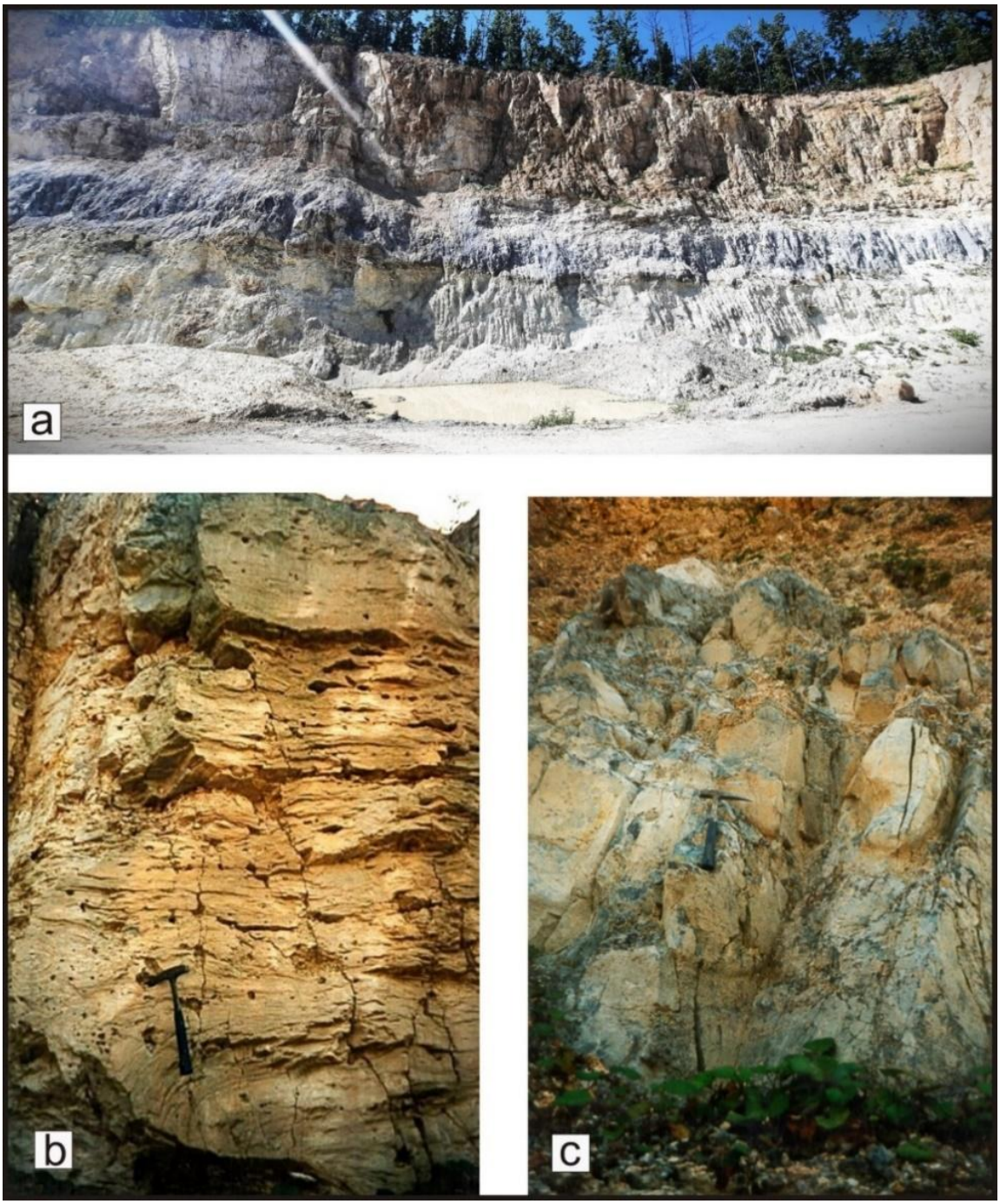


Fig. 13. a) Mujdeni quarry with the three levels of rhyolites, perlites and bentonite; b) Flow-banded vesicular rhyolites (hammer for scale); c) Macro-perlites (hammer for scale). Photo: Marinel Kovacs (a), Alexandrina Fülöp (b, c)

Stop 3. Orașu Nou quarry – fluidal rhyolites and perlites

An old quarry found at the outskirts of Orașu Nou village exposes the rhyolite lava-dome rocks (Fig. 14a) where perlite was exploited for many years. Almost the entire volume of the rhyolitic rocks is perlitized, spheroidal perlites being exposed mostly at the lower level of the quarry (Figs. 14a, b). At the upper part of the quarry, the rhyolites show fluidal texture with many vacuoles (some of them of large sizes). The perlites have typical spheroidal shapes ranging between 0.3 and 5 cm across. Due to the hydration of the glassy rhyolites, the newly formed perlitic material breaks up easily into small pieces along conchoidal fractures. Many of these show a waxy luster of typically light gray color.

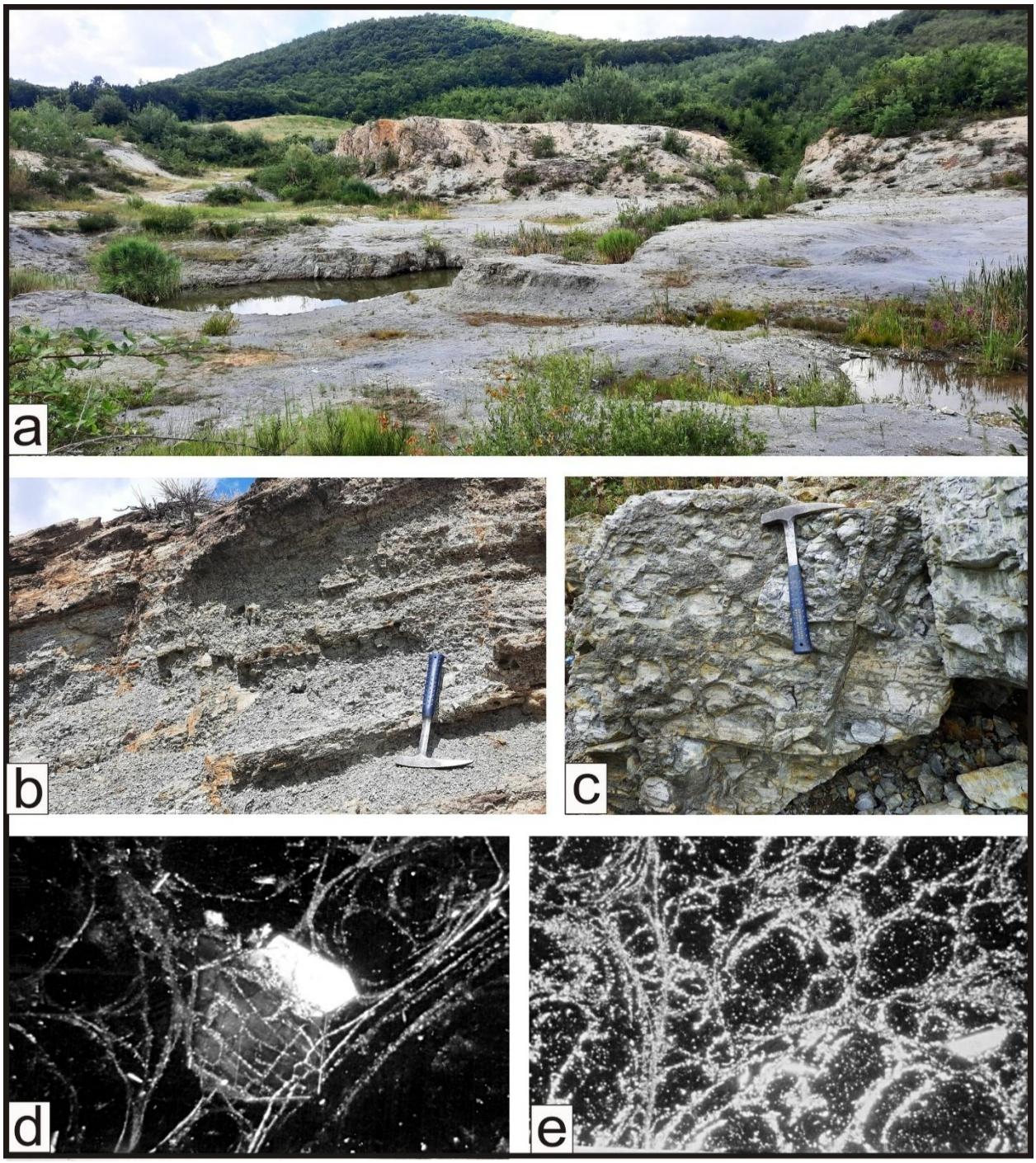


Fig. 14. a) The old quarry in Orașu Nou where perlites were exploited for decades; b) Perlitized glassy rhyolites of fluidal texture (hammer for scale); c) Close-up photo of perlitic rhyolite (hammer for scale); d, e) Photomicrographs of the perlitic rocks with typical spheroidal/perlitic texture. The pictures sizes are 3.2 x 1.9 mm. Photo: Marinel Kovacs

In places in the quarry, the fine-grained perlites form an amazing "perlitic sand". Under the microscope one can recognize the typical "perlitic microtexture" along with scarce feldspar and quartz microcrystals (Fig. 14d, e).

Stop 4. The "Stone Rosette", Ilba

The outstanding geological formation locally known as the "Stone Rosette" ("Rozeta de piatră") in Ilba locality is a regionally unique and worldwide extremely rare feature of andesitic volcanic rock occurrence. Uncovered by an old quarry, it consists of a radial arrangement of cooling-related columns (Fig. 15a, b)

resulting from the development of columnar jointing of a small-sized (ca. 150 m across) magmatic body during its solidification process. Various hypotheses were proposed to explain the actual nature of the magmatic body (i.e., effusive vs. intrusive) and its genesis. The currently accepted genetic explanation of the Ilba "Stone Rosette", according to recent on-site observations confirming and detailing earlier approaches (e.g., Szakács and Kovacs 2022) is that of a small-sized extrusive andesitic dome, subaqueously emplaced amongst unconsolidated fossiliferous sediments and covered by reworked volcaniclastic rocks after a short episode of erosion of its uppermost part. These processes occurred at the margin of one of the small easternmost embayments of the great Pannonian Basin during Upper Miocene times. The well-preserved central part of the dome body exposes its unique, both scientifically and aesthetically outstanding rosette-like structural feature of the radially arranged cooling columns.

Petrographically, the volcanic rocks of the "Stone Rosette" are represented by andesites to basaltic andesites (SiO_2 ranging between 55.5 and 57.5 wt%). A K-Ar age of 9.7-9.3 Ma was obtained for the "Stone Rosette" andesites (Kovacs et al., 2017).

The Ilba "Stone Rosette" represents a natural protected area in Romania (IUCN category III) and a unique patrimonial asset denominated as a "nature monument".



Fig. 15. a, b) The Ilba "Stone Rosette" with radially arranged cooling columns developed in the central part (core) of the small-sized extrusive andesitic dome. Geologist as scale (b). Photo: Marinel Kovacs

Stop 5. Rhyolitic volcaniclastic sequence in Ilba, Handal

On the left side of the road near the Ilba Valley a continuous North-South oriented outcrop (ca. 100 m in length and a maximum height of over 25 m) offers the possibility to observe a complex lithological succession in the volcaniclastic deposits of the earliest rhyolitic/silicic volcanism. In the southern part of the outcrop, at the base of the succession, terrigenous sedimentary deposits (Badenian) are exposed, covered by breccias with small-sized clasts, in turn, supporting coarse breccias with very various clast types, including ignimbrites. Over the coarse breccias follow conglomerates with tuffaceous matrix and subangular, some subrounded or rounded elements of various sizes (maximum 20 cm), in which the frequency of pebbles increases upwards, among which many clasts are of ignimbrite with visible fiammes of different sizes and orientations. The breccia and conglomerate deposits located above the terrigenous sedimentary deposits represent resedimented pyroclastic deposits of the debris flow type, emplaced underwater, in the Badenian sedimentary basin developed in the area (Fülöp, 2003). In the northern part of the outcrop, there is a sudden transition to homogeneous and compact ignimbrites developed at a height of about 15 m.

From the petrographic point of view, the ignimbrite deposits are represented by vitro-cristalloclastic lapilli tuffs, with pumice and accidental lithic clasts (of metamorphic, sedimentary and rarely magmatic rocks, Fülöp, 2003). They represent primary pyroclastic flow deposits resulting from a large-scale explosive volcanism. The cited author associates these deposits with the explosive volcanic activity of a caldera located west of Ilba (Fig. 6a).

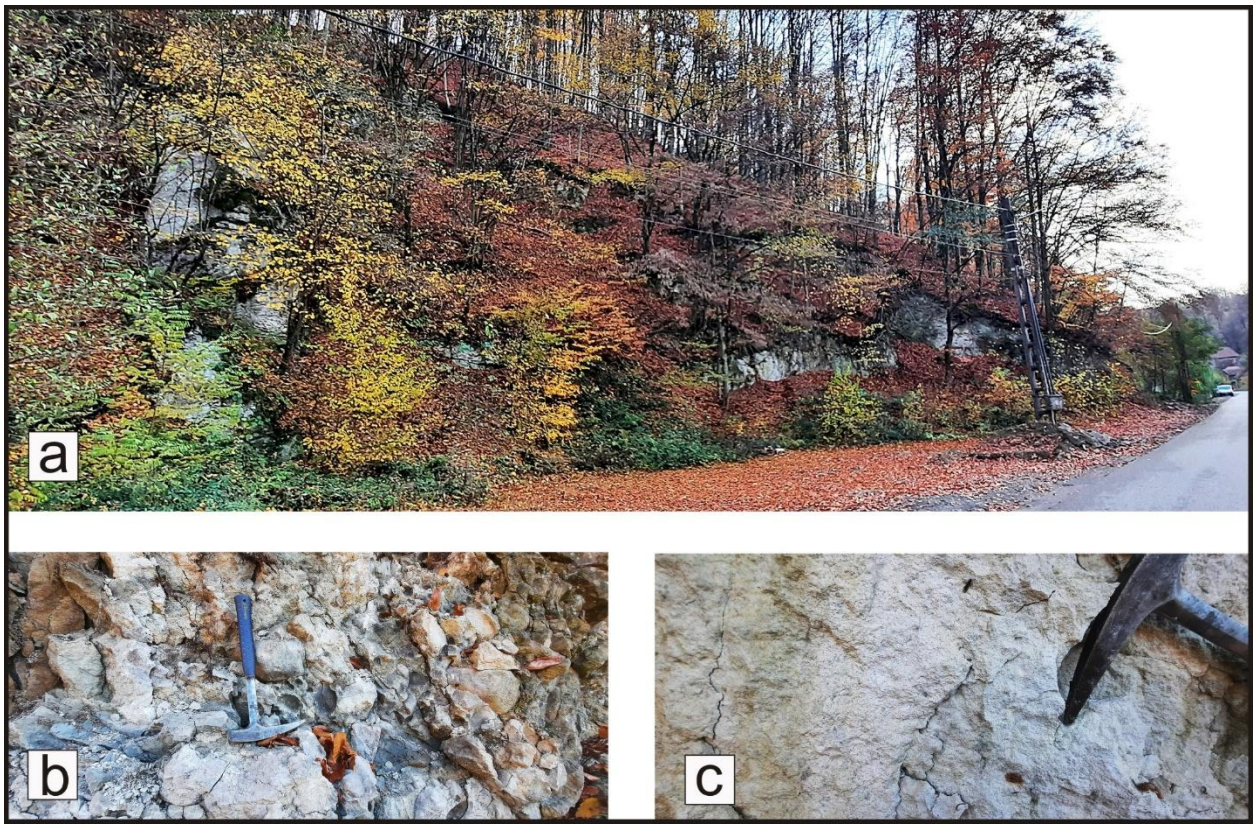


Fig. 16. a) Valley-side outcrop in the rhyolitic volcaniclastic sequence at Ilba, Handal; b) Conglomerates with tuffaceous matrix; c) close-up of the homogeneous and compact ignimbrites in the northern part of the outcrop (hammer for scale). Photo: Marinel Kovacs



Fig. 17. Outcrop in a thick layer of ignimbrites on the left side slope of the road in the Ilba, Handal area. Photo: Marinel Kovacs

Stop 6. Hydrothermalized rhyolite ignimbrites, Nistru

A large-scale outcrop exposes Badenian-age welded ignimbrites of rhyolitic composition at the site known as Golden Crown (Coroana de Aur) in Nistru village, belonging to the earliest stage of volcanic evolution in the north-western Oaș-Gutâi segment of the East Carpathian Neogene volcanic range in Romania (Fülöp, 2003). Despite moderate post-depositional hydrothermal transformation of the rocks, most of the relevant lithological and petrographical features of a high-temperature felsic pyroclastic formation resulting from a large-volume Plinian eruption can readily be observed and studied. Within the horizontally stratified ignimbrites, a 12-15 m succession of depositional units can be seen with upward decreasing thicknesses starting from a 3.5 m thick basal bed. Petrographically, they are heterogeneous crystalo-vitro-lithoclastic lapilli-tuffs rich in sedimentary, magmatic, and metamorphic lithic clasts up to 5 cm in size. Most characteristic are the up to 4.2 cm large flattened high aspect-ratio pumice clasts indicating high degrees of welding and high emplacement temperature of the explosive volcanic material transported as high-density pyroclastic flows (Fülöp, 2003). The high emplacement temperatures are also testified by the columnar jointing of the rocks mostly visible in the upper part of the exposure (Fig. 18). This particular feature of the Nistru rhyolite ignimbrites is unique in the whole Neogene volcanic areas in Romania.



Fig. 18. Hydrothermalized welded ignimbrites with columnar jointing in the upper part of the outcrop. Photo: Marinel Kovacs

Its relevance resides not only in the fact that it represents the products of the oldest Neogene volcanic activity at regional scale (Fülöp 2002, 2003), and it exposes unique lithological features, but also because it is the proximal, eruption center-close counterpart of a largely widespread felsic tuff formation known in the whole Transylvanian Basin (locally named Dej Tuff, Perșani Tuff) and far beyond in the outer skirts of the Carpathians (Slănic Tuff) (Szakács and Fülöp, 2002).

Day 2. Volcanism and metallogeny in the south-eastern part of the Gutâi Mts.

Stops 7 and 8. Cavnic epithermal ore deposit (hydrothermal alterations and waste dump of the Varvara gallery)

The Cavnic epithermal ore deposit is located in Cavnic town, situated approximately 35 km east of Baia Mare. The geological background of the area consists of volcanic rocks of the intermediate/andesitic volcanism of the OGVZ (lava flows and volcaniclastic deposits), numerous intrusive bodies, and Neogene sedimentary deposits including Paleogene flysch in the basement.

The Cavnic ore deposit consists of two distinct groups of veins considered as two individual ore deposits, Bolduț and Roata, respectively (Fig. 19). As a whole, a major NNE-SSW oriented sub-parallel veins system characterizes both ore deposits, located at a distance of 120-350 m from each other. The length of the veins varies between 300 and 2500 m, their thickness ranging between 0.5-7.0 m, with vertical extensions of 800 m in the Bolduț and 600 m in the Roata ore deposit. In the eastern part of the Bolduț ore deposit, poorly mineralized breccia pipes and breccia dykes are developed, crossed by a number of veins (Genna et al., 1994; Mariaș, 2005). The mineralization has a polymetallic character (Pb+Zn±Cu, Au), showing vertical zonality (gold-silver in the upper part - native gold and silver sulfosalts). The hydrothermal alterations consist of extensive argillic alteration with intense local silicification. Adularia is much subordinate, developed especially in the veins together with quartz. Advanced argillic alteration, kaolinite±pyrophyllite±alunite and vuggy silica occur in restricted areas in the upper part of the Cavnic epithermal system (Mariaș, 2005).

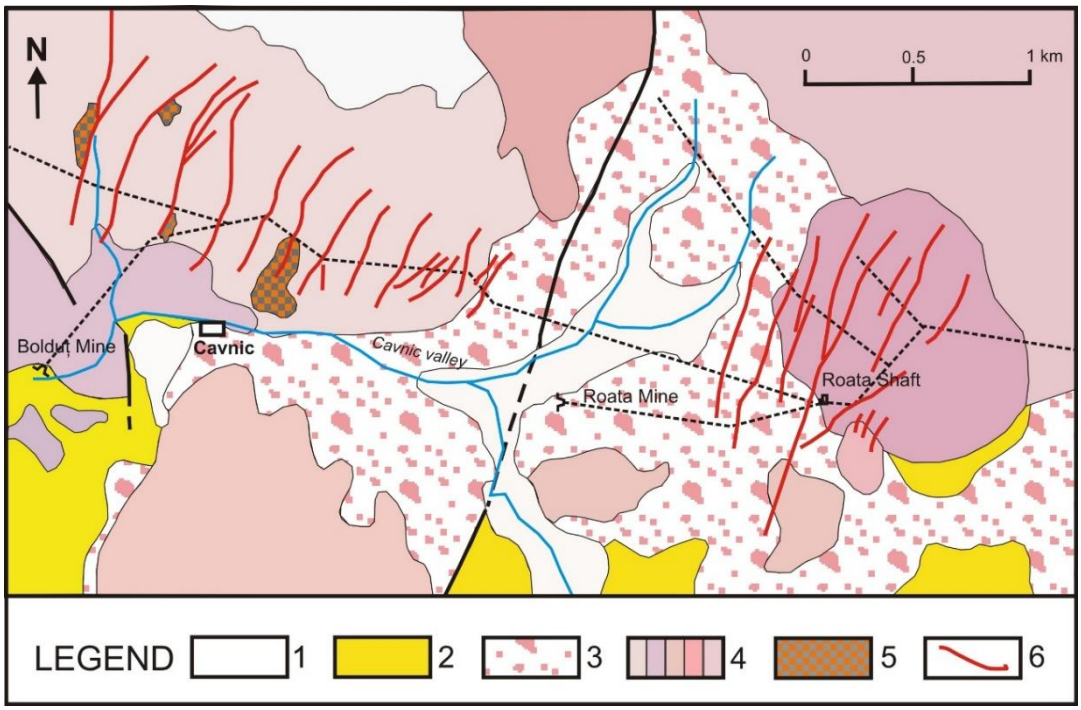


Fig. 19. Simplified geological map of the Cavnic zone showing the distribution of the main hydrothermal veins from the two ore deposits, Bolduț and Roata (redrawn and enhanced from the original, Edelstein et al., 1992b). Legend: 1. Quaternary deposits; 2. Pannonian sedimentary and volcano-sedimentary deposits; 3. Volcaniclastic deposits; 4. Various types of effusive rocks holding local names (shades of pink); 5. Intrusive rocks; 6. Veins. The dashed black lines represent the main galleries of the two mines (Bolduț and Roata) accessing the vein systems.

Fluid inclusion studies on quartz, carbonates, and sphalerite from different veins and levels in the ore deposits determined homogenization temperatures ranging between 207-325 ºC, as well as 5-14 wt% NaCl salinity values for the mineralizing fluids (Grancea et al., 2002). The metallogenetic processes were extremely complex in the Cavnic epithermal ore deposit, involving seven distinct stages (M1-M7, according to Mariaș, 1996, 2005), including repeated input of magmatic fluids, mixing with meteoric water, a boiling process and a final "thermal drop down" of the hydrothermal system.

The relationships between the volcanic rocks, intrusions and the mineralization can be observed in the Bolduț ore deposit (Fig. 20). The K-Ar ages of the volcanics range between 11.3-10.7 Ma, whereas those of the intrusions are younger (9.6-9.3 Ma, Kovacs et al., 2013). Many of the veins are hosted in both types of magmatic rocks, effusive and intrusive. A K-Ar age of 9.3±0.5 Ma was obtained on illite from a vein hosted in volcanic rocks in Roata mine (Kovacs et al., 1997b).

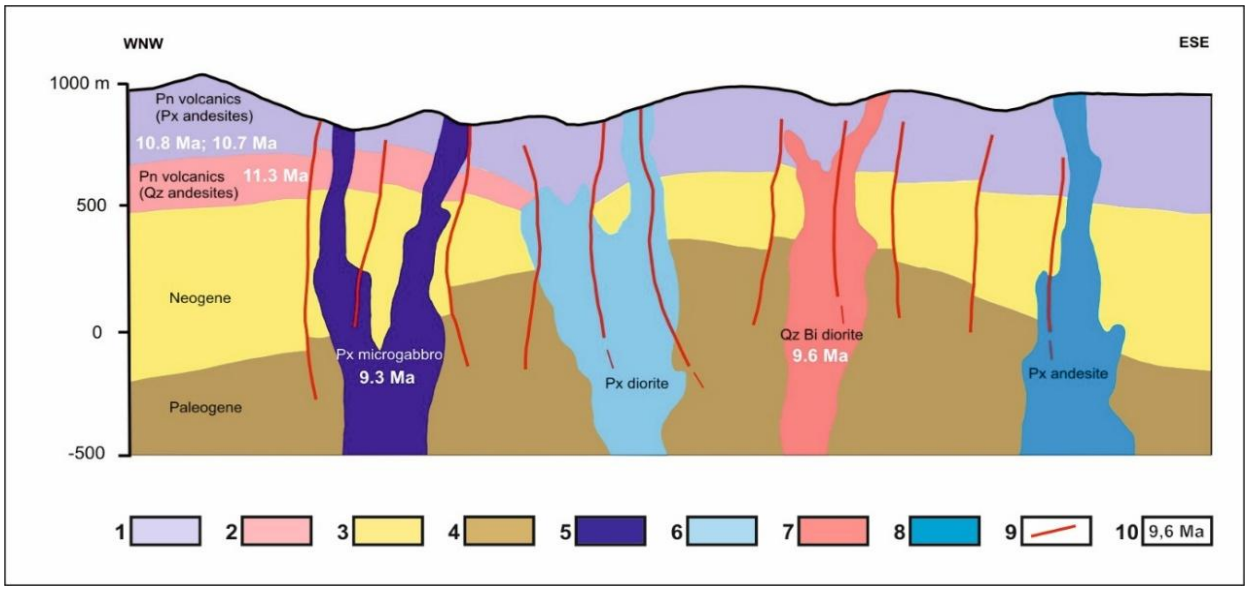


Fig. 20. Geological cross-section through the Cavnic polymetallic epithermal ore deposit - Bolduț mine. (From Kovacs et al., 2013). Legend: 1. Pyroxene andesite lava flows and associated volcaniclastic rocks; 2. Quartz andesite lava flows; 3. Pannonian sedimentary deposits; 4. Paleogene flysch-type sedimentary deposits; 5, 6, 7 and 8. Intrusive bodies; 9. Hydrothermal veins; 10. K-Ar ages.

At **Stop 7,** hydrothermal alterations in the left slope of the Cavnic valley (and the road Baia Mare-Sighetu-Marmației from the Cavnic town) are observed. The volcanic rocks show strong argillic and silicic alteration in the area considered as part of a breccia pipe, well developed underground, between two important veins - Voievod and Elisabeta (Mariaș, 2005).

Stop 8 represents the waste dump of two galleries (Varvara I and II) situated at about 500 m to the NE from the administrative buildings of the Bolduț mine. Both galleries were closed in 2006 when all mining activity related to the polymetallic and gold ore deposits stopped in the region (as in the whole of Romania). At the entrance of the Varvara II gallery, a thin oxidized vein can be observed. On the waste dump, near the galleries, fragments of the mineralization can still be found, some with banded texture, and hydrothermal quartz of several generations along with ore minerals (sphalerite, galena and pyrite).

Stop 9. "Falcon Stones" volcaniclastic sequence, Cavnic

Located west of Cavnic town, "Falcon Stones" ("Pietrele Șoimului") is the local name of a spectacular escarpment, exposing a succession of discontinuous rock formations along the local vertical cliffs, in places more than 100 m high (Fig. 21). Although extremely difficult to access and only at a few sites, the rock formations forming the "Falcon Stones" escarpment can be examined at the base of the cliffs where an impressive number of large blocks, up to 20 m long and several metres high, detached and scattered at the cliffs base on the gentle landscape of Pannonian sedimentary deposits.



Fig. 21. General view of the "Falcon Stones" escarpment at the contact with Pannonian sedimentary deposits. Photo: Marinel Kovacs.

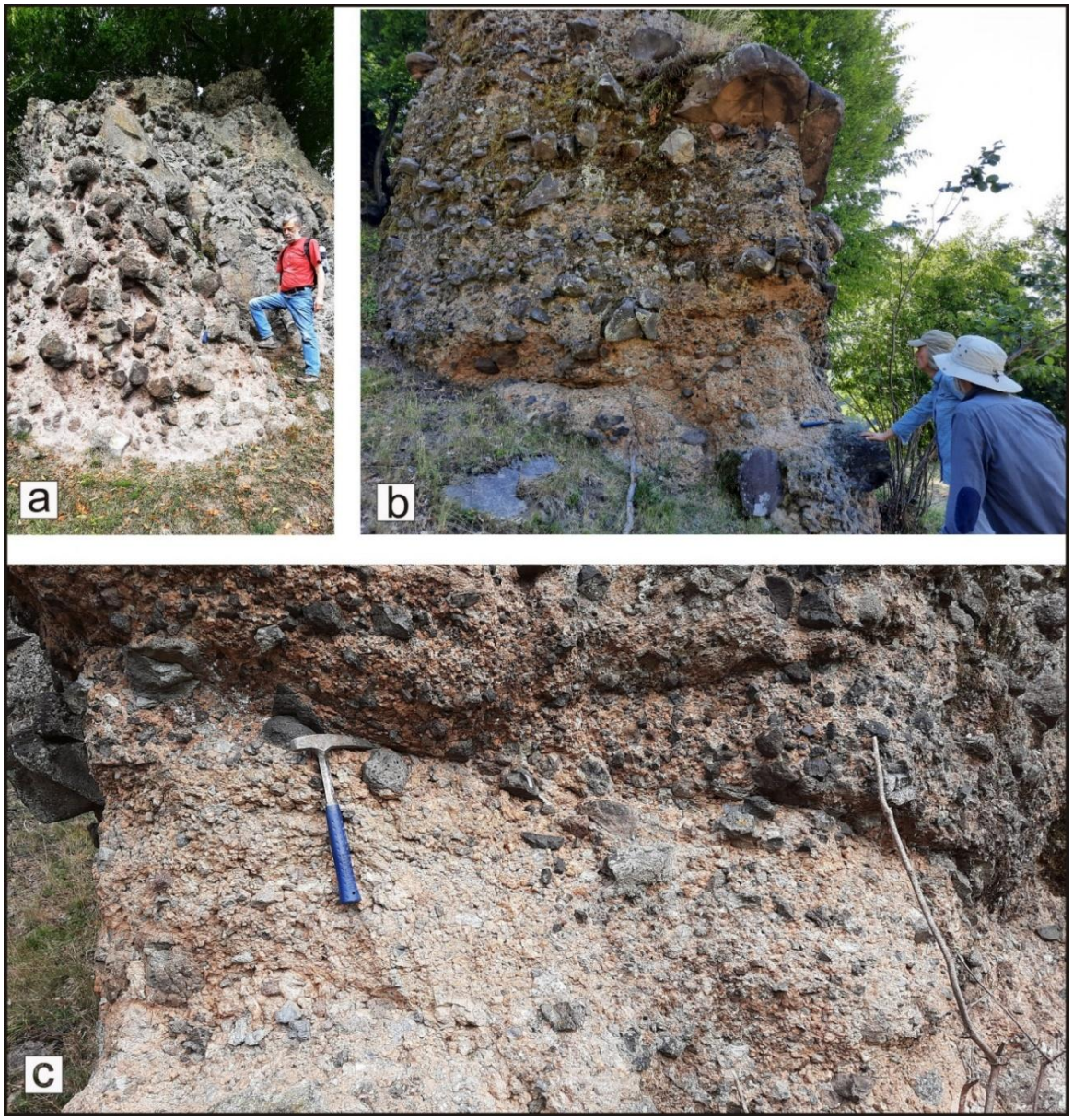


Fig. 22. a) Block-and-ash-flow deposit in a large block from the "Falcon Stone" escarpment (person for scale); b) Phreatomagmatic deposits in a large block (persons for scale); c) Detail of picture in b) (hammer for scale). Photo: Marinel Kovacs

The blocks consist of volcaniclastic deposits of various types, mostly breccias, from autoclastic lava breccias to pyroclastic deposits. According to their petrographic features, mineral composition and texture, the majority of the volcanic clasts belong to the Arșița-type basaltic pyroxene andesites, indicating their provenance in close relationship with the evolution of the Arșița dome, part of the composite nearby Mogoșa volcano. A K-Ar age of 11.4 Ma reinforces this interpretation. Block-and-ash-flow deposits were recognized in part of the blocks (Fig. 22a), testifying to the occurrence of pyroclastic episodes of dome formation during which parts of the extrusive material collapsed on the steep slopes, generating this type of deposit. A few blocks display bedded phreatomagmatic pyroclastic rocks (Fig. 22b, c), suggesting magma-water interaction during the early phase of dome growth in accordance with observations at a number of other sites indicating the presence of a shallow water environment in which the volcanic activity took place during Pannonian time. Blocks of basaltic andesite lava with an autoclastic breccia envelope were also found. All these lithological and petrographical features of the studied blocks, derived from the "Falcon Stones" escarpment, all of primary origin, offer a realistic insight into the Arșița dome-forming process, including initial phreatomagmatic explosive activity, constructional phases interrupted by destructional episodes through partial dome-collapse and block-and-ash-flow processes. These are precious pieces of evidence on the complexity of the Arșița dome formation and of the larger Mogoșa composite volcano at its early evolution stages, to which it belongs (Szakács and Kovacs, 2025).

Stop 10. Basaltic andesite sill, Șurdești

An inactive quarry located east of Șurdești locality exposes the internal body and the upper contact of a shallow sheet-like magmatic intrusion, a sill, conformable with the hosting sedimentary deposits, Pannonian-age stratified mudstones and siltstones in this case (Fig. 23). The exposure is ca. 100 m long and ca. 15 m high. The upper sub-horizontal contact between the magmatic rock body below and the bedded sedimentary deposits above is undulated, suggesting forceful lateral magma intrusion locally uplifting the sedimentary layers from above. At the western termination of the quarry, the contact dips abruptly, suggesting the lateral termination of the sill nearby.



Fig. 23. General view of the basaltic andesite sill at Șurdești. Photo: Marinel Kovacs

The magmatic rock of the sill has a basaltic andesite composition containing characteristic glomeroporphyric pyroxene phenocrysts. This petrographic feature is common with that of the volcanic rocks of the Arșița dome just north of the quarry, part of the larger Mogoșa composite volcanic edifice, suggesting that the two formations - one intrusive, another extrusive - are part of the same magmatic system. The age of the intrusion can be considered similar to the K-Ar age of the rocks of the Arșița dome (11.4-11.3 Ma).

The intrusive rock of the sill shows a cooling joint pattern of contraction fissures arranged in various directions. Post-magmatic fluid circulation along a wider fracture cutting through the sill generated colloidal silica crusts of calcedony.
The Șurdești sill represents a rare occurrence in the Oaș-Gutâi Mts. and in the whole East Carpathians Neogene volcanic range, showing an exposed contact with the enclosing sedimentary rocks.

Stop 11. The wooden Church of Saints Michael and Gabriel in Șurdești

The old wooden churches are the finest examples of Maramureș's vernacular architecture. Built primarily during the 17th and 18th centuries, these churches are distinguished by their bold Gothic-inspired towers, the fine balance of their proportions, the masterful joinery of their wooden beams, and their sculptural ornamentations. Inside, they feature naïve mural paintings influenced by the post-Byzantine and Baroque styles, valuable icons painted on wood or glass, meticulously crafted Royal Doors and other objects of historical and artistic value. The stories behind these churches are just as fascinating as their architecture, from the way they were built, the remarkable journeys some made from one village to another, to the mysteries that continue to surround many of them and the debates over their true age.

Since 1999, eight wooden churches in Maramureș County have been part of the UNESCO World Heritage. Among them, one of the most visited ones is the wooden church of Saints Michael and Gabriel in Șurdești (depicted in the photo), a village located in the Land of Chioar, near the main road connecting Baia Mare and Cavnic. Built from oak timber in 1766 for the Greek Catholic community, the church is immediately striking for its monumental tower and elegant silhouette. Although the building is often reported to be 72 metres tall, relevant sources show that it actually rises to 54 metres. That is still enough to make it the tallest wooden church in the world built before the 20th century!



Its high, slim spire features four small pinnacles at its base corners, which traditionally show that the local village possessed an Elder's Council with judicial rights. The roof has double eaves going all around the church, with a row of windows between them. During the 19th century, a porch with two storeys was added in front of the entrance door. On both sides of the doors there are four pilasters of twisted rope, and below them enormous rosettes inside concentric circles.

The Baroque-influenced iconostasis is considered the most beautiful and valuable part of the church's interior. The mural painting was executed towards the end of the 18th century by several artists, the best-known being Ștefan the Painter of Șișești, who painted the chancel in 1783 and left an inscription attesting his work. On the vault of the naos, there is the Holy Trinity, while on the ceiling of the pronaos is a rare representation of the solar system.

Until recently, this was the village's only church serving the Greek Catholic community. Today, despite the construction of a new church, the old wooden one continues to be used during the warmer months and for special religious celebrations. It is also the starting point of the *Udătoriu*, an old agrarian custom that is still being celebrated every year on the second day of Easter. The surrounding cemetery is listed as a national cultural heritage site due to its funerary monuments, with carved wooden crosses and stone slabs reminiscent of Roman sarcophagi.

Stop 12. Mine Hill (Dealul Minei), Baia Sprie

The Mine Hill (Dealul Minei) hosts the uppermost part of the Baia Sprie hydrothermal gold-silver and base metal ore deposit. Many outcrops of the gold-bearing Main/Principal vein and of several additional veins have been identified in Middle Age times, from where the centuries-long ore mining activities started and developed. The Baia Sprie epithermal ore deposit represents one of the best–known ore deposits in Romania and Europe. The deposit had been mined continuously since the beginning of the XIVth century (when it was mentioned for the first time in written documents) until 2006.

The Baia Sprie ore deposit belongs to the Herja–Băiuţ metallogenetic field of the Baia Mare Neogene metallogenetic district. A broader presentation on the geology of the Baia Sprie ore deposit has been done by Kovacs and Iştvan (1994), Damian et al. (1995), Kovacs et al. (2001) and Kovacs and Fülöp (2010) in previous field guidebooks.



Fig. 24. Overview of the Mine Hill (Dealul Minei) obtained by drone photography; Photo: Márk Varga.

The ore deposit has an impressive richness of the mineralogical association with almost 100 mineral species. It is also the **type locality for 6 minerals** (andorite, semseyite, felsöbányaite, dietrichite, klebelsbergite and szmikite). The earliest description of a new mineral, felsőbányaite, with the Hungarian name of Baia Sprie, dates to 1854. The deposit is classified as a "world-class hydrothermal ore deposit".

The geological background consists of Neogene (Sarmatian and Pannonian) sedimentary deposits, and Pannonian volcanics with associated intrusions (Fig. 25).

The ore deposit developed in a tectonic structure, i.e., a system of two parallel E–W-trending faults, bounding a graben filled in with a thick pile of volcanic products (more than 700 m in the western part, in Dealul Minei, and more than 900 m in the eastern part). This tectonic structure developed along the major wrench/transcrustal Bogdan–Dragoş vodă fault system (BDFS) in the eastward extension of the so-called Middle Hungarian Line, which separates two lithospheric blocks, ALCAPA and Tisza-Dacia (Săndulescu, 1984; Csontos and Nagymarosy, 1998; Tischler et al., 2007).

The ore deposit consists predominantly of a vein system, different types of breccias and stockworks developed in the western part of the graben structure, in the Mine Hill. The vein system consists of two main veins developed along the faults which delineate the graben: the Principal Vein in the north and the Nou (Southern) Vein, in the south (Figs. 25, a, b). Several smaller NE–SW-oriented veins occur within the graben (e.g., the Diagonal Vein). With a length of more than 5 km, the Principal Vein is one of the longest hydrothermal veins in Europe. The thickness varies between 0.5 and 22 m, and the vein extends vertically on more than 800 m. In the upper part, the Principal Vein has many branches, mostly concentrated in the western part of the ore deposit, in the Mine Hill area. The Nou (Southern) Vein is 2100 m long and 0.5–7 m thick, whereas the Diagonal Vein is approximately 600 m long and a maximum of 1 m thick.

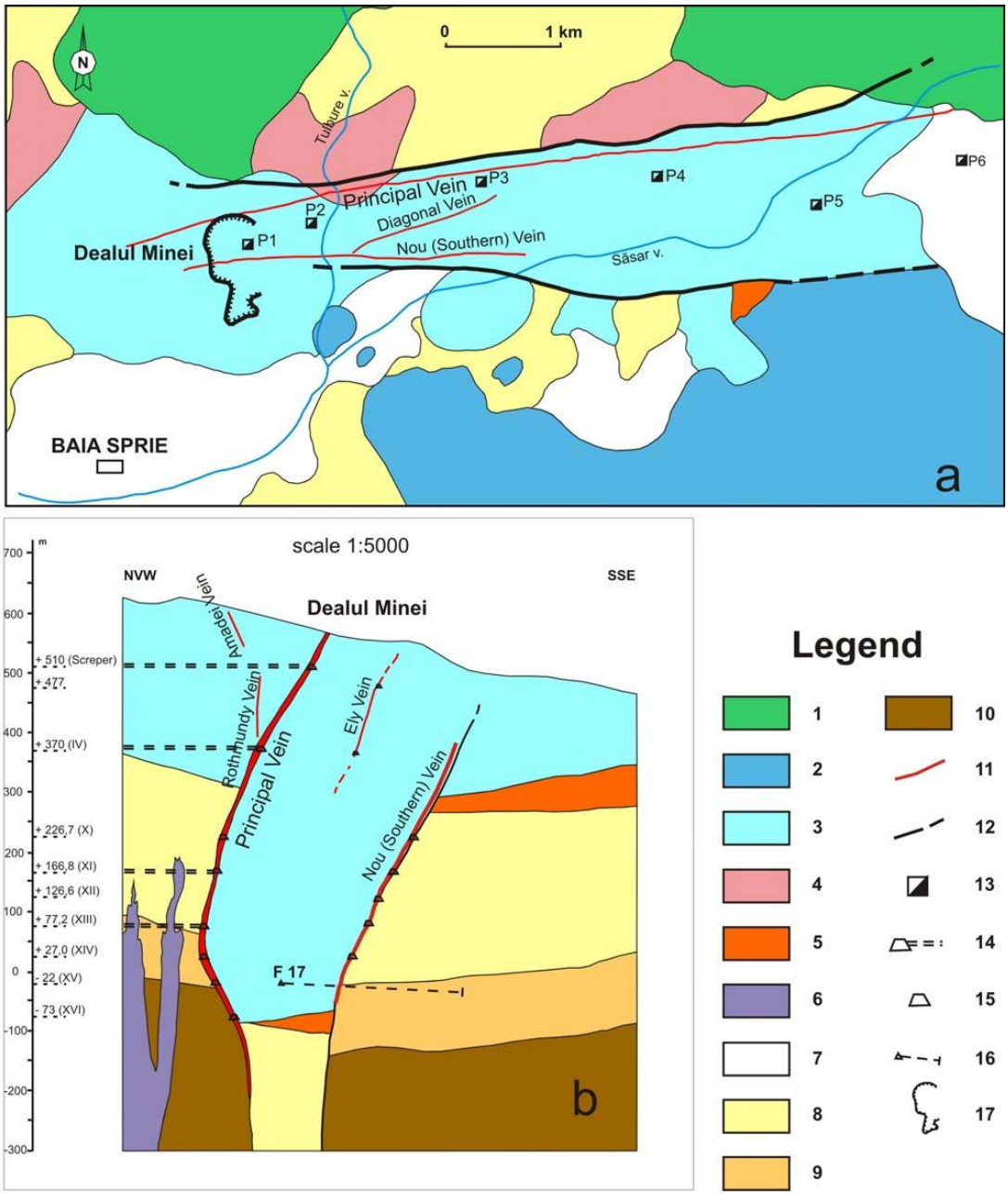


Fig. 25. a) Simplified geological map of the area hosting Baia Sprie ore deposit (acc. to Gabor et al., 1999); b) Geological cross-section through the western part of the ore deposit/Mine Hill (modified after Edelstein et al., 1992b). Legend: 1. Pyroxene andesites; 2. Basaltic andesites with pyroxene; 3. Pyroxene ± hornblende, quartz andesites (Baia Sprie type); 4. Quartz andesites; 5. Biotite dacites (Dănești type); 6. Pyroxene + hornblende andesites (intrusion); 7. Quaternary; 8. Pannonian sedimentary deposits; 9. Sarmatian sedimentary deposits; 10. Paleogene sedimentary deposits; 11. Vein; 12. Fault; 13. Shaft; 14. Crosscut; 15. Adit; 16. Borehole; 17. Open pit.

The mineralization of the Baia Sprie ore deposit has a polymetallic character (lead + zinc + copper + gold–silver). A well–defined vertical zoning was observed, especially within the Principal Vein: gold–silver in the upper part, polymetallic in the middle part and copper–rich mineralization at depth. A similar zoning is displayed by the distribution of the hydrothermal alteration types (Stanciu, 1973): chlorite alteration is developed in the deepest zone, in connection with the copper–rich mineralization, whereas the adularia–sericite and the argillic alterations occur in the middle part of the deposit in connection with the polymetallic mineralization. Adularia–quartz/sericite + argillic alteration characterizes mostly the uppermost part, well exposed at the surface (Mine Hill/Dealu Minei area).

Different types of breccias were described especially in the eastern part of the ore deposit (Genna et al., 1994; Grancea et al., 2002; Mariaş, 2005): mineralized breccia dykes of hydrothermal explosive origin, breccia veinlets and well–developed breccia pipes suggesting the genetic link between the hydrothermal events and the phreatomagmatic explosions.

The Baia Sprie ore deposit shows one of the most complex and richest mineralogical associations in Romania and Europe, consisting of almost 100 minerals described by many authors over the over 150 years of geological research. The minerals occurring in this deposit belong to native elements, sulfides and sulfosalts, oxides, carbonates, sulfates, wolframates, phosphates, arsenates and silicates. In the upper part of the Baia Sprie ore deposit, Damian et al. (2003) described Ag–sulfosalts, such as freibergite (included in galena or associated with pyrite and other silver sulfosalts), stephanite and pearceite–polybasite (associated with freibergite, pyrargyrite and miargyrite).

Homogenization temperatures measured in fluid inclusions in hydrothermal quartz ranging from 200º to 300º C were reported by Manilici et al. (1965), Borcoş et al. (1975) and Pomârleanu et al. (1985). Bailly et al. (1998) documented the characteristics of the fluid inclusions in quartz and sphalerite belonging to the four mineralizing stages (M1–M4) considered for the Baia Sprie ore deposit. They reported salinities ranging from 0 to 21 wt.% NaCl equiv. and temperatures between 150º and 300ºC. The high salinity values of the fluids, especially in the first stage, confirm the important contribution of the magmatic source to the hydrothermal fluids. The temperature and salinity oscillations during the main stage (Pb–Zn mineralization) were interpreted by the authors as due to the phreato-magmatic activity leading to boiling of the fluids and the emplacement of breccia pipes. Grancea et al. (2002) highlighted five mineralizing events/stages in the ore–forming system: M1 (Fe), M2 (Cu–W), M3 (Pb–Zn), M4 (Sb) and M5 (Au–Ag), respectively. All five stages characterized the Principal Vein and its numerous branches. Based on the fluid inclusions study and ion content of the quartz crystals, the authors pointed out the Na–K chloride composition of the hydrothermal solutions. The Br/Cl ratio of 0.30 for a sample belonging to M2–M3 stage suggests a magmatic input in the hydrothermal system of the Baia Sprie ore deposit.

In a later approach Mariaş (2005) recognized only three mineralizing events in the evolution of the ore–forming system: M1 - first mineralizing event (cupriferous) dominated by pyrite, chalcopyrite, wolframite, scheelite, ± magnetite and hematite; M2 - the second mineralizing event (polymetallic), dominated by sphalerite + galena + pyrite and chalcopyrite (a boiling assemblage); and M3 - the third mineralizing event, dominated by Ag, Pb–Ag and Cu sulfosalts, associated with quartz and carbonates.

In the Mine Hill open pit, the western and upper part of the Principal Vein crops out. Here the base metal with gold–silver mineralization developed in many vein branches and small stockworks. Native gold, associated with quartz or included in pyrite, occurred in some of the branches. High-grade gold and silver ore was mined from such branches or from the small stockworks, even more than one century ago. The Mine Hill open pit shows mineralized joints consisting of sphalerite and galena, subordinately pyrite, marcasite and chalcopyrite, with quartz, barite and carbonates as the main gangue minerals. Iron oxides and hydroxides occur as well. A strong adularia–sericite/illite and silicic alteration is developed in the open pit. The Ag–rich mineralization consists of Ag–sulfosalts included in galena (Grancea et al., 2002, Damian et al., 2003b).

Microthermometric study of fluid inclusions in quartz and sphalerite from different levels in the Dealul Minei open pit (Grancea et al., 2002) yielded homogenization temperatures in the range of 176 to 254ºC and salinities in the range of 5 to 15 % NaCl equiv. The local variation of the salinities and the presence of vapor–rich inclusions in the quartz growth zones constrained the existence of boiling processes.
The complex evolution of the hydrothermal system in the Mine Hill area is also suggested by the presence and the relationships between different gangue minerals. In the Baia Mare metallogenetic district, the red jasper marks distal and top areas of the epithermal systems (Iştvan et al., 1996). In the upper levels of the Mine Hill the red jasper is crosscut by quartz and polymetallic mineralization of higher temperature, suggesting a polyascendent ore fluid evolution.

K–Ar radiometric data obtained on adularia and illite from different levels of the Principal Vein and from the open pit (Lang et al., 1994; Kovacs et al., 1997b) show a range of 9.3 – 8.7 Ma, whereas their Ar–Ar dating yielded 7.9 Ma for the age of the hydrothermal processes.

Although located within the geographically defined area occupied by the Mine Hill, the small-sized (0.5 ha) Blue Lake (Lacul Albastru) of Baia Sprie is considered a separate geoheritage site because of its particular nature, origin, protection status (IUCN III category protected area, a hydrogeological type "Natural monument") and relevance. The Blue Lake is actually an anthropic lake generated in 1919-1920 through the collapse of the ceiling of an underground mining excavation of the "Domnișoara" vein blocked downstream by a succession of waste dumps. 40x50 m across and 4-5 m deep, the lake is renowned for the changing color of its water, varying between bluish and greenish tones according to changing water depth and temperature, season and weather conditions as well as the concentration of dissolved salts (mostly iron and copper sulfates) originating from the surrounding hydrothermally transformed and mineralized rocks. It is unique in Romania regarding its genesis related to underground mining of gold-silver and base-metal ore, whereas all other mining-related anthropic lakes in the country are found at salt-exploitation localities.

Because the multiple geological and mining heritage assets it hosts, and its geoeducational and geotouristic relevance, Mine Hill is the most prominent geoheritage site of the preparing Gutâi-Maramureș UNESCO Geopark. Moreover, it was recently proposed as a candidate among the Top 100 most important IUGS Geological Heritage Sites worldwide.



Fig. 26. a) Earth Science students from the Babeș-Bolyai University in Cluj-Napoca during their summer field work in the Mine Hill on the upper levels of the open pit and b) at the old excavations of the Leppen vein; Photo: Marinel Kovacs.

Day 3. Volcanism and Mineralogy

Stop 13. "Gutâi serpentines" volcaniclastic complex

A portion of the road connecting Baia Mare city and Sighetu Marmației town across the Gutâi Mts., known as the "Gutâi serpentines" exposes a thick sequence of volcanic formations in numerous successive outcrops. The most interesting of them occur at the most elevated segment of the road near the Gutâi Pass where a 20-25 m thick sequence of volcaniclastic rocks crop out, part of the ca. 200 m thick pile of volcanic formations. It includes volcaniclastic deposits of various nature (hyaloclastites, phreatomagmatic breccias, coarser and finer debris flow and epiclastic deposits) and coherent lava flow rocks, all together part of the complex volcanic structure of the area.

In the Gutâi Pass area, the volcaniclastic deposits host a small-sized cavity locally known as "Pintea's cave". Above the road and below the cave the outcrops expose fine-grained volcanogenic sediments containing charcoal fragments, followed upwards by coarse debris flow deposits, then again finer grained volcaniclastic deposits (Fülöp and Kovacs, 2004, Figs. 27a, b).

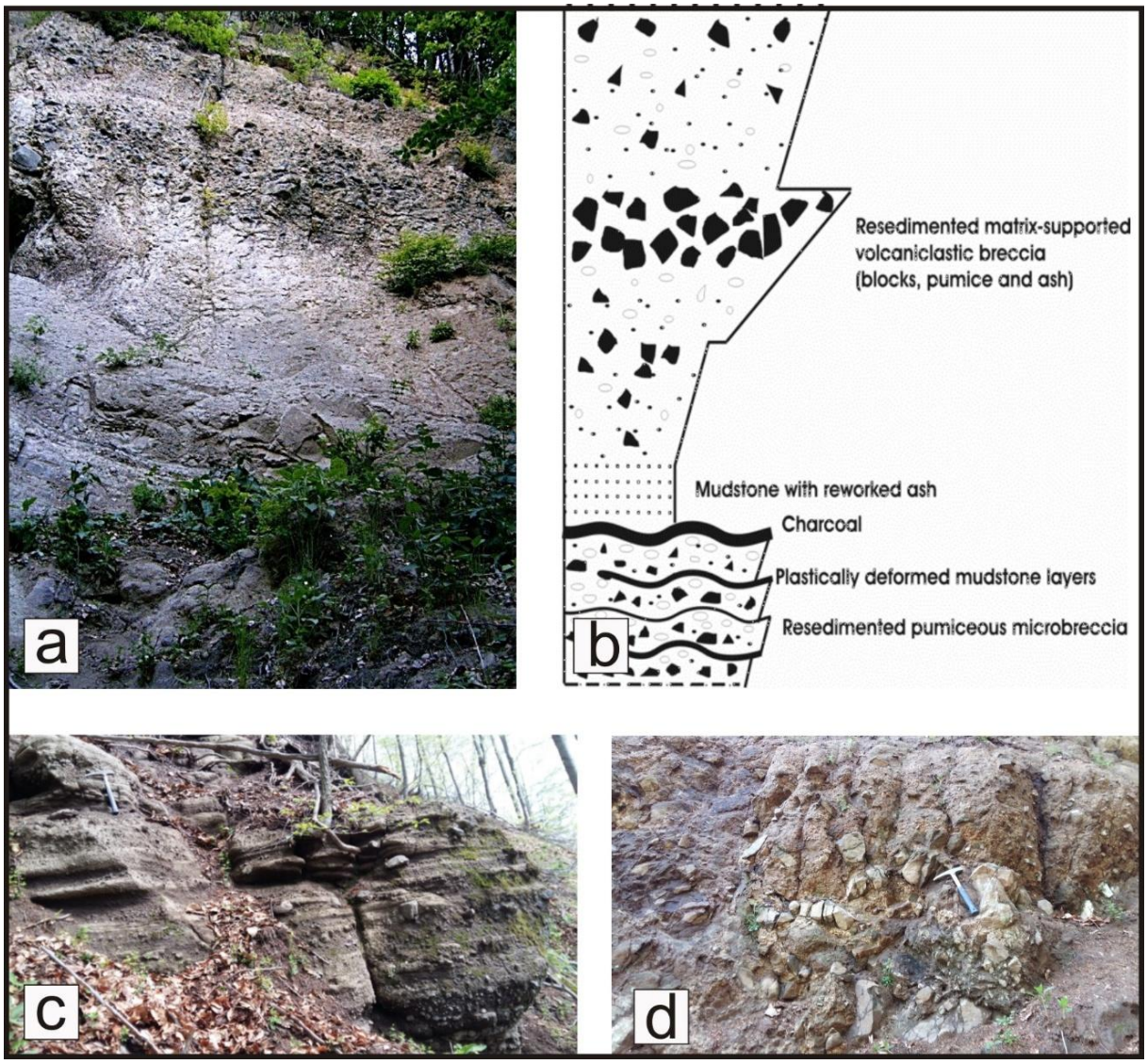


Fig. 27. "Gutâi serpentines" volcaniclastic complex. a) Outcrop in a sequence of fine-grained volcanogenic sediments containing charcoal fragments and coarse debris flow deposits around "Pintea's Cave"; b) lithological column of the sequence depicted in a) (from Fülöp and Kovacs, 2004); c) Sequence of alternating coarse- and fine-stratified volcaniclastic deposits of debris flow origin; d) Chaotic texture of thick coarse breccious volcaniclastic rocks suggesting a debris avalanche origin. Photo: Alexandrina Fülöp (a), Marinel Kovacs (c, d).

Other outcrops display thick and chaotic coarse breccious volcaniclastic rocks suggesting a debris avalanche origin (Fig. 27d). Overall, the sequence of alternating coarse and fine stratified volcaniclastic deposits, originating from reworking of primary volcanic material, either pyroclastic and effusive, occurring in this topographically higher position of the "Gutâi serpentines" area, together with those found in the lower parts of the "serpentines" which also include primary pyroclastic and effusive rock levels likely represents the medial facies of neighboring volcanic edifices where their respective products interfinger and overlap with each other in an inter-edifice area. The high frequency of secondary volcaniclastic deposits containing reworked volcanic material, together with their polymictic composition and the occurrence of carbonaceous material, all suggest such a paleogeographic depositional environment.

According to K-Ar radiometric dating of the intercalated andesite lava flow rocks (10.2 Ma, Kovacs 2002), the time frame of the formation of this thick sequence of volcanic deposits corresponds to the paroxysmal stage (9-11 Ma) of volcanic activity in the Gutâi Mts., when several volcanic centers were active successively and even simultaneously.

Due to the diversity of volcanic products, both primary and secondary, including effusive and volcaniclastic rocks of various nature and genesis, the "Gutâi serpentines" volcaniclastic sequence offers a unique insight into the internal structure and volcanic evolution of the Gutâi Mts. Miocene volcanic area.

Stop 14. "White Tulip" and "Vlaicu's Church" composite dykes

Two dykes ca. 250 m apart from each other, located in the close vicinity of the Gutâi serpentine road connecting Baia Sprie and Sighetu Marmației towns across the Gutâi Mts., represent, together with two other smaller dykes nearby, the manifestation of the penultimate magmatic phase in the Gutâi Mts. in the 8-8.5 Ma time interval (Kovacs, 2002). Unlike the other dykes, of solely andesitic composition, the "White Tulip" ("Laleaua Albă") and "Vlaicu's Church" ("Biserica lui Vlaicu") dykes are petrographically composite, consisting of two contrasting rock types: dark-colored microporphyric to aphanitic andesites and light-colored macroporphyric dacites. In both dykes, the outer andesitic rocks envelope the central dacitic component.

The ca. 900 m long and ca. 40 m wide "White Tulip" dyke is exposed in a tall roadside outcrop, an abandoned quarry, with vertical walls in the upper part and a chaotic agglomeration of large meters-sized blocks at the base, where the two color-contrasting rock types appear roughly figuring the outlines of a light-colored tulip (dacite in the central part) surrounded by the darker-colored andesite deserving its name given by a geologist (Fig. 28a). The smaller ca. 300 long and 15-20 m wide "Vlaicu's Church" dyke, known as so by the local people, shows an exhumed ruin-like morphology of a thick vertical rocky wall with a tower-like top suggesting a church (Fig. 28b) resulting from the selective erosion of the hard dyke rocks against the softer volcaniclastic rocks sideways.

Both dykes share the same petrographic, mineralogical, and chemical characteristics of the two rock components, andesite and dacite. Because the presence of a large variety of primary magmatic minerals in the rocks, readily observable by naked eye or using a hand lens, the two sites can be viewed as true open-air mineralogical museums: besides sanidine macrocrysts up to 5 cm large, one may recognize larger-sized plagioclase, quartz and biotite phenocrysts and smaller-sized amphibole and pyroxene in the dacite, and plagioclase, amphibole, pyroxene and quartz and biotite in the andesite. Moreover, the dacite component of the dyke encloses numerous microcrystalline mafic enclaves (MME) of gabbroic composition, of various sizes (up to 90 cm) and textures, in places containing up to 4 cm long large amphibole (magnesio-hastingsite) crystals (Kovacs and Fülöp, 2010, Fig. 28d).

The contact of the two component rocks of the dykes as recorded in the exposures displays various aspects suggesting the complex interaction between the earlier intruded mafic melt and the later coming

dacitic one as the dyke-hosting fractures progressively opened and filled by the magmatic melts. Evidence of mingling and mixing of the two melts are found mainly at the better exposed and accessible "Vlaicu's Church" dyke whereas other sharp contact relationships indicate that the early andesitic intrusion was already solidified when the later dacitic one was injected in the still open fracture center (Kovacs and Szakács, 2005). Chunks of andesite englobed in dacite were also observed, testifying once again to the succession of the intrusive events. Typical horizontal columnar jointing across the "Vlaicu's Church" dyke, perpendicular to the vertical dyke walls, indicates the slow-rate cooling of the dyke interior (Fig. 28c).

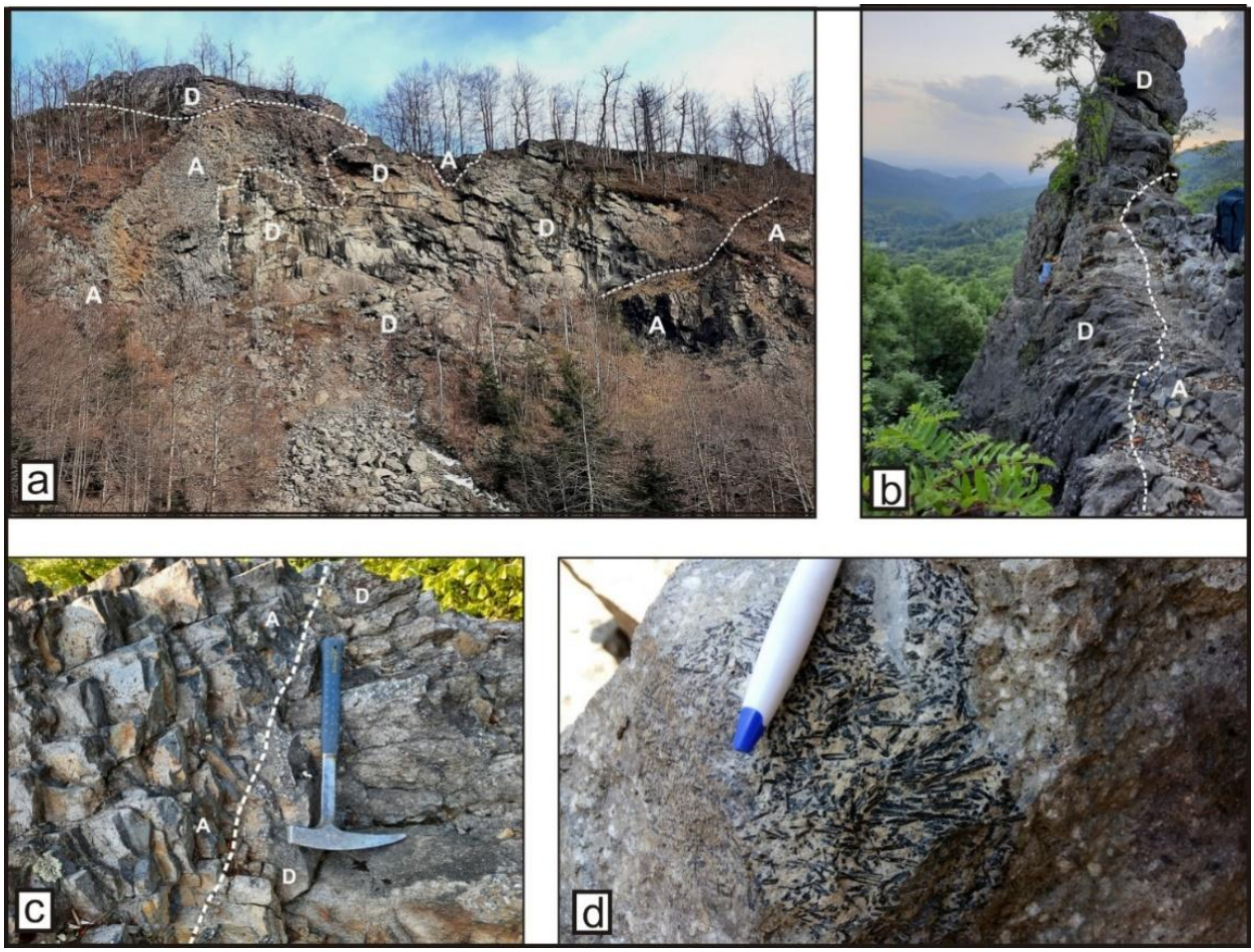


Fig. 28. The "White Tulipe" and "Vlaicu's Church" composite dykes. a) Central part of the "White Tulipe" composite dyke open in an old roadside quarry: the contact between the two rock-types (A-andesite, D-dacite) are marked by white dashed line; b) "Vlaicu's Church" composite dyke with the same mutual andesite-dacite relationship as in the "White Tulipe" dyke; c) horizontal columnar jointing of andesite at the contact with the dacite in the "Vlaicu's Church" composite dyke; d) mafic microgranular enclave in dacite with abundant large amphibole crystals; Photo: Marinel Kovacs.

Magma-mingling and -mixing processes involved in the generation of the two hybrid rocks are constrained by mineralogical, textural, and geochemical data (Kovacs et al., 2010, 2017). The magmatic plumbing system consisting of deep (lower crust) and shallow (upper crust) magma reservoirs (Kovacs et al., 2021, 2025) is consistent with the observed magma-mingling and mixing features involved in the petrogenesis of the "White Tulip" and "Vlaicu's Church" composite dykes.

The outstanding scientific relevance of these sites consists of its regionally unique features from several standpoints: 1) volcanological (representing shallow intrusions belonging to the magma feeding system of the surface-erupted volcanoes above), 2) petrographical (occurrence of two distinct rock types forming composite dykes), 3) mineralogical (the presence of sanidine macrocrysts is unique in Romania and in the

whole Carpathian-Pannonian Region), and 4) structural (exposed internal dyke structure and various space relationships and contacts between the two rock components).



Fig. 29. Macroscopic aspects of the two different rock samples of the composite dykes. a) Andesite; b) dacite; Photomicrographs: c) dacite with large-sized plagioclase and quartz; d) dacite with corroded sanidine phenocryst; e) Microgranular amphibolic-type mafic enclave with dictytaxitic texture; f) pyroxenic-type microgranular mafic enclave (from Kovacs et al., 2025).

Stop 15. "Limpedea" andesite columns, Ferneziu, Baia Mare

The site, located in an extremely easily accessible spot only 5 km from Baia Nare, exposes at its lower part a spectacular vertical wall of columnar-jointed andesites, left behind after quarrying work (Fig. 30a). For a

long time, the andesite columns at Limpedea were presented as typical basalt columns due to their polygonal shapes.

The ca. 20 m high and 1 m across columns of pentagonal and hexagonal section resulted from slow cooling of a thick ponded lava flow of high-silica andesite composition (60.7 SiO2 wt%) erupted ca. 10 Ma ago (inferred from the relationship to surrounding dated volcanics). The upper level of the abandoned quarry above the columnar lower part exposes further cooling features of the andesite lava consisting of both vertical and inclined, locally slightly curved columns (Fig. 30b). Since the contraction joints form perpendicular to the outer surface of the slowly-cooling lava body, one may study and reconstruct the original shape of the body, at least partially.

The Limpedea andesite columns represent a very popular and highly frequented climbing spot and training ground of both amateur and professional practitioners (Fig. 30c). It has a legal protection status (IUCN III category).

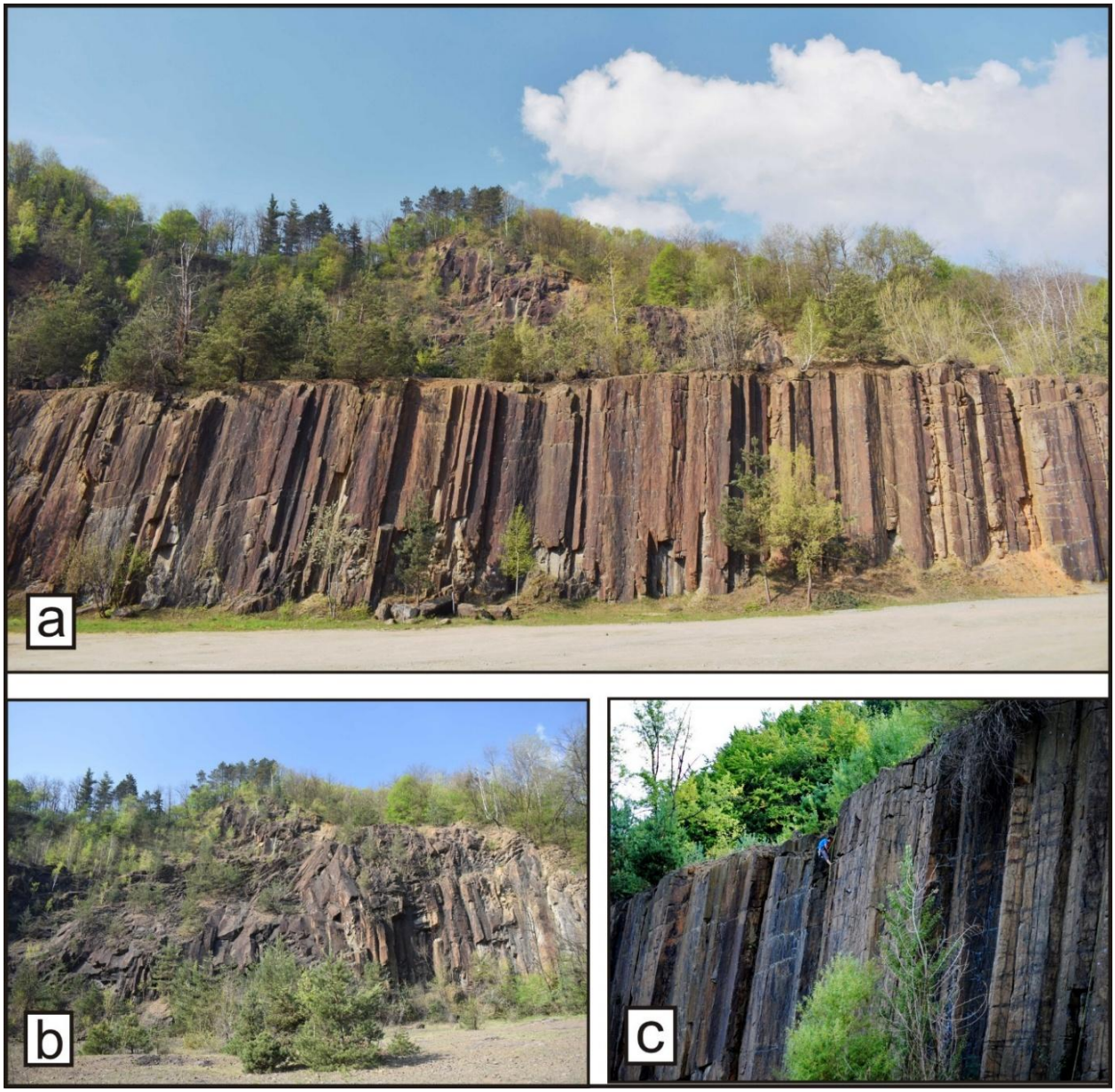


Fig. 30. Andesite columns of Limpedea (Ferneziu). a) Vertical wall of columnar-jointed andesites in the lower part of the abandoned quarry; b) vertical, inclined and slightly curved columns in the upper part of the quarry; c) one of the many climbers ascending on the site's columns; Photo: Rada Pavel (a, b), Marinel Kovacs (c).

Stop 16. "Victor Gorduza" Mineralogical Museum in Baia Mare

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The "**Victor Gorduza" County Museum of Mineralogy** in Baia Mare (Fig. 31a) is one of Romania's leading natural science museums and the largest regional mineralogical museum in Europe. Its defining characteristic is that both the permanent exhibition and the reserve collections consist exclusively of specimens originating from the Baia Mare metallogenetic district, preserving the region's exceptional geological and mining heritage. The remarkable number of specimens, together with their exceptional size, spectacular crystallographic habits, and distinctive mineral associations, has earned the collection international recognition for its uniqueness.

The Museum traces its origins to the Natural Sciences Department of the Maramureș County Museum, established on 17 January 1976. On 6 November 1989, the current permanent exhibition was inaugurated at its present headquarters. A new stage in its development began on 10 December 1992, when the Department became an independent institution as "Baia Mare–Maramureș Mineralogy Museum". Today, it bears the name of its founder and first director, Victor Gorduza, whose vision laid the foundations of Romania's foremost mineralogical museum.

Over nearly five decades of continuous development, the Museum has assembled an outstanding collection of approximately 21,000 specimens, comprising 16,715 minerals, 2,515 fossils, 564 rock and 792 ore samples. Among these, 284 mineral specimens have been included in Romania's National Cultural Heritage in recognition of their exceptional scientific, historical, and cultural value. A distinctive feature of the collection is its exclusively local regional origin, with all specimens derived from the underground mines and natural outcrops of the historic Baia Mare mining district. Following the closure of mining activities in 2006, the collection became an irreplaceable record of a geological heritage that can no longer be further documented through active mining.

The Museum fulfills its mission of preserving and promoting this geological heritage through its permanent exhibition and an extensive programme of temporary exhibitions organized both in Romania and abroad. Since its establishment, it has organized more than 230 temporary exhibitions, including 45 international exhibitions. These have presented the Museum's collections to audiences across Europe, with exhibitions held in Austria (15), France (11), Hungary (10), Germany (4), Belgium (2), the Netherlands (1), Monaco (1), and the Republic of Moldova (1), contributing significantly to the Museum's international reputation while promoting the exceptional mineral heritage of the Baia Mare mining district.

The permanent exhibition displays approximately 1,000 specimens arranged in four thematic sections - Petrography, Mineralogy, Ore Deposits, and "Mine Flowers" - providing a comprehensive overview of the geology, mineralogy, and mining heritage of the Baia Mare metallogenetic district. The ground floor of the Museum is dedicated to the sections Petrography, Mineralogy, and Ore Deposits, having an important teaching and geoeducational accent.

The **Petrography** section opens with a three-dimensional geological model illustrating the geological framework of the Baia Mare mining district, followed by representative rock specimens that provide an overview of the region's geology. The magmatic collection showcases the diversity of the Badenian–Pannonian volcanic suite (15.4–7.0 Ma; Kovacs and Fülöp, 2003), including basalts, basaltic andesites, andesites, dacites, rhyolites, and their associated contact metamorphic rocks. Sedimentary rocks are represented by clays, sandstones, conglomerates, and evaporites, principally gypsum, while metamorphic lithologies include micaschists, gneisses, pegmatites, and marbles, accompanied by explanatory material

on metamorphic processes. The section also presents building stones quarried in the region, including Buteasa marble, various types of andesite, limestone, and sandstone.

The **Mineralogy** section is divided into two complementary parts. The first introduces the physical properties of minerals, including colour, lustre, streak, and crystal habit, while the second presents mineral species arranged according to their mineralogical classes in the International Mineral Classification Scheme. Approximately 150 mineral species have been identified in the Baia Mare mining district, several of which were first described from this region. The exhibition includes representative specimens of all major mineral classes, including native elements, sulfides and sulfosalts, carbonates, sulfates, wolframates, phosphates, and silicates. A dedicated showcase displays fluorescent minerals, including fluorite and calcite. Another highlight is the collection of the "**Maramureș minerals"**, featuring nine of the ten mineral species first discovered and described in the world from the district. These include rhodochrosite (Fig 31b), dietrichite, felsőbányaite, semseyite, fizélyite, fülöppite, klebelsbergite, andorite, and the recently described baiamareite, illustrating the region's outstanding contribution to mineralogical research.

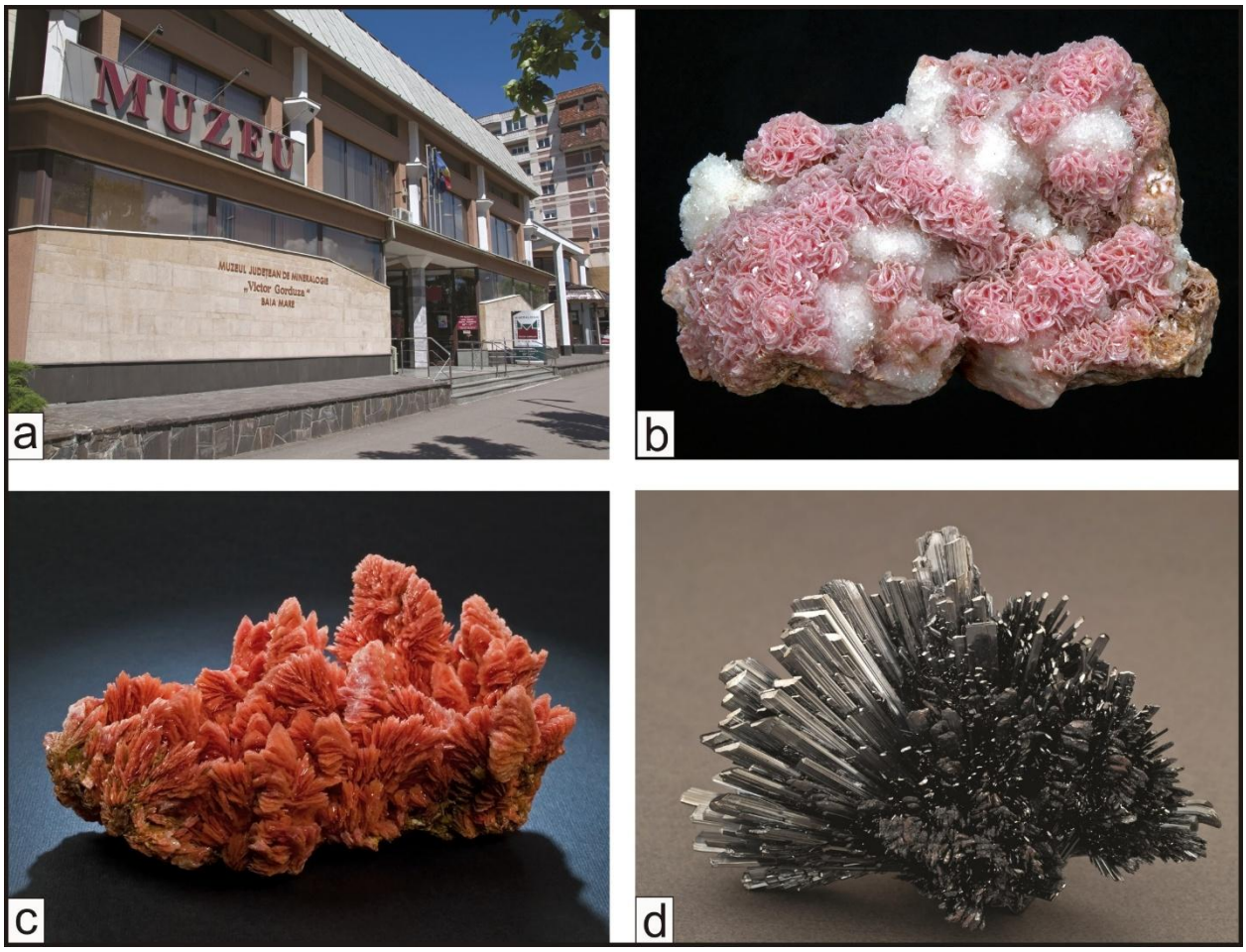


Fig. 31. a) The building of the "Victor Gorduza" County Museum of Mineralogy in Baia Mare; Some of the outstanding aesthetic mineral specimens from the Museum's permanent exhibition: b) rhodochrosite, c) red barite, d) stibnite.

The **Ore Deposits** section presents representative ore specimens from the principal mining areas of the Baia Mare district, including Turț, Ilba, Nistru, Săsar, Dealul Crucii, Valea Roșie, Herja, Baia Sprie, Șuior, Cavnic, Băiuț, Răzoare, and Baia Borșa. Geological maps, cross-sections, and interpretative panels place these deposits within their geological context. The section concludes with a display illustrating the transformation of mineral resources into finished products, including replica gold and silver ingots, copper and lead pipes, and other products manufactured from ores extracted in the Baia Mare mining district.

The "**Mine Flowers"** section, located on the first floor, showcases the Museum's finest aesthetic mineral specimens and represents the highlight of the permanent exhibition. The displayed specimens, particularly the so-called "mine flowers", are distinguished by their exceptional crystallographic and aesthetic qualities, including giant mineral aggregates, monomineral specimens, perfectly developed single crystals, multiple generations of crystal overgrowths, and striking colour variations and combinations within the same or coupled mineral species.

Among the most remarkable exhibits is stibnite, one of the emblematic minerals of the Baia Mare mining district, represented by an exceptional diversity of crystal habits characteristic of the region. Particularly noteworthy are the thick prismatic crystals from Băiuț, the acicular crystals associated with transparent barite from Baia Sprie, the spectacular radiating aggregates from Herja (Fig. 31d), and the distinctive specimens from Cavnic, together illustrating the diversity of the district's principal stibnite occurrences.
Equally impressive are the outstanding calcite specimens, displayed as well-developed rhombohedral crystals, radiating aggregates, and perfectly spherical forms. Barite, another characteristic mineral of the district, occurs as crystals reaching up to 20 cm in length and exhibits a wide range of colours, including white, grey, blue, greenish, reddish, and the exceptionally rare red variety (Fig. 31c), known only from the Baia Sprie mine.

Quartz, although a common mineral, displays remarkable diversity in crystal size, habit, colour, and mineral associations. Crystals range from 1–2 mm to 15 cm in length and are typically columnar with well-developed pyramidal terminations, although obelisk-like and sceptre-shaped crystals are also represented. Quartz occurs as transparent, milky, violet, reddish, and greenish color varieties, both as monomineralic geodes and in association with sulfide minerals.
Another distinctive feature of the Baia Mare mining district is the occurrence of exceptionally large gypsum crystals within several veins at Cavnic, where individual crystals may exceed 100 cm in length. These are commonly colourless and transparent, although blackish and yellow varieties with secondary crystal overgrowths are also present.

The exhibition is further enriched by numerous outstanding specimens of other characteristic minerals, including deep-blue vivianite crystals up to 10 cm long, prismatic wolframite crystals reaching 10 cm, blue to grey pseudo-isometric scheelite crystals up to 4 cm, multiply twinned bournonite, well-crystallized sphalerite, reddish prismatic realgar, galena crystals displaying their characteristic rounded, "melted" morphology, and distinctive rose-like marcasite aggregates coated with siderite.

The visitors are invited to discover more of the wonders of the mineral world hosted by the "Victor Gorduza" Mineralogical Museum in Baia Mare, which is nowadays much more than a museum, hosting numerous scientific and cultural events at local, regional, national, and international levels, becoming a relevant hotspot of the city's and county's intellectual life.

REFERENCES

Bailly, L., Milési, J.P., Leroy, J., Marcoux, E., 1998. Les minéralisations épithermales Au– Cu–Zn–Pb du district de Baia Mare (Nord Roumanie): nouvelles données minéralogiques et microthermométriques. *Comptes Rendus de l'Académie des Sciences, Série 2, Sciences de la Terre et des Plantes,* 327: 385–390.

Borcoș, M., Gheorghiță, I., Lang, B., 1974. Neogene hydrothermal ore deposits in the volcanic Gutâi Mts. (I. Ilba–Băița District). *Révue Roumaine de Géologie*, 18: 19–37.

Borcoș, M., Boștinescu, S., Gheorghiță, I., 1975. Neogene hydrothermal ore deposits in the volcanic Gutâi Mts. III. Dealul Crucii–Băiuț district (Herja, Baia Sprie and Șuior ore deposits). *Révue Roumaine de Géologie, Géophysique et Géographie, Géologie*, 19: 21–35.

Csontos, L., 1995. Tertiary tectonic evolution of the Intra-Carpathian area: a review. *ActaVulcanol.* 7, 1-13.

Csontos, L., Nagymarosy, A., 1998. The Mid-Hungarian line: a zone of repeated tectonic inversions. *Tectonophysics*, 297: 51–71.

Damian, G., Nedelcu, L., Iștvan, D., 1995. Baia Sprie ore deposit. In: Udubașa, G. (ed.): Minerals and mineral occurences in the Baia Mare mining district. *Third Symposium on Mineralogy, Baia Mare Excursion guides, Romanian Journal of Mineralogy*, 77 (2): 47–57.

Damian, G., Damian, F., Cook, J.N., Ciobanu, L.C., 2003. Ag-sulphosalts in upper parts of the Baia Sprie district (Romania): microanalyses and implications for the deposit zonality. *Studia Universitatis Babeș-Bolyai, Geologia, Special Issue,* 37–39.

Edelstein, O., Bernad, A., Kovacs, M., Crihan, M., Pécskay, Z., 1992a. Preliminary data regarding the K-Ar ages of some eruptive rocks from Baia Mare Neogene volcanic zone. *Révue Roumaine de Géologie, 36*, p. 45-60

Edelstein, O., Gabor, M., Ciucan, M., 1992b. Synthetised data on the mining areas of the Baia Mare and Baia Borșa zones. Baia Sprie area. *Unpublished manuscript, Archives of the IPEG Maramureș Company, Baia Mare* (in Romanian).

Edelstein, O., Pécskay, Z., Kovacs, M., Bernád, A., Crihan, M., Micle, R., 1993. The age of the basalts from Firiza zone, Igniș Mts., East Carpathians, Romania. *Révue Roumaine de Géologie*, 37: 37–41.

Fülöp, A., 2002. Transport and emplacement of the 15.4 Mă rhyolitic ignimbrites from Gutai Mts., Eastern Carpathians, Romania. *Studia Universitatis Babeș-Bolyai, Geologia*, XLVII/1:65-75

Fülöp A., Crihan, M., 2002. Badenian and Sarmaţian acidic volcaniclastics of pyroclastic origin from Oaș Mts., Eastern Carpathians (Northwestern Romania). *Révue Roumaine de Geologie*, tome 46, p. 61-72,

Fülöp, A., 2003. The beginning of the volcanism in Gutâi Mts. Paleo-volcanological and paleo-sedimentological reconstructions. *Editura Dacia*, 134 p (in Romanian).

Fülöp, A., Kovacs, M., 2003. Petrology of Badenian ignimbrites, Gutâi Mts. (Eastern Carpathians). *Studia Universitatis Babeș-Bolyai, Geologia*, 48 (1): 17–28.

Fülöp A., Kovacs M., 2004. Submarine volcanism in Oas-Gutai Mts., Eastern Carpathians, Romania. *Second International Maar Conference, Lajosmisze, Hungary, Abstracts volume (Nemeth, Martin, Goth, Lexa ed.),* 8 O-24, p. 55

Fülöp A., Kovacs M., 2007. 15.4 Felsic ignimbrites caldera in Gutai Mts., Carpathians, Romania. *Proceedings of IUGG XXIV General Assembly, Perugia*, 6766

Gabor, M., Kovacs, M., Edelstein, O., Iștvan, D., Bernad, A., 1999. Geological map of the Oaș–Gutâi–Țibleș mountains, scale 1: 25,000. *Unpublished manuscript. Archives of the IPEG Maramureș Company, Baia Mare* (in Romanian).

Genna, A., Milési, J.P., Borcoș, M., Marcoux, E., 1994. Relations entre different types de brèches et minéralisations épithermales dans la region volcanique néogène Gutâi (Baia Mare – Romania). In *Second Annual Meeting of UNESCO–IGCP Project 356 "Plate tectonic aspects of Alpine metallogeny in the Carpatho–Balkan Region" (Baia Mare), Abstracts*.

Grancea, L., Bailly, L., Leroy, J.L., Banks, D., Marcoux, E., Milési, J.P., Cuney, M., André, A.S., Iștvan, D., Fabre, C., 2002. Fluid evolution in the Baia Mare epithermal gold/polymetallic district, Inner Carpathians, Romania. *Mineralium Deposita*, 37: 630–647.

Harzhauser M., Piller W.E., 2007. Benchmark data of a changing sea – palaeogeography, palaeobiogeography and events in the Central Paratethys during Miocene. *Palaeogeogr. Palaeoclimatol. Palaeoecol*. 253, 8-31.

Iștvan, D., Halga, S., Vârșescu, I., Grancea, L., Chiuzbăian, C., 1996. New data on the upper part of the Baia Sprie deposit, East Carpathians, Romania. *Analele Ştiinţifice ale Universităţii "Alexandru Ioan Cuza" Iași, Geologie,* 42: 101–110.

Jurje M., Ionescu C., Hoeck V., Kovacs M., 2014. Geochemistry of Neogene quartz andesites from the Oaș and Gutâi Mountains, Eastern Carpathians (Romania):a complex magma genesis. *Mineralogy and Petrology*, Vol. 108, p.13-32

Kovacs, M., Iștvan, D., 1994. Cavnic and Baia Sprie ore deposits. In *Borcoș, M. & Vlad, S. (eds): Plate tectonics and metallogeny in the East Carpathians and Apuseni Mts. June 7–19, 1994. Field trip guide, IGCP Project No. 356. Bucharest: Geological Institute of Romania*, 22–25.

Kovacs, M., Pécskay, Z., Crihan, M., Edelstein, O., Gabor, M., Bernad, A., 1997a. K-Ar study of neogene volcanic rocks from the Oaș Mts. (East Carpathians, Romania). *Révue Roumaine de Geologie,* Tome 41, p. 19-28

Kovacs, M., Edelstein, O., Gabor, M., Bonhomme, M., Pécskay, Z., 1997b. Neogene magmatism and metallogeny in Oaș–Gutâi– Țibleș Mts.; a new approach based on radiometric datings. *Romanian Journal of Mineral Deposits*, 78: 35–45.

Kovacs, M., Grancea, L., Iștvan, D., Nedelcu, L., Mihalache, A., Chiuzbăian, C., 2001. Baia Sprie epithermal deposit. In: *Udubasa, G. & Kovacs, M. (eds): Geodynamics and ore deposit evolution of the Alpine–Balkan–Carpathian–Dinaride Province. ABCD-GEODE 2001 Workshop, Vata Bai, Romania, 8–12 June 2001. Field Guidebook. Romanian Journal of Mineral Deposits,* 79 (Suppl. 2), 13–16.

Kovacs, M., 2002. Petrogenesis of subduction-related igneous rocks from the central–southeastern area of the Gutâi Mts. Cluj–Napoca: *Editura Dacia,* 201 p (in Romanian).

Kovacs M**.**, Fülöp A., 2002. Neogene volcanism in Oas Mts., Eastern Carpathians, Romania. *Geologica Carpathica*, vol. 53, p. 208-210.

Kovacs, M., Fülöp, A., 2003. Neogene volcanism în Gutâi Mts. (Eastern Carpathians). A review. *Studia Universitatis Babeș-Bolyai, Geologia*, 48 (1): 3–16.

Kovacs, M., Fülöp, A., Pécskay, Z., 2006. Neogene calc-alkaline magmatism in Oas-Gutai Mts., Eastern Carpathians, Romania. Time and space evolution. *Proceedings XVIIIth Congress of the Carpatho-Balkan Geological Association,* p. 290-294

Kovacs, M, Fülöp, A., 2010a. Laleaua Albă quarry: a Neogene composite igneous body. In: *Iancu OG and Kovacs M (eds.) "Ore deposits and other classic localities in the Eastern Carpathians: from metamorphics to volcanics", IMA 2010 Field trip guide RO1, Acta Mineralogica-Petrographica,* 19:32-35

Kovacs, M, Fülöp, A., 2010b. Dealul Minei open pit, Baia Sprie. In: *Iancu OG, Kovacs M (eds) Ore deposits and other classic localities in the Eastern Carpathians: from metamorphics to volcanics, IMA 2010 Field trip guide RO1, Acta Mineralogica-Petrographica,* 19:27-32

Kovacs, M., Pécskay, Z., Fülöp, A., Jurje, M., Edelstein, O., 2013. Geochronology of the Neogene intrusive magmatism of the Oaș-Gutâi Mts., Eastern Carpathians, NW Romania. *Geologica Carpathica,* 64/4:483-496

Kovacs, M., Fülöp, A., Pécskay, Z., 2014. Dome-building volcanic activity in the Oas-Gutai Neogene Volcanic Area, Eastern Carpathians, Romania. *Proceedings XX Congress of the Carpathian-Balkan Geological Association, Buletini i Shkencave Gjeologjike, Special Issue, vol.1, p. 230-233*

Kovacs, M., Seghedi, I., Yamamoto, M., Fülöp, A., Pécskay, Z., Jurje, M., 2017. Miocene volcanism from the Oaș-Gutâi Volcanic Zone (Eastern Carpathians, Romania) – link to the geodynamic processes of Transcarpathian Basin. *Lithos,* 294-295:304-318.

Kovacs, M., Fülöp, A., Seghedi, I., Pécskay, Z., 2021. Architecture of volcanic plumbing systems inferred from thermobarometry: A case study from the Miocene Gutâi Volcanic Zone in the Eastern Carpathians, Romania. *Lithos*, 396-397, doi.org/10.1016/j.lithos.2021.106191

Kovacs, M., Szakács, A., 2025. Composite dykes in the Gutâi Miocene Volcanic Zone (East Carpathians, Romania) resulting from complex petrogenesis in multilevel magmatic plumbing system. *LASI 7 - The physical geology of subvolcanic systems-laccoliths, sills and dykes Conference, Iceland, Abstract book,* p. 33

Kovacs, M., Szakács, A., Kővágó, A., 2025. The complex magmatic plumbing system of the Miocene Laleaua Albă composite dykes (East Carpathians, NW Romania) revealed by crystal chemistry. *IAVCEI 2025 – Geneva, Volcanological Congress, Book of abstracts*.

Lang, B., Edelstein, O., Steinitz, G., Kovacs, M., Halga, S., 1994. Ar-Ar dating of adularia, a tool in understanding genetic relations between volcanism and mineralisation, Baia Mare area (Gutâi Mountains) north-western Romania. *Economic Geology*, 89: 174–180.

Manilici, V., Giușcă, D., Stiopol, V., 1965. Study of the Baia Sprie ore deposit. *Memoriile Comitetului Geologic,* 7: 113 p (in Romanian).

Marcoux, E., Grancea, L., Lupulescu, M., Milési, J.P., 2002. Lead isotope signatures of epithermal and porphyry-type ore deposits from the Romanian Carpathian Mountains. *Mineralium Deposita*, 37 (2): 173–184.

Mariaș, F., 1996. Cavnic ore deposit. Geostructural and petrometal- logenetic description. *PhD thesis, Univ. Babeș-Bolyai, Cluj Napoca,* Romania, 226 p (in Romanian).

Mariaș, F., 2005. The metallogenesis of the Baia Mare mining district. Modeling on the basis of the Cavnic hydrothermal system (Maramures). Comparative assessement with other epithermal systems. Baia Mare: *Editura Cornelius*, 450 p (in Romanian).

Nedelcu, L., Pintea, I., 1993. New data recording the significance of pyrite morphology and of the fluid inclusions in quartz crystals at Baia Sprie. *Romanian Journal of Mineralogy,* 76 (1): 79–86.

Pécskay, Z., Edelstein, O., Kovacs, M., Bernad, A., Crihan, M., 1994. K-Ar age determination of Neogene volcanic rocks from the Gutâi Mts. (Eastern Carpathians, România). *Geologica Carpathica, 45, 6*, p. 357-363

Pécskay, Z., Lexa, J., Szakács, A., Seghedi, I., Balogh, K., Konecny, V., Zelenka, T., Kovacs, M., Póka, T., Fülöp, A., Márton, E., Panaiotu, C., Cvetkovic, V., 2006. Geochronology of Neogene magmatism in the Carpathian arc and intra-Carpathian area: a review. *Geologica Carpathica,* 57 (6): 511–530.

Piantone, P., Grancea, L., Leroy, J., Bailly, L., Mariaș, Z., Nehlig, P., Marcoux, E., 1999. Fluid inclusion and isotope study of the Cavnic epithermal deposit, Romania. In *Stanley, C.J. et al. (eds): Mineral deposits, process to processing. Rotterdam: Balkema*, 1: 79–82.

Pomârleanu, V., Răduţ, M., Neagu, E., 1985. The study of the fluid inclusions from Baia Sprie–Șuior area; implications on the ther- modynamic regime of the hydrothermal solutions. *Studii și Cercetări de Geologie și Geofizică, Geologie*, 30: 102–110 (in Romanian).

Săndulescu, M., 1984. Geotectonics of Romania. Bucharest: *Editura Tehnică*: 334 p (in Romanian).

Săndulescu, M., Visarion, M., Stănică, D., Stănică, M., Atanasiu, L., 1993. Deep structure of the Inner Carpathians in the Maramureș–Tisa zone (East Carpathians). *Romanian Journal of Geophysics*, 16: 67–76.

Seghedi, I., Balintoni, I., Szakács, A., 1998. Interplay of tectonics and Neogene post-collisional magmatism in the intracarpathian region. *Lithos* 45, 483-499

Stanciu, C., 1973. Hydrothermal alteration of Neogene volcanic rocks from Gutâi Mountains. Révue Roumaine de Géologie, Géophysique et Géographie, Géologie, 17 (1): 31–47.

Stanciu, C., 1984. Hypogene alteration genetic types related to the neogene volcanism of the East Carpathians, Romania. *Anuarul Institutului de Geologie și Geofizică*, 64: 235–243.

Szakács, A., Fülöp, A., 2002. Correlating Badenian rhyolitic pyroclastics of the Western Gutai Mts. with the Dej Tuff Complex. *Romanian Journal of Mineral Deposits.* Vol. 80, 117-121,

Szakács, A., Kovacs, M., 2022. Volcanic Landforms and Landscapes of the East Carpathians (Romania) and Their Geoheritage Values. *Land,* 11(7):1064.

Szakács, A., Kovacs, M., 2025. Mogoșa, a Miocene composite volcano in the East Carpathians (NW Romania) generated by long-lived dome-building activity. *IAVCEI 2025 – Geneva, Volcanological Congress, Book of abstracts.*

Tămaș, C., Veres, D., Chauvel, C., 2024. Lead isotopic compositions of Paleozoic to Miocene ore deposits in the Western Tethyan Belt. *Ore Geology Reviews*, 175 (2024) 106346

Tischler, M., Gröger, H.R., Fügenschuh, B., Schmid, S.M., 2007. Miocene tectonics of the Maramureș area (Northern Romania): implications for the Mid-Hungarian fault zone. *International Journal of Earth Sciences*, 96: 473–496.

FIELD TRIP 4

FT4. Mesozoic tectonostratigraphic evolution of the Northern Apuseni Mountains (Pădurea Craiului and Codru-Moma Mountains)

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1. INTRODUCTION

The field trip provides a unique opportunity to observe two major mountain-building processes that shaped the Apuseni Mountains, part of the Tisza Megaunit: (A) the Middle–Late Jurassic orogeny, and (B) the 'Mid-Cretaceous' orogeny.

During the Middle Triassic, sedimentation transitioned from a continental graben to a passive continental margin setting. Following the drowning of the shallow-water Steinalm Carbonate Ramp in the middle Anisian (Pelsonian), a period of deep-water deposition resulted. This was followed by the development of a complex platform–basin system in the Middle to early Late Triassic, marked by the development of the Wetterstein and Dachstein carbonate platforms. During the Jurassic, following the demise of the Dachstein Carbonate Platform, deposition was characterized by condensed deep-water sedimentary rocks. In the Middle Jurassic, deposition changed, and generated deep-water, trench-like foreland basins in front of advancing nappes. These basins were filled with redeposited material derived from the Middle Triassic to Middle Jurassic distal passive margin of the Neo-Tethys Ocean related to ophiolite obduction. This orogen was sealed by the evolution of a Late Jurassic shallow-water carbonate platform. In the Tithonian this platform uplifted and emerged, and after a period of continental weathering with formation of bauxites the area again was flooded and Lower Cretaceous orbitolinid-bearing shallow-water carbonates deposited. In fact, in most areas the Late Jurassic – Early Cretaceous sedimentary rocks are eroded and the information is therefore limited. In the "Mid-Cretaceous" the area was affected by a second mountain building process, and exotic Triassic open-marine nappes emplaced, sealed by the Upper Cretaceous rudist limestones ("Gosau transgression"). This history is well preserved in the area of the Bihor Unit and the complex Codru Nappe System, where their lithological records provide valuable insights into the Mesozoic geodynamic evolution of the Western Tethyan Realm.

The nappe architecture and today´s tectonic structure of the Bihor and the Codru nappes was structured mainly during the "Mid-Cretaceous" tectonic pulse ("Mid-Cretaceous orogeny"), the subsequent rotation of Tisza (Balla, 1984; Csontos and Vörös, 2004), and the Miocene and younger strike-slip tectonics (e.g. Linzer et al., 2002). A key argument supporting this interpretation is the widespread occurrence of Gosau-type facies in the post-tectonic cover (Săndulescu, 1984). However, the data presented in this field trip suggest that many units have been first significantly affected by the Middle-Late Jurassic orogeny forming a Jurassic nappe stack, a feature that has never been highlighted for the Northern Apuseni Mountains. This is related to the fact that the sedimentary sequences associated with the older tectonic cycles (e.g. Middle-Late Jurassic orogeny) have undergone fragmentation and metamorphism, making their identification and interpretation more challenging.

Our field trip to the Apuseni Mountains in the frame of a CBGA Congress 2026 will take us in parts in similar areas and identical outcrops as presented during a field trip in the year 1981 in the frame of a CBGA

congress (Bleahu et al., 1981), interestingly nearly at the same time. A comparison of the field trip 1981 and 2026 will show the participants the progress in knowledge since that time. In fact, the presented results and interpretations in the year 1981 experienced until 2014 (Kovacs et al., 2014) no significant modification. However, new stratigraphic, facies, and sedimentological data provide us the opportunity to present new interpretations, how the rocks told us their history.

2. MESOZOIC GEODYNAMIC HISTORY OF THE WESTERN TETHYS REALM

The original arrangement of Mesozoic oceanic and continental domains within the Circum-Pannonian Realm remains one of the most controversial topics in Mediterranean geology. Consequently, the published palaeogeographic reconstructions differ considerably (e.g. Sengör 1984, 1985, 1998; Kozur, 1991; Haas et al., 1995; Marcoux and Baud, 1995; Fourcade et al., 1995; Csontos and Vörös, 2004, Stampfli and Borel, 2004; Stampfli and Kozur, 2006; Schmid et al., 2008; Robertson, 2012; Muttoni et al., 2015; Gawlick and Missoni, 2019, and references therein), reflecting contrasting interpretations of both the number and geometry of Mesozoic oceanic basins. More than a century after the pioneering works of Suess (1888; 1901) and Neumayr (1885), the fundamental question–"*Where and what was the Tethys*?"–and the reconstruction of its complete Wilson cycle remain subjects of active scientific debate (Gawlick and Missoni 2019).

Tectonostratigraphy provides one of the most powerful tools for palaeogeographic reconstruction because it allows the depositional history of sedimentary successions to be interpreted within their plate-tectonic framework (Gawlick and Missoni, 2019). Despite these uncertainties, the sedimentary record preserved throughout the eastern Mediterranean mountain belts reveals a remarkably consistent tectonostratigraphic evolution. This evolutionary pattern can be recognized in virtually all proposed Mesozoic oceanic domains of the Circum-Pannonian Realm (Gawlick and Missoni, 2019 and references therein). Rather than supporting the existence of numerous independent oceanic basins, these successions consistently record in fact the evolution of **two main oceanic domains**, each characterized by a distinct Wilson cycle. Understanding this, it provides the key for reconstructing the Mesozoic palaeogeography of the Western Tethyan Realm and to distinguish regional tectonic events.

(1) The Tethys Ocean (in the classical sense of Suess, 1888, 1901) following a complete Wilson cycle:

- Late Permian to early Middle Triassic rifting accompanied by graben formation and syn-rift sedimentation.
- Late Middle Triassic to early Middle Jurassic development of passive margins characterized by widespread shallow- and deep-marine sedimentation. **Important to note, that we have a carbonate dominated passive continental margin setting**.
- Middle to early Late Jurassic active margin associated with ophiolite obduction, mountain uplift, and progressive unroofing beginning near the Kimmeridgian–Tithonian boundary. **Important to note, that the second (eastern) part of the Neo-Tethys remained open**.
- Closure of the remaining Neo-Tethys (= Vardar) Ocean started during the Late Cretaceous.

(2) **The Alpine Atlantic Ocean** (=Alpine Tethys Ocean in other nomenclature, e.g. Dercourt et al., 1993; Fourcade et al., 1995; Stampfli and Borel, 2004; Stampfli and Kozur, 2006, Schmid et al., 2008; 2020) that followed a younger and distinct Wilson cycle characterized by:

- Early-Middle Jurassic rifting and graben development linked to the opening of the Central Atlantic. Note, that Ricou (1995) named the Central Atlantic "Atlantic Tethys".
- Middle Jurassic to Late Cretaceous development of passive continental margins.
- Late Cretaceous to Paleogene subduction, Paleogene collision and subsequent mountain uplift and regional unroofing, which became widespread during the Miocene (Ratschbacher et al., 1991).

These two independent Wilson cycles generated three fundamentally different orogenic belts in the Western Tethys Realm:

- The first was the **Jurassic Neotethyan Orogenic Belt** (Missoni and Gawlick, 2011), resulting from the closure of the western Neo-Tethys Ocean and the emplacement of extensive ophiolite nappes during the Middle and Late Jurassic (Gawlick et al., 2008; Schmid et al. 2008).
- The second was the enigmatic **Mid-Cretaceous orogeny**, which fundamentally reorganized the palaeogeography of the eastern Mediterranean and Circum-Pannonian region but remains one of the least understood tectonic events of the Mesozoic (e.g., Janak et al., 2006; Schmid et al., 2008; Sandmann et al., 2016; Plašienka, 2018; Kurz et al., 2024).
- The third episode was the development of the **Alpine Belt** during the Paleogene and Neogene, related to the closure of the Alpine Atlantic (Ligurian–Piemont–Penninic–Vah–Ceahlău-Severin Ocean) (e.g. Frisch and Meschede, 2005; Schmid et al., 2008; Kurz et al., 2024 and references therein) and contemporaneous movements along the Axios–Vardar–Sava–Periadriatic plate boundary (Djerić et al., 2026).

3. THE TISZA MEGA-UNIT

The Tisza mega-unit (Schmid et al. 2008, 2020) or terrane (Bleahu et al. 1994, Balantoni 1997, Csontos and Vörös, 2004; Ebner et al., 2007, 2008, 2010; Balintoni et al., 2010, 2014; Kovács et al., 2010, 2011; Haas et al., 2011) is the most enigmatic and controversial discussed tectonic unit in the Pannonian realm. Tisza should consist of a "Mid-Cretaceous" nappe stack (e.g. Balintoni, 1994; Árkai et al., 2000; Schuller et al., 2009; Balen et al., 2017; Reiser et al., 2017). This nappe is subdivided in several nappe systems, the Mecsek (lowermost), the Bihor, the Codru, and the Biharia nappe system (topmost) (Figs. 1, 2). Note, that Schmid et al. (2008, 2020) attribute the Biharia nappe system to the Dacia mega-unit and correlate it with the Bucovinian nappes (= Median Dacides in the sense of Sandulescu, 1984; compare Balintoni and Puste, 2002).

Interestingly the Tisza mega-unit as exotic and enigmatic element in the Pannonian realm is widespread attributed to have European affinity (Schmid et al., 2008; 2020; Merten et al., 2011; Handy et al., 2021) and therefore separated from all other palaeogeographically related tectonic units, e.g. the ALCAPA mega-unit (Eastern Alps and Western Carpathians).

As stated by Schmid et al. (2008) from the Jurassic onwards the Tisza mega-unit shows clear Adriatic affinities (Vörös, 1977, 1993; Lupu, 1984; Haas and Pero, 2004) and is located south of the Alpine Atlantic (compare Csontos and Vörös, 2004, Handy et al., 2025). In contrast, in Triassic times also ALCAPA was connected to Europe (Tollmann, 1976; Haas et al., 1995; Kovács et al., 2011; Haas et al., 2011) and mirrors the distal evolution of the Germanic basin or the Polish basin with the difference that the Eastern Alps and the Western Carpathians formed the northwestern passive continental margin of the Neo-Tethys Ocean with a slightly different Triassic evolution as Tisza more to the east. In fact, the Triassic sedimentological evolution of the units in the Western Carpathians are in parts transitional between the Triassic sedimentological evolution of the Eastern Alps to Tisza. In the Tisza mega-unit, the Triassic sedimentological evolution is more influenced by the hinterland, especially the shedding of siliciclastic material (e.g., Lunz siliciclastics, Keuper siliciclastics, Kössen siliciclastics). Even the Southern Alps experienced in cases a direct influence from the European hinterland, but in addition from a source area to the west (Raibl and Trevenzas formations). Thus, no significant difference can be recognized between these different tectonic mega-units.

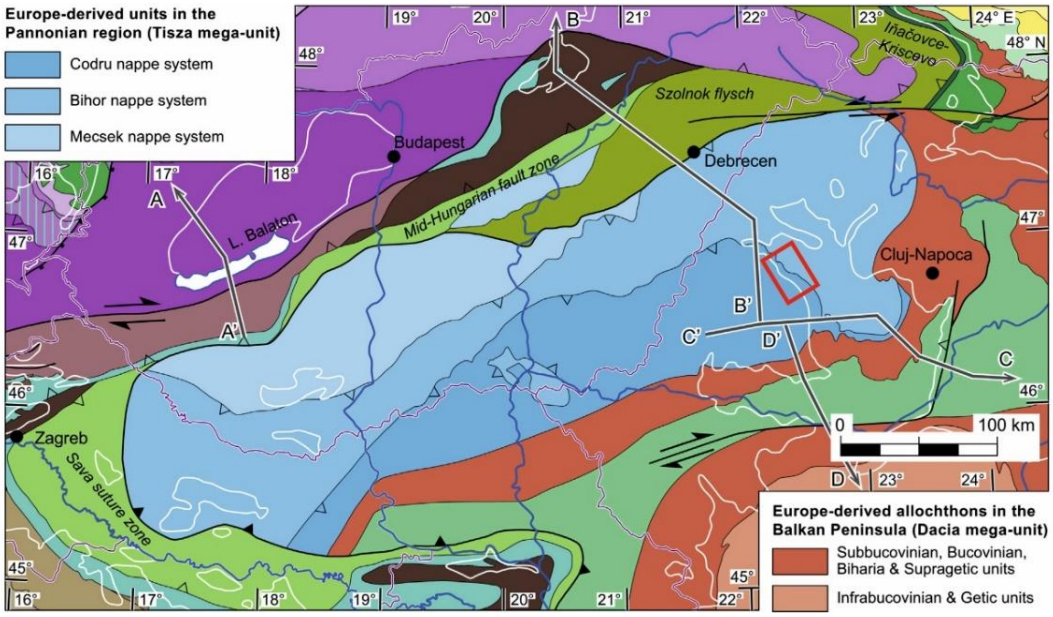


Fig. 1. Most important mega-units/nappe systems in the Alpine-Carpathian-Dinaridic-Pannonian realm around Tisza according to Schmid et al. (2008, 2020). The field trip area is marked by a red box. For the exact geographic position of the field trip area see **Fig. 8**

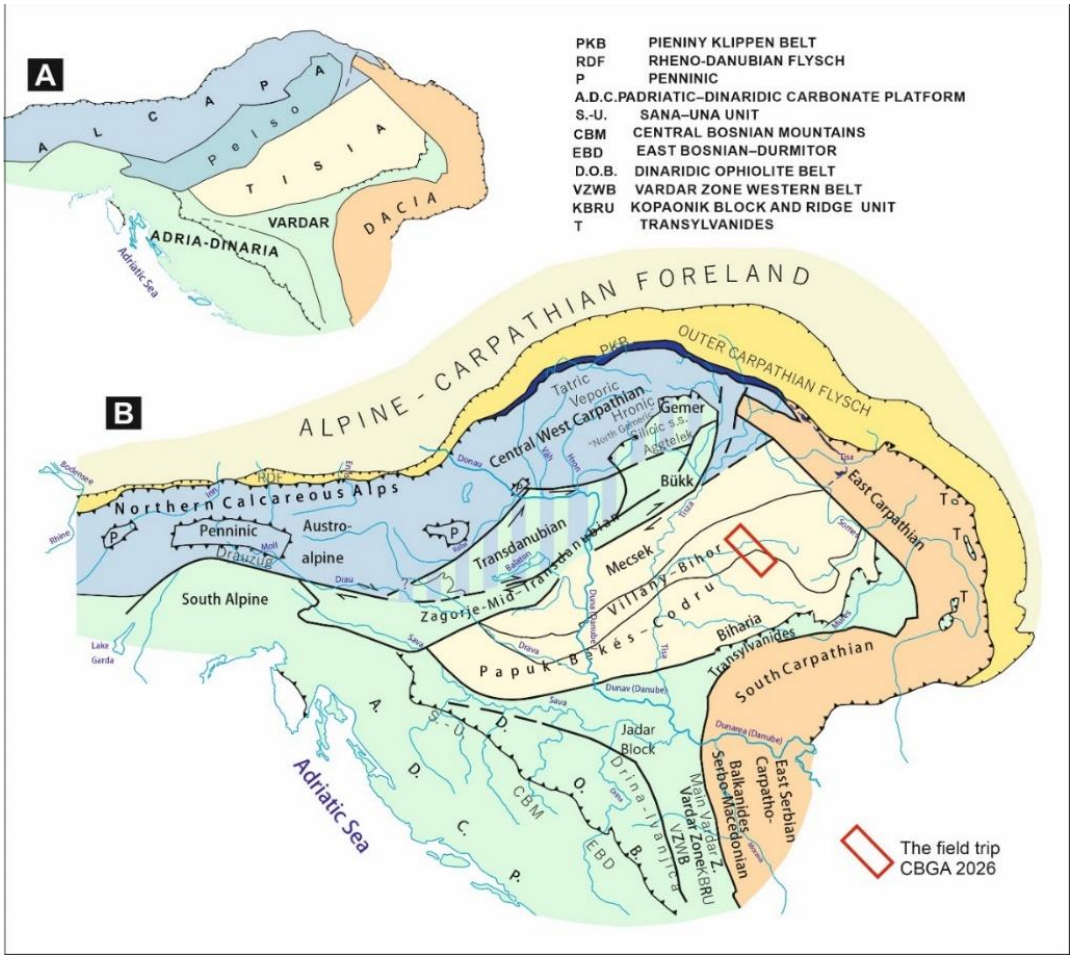


Fig. 2. Mega-units and mountain belts in the Alpine-Carpathian-Dinaridic-Pannonian realm and field trip area. A - Most important mega-units/nappe systems in the Alpine-Carpathian-Dinaridic-Pannonian realm. The field trip area is marked by a red box. B - Most important mega-units/nappe systems in the Alpine-Carpathian-Dinaridic-Pannonian realm according to Kovács et al. (2010; 2011). The field trip area is marked by a red box. For the exact geographic position of the field trip area see **Fig. 8.**

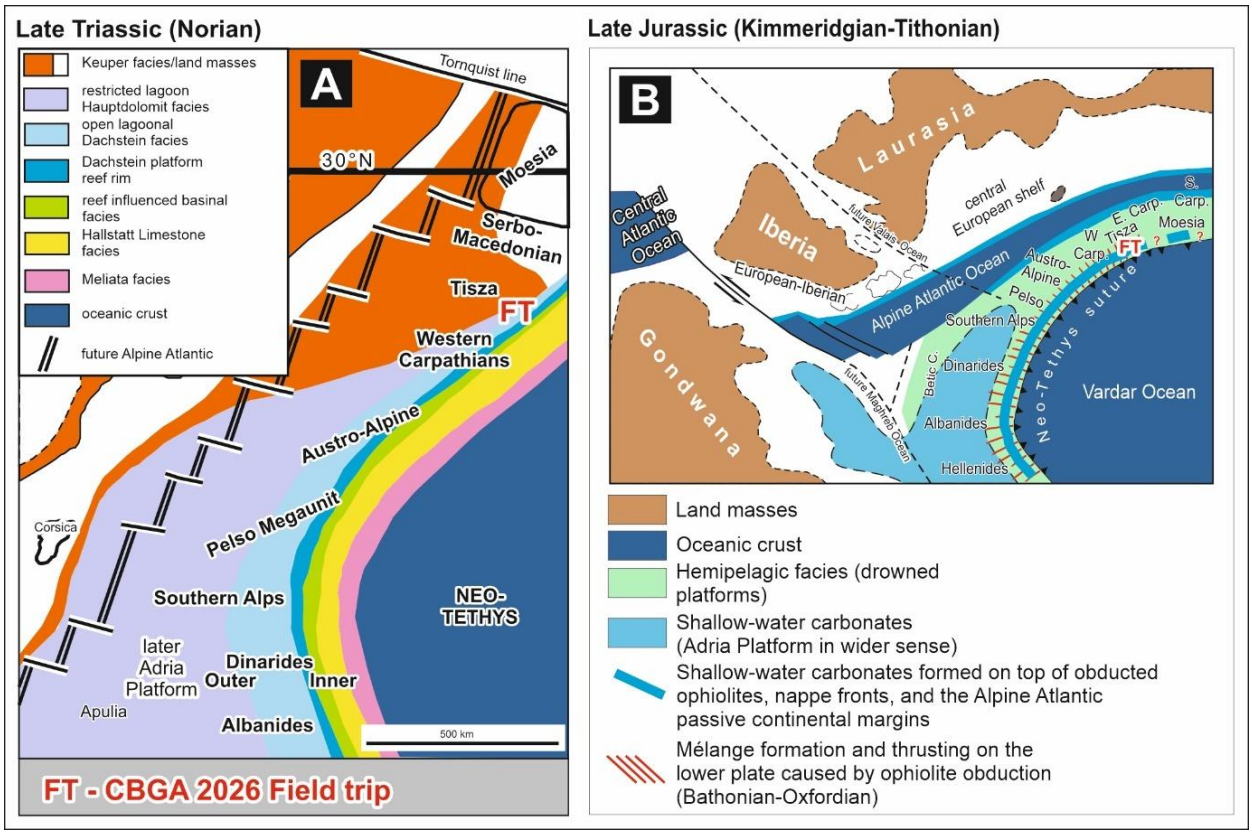


Fig. 3. A - Late Triassic palaeogeography based on Krystyn and Lein in Haas et al. (1995), modified after Gawlick and Missoni (2019). B - Late Jurassic palaeogeography based on Pleș et al. (2024).

However, the evolution of the Dinarides/Albanides/Hellenides is different, where the influence of siliciclastic shedding from a hinterland is minor or missing. Therefore, we see no reason to separate the Tisza mega-unit in the Pannonian realm as an exotic or enigmatic tectonic mega-unit or terrane, especially not with clear European affinity. In Triassic times the Tisza megaunit is the eastward continuation of the Eastern Alps/Western Carpathians, with a restricted facies evolution in the lower nappe stack, and open-marine facies preserved in the higher nappe stack, which resembles the known facies evolution as known from the Northern Calcareous Alps, the Western Carpathians or the Southern Alps. The similarity of the Apuseni Mountains and the Austroalpine was already stated by Bădescu (1997). In Jurassic times all these mega-units were separated from Europe by the opening of the Alpine Atlantic and are now part of the wider Adria plate between the Alpine Atlantic to the north and the Neo-Tethys to the southeast.

4. NAPPE STRUCTURE OF THE NORTHERN APUSENI MOUNTAINS: HISTORICAL OVERVIEW BASED ON THE VIEW OF THE "MID-CRETACEOUS" MOUNTAIN BUILDING PROCESS

The Northern Apuseni Mountains are characterized by a complex nappe structure comprising an alternation of carbonate and detrital deposits similar with the north Alpine facies belts. This nape stack was defined by Săndulescu (1984) as the *Inner Dacides* and they comprise a series of basement nappes composed, at least in part, of crystalline formations (metamorphic and, in some cases, granitic), overlain by Mesozoic or Permian–Mesozoic sedimentary sequences. The Inner Dacides consists of the following tectonic units: the Bihor Unit, which occupies the structurally lowest position within the tectonic stack, the complex Codru Nappe System, and the Biharia Nappe System (Bleahu, 1976). In a broader tectonic framework, the Bihor Unit and the Codru Nappe System are assigned to the Tisza mega-unit (cf. Csontos and Vörös, 2004;

Schmid et al., 2008), except the Biharia Nappe System which was assigned by Schmid et al. (2008, 2020) to the Dacia mega-unit.

Given that the present field trip is focused on the Bihor Unit and the Codru Nappe System, the following overview is restricted to these tectonic units. Furthermore, we exclude from the discussion the older so called "basement rocks" or Palaeozoic series (Bleahu and Dimitrescu, 1957; Ianovici et al., 1976; Balintoni, 1997). As there are not many reliable geochronological age data available of these "basement (crystalline) rocks" it cannot be excluded that some of them experienced also a Mid-Cretaceous metamorphic overprint (compare Árkai et al., 2000) and are therefore not as old as believed. We focus therefore on the latest Permian to Mesozoic sedimentary cover rocks which can be attributed to the Neo-Tethys Wilson cycle, in the Jurassic overprinted by the Alpine Atlantic Wilson cycle.

***Note**: in the description of the different sedimentary successions in the different units we use the nomenclature of formations according to those authors. In several cases the use of these names is not correct and has to be revised.*

4.1. The Bihor Unit

The metamorphic and sedimentary rocks of the Bihor Unit cover extensive areas in Bihor and Pădurea Craiului Mountains. The Bihor Unit preserve an almost complete Mesozoic sedimentary succession (Fig. 4) dominated by carbonate rocks (Ianovici et al., 1976). The Permian formations represent the oldest deposits and are characterized by breccias with a red sandy/silty/clayey matrix, quartzitic conglomerates, bioturbated violet sandstones and breccias containing crystalline schist clasts (Cociuba, 1999).

Triassic

The Triassic sedimentary succession of the Bihor Unit is well represented in the Pădurea Craiului Mountains, where it crops out in the eastern sector, as well as in the central and western areas beneath younger deposits.

The Lower Triassic deposits (Fig. 4) are predominantly detrital, consisting of conglomerates, sandstones, and claystones, comparable to the Werfen Beds of the Northern Calcareous Alps (Cociuba, 1999).

The Middle Triassic (Fig. 4) is composed of the following units (Patrulius, in Ianovici et al., 1976):

- Lower stratified dolomites, reaching thicknesses of up to 100 m;
- The Bucea Limestone (Anisian, Gutenstein facies), consisting of dark grey to black lagoonal micritic facies, with thicknesses of several hundred metres;
- Upper massive grey dolomites, ranging from 50 to 500 m in thickness (?Steinalm)
- The Lugaș Formation, up to 200 m thick, comprising the Vida Limestone, the Peștiș Shales, and the Butan Limestone;
- Massive upper Ladinian–lower Carnian lagoonal and reefal Wetterstein carbonates with various benthic foraminifera, calcareous algae, calcified sponges and microencrusters.

The Upper Triassic deposits of the Bihor Unit (Fig. 4) are represented exclusively by believed lower Carnian lagoonal limestones, identified mainly within the Mișid Valley (Pădurea Craiului Mountains). In this area, Dragastan et al. (1982) described an assemblage of calcareous algae that includes characteristic Carnian species (*Clypeina besici*).

Jurassic

The Jurassic formations (Fig. 4) of the Pădurea Craiului Mountains crop out west of the Triassic units and represent an almost continuous sedimentary cycle spanning the Hettangian–Tithonian interval, with a total thickness exceeding 400 m (Cociuba, 1999).

The Lower Jurassic sedimentary succession of the Bihor Unit (Fig. 4) consists of alternating continental (including sandstones, conglomerates, breccias, fire clays) and locally marine-influenced deposits (marls and carbonates) recording predominantly fluvial environments periodically affected by marine transgressions (Bleahu et al., 1970, Patrulius, in Ianovici et al., 1976; Cociuba, 1999). Within this time interval, three main types of deposits have been distinguished: (1) the detrital Gresten-type sequence (Hettangian–early Sinemurian), (2) carbonate sequence (late Sinemurian–Pliensbachian) and (3) the marly sequence (Toarcian) (Cociuba, 1999; Patrulius, in Ianovici et al., 1976).

The Middle Jurassic (Fig. 4) is represented by highly condensed hemipelagic deposits, generally not exceeding 10 m in thickness, a feature attributed to low sedimentation rates and episodes of non-deposition. Among these, a major hiatus is recorded at the base of the middle Bajocian, where the early Bajocian is partially or entirely absent, as well as another at the base of the middle Callovian (Cociuba, 1999). These gaps have been identified primarily through ammonite biostratigraphic analyses within condensed successions. Patrulius (1976), Ianovici et al. (1976), and Lazăr et al. (2015) distinguish the following stratigraphic succession for the Middle Jurassic:

- Early Aalenian. Glauconitic marls and marly limestones with cephalopods and rare phosphatic nodules;
- Late Aalenian. Black oolitic limestones with cephalopods and phosphatic concretions. This interval is also marked by a major turnover in belemnite faunas;
- Early Bajocian. Marls and limestones with ammonites, belemnites and ferruginous oolites of violet coloration, reaching thicknesses of up to 2 m.
- Middle–late Bajocian (2.5 m thick). Consists of a basal bioclastic grainstone with quartzitic microconglomerate intercalations, passing upward into ooidal crinoidal grainstone–packstone rich in *Entolium* and *Oxytoma* bivalves and ammonites (*Stemmatoceras*).
- Bathonian–early Callovian (0.2-0.5 m). It is a heterochronous condensed horizon consisting of grey-green to reddish bioclastic ooidal packstone–grainstone with nodular development, cavities and fractures filled by bioclastic wackestone–packstone, and oncoidal floatstone–rudstone, capped by a ferruginized hardground with crusts extending into fissures and neptunian dykes, and containing a diverse ammonite-dominated fauna (including abundant Perisphinctidae) alongside belemnites, sponges, crinoids, and rare benthic taxa, representing a condensed Bathonian–early Callovian interval (Patrulius, 1976, 1996; Lazăr et al., 2015).
- Middle–late Callovian (2-5 m thick). It is represented by reddish to grey-green marly limestones and glaucony-bearing bioclastic grainstone–packstones with planktonic foraminifera (*Globigerinelloides*), bivalves (*Bositra buchi*), and a diverse ammonite–belemnite fauna (*Hibolites*, *Grossouvria*, *Pseudopeltoceras*), showing variable microfacies and indicating deposition from proximal to distal offshore settings below storm wave base (Patrulius, 1996; Lazăr et al., 2015).

The Late Jurassic comprises thick carbonate deposits with diverse microfacies. Based on micropalaeontological associations and their depositional environments, several formations have been distinguished (Ianovici et al., 1976; Cociuba, 1999, 2000; Bucur and Cociuba, 2001) (Fig. 4).

- Vad Limestone (Oxfordian–Kimmeridgian). Deep-water hemipelagic limestones with ammonites and planktonic crinoids (*Saccocoma*). The formation is characterized by a homogeneous peloidal micritic microfacies and a generally poor microfauna including ostracods, *Saccocoma* fragments, sponge spicules, and algal filaments (Cociuba, 1999). The macrofauna includes rare ammonites (Patrulius and Istocescu, 1967). Thickness varies between 10 and 100 m, increasing towards the northeastern part of the massif and decreasing towards the central and southwestern areas (Cociuba, 1999). In the southwestern Pădurea Craiului Mountains, the base of the formation is no older than

earliest Oxfordian, constrained by the Oxfordian–Kimmeridgian boundary marked by *Alveosepta jaccardi* (Bucur and Cociuba, 2001).

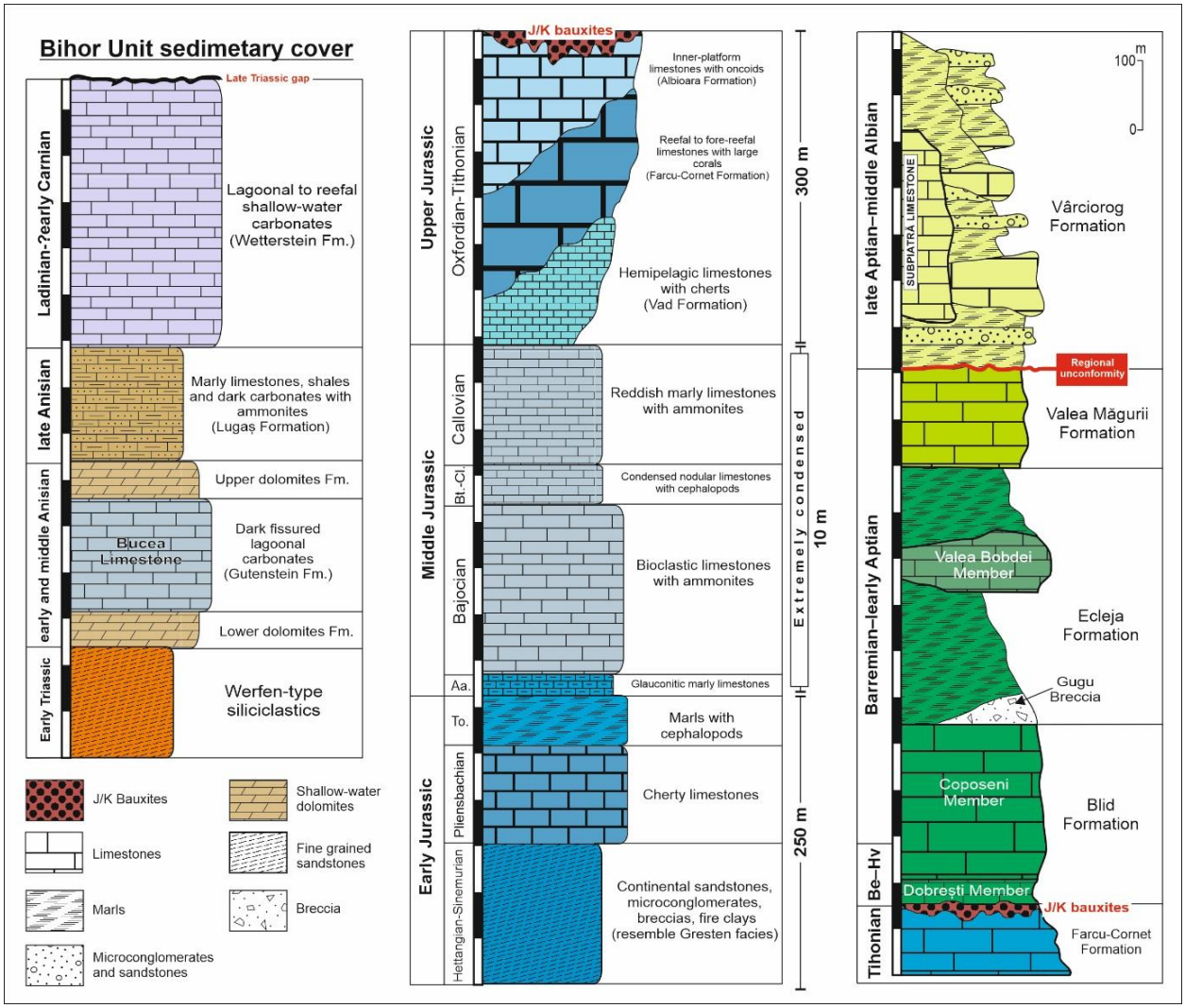


Fig. 4. Schematic drawing of the Bihor unit sedimentary deposits based on Bleahu et al. (1970, 1972, 1994); Patrulius, 1971; Patrulius et al., 1976; Patrulius, in Ianovici et al. (1976); Săndulescu (1984); Bucur and Cociuba (2001); Lazăr et al. (2015).

- Farcu–Cornet Limestone (Oxfordian–Kimmeridgian–Tithonian). Platform margin carbonates containing large corals, sponges (*Ellipsactinia*), and various encrusting organisms. The lower part displays microfacies similar to those of the underlying Vad Limestone, interpreted as relict facies of the latter (Cociuba, 1999; Ianovici et al., 1976). Patrulius (in Ianovici et al., 1976) grouped the Farcu, Cornet, and Aștileu limestones under the "Farcu–Cornet Formation," interpreting the Upper Jurassic limestones as displaying facies comparable to the Štramberk Carbonate Platform.
- Aștileu Limestone (Kimmeridgian–Tithonian). Shallow-water limestones developed in a platform margin setting, characterized by oolitic facies forming sands and ooid/bioclastic shoals (Bucur and Cociuba, 2001). The main biota consists of foraminifera, together with echinoid and crinoid fragments, which commonly act as nuclei for ooid formation. According to Cociuba (1999), this facies is frequently associated with adjacent reefal and lagoonal environments (Farcu–Cornet and Albioara limestones).
- Albioara Limestone (middle Kimmeridgian–middle Tithonian). It consists of bioclastic carbonate deposits, predominantly micritic, with fenestral structures and bacinellid oncoids, characterizing

inner-platform (lagoonal) facies belts. Bucur et al. (1993) documented a foraminiferal and algal assemblage comprising *Parurgonina caelinensis*, *Mohlerina basiliensis*, *Neokilianina rahonensis*, *Kurnubia palastinensis*, *Salpingoporella annulata*, and *Macroporella lazuriensis*, which constrains the age to the middle Kimmeridgian–middle Tithonian. The Albioara Limestone shows a vertical evolution from finely laminated micritic limestones with micro-oncoids in the lower part (=Secătura Member cf. Bordea and Bordea, 1987) to spiritic/micritic limestones with large bacinellid oncoids in the upper part (=Valea Cuților Member cf. Cociuba, 2000).

Toward the end of the Upper Jurassic, the area underwent emergence, leading to the development of karstic environments that favoured the accumulation of lateritic sediments and the formation of numerous bauxite lenses in the region.

Cretaceous

The Lower Cretaceous deposits of the Bihor Unit crop out across most of the western sector of the Pădurea Craiului Mountains and consist predominantly of limestones with subordinate marl intercalations and detrital deposits (Patrulius, in Ianovici et al., 1976; Dragastan et al., 1988, 1989; Cociuba, 1999, 2000; Bucur et al., 2010, 2013; Pleș et al., 2016). Cociuba (2000) grouped the Lower Cretaceous successions into four main lithostratigraphic units: the Blid Formation (including the Dobrești and Coposeni members), the Ecleja Formation (with the Valea Bobdei Limestone as a member), the Valea Măgurii Formation, and the Vârciorog Formation. The complexity of this succession, together with the lack of continuous field exposures, has led to numerous interpretations and uncertainties regarding the delimitation and stratigraphic position of the formations of this interval (Cociuba, 1999, 2000; Bucur et al., 2010, 2013). One of the most recent stratigraphic columns for the Lower Cretaceous deposits of the Pădurea Craiului Mountains is presented by Suciu et al. (2021) and Pleș et al. (2025) (Fig. 4).

- The Blid Formation (Berriasian–late Barremian) represents a transgressive succession resting unconformably on the Upper Jurassic deposits. It consists of stratified bioclastic micritic limestones deposited in shallow-water carbonate platform environments (Dragastan et al., 1986; Cociuba, 2000). The Dobrești Member (Berriasian–Hauterivian), also known as the "charophyte limestone" (Patrulius, in Ianovici et al., 1976), is composed of dark inner-platform limestones containing charophytes, ostracods, and foraminifera, with occasional basal bauxite lenses. Its age is constrained by calcareous algae (*Salpingoporella anulata*, *S. katzeri*, *Clypeina parasolkani*) and benthic foraminifera (*Haplophragmoides joukowskyi, Montsalevia salevensis, Coscinoconus molestus*) (Cociuba, 1999; Bucur, 2000). The Coposeni Member (?Hauterivian–late Barremian), also referred to as the "*lower pachyodont limestone*" (Patrulius, in Ianovici et al., 1976), consists of thick-bedded grey limestones deposited in an Urgonian-type facies. It contains a rich micropaleontological assemblage dominated by orbitolinid foraminifera and dasycladalean algae, including *Paracoskinolina jourdanensis*, *Palorbitolina lenticularis*, *Salpingoporella melitae*, and *S. muehlbergii*, which are of key stratigraphic significance (Bucur and Cociuba, 1998; Cociuba, 2000).
- The Ecleja Formation ("Ecleja Marls", ?Barremian–early Aptian). The Ecleja Formation is widely exposed in the study area and consists of a succession of grey marls with interbedded limestone levels containing orbitolinid foraminifera (Cociuba, 1999). Two members have been distinguished: the Gugu Breccia (latest Barremian–early Aptian) and the Valea Bobdei Limestone Member (early Aptian) (Patrulius et al., 1982; Cociuba, 2000; Suciu et al., 2021). The Barremian age of the clasts suggests that the stratigraphic position of the Gugu Breccia at its type locality could be latest Barremian–earliest Aptian, a fact demonstrated also by the absence of elements from Lower Cretaceous carbonate platforms higher in the stratigraphic column (e.g., Aptian or Albian) of the Bihor Unit (Suciu et al., 2021). The Valea Bobdei Member (Bedoulian) consists of bioclastic limestone beds rich in foraminifera, algae, echinoid fragments, and rudists. The age is mainly

constrained by orbitolinid foraminifera, including *Orbitolinopsis kiliani*, *O. buccifer*, *Palorbitolina lenticularis*, *Paracoskinolina maynci* (Cociuba, 1999, 2000).

- Valea Măgurii Formation (early Aptian). Formerly known as the "*middle pachyodont limestone*" (Patrulius, in Ianovici et al., 1976), the Valea Măgurii Formation overlies the marls of the Ecleja Formation and consists of thick-bedded grey bioclastic limestones rich in rudists, benthic foraminifera, and green algae (Cociuba, 1999; Bucur et al., 2008). Cociuba (2000) noted micropalaeontological similarities between this unit and the Valea Bobdei Member of the Ecleja Formation, both supporting a Bedoulian (early Aptian) age. The upper boundary of the formation is marked by a distinct erosional surface representing a regional discontinuity, best observed in the Valea Măgurii quarry near Dobrești village.
- Vârciorog Formation (late Aptian–middle Albian). The Vârciorog Formation, defined by Patrulius, in Ianovici et al., 1976) as the "*complex of glauconitic sandstones and upper pachyodont limestones*" represents the uppermost unit of the Early Cretaceous in the Pădurea Craiului Mountains (Cociuba, 2000). It consists of a mixed lithological assemblage of glauconitic sandstones, conglomerates, and marls alternating with bioclastic limestones (Cociuba, 2000; Bucur et al., 2008; Pleș et al., 2016; 2025). Laterally, the formation includes the Subpiatră Limestone (Clansayesian–middle Albian) that exhibits typical shallow-water features, including rudist bioherms, extensive bacinellid oncoid beds and coral bioconstructions (Bucur et al., 2010a, 2010b; Pleș et al., 2025). The Subpiatră Limestone is considered a lateral equivalent of limestone units within the Vârciorog Formation (Bucur et al., 2010a).

The early Late Cretaceous "*red detrital formation*", an informal term introduced by Patrulius (in Ianovici et al., 1976), represents the final sedimentary deposits of the Cretaceous succession in the Pădurea Craiului Mountains (Bihor Unit). It consists of a complex of red conglomerates, sandstones, marls, and argillaceous shales (Cociuba, 1999). Planktonic foraminifera identified within this unit include *Hedbergella brittonensis*, *Praeglobotruncana delrioensis*, *Globotruncana lapparenti*, and *Rotalipora montsalvensis* (Istocescu, 1970; Ianovici et al., 1976). Based on this assemblage, the formation has been assigned a ?late Albian–Cenomanian–middle Turonian age (Cociuba, 1999; Lazăr et al., 2015).

4.2. The Codru Nappe System: various views create a complexity

In the subsequent sub-chapters, we summarize briefly the mainly used and preferred nappe concept of Bleahu et al. (1970; 1972; 1994), Patrulius (1971; 1976), Patrulius et al. (1979), and Săndulescu (1984), including in the description of their nappes also opposing interpretations. The nappe concept of Balintoni (1994) and Balintoni et al. (2014) we cannot use and discuss, because most of the nappes in the Codru-Moma nappe system are detached from their basement. The controversial interpretation of the nappe structure persists despite the fact that these authors did not recognize the existence of two distinct mountain-building phases. Their reconstruction of the Triassic facies belts relies solely on the present-day superposition of structural units and does not consider the original arrangement of facies belts as established by Wilson (1975) and further developed by Flügel (1978, 1987). At least following the introduction of the rimmed carbonate shelf concept and facies belt model of Wilson (1975), the classical definition of the Codru-Moma nappe system adopted by Bleahu et al. (1994) and Patrulius et al. (1979) should have been reconsidered. Nevertheless, the more recent reconstructions of Kovács et al. (2011, 2014) and Haas et al. (2011) continue to follow the classical nappe concept. Although a detailed discussion of the controversies surrounding the Codru-Moma nappe system is beyond the scope of this field trip guide, it is important to recognize that this interpretation forms the basis for modern correlations of tectonic units throughout the Circum-Pannonian realm (Schmid et al. 2008, 2020).

According to Bleahu et al. (1970; 1972; 1994), Patrulius (1971; 1976), Patrulius et al. (1979), and Săndulescu (1984), the nappes composing the Codru Nappe System consist, with two exceptions, of Permian–Mesozoic sedimentary successions which display a progressive transition from external to internal zones characterized by increasingly typical Mesozoic lithofacies and biofacies. The Codru Nappes show an

uneven areal distribution, with the most extensive units corresponding to the Codru-Moma, Bihor, and southern Pădurea Craiului Mountains. The Codru Nappe System should comprise, from bottom to top, the **Vălani**, **Finiș-Gârda**, **Dieva (including Tărcăița)**, **Moma-Arieșeni**, **Vașcău**, and **Colești** nappes.

4.2.1. The Vălani Nappe

The Vălani Nappe (or Vălani Unit) represents the structurally lowest nappe of the Codru Nappe System and it is a cover nappe composed exclusively of sedimentary formations. The Vălani Nappe shows mixed lithostratigraphic characteristics relative to the Bihor Unit and the Finiș–Gârda Nappe (Patrulius, 1971; Bleahu et al., 1981), being defined, on the one hand, by the presence of Carpathian Keuper deposits and, on the other hand, by the development of Lower Cretaceous successions that possess comparable facies to those of the Bihor Unit in the Pădurea Craiului Mountains. Its pre-thrust position is interpreted to have been along the inner margin of the Bihor Unit, from which it was likely detached as a large tectonic slice (klippe) during pre-Gosau thrusting events and subsequently emplaced at the base of the Codru Nappe System (Săndulescu, 1984)

Triassic

The sedimentary succession of the Vălani Unit (Fig. 5) begins with Permian deposits followed by Lower Triassic (Induan–Olenekian) sediments developed in Werfen-type facies (gerzo-argillaceous facies; Patrulius, 1971; Patrulius in Ianovici et al., 1976). These are represented by fluvial quartzitic sandstones, microconglomerates, and conglomerates in thick beds, grading upward into silty-clayey shales (Patrulius, in Ianovici et al., 1976). Lithologically, these deposits are comparable to Werfen-type successions in the Bihor Unit.

The Middle Triassic of the Vălani Unit (Fig. 5) is dominated by carbonate deposits (dolomites and limestones). The Anisian consists mainly of grey dolomites comparable to those of the Bihor Unit and Finiș-Gârda Nappe, showing a transition from bedded lower intervals to more massive upper parts, locally affected by erosion (Patrulius, in Ianovici et al., 1976).

A key unit is the so-called late Anisian–Ladinian *Roșia Limestone* (Patrulius et al., 1976), a dark, deep-water, bedded limestone widely distributed across the Codru Nappe System. In the Vălani Unit, it is well exposed in the Căbești and Valea Strâmturii areas, where it is believed to have formed two continuous segments of the same succession (Patrulius et al., 1976) spanning the late Anisian–Ladinian–early Carnian interval. According with Patrulius et al. (1976), at the Căbești outcrop this succession should begin with dark bedded limestones overlying Anisian dolomites. This is followed by marly limestones with rare *Daonella* and crinoid fragments, and then nodular bioclastic limestones with richer microfauna and conodonts (e.g., *Tardogondolella mungoensis*, *Gondolella navicula*), indicating a Ladinian (Longobardian) age (cf. Patrulius et al., 1976). In Valea Strâmturii, the Roșia Limestone is thinner and consists of micritic and pelsparitic limestones with rare silicified nodules and a conodont-rich fauna indicating a Fassanian–Longobardian–Carnian transition (cf. Patrulius et al., 1976).

The upper Ladinian deposits grades into massive Upper Triassic bioconstructed limestones of Carnian age (*Strâmtura Limestone*), a thick and locally recrystallized, huge Wetterstein reefal block, with a basal brecciated level (Patrulius, in Ianovici et al., 1976; Patrulius et al., 1976). This unit is overlain by Norian (Carpathian Keuper) deposits up to ~100 m thick, consisting of red to violet or green conglomerates, sandstones, and clay shales (Bordea et al., 1975; Patrulius, in Ianovici et al., 1976).

Jurassic

Lower Jurassic (Hettangian–Pliensbachian) deposits (Fig. 5) lie unconformably above the Norian (Carpathian Keuper) deposits and consist of quartzitic sandstones, yellowish shales, and pelagic limestones with ammonites and belemnites. The lower two units correspond to Hettangian–early Sinemurian, while the upper pealgic limestones indicate a late Sinemurian–Pliensbachian age (Patrulius, in Ianovici et al., 1976).

Upper Jurassic (Kimmeridgian–Tithonian) successions of the Vălani Nappe (Fig. 5) are best exposed in the Roșia–Căbești gorge and Valea Strâmturii and consist of up to 250 m of dark micritic and pelsparitic limestones with minor bioclastic levels containing various shallow-water fossils. Lower intervals are rich in pelagic crinoids (*Saccocoma*), while upper levels contain calpionellids (*Calpionella alpina*, *Crassicolaria*), indicating a Tithonian age (Patrulius, in Ianovici et al., 1976).

Cretaceous

The Lower Cretaceous succession of the Vălani Nappe (Fig. 5) is thinner than its counterpart in the Bihor Unit and, according to Patrulius, in Ianovici et al. (1976), comprises deposits comparable to the main lithostratigraphic units recognized in the Bihor Unit.

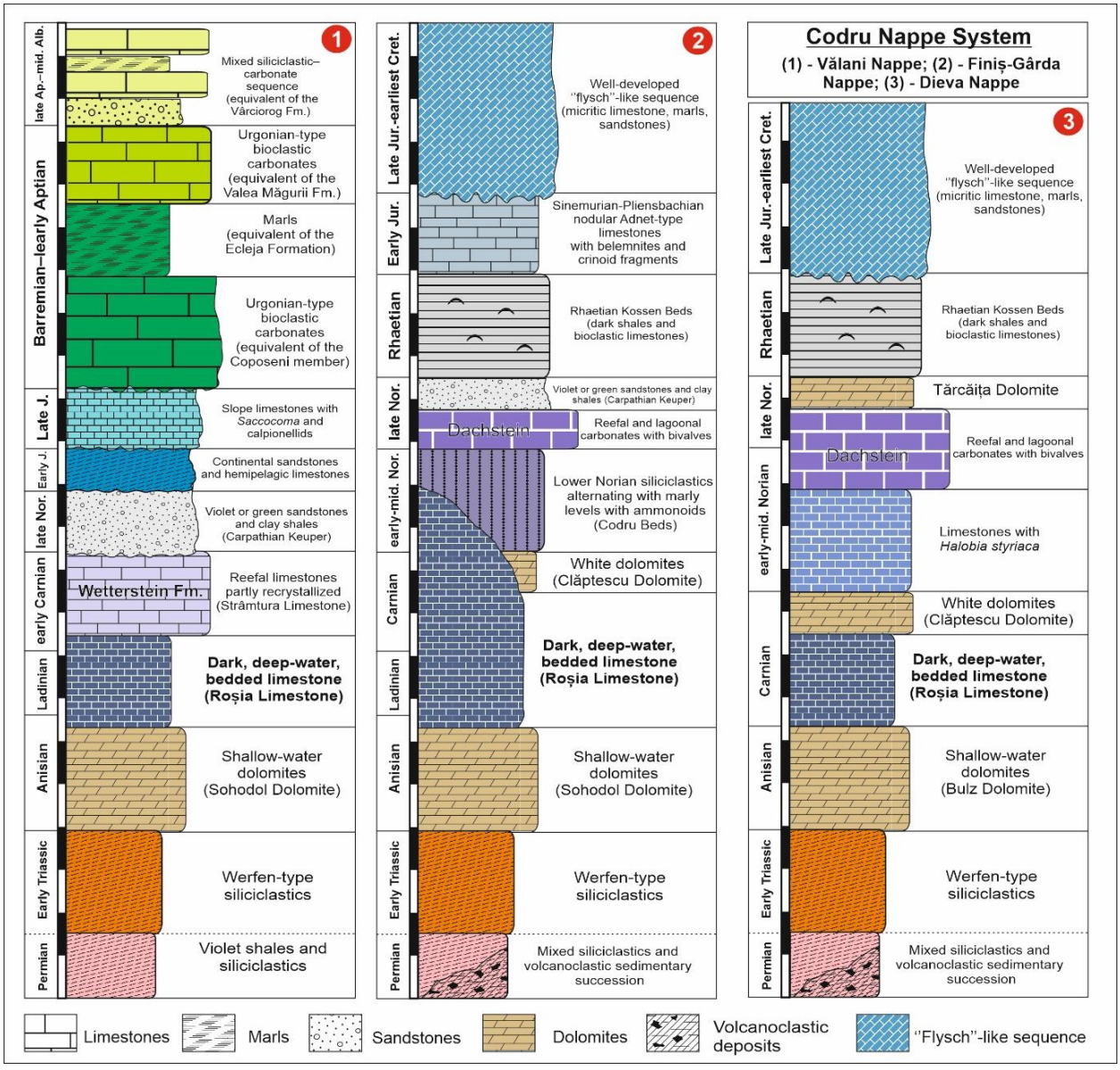


Fig. 5. Schematic drawing of the lower Codru Nappe system sedimentary deposits based on Bleahu et al. (1970, 1972, 1981, 1994); Patrulius (1971); Patrulius et al., 1976, 1979; Ianovici et al. (1976); Săndulescu (1984).

These include Barremian Urgonian-type limestones with rudists, benthic foraminifera, and calcareous algae (the "lower pachyodont limestone", equivalent to the Coposeni Member), the Ecleja Marls with orbitolinids, lower Aptian rudist-bearing carbonates corresponding to the Valea Bobdei Member and the Valea Măgurii Formation (the "middle pachyodont limestone"), and an upper Aptian–Albian mixed

siliciclastic–carbonate succession comparable to the Vârciorog Formation of the Bihor Unit (Patrulius, in Ianovici et al., 1976; Dohan et al., 2025).

4.2.2. The Finiș-Gârda Nappe

The Finiș–Gârda Nappe is the most extensive tectonic unit of the Codru Nappe System (Bleahu & Dimitrescu, 1957; Ianovici et al., 1976; Bleahu et al., 1981). Unlike the Vălani Nappe, it includes both pre-Alpine metamorphic basement and Permian–Mesozoic sedimentary cover. Excluding the areally restricted Vălani Nappe, the Finiș–Gârda Nappe forms the structurally lowest major unit of the Codru Nappe System (Săndulescu, 1984). The pre-Alpine metamorphic basement of the Finiș–Gârda Nappe is characterized by an association of crystalline schists with gneisses and granitoid gneisses (Săndulescu, 1984).

Permian deposits are well developed in the Finiș–Gârda, Dieva, and Moma–Arieșeni nappes and are composed predominantly of conglomerates, sandstones, volcaniclastic rocks, breccias, and red shales, with the most complete successions exposed in the Finiș and Gârda Seacă valleys (Ianovici et al., 1976).

Triassic

The best-known succession of the **Lower Triassic** Werfen siliciclastic sequence of the Finiș-Gârda Nappe is exposed on the eastern slope of the main ridge of the Codru Mountains. The succession comprises three lithostratigraphic units: a basal 300 m-thick package of massive quartzitic conglomerates and sandstones, overlain by approximately 150 m of bedded quartzitic sandstones, and capped by a 100–125 m-thick succession of red siltstones with thin, sporadic sandstone intercalations (Ianovici et al., 1976).

Middle Triassic deposits (Fig. 5) are represented by Anisian dolomites (namely the *Sohodol Dolomites*) and a Ladinian well-bedded hemipelagic carbonate sequence (lower part of the *Roșia Limestone* cf. Patrulius et al., 1976).

The *Roșia Limestone* has its type-section within the Finiș-Gârda Nappe. According to Patrulius et al. (1976), the Roșia Limestone type section comprises the following deposits:

- **Ladinian (Fassanian)**. Approximately ten meters of black beded limestones lacking siliceous nodules with Ladinian conodonts (Reifling Formation cf. Bleahu et al. 1970; Patrulius et al., 1976).
- These basal limestones are overlain by approximately 12 m of marls and marly limestones with yellowish colors that contain very rare halobiid bivalves, including *Daonella* cf. *lenticularis* indicating a Ladinian age.
- The next unit, about 13 m thick, consists of partly marly, nodular, limestones containing relatively abundant crinoid debris. Its microfauna includes foraminifers, conodonts, and holothurian sclerites.
- **Longobardian-Cordevolian**. Approximately 7 m higher, the microfauna changes markedly with the appearance of Longobardian to Cordevolian taxa.
- The succeeding unit comprises approximately 40 m of limestone containing abundant chert nodules. It's less diverse microfauna includes foraminifers such as *Turritellella mesotriassica*, miliolids, *Nodophthalmidium*, rare holothurians (*Theelia*), and sparse conodonts.
- These chert-bearing limestones are followed by about 40 m of partly marly limestones lacking chert nodules and containing lenticular interbeds of marly shale in their lower part. These rocks yield crinoids, including *Osteocrinus*, together with miliolids and *Nodophthalmidium*.
- **Early Norian**. The upper part of the succession consists of approximately 115 m of limestone in which chert nodules become progressively less abundant upward.
- **Middle Norian**. The uppermost 40 m of the Roșia Limestone lack chert nodules entirely and contain only sparse holothurian sclerites. This interval also contains rare ammonites that cannot be extracted from the surrounding limestone.

Besides the upper part of the *Roșia Limestone*, other Upper Triassic deposits of the Finiș-Gârda Nappe (Fig. 5) are represented by:

- **Carnian** white dolomites (*Clăptescu Dolomite*) in Codru Mountains (Bleahu, 1971);
- **Lower Norian** siliciclastics alternating with marly levels with ammonoids (*Codru Beds*) (Ianovici et al., 1976) are developed as an approximately a 300-meter-thick sequence.
- **Upper Norian** Dachstein reefal and lagoonal carbonates with megalodontid bivalves. The thickness of these levels is considerably reduced (approximately 30 meters thick) in comparison with coeval deposits of the other nappes of the Codru Nappe System.
- **Upper Norian** *Carpathic Keuper*, represented by a 400-meter-thick sequence of alternating green shales, fine sandstones and micritic carbonates (Patrulius et al., 1976).
- **Rhaetian Kössen Beds** (dark shales and bioclastic limestones) (Ianovici et al., 1976).

Jurassic

Representative **Lower Jurassic successions** of the Finiș-Gârda Nappe are exposed in the Șeasa area (Codru Mountains) and Moneasa area (western Moma Mountains).

- In the Șeasa Valley, the Rhaetian black argillaceous shales and *Thecosmilia*-bearing limestones are overlain by a 150 m-thick coarse detrital succession composed of silty marly shales and subordinate sandstones, particularly abundant in the lower part of the sequence. This is followed by a 75 m-thick carbonate succession of late **Sinemurian–Pliensbachian** age, subdivided into two lithostratigraphic units: a lower interval of grey, locally sandy limestones containing *Gryphaea* and rare brachiopods, and an upper interval of red, locally nodular limestones with micritic lenses, yielding abundant belemnites, and bivalves (Ianovici et al., 1976).
- In the Moneasa area, the **lower Sinemurian** is represented by grey to dark-grey sandy limestones containing ammonites and brachiopods, resting directly on the Rhaetian black limestones. The overlying upper **Sinemurian–Pliensbachian** succession begins with grey and red encrinitic limestones and passes upward into massive red, nodular to brecciated limestones (Adnet facies), characterized by abundant belemnites and *Gryphaea* (Ianovici et al., 1976).

The **Upper Jurassic and Lower Cretaceous** deposits of the Finiș-Gârda Nappe (Fig. 5) consist of a thick flysch-like sequence, extending from the Tithonian–Berriasian to the early Hauterivian and reaching an estimated thickness of approximately 700 m.

4.2.3. The Dieva Nappe

The Dieva Nappe, originally defined by Bleahu (1965), should represent the upper structural unit of the Finiș-Gârda Nappe and is best developed in the eastern Codru Mountains. Isolated tectonic remnants equivalent to the Dieva Nappe have also been described in the northern and southern Bihor Mountains (Bordea and Bordea, 1973; Bordea et al., 1975). Throughout its distribution, the Dieva Nappe is a cover nappe composed exclusively of sedimentary rocks, without pre-Alpine metamorphic basement (Ianovici et al., 1976).

The **Permian** deposits of the Dieva Nappe (Fig. 5) are broadly similar to those of the Finiș–Gârda Nappe, being represented predominantly by a thick volcanoclastic-sedimentary succession.

Triassic

The **Lower Triassic** sedimentary deposits of the Dieva Nappe are represented by massive, Werfen siliciclastics developed in thick beds (Ianovici et al., 1976).

Middle Triassic. In the Dieva Nappe, the Anisian is represented by up to 350 m of massive black dolomites (*Bulz Dolomite*). The Ladinian has not been documented and may be locally absent, with Carnian–lower Norian siliceous limestones resting directly on the Anisian dolomites.

The Late Triassic succession reaches approximately 900 m in thickness. According to Ianovici et al. (1976), the succession comprises the following lithostratigraphic units (from base to top):

- Approximately 200 m of the *Roșia Limestone*; 110 m in Patrulius et al. (1979);
- Massive white Carnian dolomites (*Clăptescu Dolomites*); 100 m – Patrulius et al. (1979);
- Norian limestones containing *Halobia styriaca*;
- Reefal and peri-reefal Dachstein limestones;
- Stratified dolomites of the *Tărcăița Dolomites* (approximately 120 m in Patrulius et al. 1979), with intercalations of dark limestones, shales, pink limestones, and ooidic limestones (Kössen Beds) above.

Lower and Middle Jurassic deposits are not preserved within the Deva Nappe. However, the uppermost Jurassic–lowermost Cretaceous interval is represented by a Tithonian–Lower Cretaceous marl–sandstone succession with flysch-like characteristics, comparable to the development observed in the Finiș–Gârda Nappe (Bleahu, 1965; Patrulius et al., 1971; Ianovici et al., 1976).

4.2.4. The Moma-Arieșeni Nappe

In earlier tectonic models of the Northern Apuseni Mountains, the Moma–Arieșeni Nappe was regarded as the uppermost unit of the Codru Nappe System (Bleahu and Dimitrescu, 1957; Patrulius and Bleahu, 1967). While some authors consider them to represent two distinct nappes (Bleahu, 1976; Bleahu et al., 1981), others regard them as a single tectonic unit (Patrulius, 1976). Regardless of this interpretation, both units should occupy an intermediate structural and paleogeographic position between the more external Dieva Nappe and the more internal Vașcău Nappe (cf. Săndulescu, 1984). The oldest rocks occur in the Arieșeni Nappe and consist of Carboniferous green schists (Săndulescu, 1984). Both nappes contain well-developed Permian molasse successions associated with volcanic rocks (Ianovici et al., 1976). In the following we present the sedimentary succession as a single tectonic unit, the Moma–Arieșeni Nappe.

Triassic

The Triassic sedimentary cycle (Fig. 6) begins unconformably above the ?Middle Permian succession, although the Permian–Triassic boundary is difficult to identify because of the similar lithofacies.

The **Lower Triassic** Werfen beds reach their greatest thickness within the Codru Nappe System (up to ~1200 m) and consist predominantly of quartzitic sandstones, followed upward by fine-grained sandstones, siltstones, and clay shales (Ianovici et al., 1976).

The **Anisian** is represented by grey stratified dolomites interbedded with fossiliferous limestones containing *Costatoria costata*, while the upper part locally includes crinoidal limestones rich in *Daocrinus* (Panin et al., 1982; Bucur, 2001).

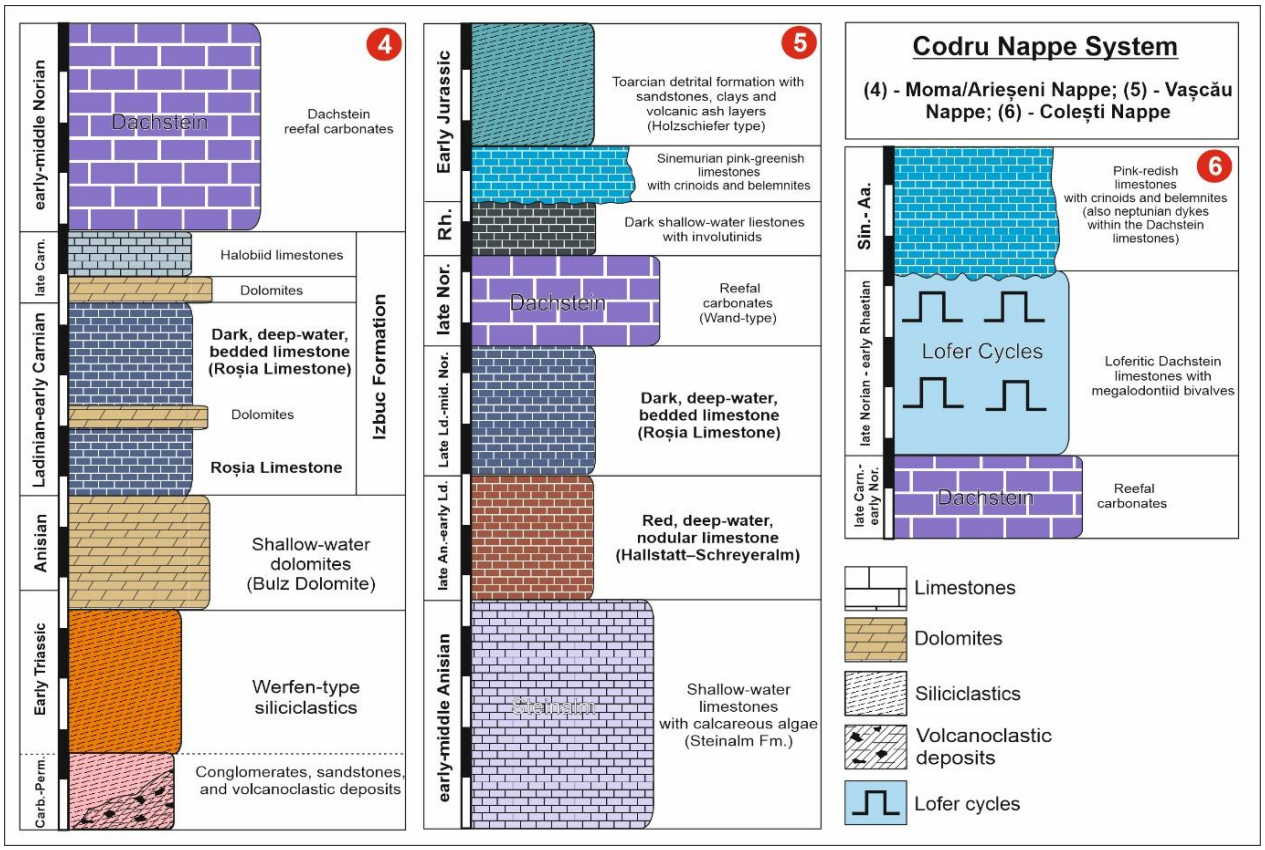


Fig. 6. Schematic drawing of the upper Codru Nappe system sedimentary deposits based on Bleahu et al. (1970, 1972, 1981, 1994); Patrulius et al., 1976; Patrulius, in Ianovici et al. (1976); Săndulescu (1984)

The **upper Anisian–upper Carnian** succession is assigned to the *Izbuc Formation* (Panin and Tomescu, 1974), which comprises Wetterstein limestones with crinoids (*Isocrinus tyrolensis*) (Bleahu et al., 1972), ostracods, and conodonts, followed by a complex succession including Roșia-type limestones, cherty limestones, micritic limestones with *Daonella*, Hallstatt-type brecciated limestones and a second Roșia Limestone interval. Rich assemblages of foraminifers, ostracods, ammonoids, bivalves, and conodonts constrain this succession to the **Ladinian–late Carnian** interval (Ianovici et al., 1976).

The Triassic succession culminates with 150–200 m of massive **Dachstein-type limestones (late Carnian–Norian)**, locally interbedded with hemipelagic limestones rich in halobiid bivalves. The upper part contains abundant calcareous sponges, corals, bivalves, and crinoids, whereas the conodont assemblages indicate a late Carnian age (Panin et al., 1982). **Late Norian – Rhaetian** gap according to Bleahu et al. (1981; 1994).

4.2.5. The Vașcău Nappe

The structurally highest units of the Codru Nappe System are believed to be the Vașcău and Colești nappes, both cover nappes composed exclusively of Mesozoic sedimentary rocks (Bleahu et al., 1970; Panin et al., 1980; Săndulescu, 1984). Initially regarded as a single unit, the Colești Nappe was later distinguished from the Vașcău Nappe based on differences in Upper Triassic and Lower Jurassic lithofacies (Panin et al., 1982). Both nappes are characterized by well-developed Hallstatt- and Dachstein-type Triassic carbonate successions, closely resembling Austroalpine facies. Compared to the more external Codru nappes, the Vașcău Nappe displays an entirely carbonate Triassic succession (including Steinalm, Schreyeralm, Wetterstein, and Dachstein facies) (Săndulescu, 1984).

Middle Triassic

The Anisian of the Vaşcău Nappe (Fig. 6) shows distinctly different facies characteristics compared to the other units of the Codru Nappe System, as it consists of Steinalm limestones, locally dolomitized, overlain by red ammonoid-bearing limestones (Schreyeralm–Hallstatt facies) (Ianovici et al., 1976).

- **Anisian Steinalm limestones** reach a thickness of about 550 m and consist of white to grey limestones, partly dolomitized, rich in dasycladalean algae (*Physoporella pauciforata*, *Macroporella alpina*, *Teutloporella tabulata*) and benthic foraminifera (*Endotriadella wirzi*, *Meandrospira dinarica*). These fossils indicate a late Anisian age (**Pelsonian–lower Illyrian**) (Bleahu, 1972; Bucur, 2001).
- These are overlain by red micritic **Illyrian-Ladinian** Hallstatt–Schreyeralm limestones. (Bleahu et al. 1972). In some areas, argillaceous shales and marly limestones also occur. These carbonates contain ammonoids (*Flexopychites loczyi,* cf. Ianovici et al., 1976). Conodont assemblages from the lower part of the succession indicate a Fassanian (lower Ladinian) age while those from the upper part suggest a Longobardian (upper Ladinian) age (Panin et al., 1982; Bucur, 2001).

Late Triassic

The Upper Triassic deposits (Fig. 6) show greater facies variability due to increased input of argillaceous and terrigenous material. The basal part consists of black, bedded limestones with cherts, a lithological unit consistent across all three upper Codru nappes (Moma-Arieșeni, Vaşcău, and Colești) (Ianovici et al., 1976). The Upper Triassic succession in the Vaşcău Plateau includes:

- ***Roșia Limestone*** **(?late Ladinian–Norian)**, composed of black micritic limestones, bedded or massive, with siliceous nodules.
- Overlying the Roșia limestones is the *Wand Limestone* (**late Norian–Rhaetian**), about 100 m thick, with a white-grey to pink coloration. It consists of biosparites with dasycladalean algae (*Macroporella* sp), crinoids, echinoderms, calcareous sponges, and foraminifera (*Agathammina austroalpina*, *Trochammina laevis*) (Panin et al., 1982; Bucur, 2001).
- This unit is followed by black **Rhaetian** limestones with involutinids, consisting of black and grey bedded limestones with frequent chert nodules. The foraminiferal assemblage is diverse (*Involutina communis*, *Parvalamella friedli*, *Ophtalmidium carinatum*) (Panin et al., 1982; Bucur, 2001), and large megalodont bivalves have also been identified (Ianovici et al., 1976).

Early Jurassic

The Triassic carbonates are overlain by detrital, argillaceous, and marly deposits with interbedded limestones assigned to the Early Jurassic and possibly the lowermost Middle Jurassic.

- **Sinemurian**. Pink-greenish limestones (60–80 m thick) represent the first Lower Jurassic unit in the Vaşcău Nappe. These are micritic limestones rich in crinoids, belemnites, and ammonoid fragments (Panin et al., 1982; Bucur, 2001), overlain by a sandy succession.
- **Toarcian**. ***The Toarcian detrital formation*** overlies the Sinemurian limestones transgressively and is 250–300 m thick. It consists of calcareous sandstones, clays, black crinoid-bearing limestones, volcanic ash layers, and siliceous horizons, containing bivalves and belemnites (Panin et al., 1982; Bucur, 2001).

4.2.6. The Colești Nappe

The Colești Nappe is believed to occupy the highest structural position relative to the Moma-Arieșeni and Vaşcău nappes within the Codru Nappe System and is mainly composed of Upper Triassic Dachstein-type limestones and Lower Jurassic deposits, which locally include neptunian dykes (Panin et al., 1982).

Late Triassic

The Dachstein limestones are grey in colour, partly dolomitized and recrystallized. They are both bioconstructed and bioclastic, and contain abundant calcareous sponges, corals, gastropods, bivalves, ammonoids, crinoids, and calcareous algae (Ianovici et al., 1976). These deposits are typical of reefal and carbonate platform slope environments (Panin et al., 1982; Bucur, 2001). In the basal part of the succession, lumachelle levels with *Halobia styriaca* and *H. austriaca* indicate a late Carnian–early Norian interval (Panin et al., 1982). A foraminiferal assemblage (*Alpinophragmium perforatum*, *Tolypammina gregaria*, *Involutina communis*, *Ophtalmidium* sp., duostominids) suggests a Norian–Rhaetian age (Bucur, 2001).

The upper part of the succession contains **Norian–Rhaetian** loferitic deposits (Fig. 6), characteristic of peritidal to lagoonal environments (Baltreș, 2000). At the base of these deposits, carbonate breccias occur, overlain by bioclastic limestones rich in gastropods, cyanobacteria, megalodont bivalves, and foraminifera (*Involutina communis*, *Parvalamella friedli*, *Agathammina sp.?*) (Panin et al., 1982). The loferitic sequence is capped by micritic limestones with fenestral structures, typical of inner carbonate platform environments (Baltreș, 2000; Bucur, 2001).

Rhaetian reefal and peri-reefal limestones follow next in succession with abundant Jurassic neptunian dykes.

Early Jurassic

The Jurassic deposits of the Colești Nappe are represented by neptunian dykes developed within the Dachstein reefal and peri-reefal limestones, with irregular distribution within pre-existing cavities. The fill of these dykes consists of reddish limestones containing crinoid fragments, echinoderms, belemnites, and foraminifers (*Involutina liassica*). Their occurrence within the Colești Nappe indicates an Early Jurassic age (Ianovici et al., 1976; Bucur, 2001).

4.3. Triassic facies belts and resulting nappe structure: intraplatform basins and "Mid-Cretaceous" mountain building process

The nappe concept of the Apuseni Mts., and especially of the Codru Nappe System was based mainly on the arrangement of the facies belt during Triassic times. Even if the concepts and the definition of the different nappes vary a bit in the view of the different authors, the overall concept is very well recognizable (see Fig. 7).

All authors follow generally the view of long-living intraplatform basins, these are namely the Roșia basins. In the time this nappe concept was established, the model of long-living intraplatform basins was believed elsewhere in the Western Tethys Realm (Mojsisovics, 1905, Zankl, 1967, Auboin et al., 1970, Rampnoux, 1974). It is out of the scope of this field trip guide to discuss the existence of long-living intraplatform basins in a carbonate dominated shelf environment. Interested readers in that topic are referred to Gawlick et al. (2026, and references therein).

The most proximal Roșia basin (the Finiș nappe) is located between the Vălani nappe and the Dieva nappe and the more distal Roșia basin is located in the Vașcău nappe. In both cases one has to recognize that long-living reef rims on both sides of each of these believed intraplatform basins did not exist. The facies zone of the belived position of the proximal Roșia basin is also highly influenced of the Europaean hinterland, that is the siliciclastic shedding which normally hampers shallow-water carbonate production. This contrasts the evolution of the more distal intraplatform basin in the Vașcău nappe, where basinal sedimentary rocks deposited predominantly during the Middle Triassic to the Carnian, a time span with restricted shallow-water carbonate production elsewhere in the Western Tethys Realm after the demise of the Steinalm Carbonate Ramp. Only short intervals of shallow-water carbonate production can be

recognized (in the late Illyrian and the early Longobardian) before the evolution of the Wetterstein Carbonate Platform cycle in the early Carnian.

Furthermore, the existing nappe concept was based on the view of a single mountain building process that is the "Mid-Cretaceous" orogeny. The Middle-Late Jurassic mountain building process in the frame of ophiolite obduction was not known, not detected, and in fact was not possible to recognize, because all models of that time were based on the geosyncline model.

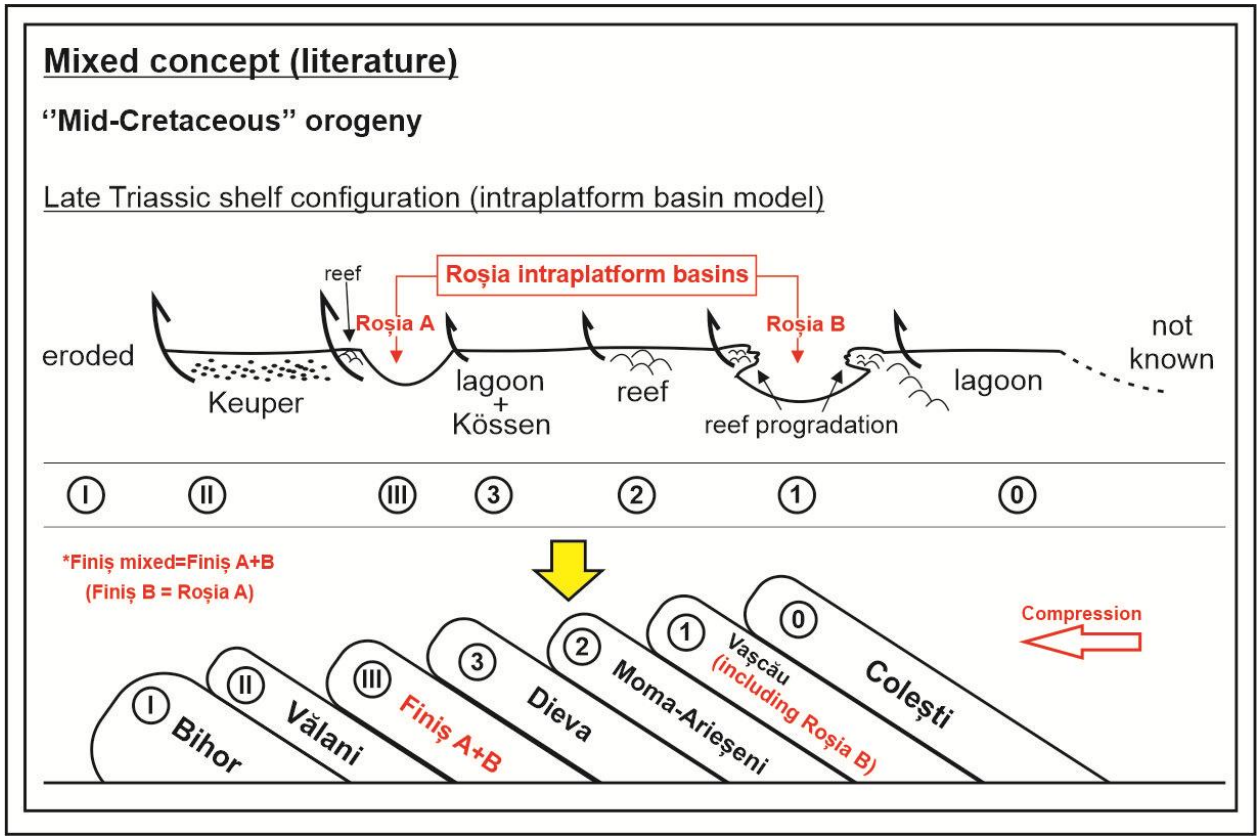


Fig. 7. Classical reconstruction commonly adopted in the literature, in which the present-day arrangement of the Bihor, Vălani, Finiș, Dieva (Tărcăița), Moma-Arieșeni, Vașcău, Colești, and Roșia units is interpreted as the result of a single thrusting history that combines structures formed during the Middle Jurassic and "Mid-Cretaceous" orogenies. Consequently, the reconstruction of the Triassic facies belts is based on the present structural superposition, resulting in mixed paleogeographic positions of several units.

It is out of the scope to refer here now the history of changing concepts during the time of geological exploration. The main problem in the Codru Nappe System is the preservation of the different facies belts, the nappe stack, the newly formed Jurassic basins due to the fact, that the Jurassic mountain building process is masked by the "Mid-Cretacous" mountain building process, two times with significant shortening, uplift and erosion and subsequent block rotations and strike-slip movements.

However, in fact the evolution of the different preserved sedimentary successions, their age and their facies will tell us the history, even if a lot of pieces of the puzzle are missing/destroyed/not detected.

5. THE FIELD TRIP

The field trip stops presented in this chapter are organized according to the different geological units rather than following the chronological order in which the stops will be visited during the field trip. This arrangement is intended to provide a coherent overview of the geology, stratigraphy, and evolution of each unit. The actual sequence of stops may therefore differ from the order in which they are presented here (Fig. 8).

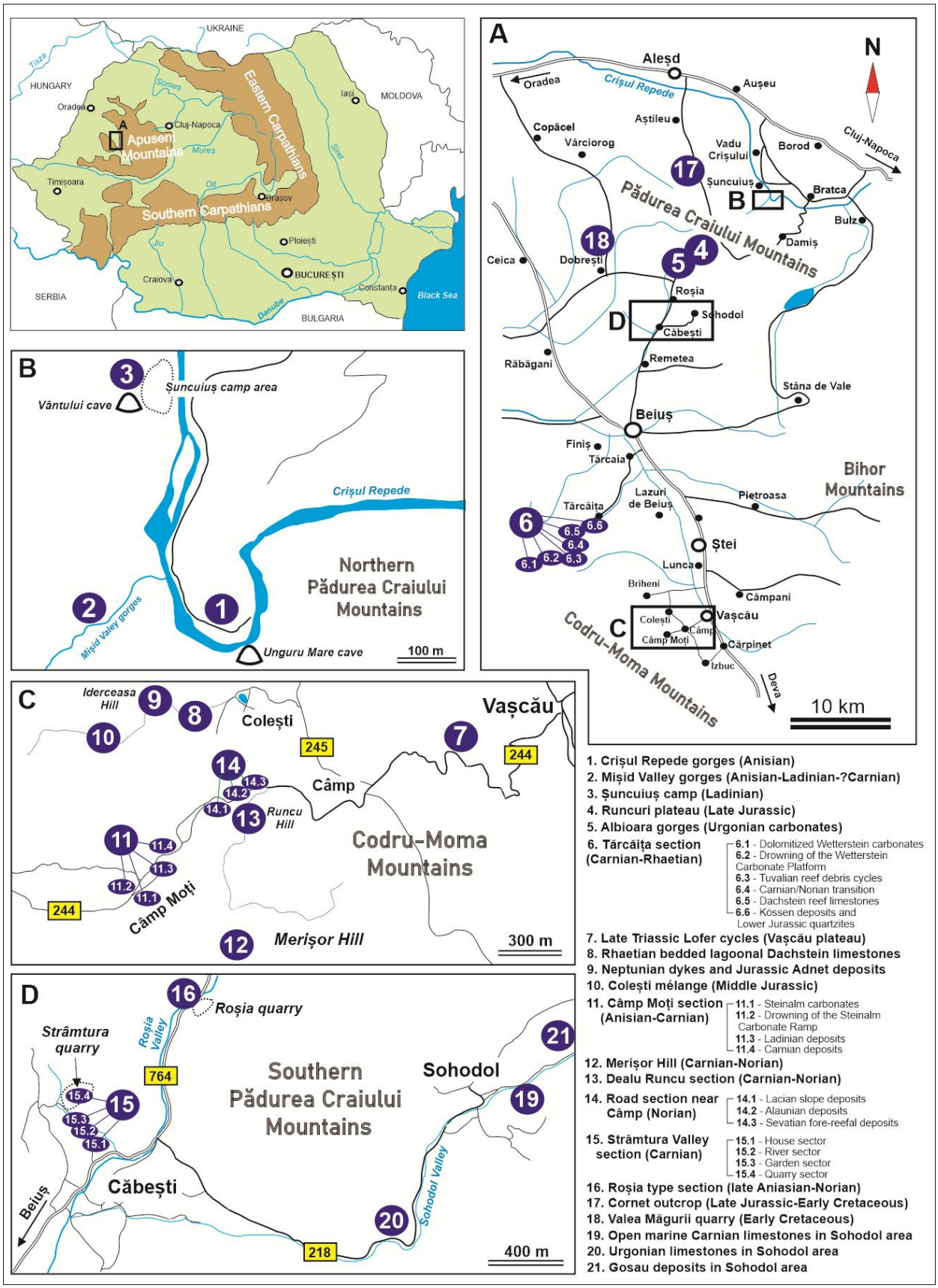


Fig. 8. Location of the stops

For a better overview of the palaeogeographic provenance of the different sections we will visit during our field trip, the sedimentary successions are plotted into the stratigraphic table of the Northern Calcareous Alps (Fig. 9). This Stratigraphic table of the Northern Calcareous Alps is constructed on base of the different facies zones well constrained for the long-living (~26-27 million years) Late Triassic Dachstein Carbonate Platform with the following main facies belts, listed here from North (proximal) to South (distal) according to Present geological coordinates:

- **Keuper facies**: not preserved in the Northern Calcareous Alps but in other units of the Eastern Alps and more widespread in the Western Carpathians. The most proximal facies connecting the facies belts of the Dachstein Carbonate Platform formed on the (northern, northwestern, western) passive continental margin of the Neo-Tethys Ocean with continental Europe. In contrast to the Eastern Alps the Keuper facies is more common and widespread distributed in the Tisza unit.
- **Hauptdolomit facies** (Dolomia Principale in the Southern Alps): the most restricted and proximal facies of the Dachstein Carbonate Platform. The Hauptdolomit facies belt shows in several cases the influence of the continental Keuper facies in form of shedding of siliciclastic material into this facies belt. In cases of sea-level drops the Keuper facies is intercalated with the Hauptdolomit facies. Uniform deposition practically during the whole Norian in the late Norian and Rhaetian the Hauptdolomit facies was influenced by the shedding of siliciclastics from the Europaean hinterland and a deep lagoon was formed, because carbonate production could not counterbalance the thermal subsidence due to the siliciclastic influence. The older part of Kössen Basin was formed (Hochalm Member). However, during the Rhaetian shallow-water carbonate production established again widespread, and shallow-water limestones were formed, which resemble the lagoonal Dachstein Limestone, but are only Rhaetian in age. Due to ongoing shedding of siliciclastics from the Europaean hinterland some parts of the Hauptdolomit facies remain deeper, and depression prevailed until the Jurassic (Schattwald Basin) where in the Early Jurassic grey siliceous limestones deposited.
- **Dachstein Limestone facies – lagoon**: the open lagoon of the Dachstein Carbonate Platform is the transitional facies between the Hauptdolomit facies and the Dachstein Limestone reef facies and characterized by deposition of (Lofer) cycles. The transition to the Hauptdolomit facies as well as to the reef belt is gradual and depends on sea-level changes and environmental perturbations. Uniform deposition practically during the whole Norian was in the late Norian and Rhaetian affected by the shedding of siliciclastic material from the Europaean hinterland. Like in the Hauptdolomit facies a deep lagoon was formed, the older part of the Kössen Basin (Hochalm) member. During the Rhaetian shallow-water carbonate production established again, and on the rims of the Kössen Basin reefs established and prograded rapidly over the deep lagoon, that is the Kössen Basin. However, this Rhaetian reef progradation could not fill the Kössen Basin totally, and in the transitional area between the Hauptdolomit facies and the lagoonal Dachstein Limestone facies a part of the Kössen Basin could not be filled because of continuous shedding of fine-grained siliciclastic material from the Europaean hinterland (Eiberg Basin). This basin remains also deeper as the adjacent shallow-water Dachstein Carbonates during the Early Jurassic after the demise of the Dachstein Carbonate Platform in the frame of the Triassic/Jurassic mass extinction. In this depression (Eiberg Basin) in the Early Jurassic grey siliceous limestones deposited.
- **Dachstein reef belt**: the Dachstein reef belt formed during Norian/Rhaetian times the wave resistant reef rim, necessary to form a flat-topped platform. The position of the reef rim shifted through that time due to sea-level changes and various environmental perturbations with the result, that the transitional facies zone between the reef rim and the open shelf environment (Hallstatt shelf) was a relatively broad zone. During Norian times the reef rim was in a relative stable position, but experienced in the Rhaetian a significant backstepping.

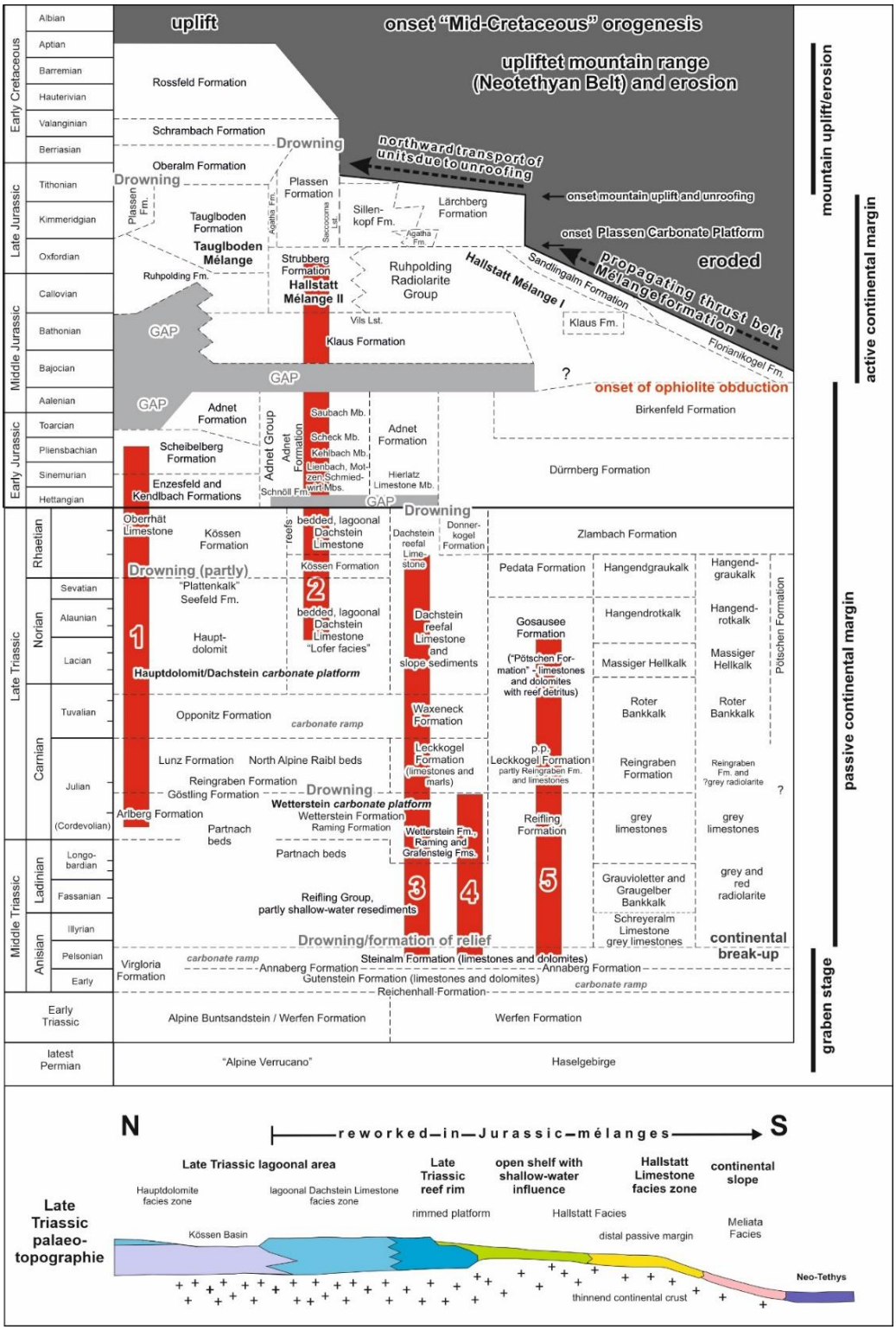


Fig. 9. Position of the sections/nappes in the Codru Nappe System excluding the Bihor nappe that will be studied in the frame of this fieldtrip plotted into the stratigraphic table of the Northern Calcareous Alps based on Gawlick et al. (2009 and references therein) and Gawlick and Missoni 2019: 1 – Tărcăița section; 2 – Colești section and melange; 3 – Câmp section; 4 – Strâmtura section; 5 – Roșia Section;

- **Hallstatt shelf**: the open marine environment is characterized by the deposition of deep-marine limestones influenced by the evolution of the Dachstein Carbonate Platform. Two different facies belts of this shelf can be distinguished – A) the grey Hallstatt facies with strong influence of the platform (e.g. turbidites), and B) the various coloured Hallstatt facies with its classical Hallstatt

Limestone sections studied since more than 150 years in the Northern Calcareous Alps and crucial for the subdivision of the Middle and Late Triassic time scale.

- Transitional to the Neo-Tethys Ocean the **Meliata facies** can be distinguished, deposited on the continental slope and its footwall.

This shelf configuration for the Late Triassic is an overall feature all along the northern/ northwestern/western passive continental margin of the Neo-Tethys and can be traced in the entire Western Tethys Realm with some unimportant regional variations which allow to reconstruct a more detailed provenance of some units in the Circum-Pannonian realm. However, in every mountain range in the surroundings of the Pannonian basin and in every country a slightly – in some case completely – different nomenclature resp. formation names are used. It is out of the scope of this field trip guide book to correlate all the different formation names.

***Note**: according to the mixture of the generalized sedimentological evolution of the different nappes practically all existing formations in the Codru-Moma nappe system needs a revision based on exact stratigraphic data combined with microfacies analysis. Most of the existing formations will be emended, while others will be precised and some are not valid. Furthermore, it will need the definition of several formations.*

Stop no. 1 – Crișul Repede gorges (Unguru Mare cave area, Șuncuiuș) - Steinalm carboantes

On the right bank of the Crișul Repede river gorges, the Steinalm carbonates are exposed as grey to white, partly recrystallized and locally dolomitized bioclastic limestones, occurring in metre-scale beds. The microfossils are generally difficult to identify macroscopically because of poor preservation and recrystallization; however, some algal remains can still be recognized.

Stop no. 2 - Mișid Valley gorges (upper Illyrian – Longobardian 1-?early Carnian)

The Mișid Valley Gorges are located in the northwestern part of the Pădurea Craiului Mountains. The gorge is relatively short, extending for approximately 2 km. About 400 m beyond the Șuncuiuș camp area (Stop no. 3), a bridge over the Crișul Repede river, located just before the bridge leading to Unguru Mare Cave, marks the entrance to the Mișid Valley Gorges near the confluence of the Mișid Valley and the Crișul Repede River.

The stratigraphic succession records a progressive change from shallow-water carbonate-platform environments toward more open-marine conditions. The lower part of the section is represented by lagoonal carbonates (partly karstified), followed by turbiditic beds containing abundant crinoidal debris. Condont samples collected from the area, contain *Paragondolella trammeri* and *P. excelsa* suggesting most probably a late Illyrian age for part of the succession.

Reefal and lagoonal deposits (back-reef facies) of probably Longobardian 1 age, partly karstified, are developed next in succession, with evidence of storm influence (tempestites). Four main microfacies types have been identified: (1) peloidal–oncoidal wackestone (MFT1), characterized by fenestral fabrics and containing rare gastropods and foraminifera; (2) bioclastic packstone–wackestone (MFT2), containing *Endotriadella wirzi*, *Palaeolituonella meridionalis*, *Reophax* sp., *Endoteba* sp., *Duostomina* sp., and *Diplotremina* sp.; (3) bioclastic grainstone (MFT3), rich in foraminifera and calcareous algae, including *Pseudodiplopora* sp.; and (4) sponge–microencruster boundstone (MFT4). The latter are characterized by extensive karstification and contain abundant sponges (*Solenolmia manon*, *Olangocoelia otti*), diverse microencrusters (*Tubiphytes obscurus*, *Radiomura cautica*, *Baccanella floriformis*, *Bacinella ordinata*, and *Ladinella porata*), together with early marine cement crusts (see Fig. 10A-F).

The upper interval is characterized by red-grey micritic limestones containing *Osteocrinus*. The occurrence of *Osteocrinus* together with the micritic character of the limestone suggests a more open-marine depositional setting compared with the underlying lagoonal and back-reef deposits. The interval is considered typically for the late Ladinian to early Carnian of the Western Tethys Realm.

Overall, the succession from lagoonal carbonates through back-reef/biohermal deposits to open-marine *Osteocrinus*-bearing limestones is interpreted as a late Illyrian–Longobardian 1 forerunner of the Wetterstein Carbonate Platform. Further sampling of the *Osteocrinus*-bearing levels may help to refine the age of this transition and establish its relationship to the early development of the Wetterstein Carbonate Platform.

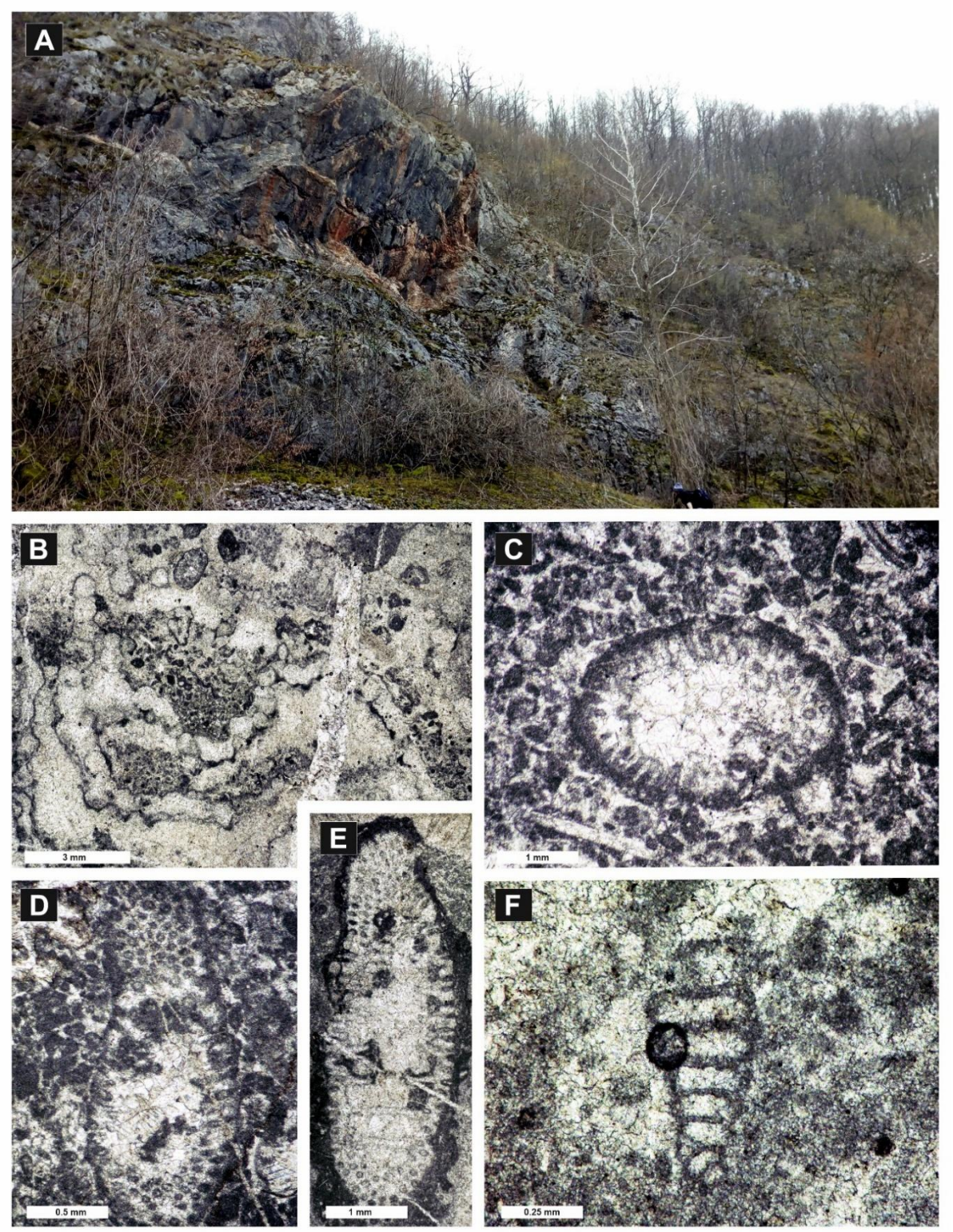


Fig. 10. (Stop no. 2). Mișid Valley Gorges. A – Outcrop view of the Longobardian lagoonal carbonates from the Mișid Valley Gorges. B – Calcareous sponge (*Olangocoelia otti*) encrusted by microbial crusts. C-E – Dasycladalean alga (*Pseudodiplopora* sp.). F – Bioclastic grainstone with *Paleolituonella meridionalis*.

Stop no. 3 - Șuncuiuș camp area (late Ladinain-?early Carnian carbonates)

This stop is located close to a camping area near the village of Șuncuiuș (Bihor County, Romania), not far from the entrance of Peștera Vântului (Wind Cave). The carbonates exposed in Șuncuiuș camp area are predominantly massive and crop out along steep valley slopes, particularly on the left bank of the Crișul Repede River. The focus of this stop is one of such sections exposed along the trail between Peștera Vântului and Șuncuiuș Camp, following an approximately north–south orientation.

In terms of facies, the carbonates from this area are similar to the Longobardian 1 reefal and lagoonal deposits (back-reef facies) of the Mișid Valley (Stop no. 2) and represent an early development of the Wetterstein Carbonate Platform. They are dominated by granular-sparitic and micritic microfacies, accompanied by small bioconstructions composed of calcareous sponges, encrusting organisms, and microbialites. Three principal microfacies types have been distinguished: (MFT1) bioclastic–peloidal packstone, (MFT2) bioclastic grainstone, and (MFT3) microbial boundstone with encrusting organisms and calcareous sponges (see Fig. 11A-D).

The bioclastic–peloidal packstones (MFT1) represent shallow, low-energy subtidal deposits of the inner-platform environment (restricted lagoon to tidal-flat settings), characterized by abundant micrite, microbial fabrics, dasycladalean algae (*Diplopora nodosa*), and benthic foraminifers (duostominids and cuneolinids). Bioclastic grainstones (MFT2) contain the most diverse skeletal assemblage, including algae, benthic foraminifera, calcified sponges, echinoderms, mollusks, and microencrusters (*Tubiphytes*, *Radiomura cautica*, *Baccanella floriformis*). Their grain-supported texture and reworked intraclasts indicate deposition under relatively higher-energy conditions in an open-platform setting adjacent to patch reefs. Microbial boundstones (MFT3) form small sponge–microbial patch reefs in a back-reef position. The microfacies association and fossil assemblage are typical of late Ladinian–early Carnian Wetterstein carbonates of the Western Tethys.

Stop no. 4 – Runcuri plateau (Upper Jurassic oncoidal carbonates and Jurassic/Cretaceous boundary bauxites)

The Runcuri Plateau is located in the northwestern part of Roșia Commune, Bihor County, near the Albioarei Gorges, with Cuților Valley situated to the south. This stop focuses on the Upper Jurassic carbonates of the Bihor Unit that crop out in the central-northern part of the Runcuri Plateau, close to a former bauxite exploitation site.

The exposed deposits consist of late Kimmeridgian–middle Tithonian limestone beds (Albioara Formation) showing alternating oncoid-rich levels and fine micritic (muddy) facies with benthic foraminifera and calcareous algae (*Parurgonina caelinensis*, *Alveosepta jaccardi*, *Macroporella lazuriensis*, and *Salpingoporella annulata*). The limestones are affected by numerous fractures filled with sparry calcite or reddish terrigenous material.

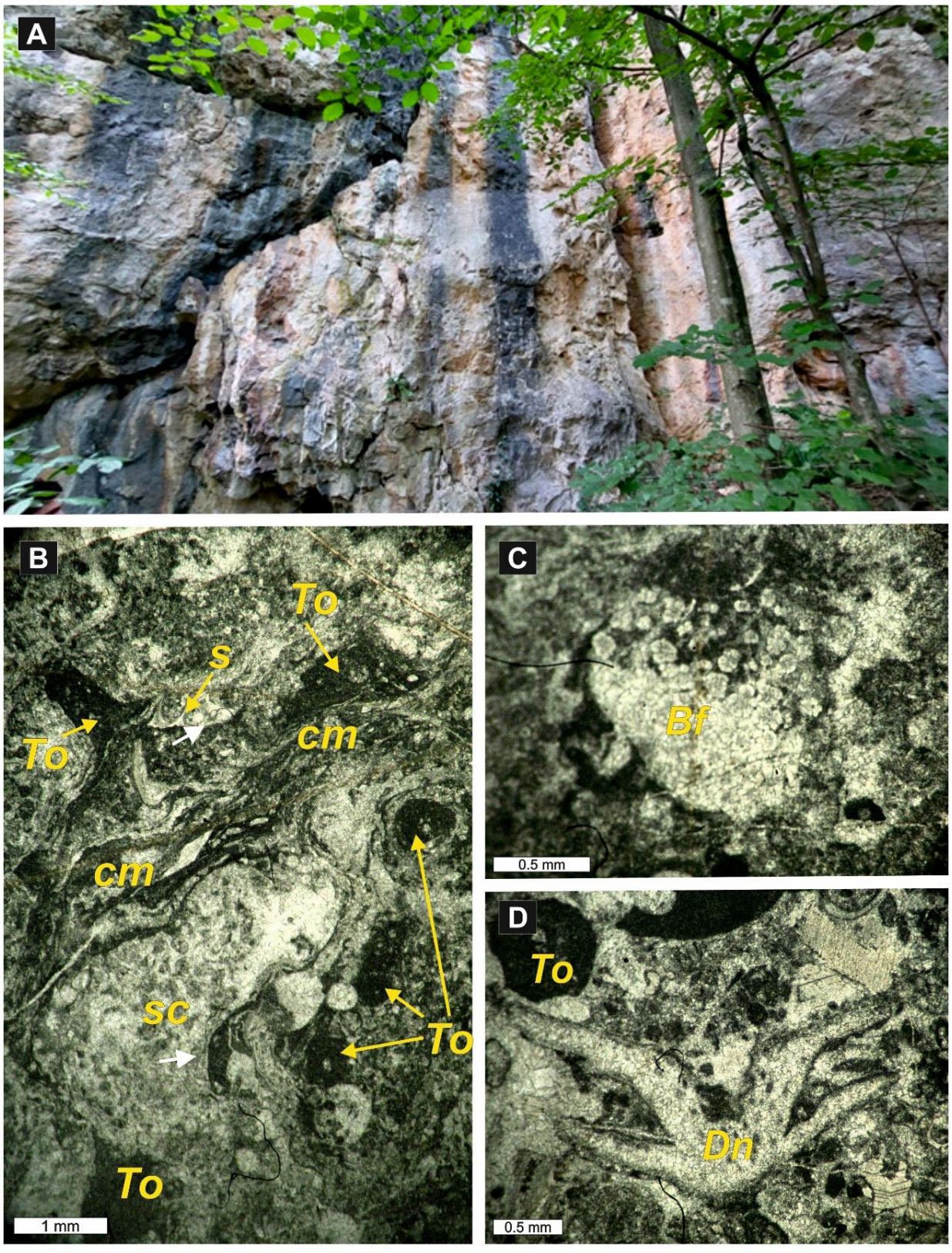


Fig. 11. (Stop no. 3). Șuncuiuș camp area. A – Outcrop view of massive upper Ladinian Wetterstein carbonates from the Șuncuiuș camp area. B – Overview of a microbial boundstone with encrusting microorganisms, sponges, and microbialites (MFT3). The presence of calcareous sponges (*sc*) of the genus *Solenolmia*, numerous specimens of *Tubiphytes obscurus* (*To*), serpulids (*s*), and microbial crusts (*cm*) is notable. C – *Bacanella floriformis* (*Bc*) within a microbial boundstone containing encrusting organisms (MFT3). D – *Diplopora nodosa* (*Dn*) and *Tubiphytes obscurus* (*To*) within a bioclastic grainstone/rudstone (MFT2).

A distinctive feature is the abundance of bacinellid oncoids in the uppermost level, reaching sizes of up to 2 cm, together with their commonly elongated shapes. This morphology is characteristic of several carbonate formations from the Pădurea Craiului Mountains. Oncoids are the main features of these limestones (Fig. 12A-C), accompanied by rare fragments of mollusc shells and calcareous sponges. These limestones contain two main types of oncoids, distinguished by their size, morphology, cortical structure, and nucleus characteristics.

- **Type A oncoids** (Fig. 13A) are the dominant variety and are generally larger, ranging from 0.9 to 2.6 cm. They display ellipsoidal to oval shapes and are commonly slightly flattened by post-depositional compaction. Their cortex is mainly micritic and commonly exhibits a typical bacinellid structure, consisting of sparitic vesicles enclosed by thin micritic bands. Weak concentric pseudo-lamination may occur, reflecting successive growth stages of cyanobacterial and calcimicrobial microstructures. These oncoids are usually nucleus-free, although rare nuclei may consist of mollusc fragments or dasycladalean algae.
- **Type B oncoids** (Fig. 13B) are smaller (0.7–1.8 cm), predominantly subspherical, and commonly show lobate outlines. Their cortex is characterized by alternating bacinellid structures and micritized zones, producing a micritic fabric with abundant sparitic cavities. Unlike Type A, they commonly contain well-preserved nuclei, mainly represented by sclerosponges (especially *Cladocoropsis*), dasycladalean algae and mollusc fragments. Rarely, two Type B oncoids can become incorporated into composite macro-oncoids surrounded by a final bacinellid cortical layer. Both oncoid types occur within micritic, muddy facies classified as bioclastic oncoidal floatstones, together with benthic foraminifers and dasycladalean algae. The abundance of Type A oncoids indicates their dominance within the Runcuri Plateau carbonate deposits, whereas Type B oncoids represent a less common but characteristic component. These facies are also notable for the frequent occurrence of large benthic foraminifers, particularly *Parurgonina caelinensis*.

Both oncoid types (A and B) are characterized by a bacinellid cortical structure and, in many cases, a specific pseudo-lamination related to the gradual development of the cortex through successive growth stages of bacinellid microstructures and cyanobacterial activity. Although the morphology of the studied oncoids may indicate minor fluctuations in hydrodynamic conditions, their bacinellid structure and the other characteristics collectively suggest a calm, low-energy setting within the inner platform environment. The dominance of microbial fabrics, muddy facies, and the low proportion of skeletal components within the studied limestones indicate an environment with relatively low nutrient input. The presence of photophilic organisms, including calcareous algae and cyanobacteria/calcimicrobes, further supports deposition in a shallow, well-lit subtidal environment.

In several places, bauxite lenses or bodies (Fig. 13C) can be observed directly overlying the oncoid-rich carbonate deposits, highlighting the close relationship between carbonate sedimentation, exposure of the platform, and later bauxitic development in this area.



Fig. 12. (Stop no. 4). Runcuri plateau. A-B – Upper Jurassic inner-platform carbonates with abundant bacinellid oncoids (Albioara Formation); C – Outcrop view showing the development of bauxitic lenses on top of the karstified Upper Jurassic carbonates of the Albioara Formation.

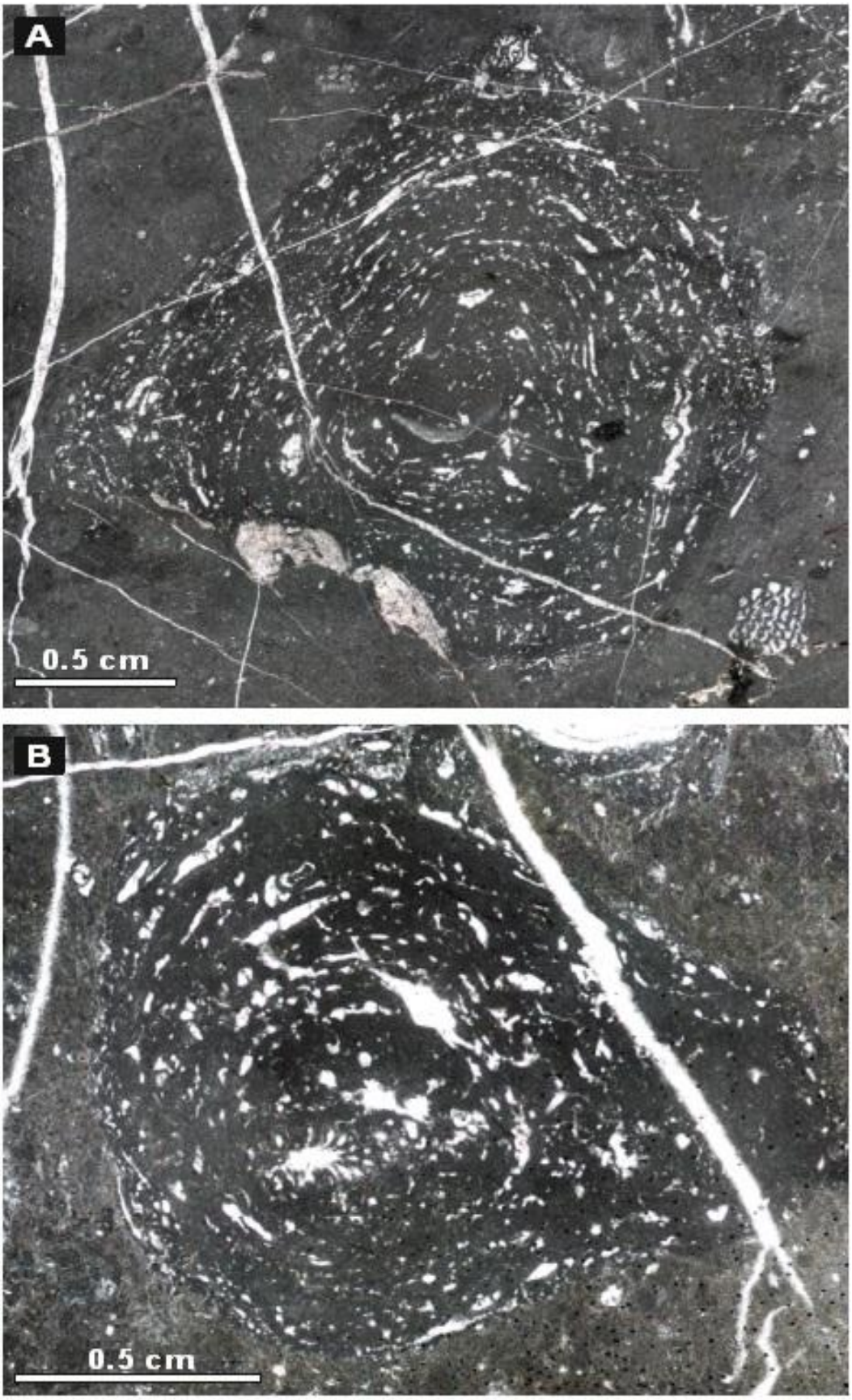


Fig. 13. (Stop no. 4). Runcuri plateau. A - Type A bacinellid oncoid in the limestones from the Runcuri Plateau showing a pseudo-concentric lamination of the cortex, generated by successive growth phases of bacinellid mesh. Notice the presence of the foraminifer *Parurgonina caelinensis* in the lower right side of the photo. B – Type B bacinellid oncoid with a bioclastic nucleus represented by the alga *Macroporella lazuriensis*.

Stop no. 5 – Albioara Gorges (Barremian Urgonian shallow-water carbonates)

This last stop of the first day focuses on the Early Cretaceous shallow-water limestones (Fig. 14A-E) from the southern part of the Albioarei Gorges. This area is located in the southwestern part of the Pădurea Craiului Mountains, between Ponorul Albioarei upstream and the village of Țarina (Roșia village) downstream.

The entire Albioara gorge sector is developed within Mesozoic carbonate rocks, including Upper Jurassic limestones (Kimmeridgian–Tithonian) and Lower Cretaceous Urgonian-type limestones (Barremian), forming a gorge approximately 3 km long. The county road DJ 764 (Bratca–Beiuș) crosses the gorge sector. The Albioarei Gorges host numerous caves and springs on both sides of the valley, as well as abandoned mining galleries developed for the exploitation of bauxite lenses.

The carbonate succession exposed in this area is mainly characterized by bioclastic–oncoidal micritic facies and peloidal–fenestral facies. Microfacies analysis allowed the identification of five main microfacies types: bioclastic wackestone with foraminifers and algae (MFT1); microbial–oncoidal bindstone (MFT2); bioclastic–oncoidal wackestone (partly fenestral) (MFT3); peloidal–fenestral wackestone/packstone (MFT4); and fenestral mudstone (MFT5).

The differences between these microfacies are related to their texture and structure, micro- and macrofossil content, and depositional characteristics.

Although these deposits represent relatively low-energy environments from the internal part of a carbonate platform (peritidal carbonates), the observed microfacies and micropaleontological variations reflect the transition between different sub-environments within the same depositional system. Bioclastic and oncoidal wackestones can be interpreted as deposits of a shallow subtidal lagoonal setting. Microbial bindstones containing bacinellid structures and oncoids indicate a shallow, restricted subtidal environment. Peloidal–fenestral wackestones and packstones represent intertidal carbonates, whereas fenestral mudstones with desiccation cracks are characteristic of supratidal ponds and marsh-like environments affected by periodic exposure. The fossil content of these facies is diverse and includes foraminifers, dasycladalean algae, *Rivularia*-type cyanobacteria, gastropods, bivalves (rudists), and worm tubes (serpulids and terebellids). The identified microfossil assemblage, including *Mouladella jourdanensis*, *Pseudolituonella gavonensis*, *Bulbobaculites felixi*, *Pfenderina globosa*, *Debarina hahounerensis*, *Salpingoporella muehlbergi*, *S. melitae*, *S. hispanica*, *Clypeina* sp., *Belorusiella* cf. *taurica*, *Haghimashella* sp., *Praechrysalidina* sp., *Ammobaculites* sp., and *Mayncina* sp., is characteristic of Urgonian facies (see Fig. 14B-E). Based on this microfossil association, the studied limestones are assigned a Barremian age.

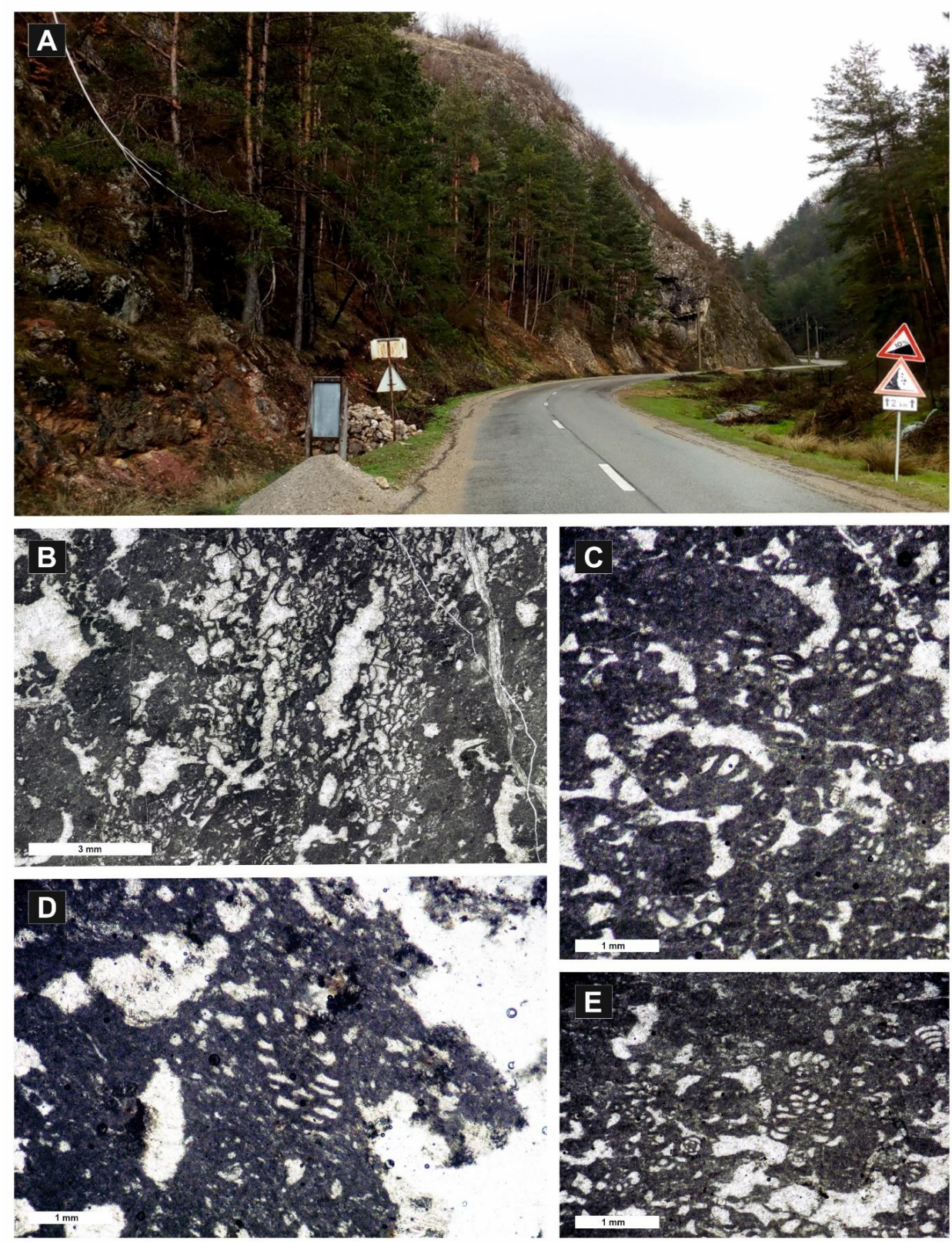


Fig. 14. (Stop no. 5). Albioara Gorges. A – Outcrop view of the Barremian Urgonian-type carbonates from the lower part of the Albioara Gorges, near the village of Roșia (Bihor County). B – Microbial bindstone with bacinellid oncoids; C–E – Bioclastic wackestones/packstones with foraminifers (*Bulbobaculites felixi*, *Mouladella jourdanensis*, *Pseudolituonella gavonensis*, *Haghimashella* sp., and *Ammobaculites* sp.).

Stop no. 6 – Tărcăița Valley section (Carnian to Rhaetian)

The Tarcăița River section (Fig. 15) provides one of the most complete Upper Triassic successions of the region (from the Carnian to the Rhaetian), recording the sedimentary evolution of both Wetterstein and Dachstein Carbonate platforms of the Codru Nappe System. The approximately 980 m thick succession documents repeated alternations between platform growth and drowning events, reflected by major lithological changes and supported by conodont and macrofossil assemblages. These events are marked by abrupt transitions (drowning events) from shallow-water carbonate facies to deeper-water nodular limestones and marls, siliciclastic events, exposures, and renewed platform sedimentation.

6.1 – Dolomitized Wetterstein platform carbonates (Julian 1)

This interval is dominated by approximately 200 meters thick sequence of grey shallow-water dolomites and dolomitic limestones with several thin levels of sandstones, siltstones and claystones. The dolomites are thick-bedded and laterally continuous, suggesting stable carbonate production under relatively low-energy conditions. Thin siliciclastic horizons probably reflect short-lived episodes of increased siliciclastic input. Conodont assemblages from this interval include: *Paragondolella foliata* and *Paragondolella polygnathiformis*, species that confirm a Julian (Carnian) age for this lower part of the Tărcăița succession. Around 230–235 m, sharp facies change marks a major drowning event of the Wetterstein Carbonate Platform. The thick-bedded shallow-water dolomites and dolomitic limestones of the Wetterstein Formation are abruptly overlain by thin-bedded dark-grey nodular limestones and marly limestones, recording the rapid cessation of shallow-water carbonate production and the transition to hemipelagic sedimentation.

6.2 – Drowning of the Wetterstein Carbonate Platform and the development of Julian 2 hemipelagic sequence

After the drowning of the Wetterstein (Julian 1/2 boundary) an approximately 50 m level of hemipelagic carbonates developed. The lower part of this interval consists mainly of thin-bedded dark-grey nodular limestones intercalated with marly limestones. Chert nodules occur locally, and slump structures indicate deposition on unstable slopes. The facies suggest sediment accumulation in an outer-platform to basin setting below normal wave base. The conodont fauna (including *Gladigondolella* ME and *Gladigondolella tethydis*) and holoturian fauna indicate an Iulian 2 age for this sequence. However, conodont faunas throughout the whole succession could not be isolated. The reasons for this phenomen are unclear, but it seems that the environmental conditions in this deep-water environment don´t allow conodonts to live there.

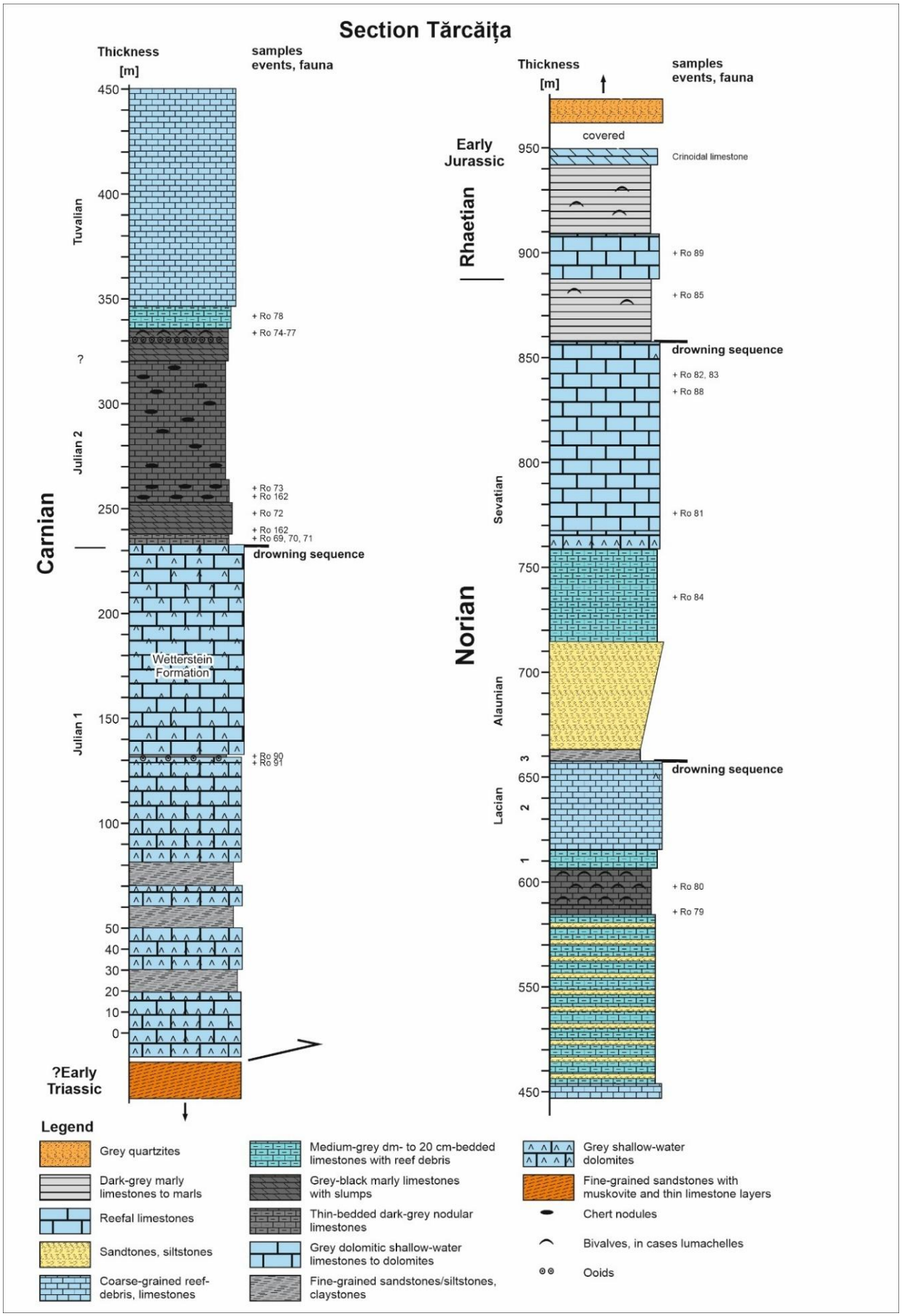


Fig. 15. (Stop no. 6). Tărcăița Valley section (Carnian to Rhaetian) profile

6.3 – Upper Carnian (Tuvalian) well-bedded cycles of reef debris deposits

This part of the Tărcăița section is characterized by alternating coarse-grained reef-debris carbonates with medium-grey cm-bedded limestones with abundant shallow-water debris and thin siliciclastic levels. Altogether these facies may represent a forerunner of the Dachstein Carbonate Platform.

6.4 – Carnian-Norian transition and the onset and demise of the first Lacian Dachstein reef cycle

Above the Tuvalian cyclically developed facies, the succession begins with a bivalve-rich lumachelle, followed by a thin interval of centimetre-bedded limestones containing abundant shallow-water bioclastic debris. This interval may constrain the Carnian/Norian boundary. Up section, the succession passes into a relatively thick package of coarse-grained reef-debris carbonates, marking the onset of the Dachstein Carbonate Platform. These deposits may correspond to the Lacian Dachstein reef cycle described by Zöhrer et al. (2026) from Montenegro. However, these reefal Dachstein limestones differ significantly from those of the wave resistant reef rim formed in direction to the open shelf. This reef was formed under more restricted conditions in a low-energy environment. Further studies are needed to clarify the difference in detail of the various reef types in different palaeogeographic postions. On top of these reef-influenced deposits, a regional drowning unconformity is recognized, marked by an abrupt change from shallow-water platform carbonates to fine-grained siliciclastic deposits. This surface records the demise of the first Dachstein Carbonate Platform reef cycle recorded in the Tărcăița section, consequently the onset of deeper-water sedimentation. During the Alaunian, yellow sandstones and siltstones accumulated above the drowning surface before gradually giving way to medium-grey limestones rich in reef-derived skeletal debris. This coarsening up and increasingly carbonate-rich succession reflects progressive shallowing, renewed carbonate production ultimately leading to the re-establishment of extensive reef development.

6.5 – Onset and drowning of the second Dachstein reef cycle (Sevatian)

This part of the Tărcăița succession comprises an approximately 80 m thick interval of massive Dachstein reef limestones interbedded with shallow-water dolomitic limestones. The reef facies are characterized by abundant corals, calcified sponges, and microencrusters. Importantly, the limestones are extensively recrystallized, locally obscuring their original textures and fossil content, and are cut by several generations of fractures and fissure sets that reflect various post-depositional processes. The end of this cycle is also marked by a drowning sequence.

6.6 – Rhaetian shallow-water carbonates (Kössen deposits) and Lower Jurassic quartzites

The Rhaetian succession records repeated alternations between reef limestones and dark-grey marly limestones to marls. The marls contain abundant bivalves, locally forming lumachelles. These marly levels are topped by a thin level of crinoidal limestones. Lower Jurassic quartzites follows next.

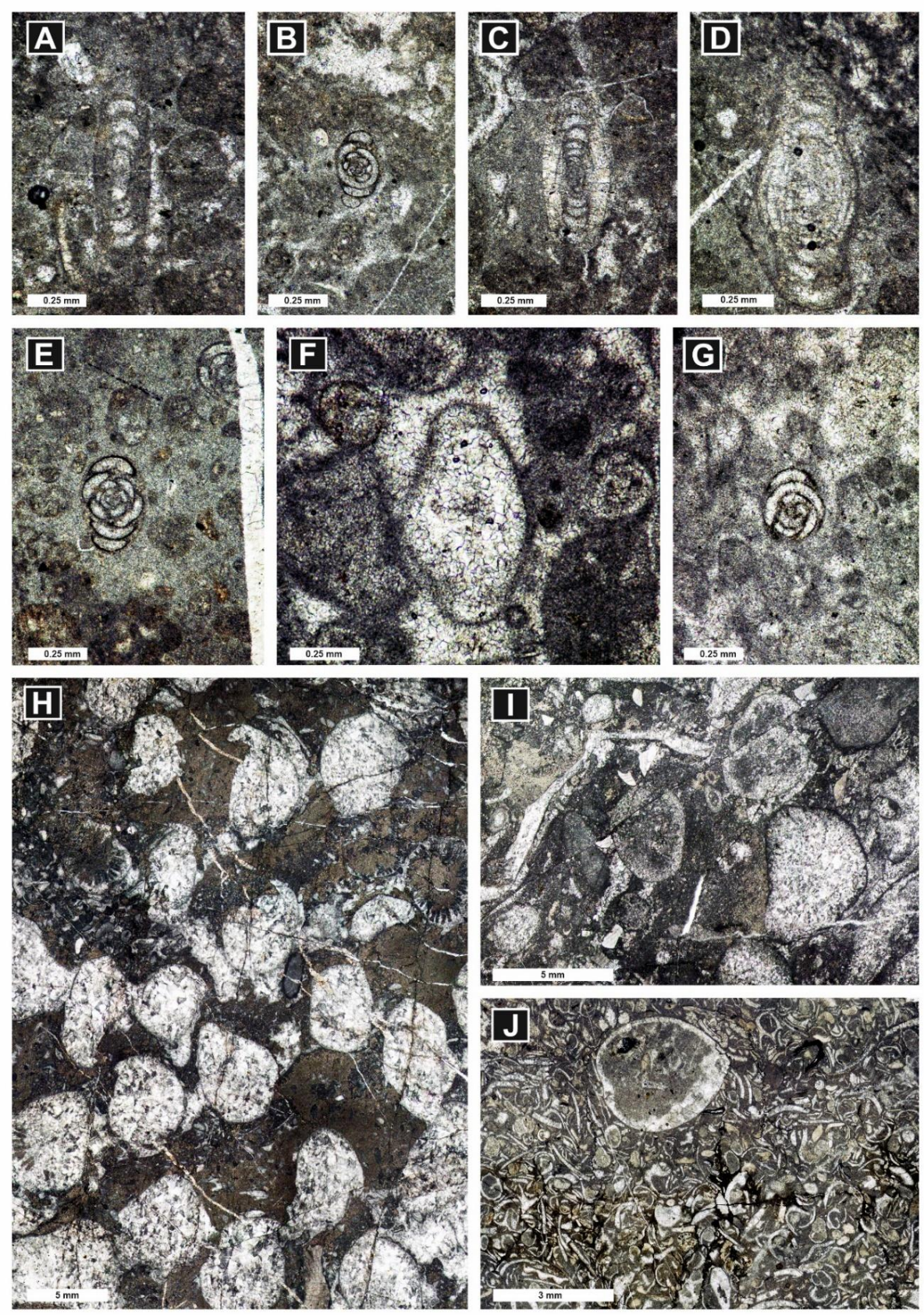


Fig. 16. (Stop no. 6). Microfossils from Tărcăița Valley section (Carnian to Rhaetian). A – *Semiinvoluta* sp. (sample 1564); B - *Parvalamella friedli* (sample 1569); C - *Triadodiscus eomesozoicus* (sample 1571); D - *Angulodiscus* sp. (sample 1601); E - *Parvalamella friedli* (sample 1621); F- involutinid foraminifer (sample 1928); G - *Parvalamella friedli* (sample 1948). H-I – Dolomitized coral boundstone from the upper part of the profile; J – Bioclastic packstone (Kössen beds)

Stop no. 7 – Late Triassic peritidal carbonates (Lofer cycles) (Norian–early Rhaetian)

In the Câmp quarry (near Vaşcău), a rare outcrop of Upper Triassic carbonates exposes more than twenty cyclically developed carbonate units comparable to the Lofer cycles described by Fischer (1964) from the Northern Calcareous Alps. These cycles (see Fig.17A-D) occur within a stratigraphic interval of approximately 35 m. Baltreş (2000) identified 21 peritidal cycles (parasequences) within the carbonate succession from this quarry, with individual cycle thicknesses ranging from 0.5 to 4 m. Each cycle records a shallowing-upward evolution from subtidal to intertidal conditions and consists of three vertically arranged units (Baltreş, 2000):

- **Carbonate breccia**. This unit develops above an erosional unconformity and consists of limestone intraclasts and a red brecciated palaeosoil horizon. Deeply penetrating solution cavities and collapsed fossil molds filled with reworked red soil material occur beneath the unconformity, indicating subaerial exposure, karstification, and subsequent marine transgression.

- **Shallow subtidal limestones**. This transgressive phase is represented by grey shallow-marine limestones containing abundant megalodontid bivalves (Fig. 17A), commonly preserved in life position, together with gastropods. The microfacies include mudstone, pellet-intraclastic packstone, and grainstone with rare microfossils (*Aulotortus communis*, *Aulotortus sinuosus*, *Parvalamella friedli*, *Girvanella nodules*, and *Solenopora*).

- **Upper intertidal regressive unit**. The upper part of the cycle records progressive shallowing and transition toward intertidal conditions. It consists of thin, white oncoidal rudstone to wackestone with pellet-rich fabrics and fenestral structures (including stromatactis-like fenestrae), reflecting tidal-flat deposition.

The stacking architecture of parasequences was controlled by long-term, third-order variations in accommodation space, whereas individual cycle thicknesses were governed by the accommodation available during deposition (Baltreş, 2000; Bucur, 2001).

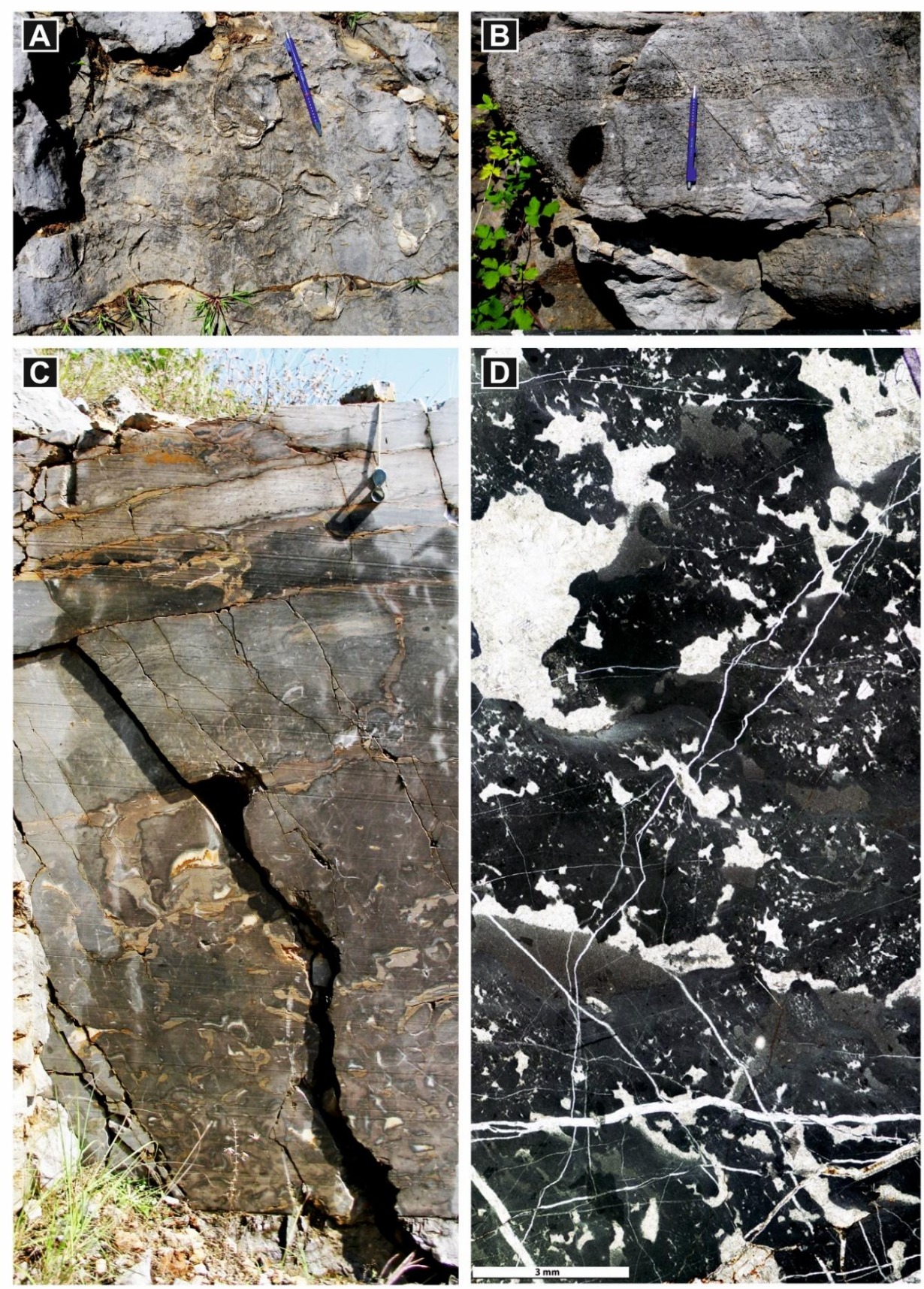


Fig. 17. (Stop no. 7). Late Triassic peritidal carbonates (Lofer cycles). A – Megalodontid bivalves; B – Intertidal fenestral fabric; C - Large limestone slab showing the development of a Lofer cycle; D – Microfacies showing large stomatactics-like fenestral structures from the Lofer Cycles.

Stop no. 8 - Colești Rhaetian Dachstein lagoonal limestones (Colești Nappe)

The exposed succession begins with approximately 100 m of Upper Triassic Dachstein limestones (Figs. 18, 19A-B). The lower part consists of massive Norian Loferitic Dachstein limestones, characterized by cyclic peritidal deposits, which pass upward into Rhaetian bedded lagoonal Dachstein limestones. Towards the uppermost part of this lagoonal succession, isolated coral patch reefs begin to develop. Numerous neptunian dykes also cut the inner-platform carbonates, indicating synsedimentary to early post-depositional extensional fracturing and fissure infillings. Jurassic ammonites occur within the infillings of dykes.

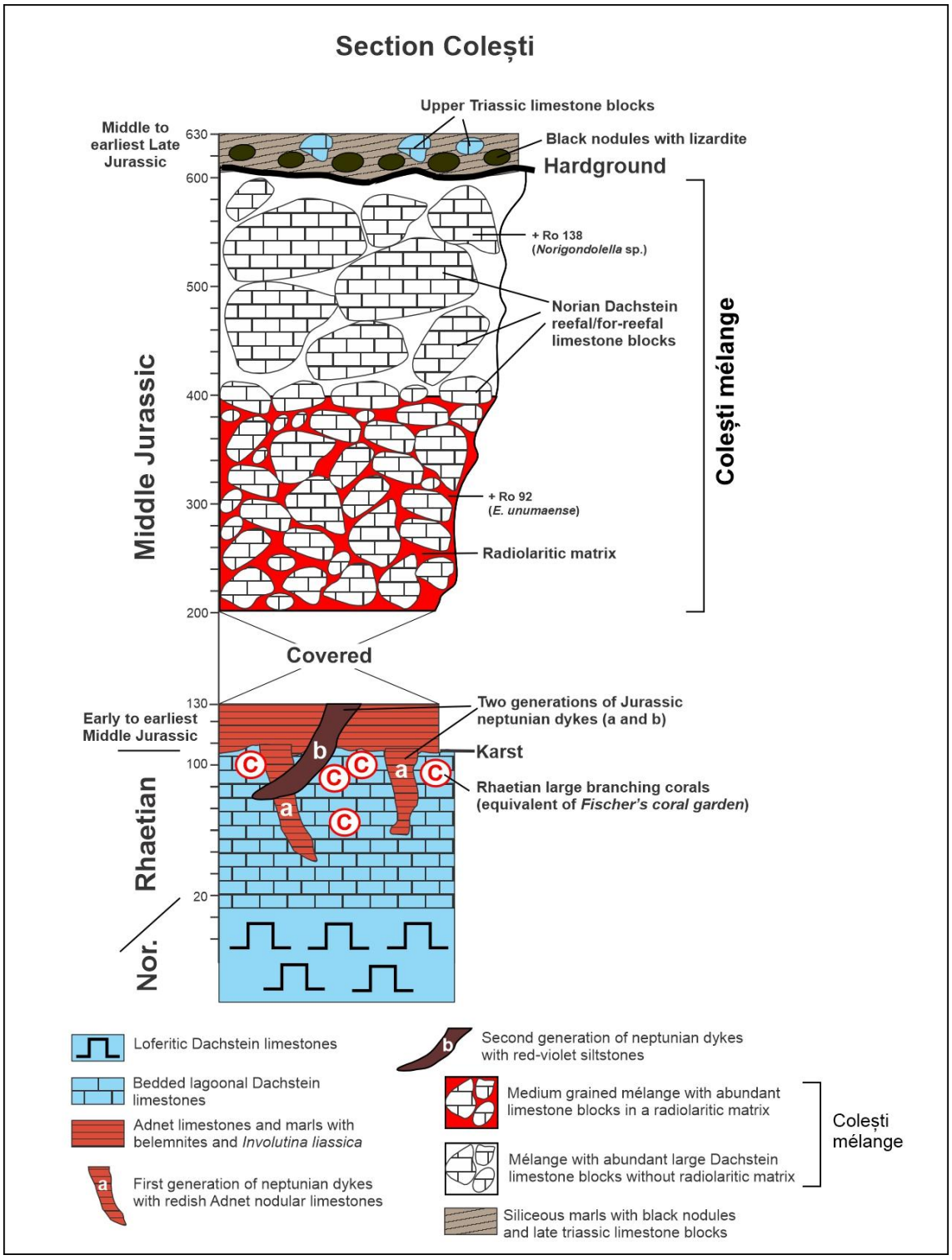


Fig. 18. (Stops no. 8, 9, 10). Colești section profile (Norian-Rhaetian) and the Colești mélange

Stop no. 9 – Upper part of the bedded lagoonal limestones with corals and neptunian dykes with Jurassic infillings (Colești Nappe)

Near the top of the Rhaetian Dachstein succession (Figs. 18, 19C-F), the platform is affected by karstification, producing an irregular erosional surface with cavities and dissolution features. Several large branching corals occur immediately beneath this surface, representing one of the latest phases of reef development before platform demise. The interseptal spaces of the corals are filled with reddish Jurassic sediments, which also constitute the infill of the neptunian dykes. This relationship indicates that fissure formation and sediment infilling postdated reef growth. Similar occurrences have been described from the famous ***Fischer's coral garden*** at Steinplatte in the Northern Calcareous Alps, where Jurassic sediments infill cavities within Upper Triassic reef corals and associated neptunian dykes.

The karst surface is overlain by approximately 30 m of Adnet nodular limestones and marls, containing abundant belemnites and *Involutina liassica*. These deposits record the abrupt transition from shallow-water carbonate production to pelagic sedimentation during the earliest Jurassic.

The Dachstein limestones are cut by two generations of neptunian dykes, which provide important evidence for synsedimentary extensional tectonics. First-generation dykes (a) are filled with reddish Adnet nodular limestones identical to the overlying Lower Jurassic succession, indicating that fracturing occurred shortly after platform drowning. Second-generation dykes (b) truncate the earlier dykes and contain red-violet silty sediments, demonstrating renewed tectonic activity during continued basin evolution. The development of multiple generations of neptunian dykes indicates repeated fracturing of a lithified carbonate platform under submarine conditions and progressive tectonic instability.

Stop no. 10 – Colești Melange (Jurassic radiolarite matrix, emplacement of blocks and lizardite nodules)

Above an approximately 70 m covered interval, the section exposes nearly 400 m of a previously unknown mélange namely here the Colești Mélange.

During the Middle Jurassic, the onset of ophiolite obduction within the Neotethyan realm marked the transition from passive-margin sedimentation to a compressional tectonic regime. This tectonic event led to the fragmetation of the former Triassic passive margin and the emplacement of the Codru nappe stack (Figs. 18, 20A-D, 21). As tectonic instability intensified, the overlying Câmp Nappe System became progressively fragmented during nappe transport and deformation.

Large portions of the Norian Dachstein Carbonate Platform were detached from the Câmp nappes and transported downslope as submarine slides, debris flows, and rock slides. These gravity-driven mass-transport deposits formed the Colești Mélange, where limestone blocks of highly variable size became embedded within a Middle Jurassic radiolarian-rich deep-marine matrix (Fig. 20A).

The lower part (approximately 200–390 m) consists of a block-in-matrix fabric, where numerous limestone blocks ranging from decimetres to several metres are enclosed within a radiolaritic matrix. The blocks consist predominantly reefal and fore-reefal Norian Dachstein limestones derived from the advancing uppermost nappe (Câmp nappe system), while the matrix is composed of red radiolarian-rich siliceous sediments. The chaotic internal organization and variable block orientations indicate emplacement by submarine mass-transport processes. Biostratigraphic data from the radiolaritic matrix (*Eucyrtidiellum unumaense*) indicate a Middle-early Late Jurassic age for matrix deposition, demonstrating that the incorporation of the limestone blocks occurred during the Jurassic orogeny.



Fig. 19. (Stops no. 8, 9). Colești section (Norian-Rhaetian): A-B – Outcrop view of the Rhaetian bedded lagoonal Dachstein limestones; C - First-generation neptunian dykes filled with reddish Adnet nodular limestones identical to the overlying Lower Jurassic succession; D – Corals with the intra-framework spaces filled with redish Adnet type Jurassic sediments; E – Neptunian dyke infilling with belemnite fragments and many Triassic limestone clasts; F – Microfacies of the Jurassic neptunian dykes infillings with crinoids and *Involutina liassica*.



Fig. 20. (Stop no. 10). Middle Jurassic Colești mélange: A – The formation of the first Norian limestone fore-reefal blocks derived from the Câmp nape system and embedded within a Middle Jurassic redish radiolarian matrix (lower part of the Colești Mélange); B-D – Various fore-reeefal norian blocks from the Colești Mélange with calcified sponges, microencrusters and early-marine cements.

Upsection (approximately 390–600 m), the mélange becomes progressively coarser. Large Norian reefal and fore-reefal limestone blocks, locally tens of metres across, dominate the succession. In this interval the radiolaritic matrix becomes scarce or absent.

Near the top of the succession, the mélange is truncated by a prominent hardground. The hardground is overlain by siliceous marls containing black lizardite-bearing nodules together with scattered Norian limestone blocks. The lizardite-bearing nodules most likely represent fragments of Jurassic serpentinized ophiolites. These clasts were eroded from the obducted ophiolitic rocks and subsequently transported into the basin, where they became incorporated into the sedimentary succession of the Colești Jurassic basin. Conodonts recovered from one of the limestone blocks (*Norigondolella* sp.) confirm their Norian origin and demonstrate derivation from the overlying Câmp nappe system.

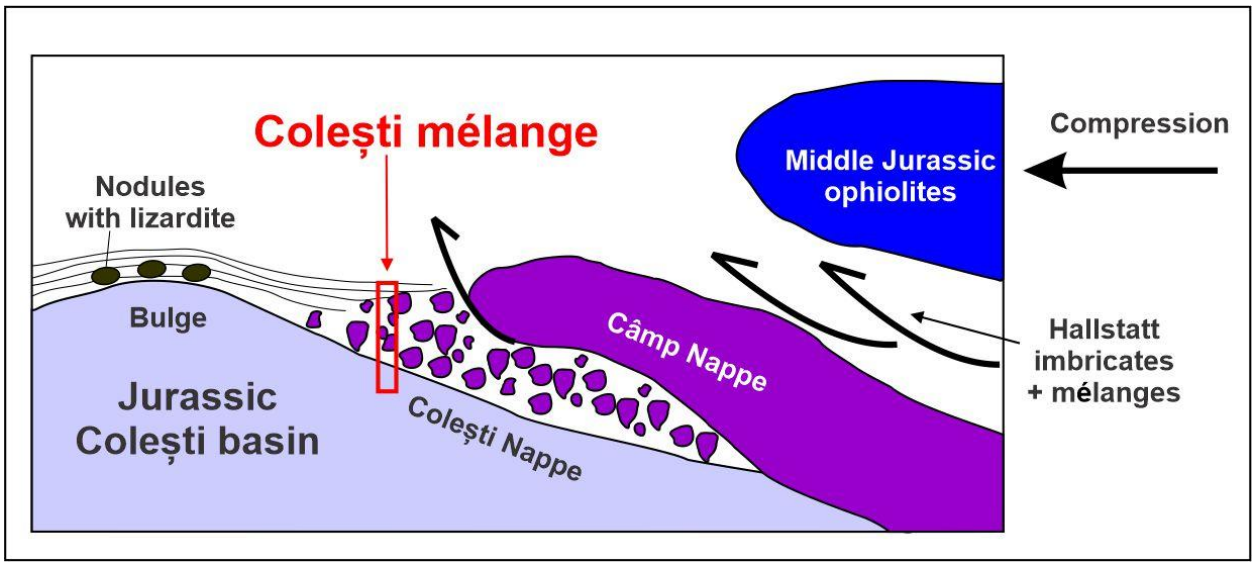


Fig. 21. Formation of the Middle Jurassic Colești Mélange

Stop no. 11 – Anisian to Carnian evolution of the Câmp Moți West section

The Câmp Moți West section (Fig. 22) exposes an approximately 80 m thick Middle–Upper Triassic succession spanning the Pelsonian (middle Anisian) to the Julian (ealy Carnian). The section documents the late evolution of the Steinalm/Ravni Carbonate Ramp, its drowning and replacement by the pelagic Schreyeralm facies, the subsequent Ladinian development of a mixed shallow-water to pelagic carbonate system, and the late evolution of the Wetterstein Carbonate Platform during the Late Carnian, followed by the deposition of the Lunz-type siliciclastics.

11.1 – Pelsonian evolution of the Steinalm/Ravni Carbonate Ramp and its demise

The section begins with approximately 8 m of grey shallow-water limestones assigned to the Steinalm Formation. These thick-bedded platform carbonates are strongly recrystallized; however, locally they contain well-preserved specimens of dasycladalean green algae (*Poncetella hexaster*, *Physoporella pauciforata*, *Oligoporella pilosa*, *Euteutloporella peniculiformis*, and *Oligoporella* sp.) (Fig. 23A-I). The uppermost part of the Steinalm Formation is marked by a karstified surface associated with a minor stratigraphic hiatus, recording a phase of subaerial exposure. This emersion surface is overlain by a drowning sequence, represented by the abrupt transition to deeper-water hemipelagic deposits, marking the

demise of the Steinalm/Ravni carbonate ramp and the onset of red nodular limestone (Schreyeralm facies in old literature) sedimentation. Note, the term Schreyeralm Limestone is restricted to those red nodular limestones deposited on the distal open shelf and should be used only for the basal member of a complete Hallstatt Limestone sequence (Krystyn, 2008).

11.2 – Drowning of the Steinalm/Ravni Carbonate Ramp and the development of Scheryeralm hemipelagic limestones (Illyrian)

Above the karstified surface, a thin succession of dark-red, siliceous, laminated limestones with intercalated volcanic ash layers records the development of the Schreyeralm facies. These condensed hemipelagic deposits mark the rapid drowning of the Steinalm/Ravni Carbonate Ramp and the establishment of deeper-water sedimentation. The interval also yielded ammonoid assemblages described by Bleahu et al. (1969), providing additional biostratigraphic control for this upper Anisian sequence. Conodont samples contain *Neogondolella longa*, *Paragondolella excelsa*, and *Paragondolella eotrammeri*, an assemblage that confirms a late Illyrian (late Anisian) age for the red hemipelagic sequence. This indicates, that the underlying Steinalm shallow-water carbonates were uplifted during the late Pelsonian. In the frame of the break-up of the Neo-Tethys Ocean in the late Pelsonian a Horst-and-Graben morphology was formed elsewhere in the Western Tethys Realm, forming a typical break-up unconformity, recently in detail worked out for the Dinarides (Sudar et al. 2013, 2023, 2025, Gawlick et al. 2023, Mrdak et al. 2024, 2025a, b). Typical for a horst position is the intense karstification and recrystallization of the uplifted Steinalm shallow-water carbonates. During the late Illyrian sea-level rise also, and the horsts get flooded (Gawlick et al. 2012, 2021) as demonstrated in the Dinarides or Northern Calcareous Alps. A significant tectonic influence here in the Tisza unit in contrast to the Dinarides (Mrdak et al. 2025a, b) can be excluded, as the overlying sedimentary rocks differ significantly.

11.3 – Ladinian evolution of the section (Fassanian–Longobardian)

The drowning sequence is overlain by Fassanian red nodular limestones, representing continued pelagic sedimentation during the Ladinian. Upsection, these deposits grade into strongly recrystallized grey shallow-water limestones of Longobardian age, intercalated with thin turbiditic beds and characteristic *Daonella*-bearing horizons. This upward transition records the gradual re-establishment of shallow-water carbonate sedimentation following the Anisian drowning event, although the occurrence of turbidites and *Daonella* levels indicates intermittent deeper-water influence and continued connection with adjacent basinal environments.

The uppermost part of the shallow-water limestone succession is capped by a breccia horizon and a karstified surface, recording a period of subaerial exposure. The overlying red-grey nodular limestones, rich in cephalopods, mark the second major drowning event recorded in the section, and the establishment of an open-marine basinal environment dominated by hemipelagic carbonate sedimentation (red deep-water limestones). The conodont assemblage indicates a Longobardian (late Ladinian) age for the upper hemipelagic succession with red nodular limestones.

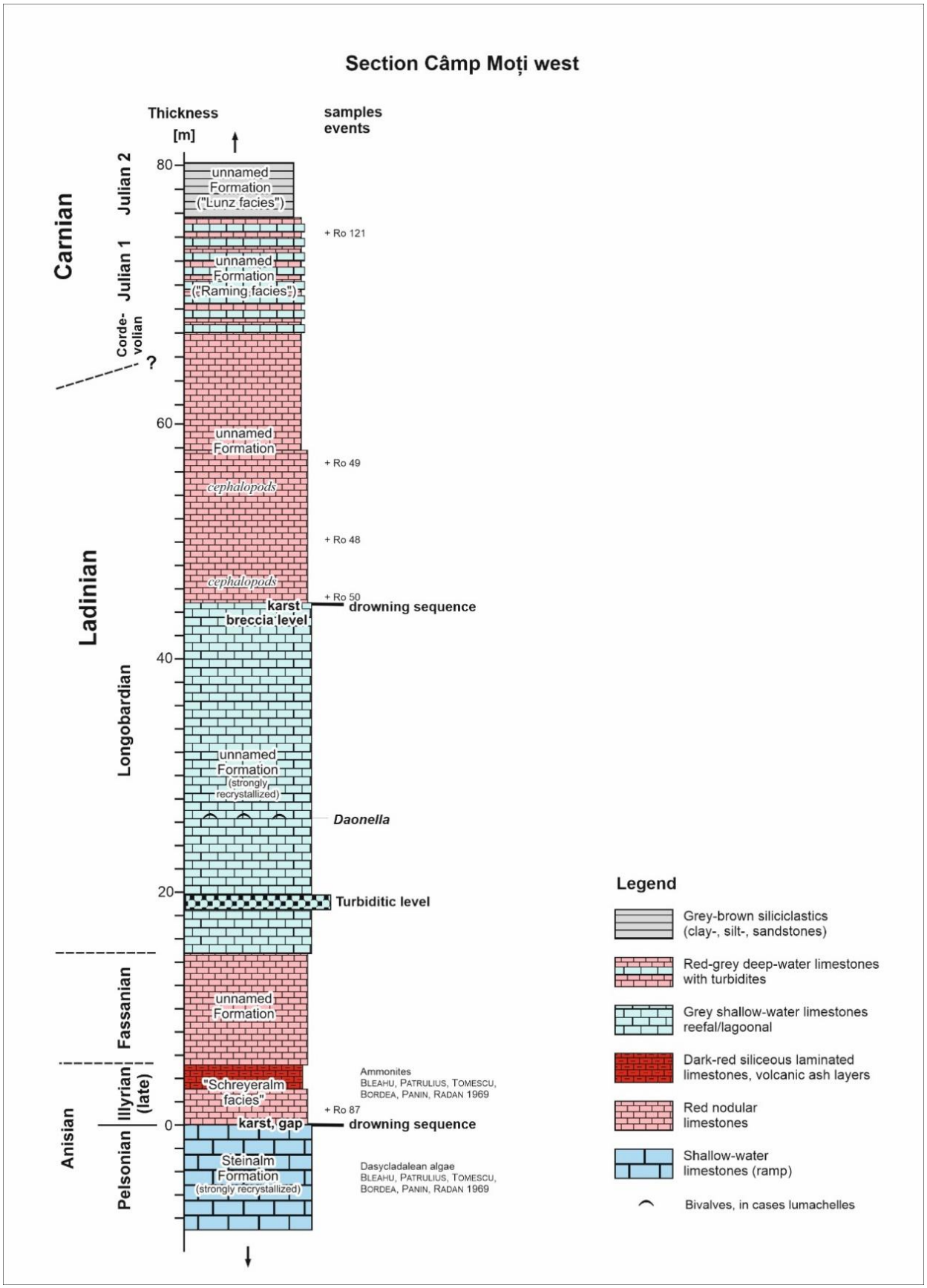


Fig. 22. (Stop no. 11). Câmp Moți west section (Aniasian to Carnian) profile

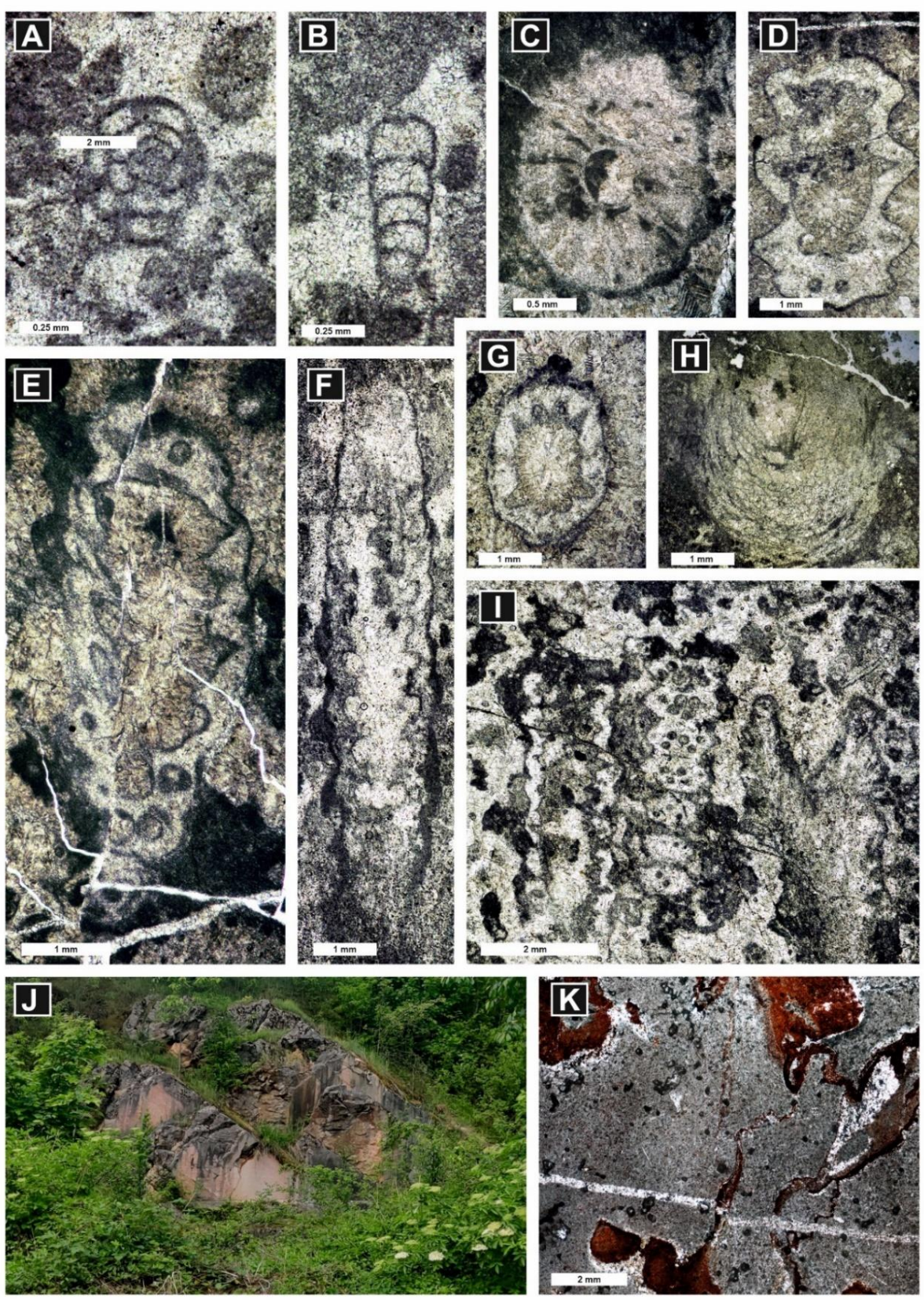


Fig. 23. (Stop no. 11). A-I - Microfossils from the Câmp Moți west section (Steinalm carbonate ramp algae and foraminifers) A – *Meandrospira dinarica* (sample 4743); B - *Endotriadella wirzi* (sample 4764); C - *Poncetella hexaster* (sample 4747); D-F - *Physoporella pauciforata* (samples 330-D; 4757-E; 13825-F); G - *Oligoporella pilosa* (sample 4748); H - *Euteutloporella peniculiformis* (sample 4764); I - *Physoporella pauciforata*, *Oligoporella* sp. and *Euteutloporella peniculiformis* (sample 13829). J-K – Upper Ladinian red Limestones J - Outcrop view of the Ladianian red nodular limestones old quarry; K – Microfacies of the nodular limestones.

11.4 – Carnian evolution of the section

The red pelagic limestones grade into the "Cordevolian" and are overlain by a sequence displaying Raming facies characteristics. It is composed of thin-bedded grey, slope limestones with turbidites interlayered with reddish-grey deeper-water limestones. Conodonts (*Paragondolella inclinata*, *P. polygnathiformis*, *Gladigondolella tethydis*, *G. malayensis*, *Gladigondolella* ME, *Budurovignathus japonicus*, and *Neocavitella* sp.) constrains this upper part of the Câmp Moți West succession to the Julian 1 (early Carnian). This carbonate succession records the gradual recovery of carbonate sedimentation (demonstrated by the presence of turbiditic material derived from a Wetterstein Carbonate Platform – highstand shedding processes), and reflects deposition on a shallow-water platform margin (slope) periodically influenced by deeper-water conditions and gravity-driven sediment transport.

The carbonates with the Raming facies are unconformably overlain by Lunz-type siliciclastics, consisting predominantly of grey to brown claystones, siltstones, and fine-grained sandstones. These abrupt facies change marks a significant increase in terrigenous sediment supply and the concomitant decline of carbonate production across the platform. The siliciclastics are interpreted as the regional expression of the Carnian Pluvial Episode, during which intensified chemical weathering, increased continental runoff, and enhanced siliciclastic input resulted in the widespread deposition of siliciclastic sediments throughout the Western Tethyan Realm (Lein et al. 2012; Gawlick et al. 2017; Mrdak et al. 2023).

Stop no. 12 (optional) – Merișor Hill. Tuvalian forerunner of the Dachstein Carbonate platform and reefal/fore-reefal Dachstein carboantes (Câmp nappe system)

The southwestern flank of Merișor Hill (Vașcău Plateau, Codru-Moma Mountains) offers a unique opportunity to examine the depositional patterns, sedimentary features, and compositional characteristics of an Upper Triassic carbonate succession formed during the late Carnian to early Norian (Fig. 24).

The conodont assemblages, supported by other paleontological groups such as halobiid bivalves and encrusting microorganisms, indicate a sedimentary evolution ranging from the late Carnian (Tuvalian) to the early Norian (Lacian 2).

Starting in the Tuvalian, the studied succession displays a roughly 140-meter-thick cyclic depositional pattern that allow us to distinguish four thick-bedded, fore-reefal, small-order carbonate cycles, three of them in the late Carnian, and one in the early Norian (Figs. 24, 25A-B). In the late Carnian, as indicated by the depositional textures of their main components, each of these reef-influenced cycles is characterized by a shallowing-up trend, followed by karstification features and breccia formation toward their uppermost part, and subsequently by a drowning phase marked by the deposition of dm-thick pelagic carbonate levels containing fine-grained turbiditic material.

The demise of the last Tuvalian cycle records the Carnian/Norian boundary and is marked by the appearance of *Halobia austriaca* lumachelles (Fig. 25C), the FAD of *Norigondolella navicula* as well as by the deposition of deeper-marine carbonate levels containing ammonoids (Fig. 25D). These bivalve agglomerations formed after the subsequent drowning of this final reef-influenced cycle, accumulating within small depressions that most likely developed on the inherited erosional topography associated with the demise of the third cycle. Above the *Halobia* lumachelles, a twenty-meter-thick sequence of coarse-grained carbonates with reef debris that contain Lacian conodonts are developed next in succession, followed by the appearance of another *Halobia* lumachelle (*Halobia styriaca*).

Above this level, massive Dachstein reef limestones are developing containing various reef dwellers (mainly encrusting microorganisms) and coral fragments, indicating the first cycle of the Dachstein Carbonate Platform (Fig. 25E).

Overall, based on our new data, the Tuvalian part of the carbonate succession at Merișor Hill represents a previously undocumented, cyclically developed transitional Late Triassic facies that resembles a carbonate ramp affinity, formed after the demise of the Wetterstein Carbonate Platform and before the onset of the Dachstein Carbonate Platform. It represents most likely a forerunner of the emergence of the early Norian Dachstein reef cycle (Zöhrer et al., 2026).

Stop no. 13 – Câmp forest section. Carnian to Norian transition (Câmp nappe system)

The Dealu Runcu section (Vașcău Plateau, Codru-Moma Mountains) is approximately 165 m thick and spans the Tuvalian (late Carnian) to Alaunian (middle Norian) (Fig. 26).

The lower part of the section (0–25 m) consists of alternating fine- to medium-grained limestones rich in thin-shelled bivalves ("filaments") and crinoid debris, and medium-grained limestones with shallow-water material (including microbialite-microencrusters, calcified sponges and coral fragments). Several horizons contain karstified surfaces. The fossil assemblages are composed of *Ladinella porata*, *Baccanella floriformis*, *Radiomura cautica*, *Microtubus communis*, *Paleolituonella meridionalis*, *Aulotortus sinuosus*, *Parvalamella friedli*, *Boueina marondei*, *Diplopora tubispora* and *Tubiphytes* sp. (Fig. 27A-I) is typical of Upper Triassic shallow-water carbonate platforms and is particularly indicative of the late Carnian–Norian interval (Chablais et al., 2010a, b).

At approximately 22–25 m, a thin interval of slump deposits records soft-sediment deformation produced by instability along the platform slope. Carbonate sedimentation resumes above the slump interval with bedded limestones. Around 35–37 m, a carbonate breccia overlies a level where bedding becomes noticeably tilted. This horizon is interpreted to record a regional tectonic event at the Carnian–Norian boundary, recognized across many sectors of the Neotethyan realm (see Zöhrer et al., 2026).

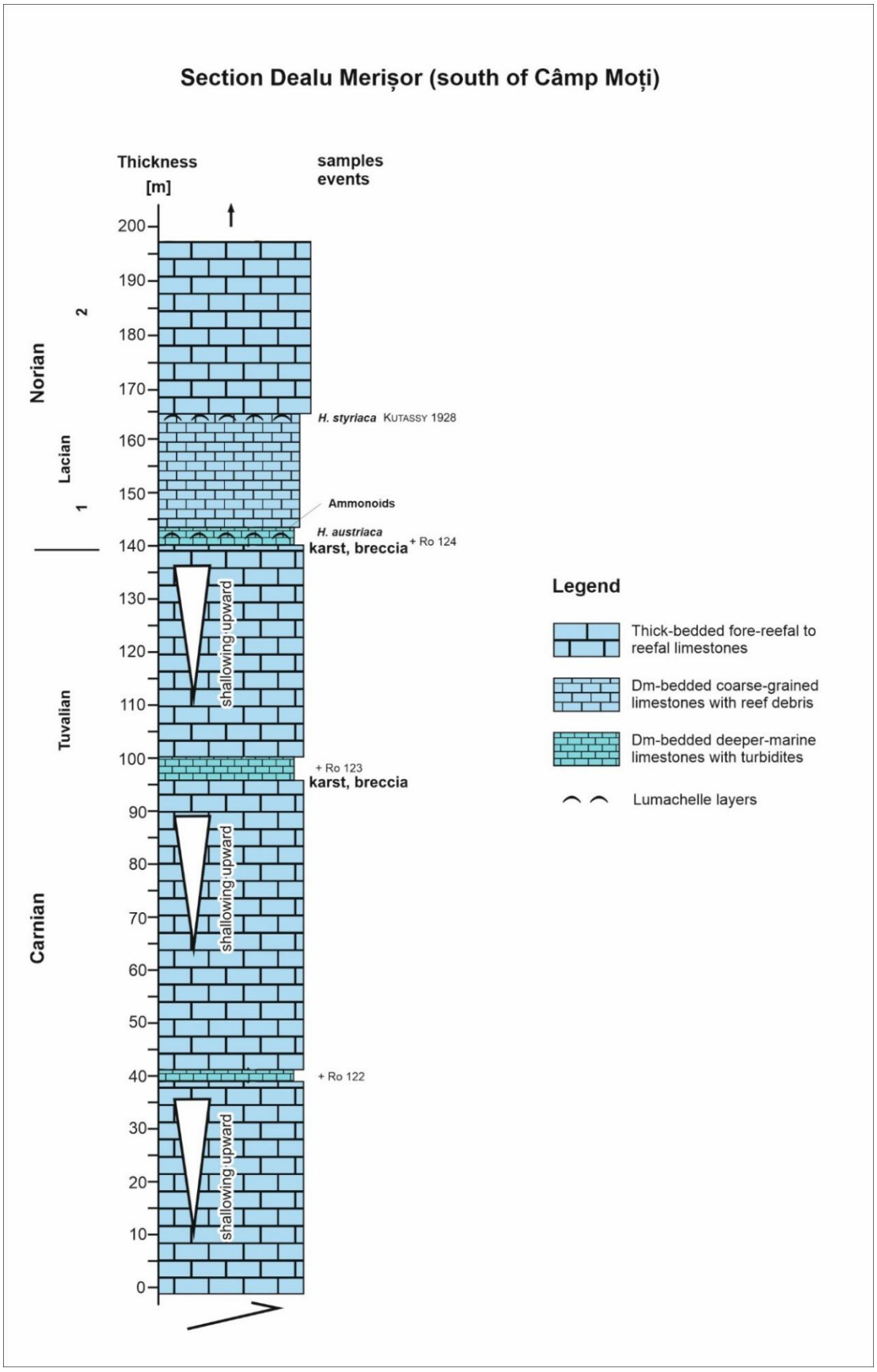


Fig. 24. (Stop no. 12). Dealu Merișor (Merișor Hill) section profile (Carnian to Norian).

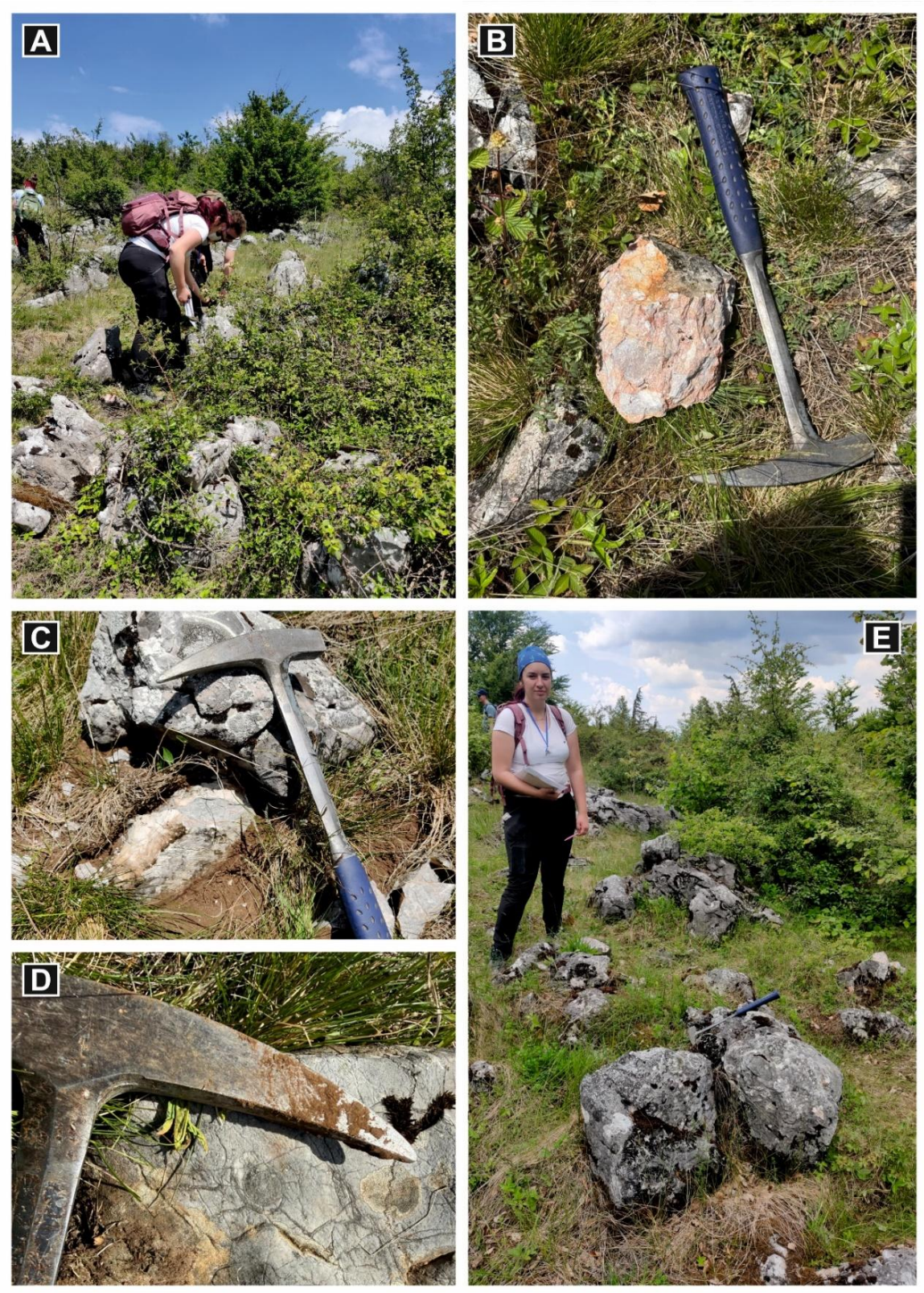


Fig. 25. (Stop no. 12). Field pictures from the Dealu Merișor section: A - Thick-bedded, fore-reefal, small-order carbonate cycles from the lower part of the section; B – Karstified/brecciated horizons from the top of the cycles; C - Demise of the last Tuvalian cycle and the identification of *Halobia austriaca* lumachelles around the Carnian/Norian boundary; D - Deeper-marine carbonate levels containing ammonoids above the *Halobia* level; E – Massive Dachstein reefal/fore-reefal carbonates from the top of the section.

Between approximately 40 and 56 m, thick-bedded coarse-grained limestones dominate the succession with various shallow-water intraclasts and microbialite fabrics A second interval of slump deposits, extending from approximately 56 to 73 m, marks renewed platform-margin instability. The thickness of this deformed interval suggests an important episode of gravitational collapse affecting unconsolidated sediments along the slope.

Above the slump deposits, coarse-grained limestones reappear and grade upward into fine-grained limestones with crinoids and filaments. At approximately 86 m, fissure fills are developed beneath a horizon interpreted as marking backstepping of the carbonate platform. The overlying succession (approximately 87–105 m) consists predominantly of medium-grained limestones containing abundant thin-shelled bivalves and crinoids.

A second carbonate breccia occurs near 105–107 m, recording another episode of platform-margin instability. From approximately 107 m to the top of the section (165 m), the succession records packages of bedded limestones. Fine- to medium-grained facies gradually pass upward into thick-bedded coarse-grained limestones with shallow-water debris assigned to the Alaunian.

Stop no. 14 – Road section near Câmp. Norian evolution of the Dachstein Carbonate Platform (Câmp nappe system)

The exposed succession is approximately 115 m thick and spans the late Lacian to Sevatian (early-upper Norian) (Fig. 29). It is dominated by fore-reef limestones and hemipelagic limestones rich in thin-shelled bivalves (“filaments”) and crinoids.

14.1 - Lacian slope carbonates (Fig. 30A-D)

The lowermost exposed part of the section belongs to the Lacian and consists of approximately 10 m of medium- to coarse-grained limestones containing abundant shallow-water skeletal debris. In this area, laterally continuous, carbonate bodies composed of well-sorted, intraclast-rich limestones are exposed. These deposits are interbedded with hemipelagic limestones. Their components include coral and sponge fragments, ammonoids, carbonate intraclasts, and micritic granules of various sizes. The bioclasts display clear evidence of transport, including abrasion, rounding, and fragmentation. The intervening hemipelagic limestones are represented by bioclastic wackestones to packstones containing sponge spicules, abundant echinoderm fragments, and ammonoids. The combination of well-sorted and graded carbonate bodies, erosional basal contacts, and intercalation with hemipelagic limestones indicates deposition from grain flows or concentrated density flows (Flügel, 2004). These sedimentological characteristics indicate deposition on a carbonate slope, where gravity-driven sediment transport redistributed shallow-water carbonate material into deeper marine environments. These deposits record the second progradational reef cycle (early Norian) of the Dachstein Carbonate Platform described by (Zöhrer et al., 2026).

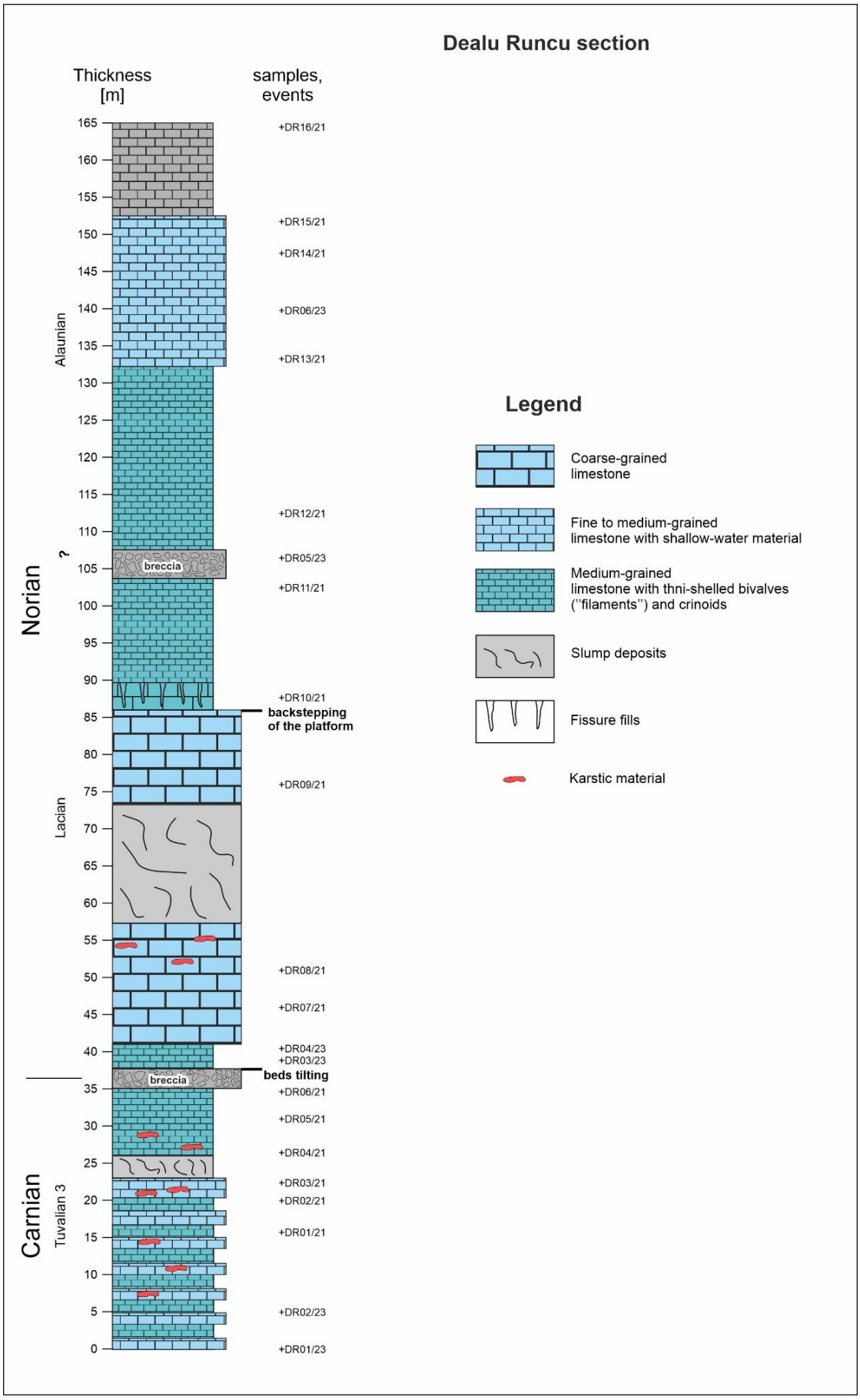


Fig. 26. (Stop no. 13). Dealu Runcu section (Carnian to Norian) profile.

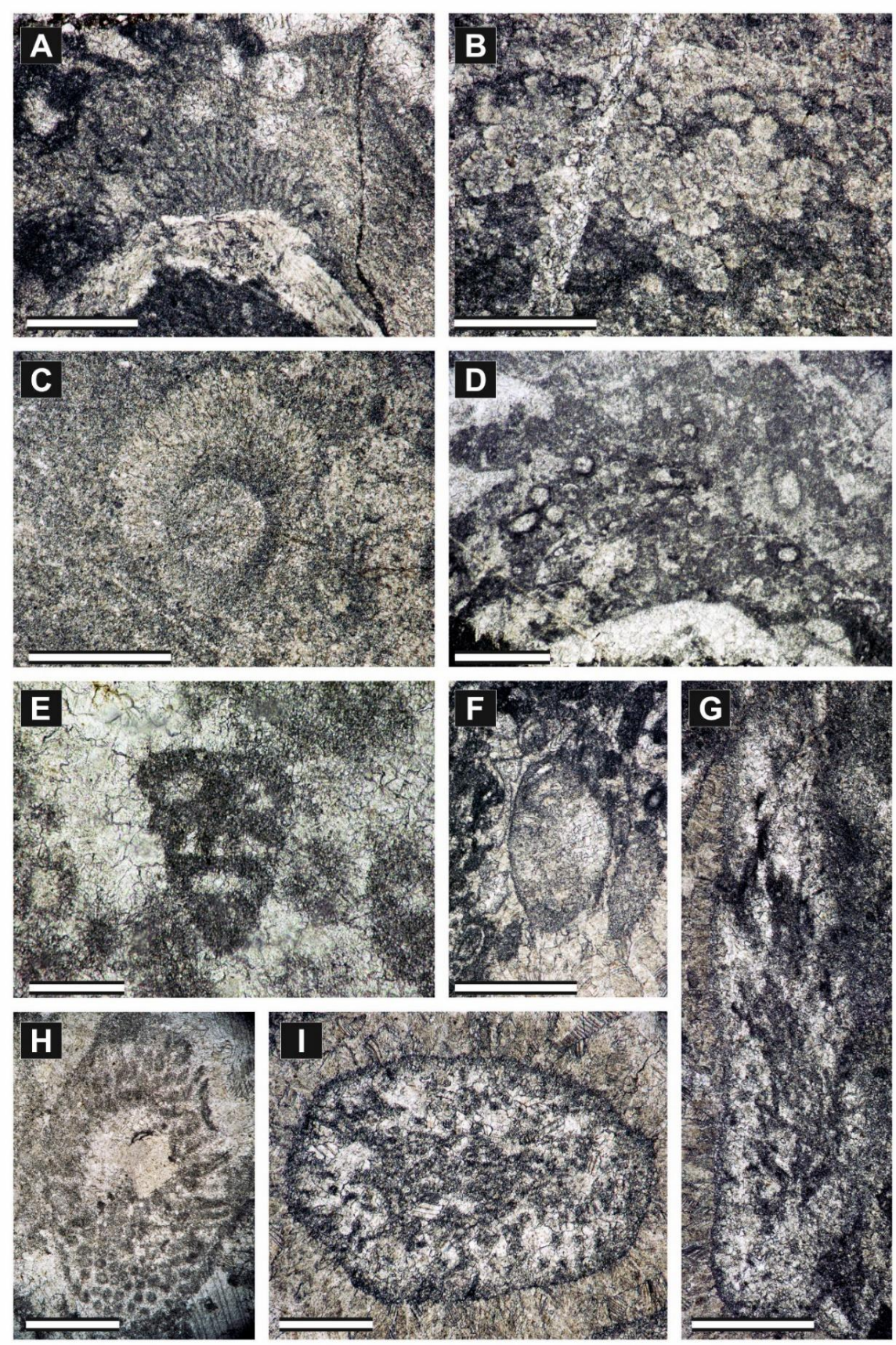


Fig. 27. (Stop no. 13). Microfossils from the limestones of the Dealu Runcu section. A - *Ladinella porata*; B - *Baccanella floriformis*; C - *Radiomura cautica*; D - Microtubus communis; E - *Paleolituonella meridionalis* (Luperto); F - *Aulotortus sinuosus*; G, I - *Boueina marondei*; H - *Diplopora tubispora*. (Scale bars: A–C, E, G, I = 0.25 mm; D, F, H = 0.5 mm).

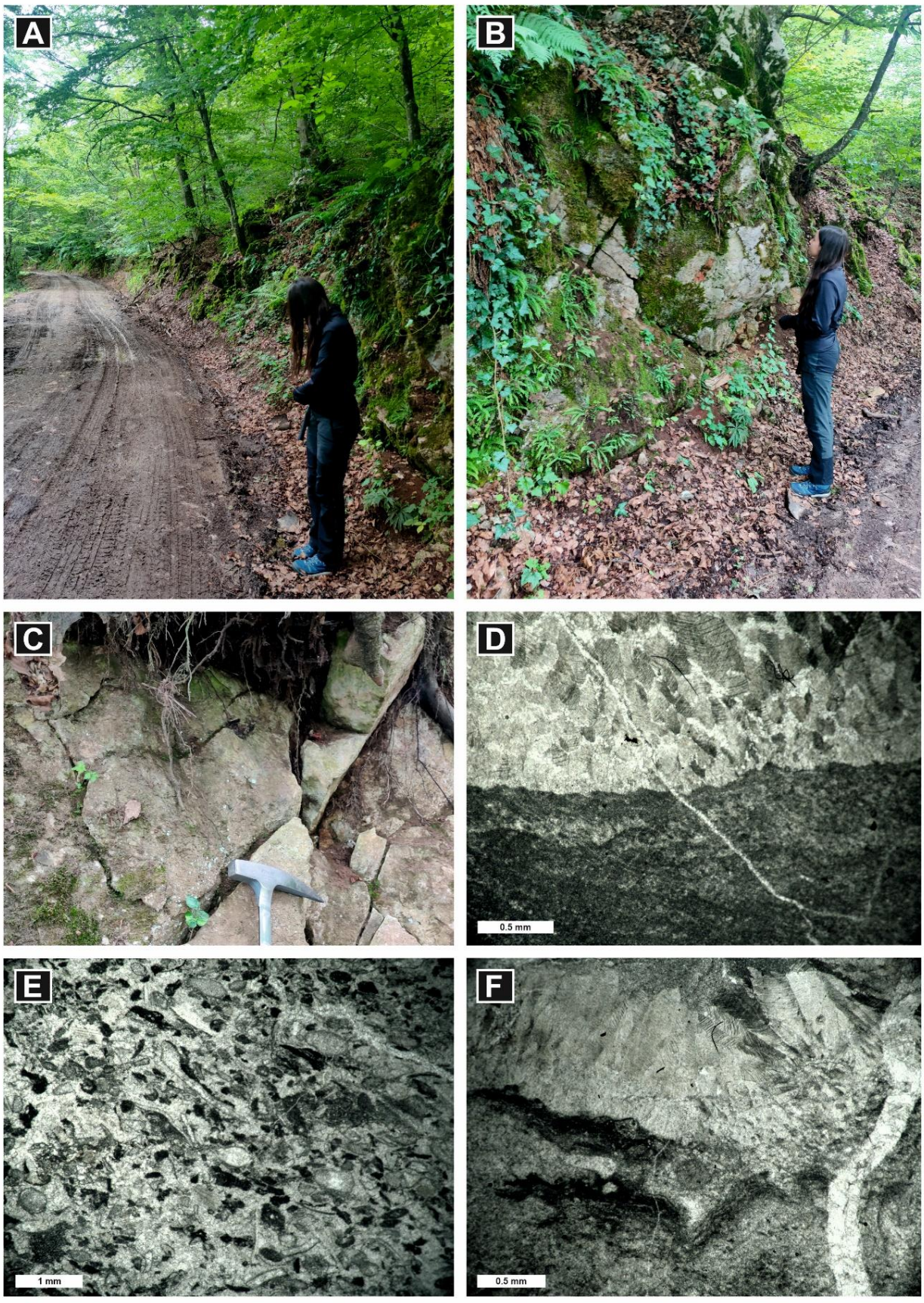


Fig. 28. (Stop no. 13). A-C - Outcrop view from the middle-upper part (Norian) of the profile of Dealu Runcu. D – Microbialites and cement crusts; E – Bioclastic grainstone facies with shallow-water material; F – Large early marine cement crusts and microbialites from the middle part of the section;

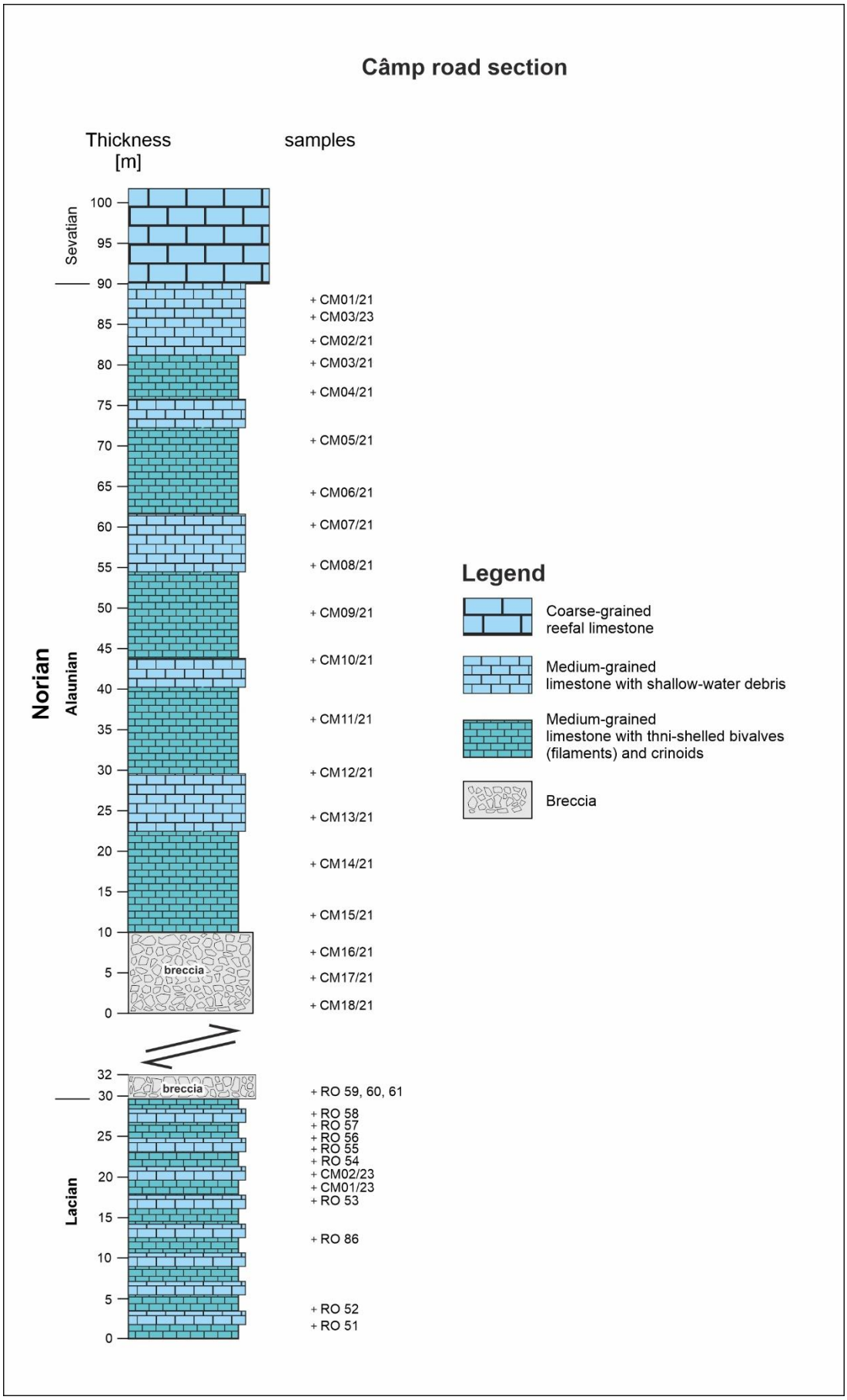


Fig. 29. (Stop no. 14). Câmp road section profile (Norian)

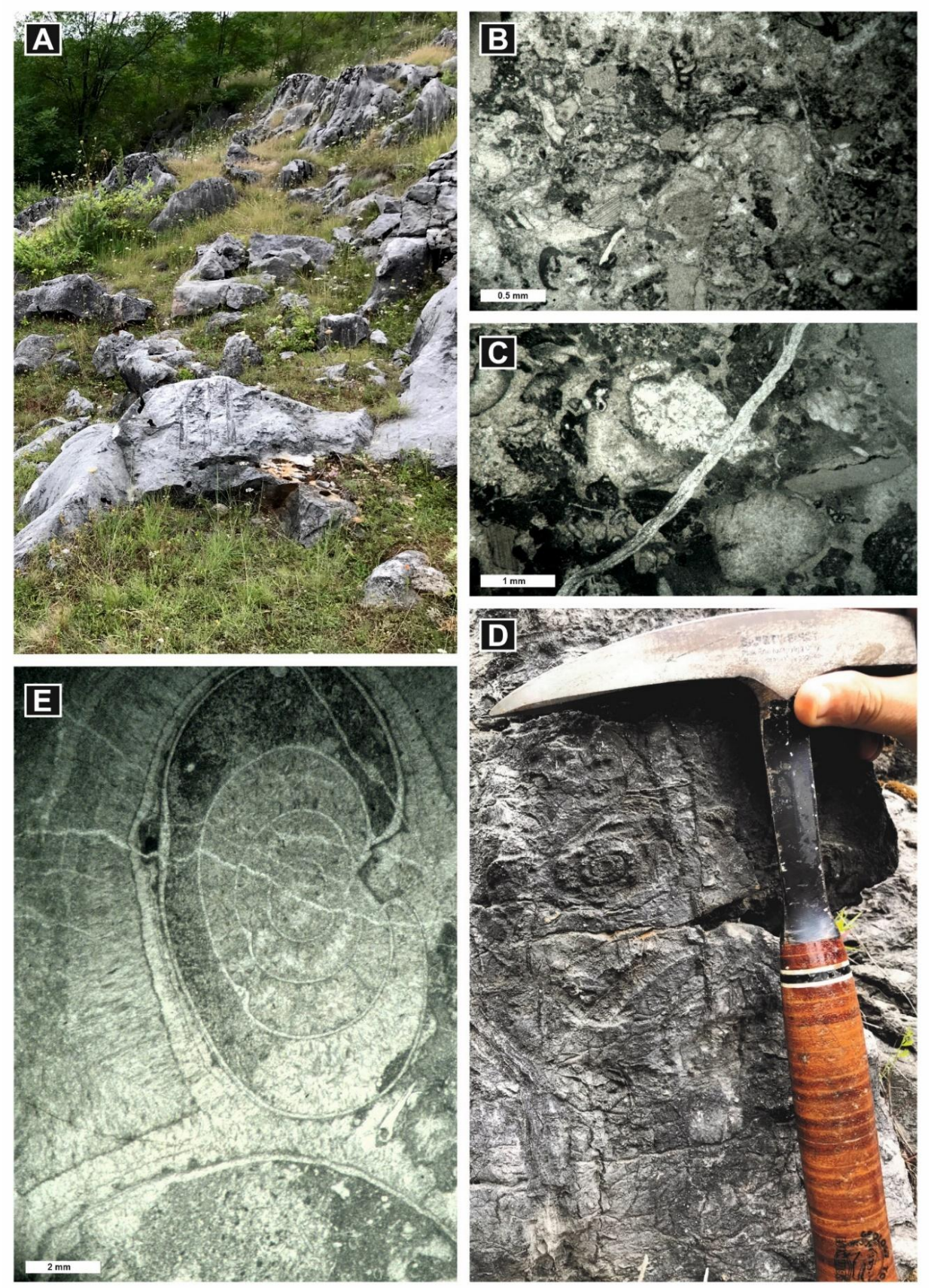


Fig. 30. (Stop no. 14). Lacian part of the Norian road section near Câmp: A – Outcrop view of the carbonate beds that contain abundant shallow-water sediments, together with rare ammonoids; B-C – Microfacies pictures showing coarse-grained grainstone/rudstone facies with reef-derived intraclasts; E – Juvenile ammonoids and thick early marine cement crusts; D – A well-preserved ammonoid specimen.

14.2 - Alaunian carbonates

The Alaunian succession begins with a thick polymictic carbonate breccia (Fig. 29) that forms the basal part of the exposed interval. Above the breccia, carbonate sedimentation resumes with medium-grained limestones rich in thin-shelled bivalves and crinoid debris. The remainder of the succession is characterized by the repeated vertical alternation of medium-grained limestones containing filaments and crinoids and medium-grained limestones rich in shallow-water skeletal debris, deposited under moderate hydrodynamic energy and reflecting increased export of material from fore-reefal environments.

14.3 – Sevatian fore-reef carbonates

The Sevatian part of the section is represented by coarse-grained fore-reefal limestones with calcified sponges, corals and microencrusters. The deposits crop out in an abandoned quarry and are poorly sorted, massive, and lack internal stratification, while the clasts are randomly distributed. Clasts range from angular to subrounded and vary in size. They consist predominantly of bioclastic grainstones/rudstones and bio-intraclastic rudstones. The angular to subrounded reef-derived clasts, their poor sorting, wide grain-size distribution, chaotic fabric, and fine-grained carbonate matrix indicate deposition by gravity-driven mass flows (Flügel, 2004). The fauna includes corals, calcified sponges (Parachaetetes sp.), foraminifers (*Kaeveria fluegeli*, *Parvalamella friedli*, *Aulotortus sinuosus*, *Aulotortus* cf. *tumidus*, *Ammobaculites* sp., *Duostomina biconvexa*, *Duostomina* sp., *Diplotremina* sp.), encrusting microorganisms (*Tubiphytes*), gastropods, bivalves, echinoderm ossicles and spines, sponge spicules, and worm tubes (Fig. 31A-Q). Based on their composition, texture, and sedimentary architecture, these Sevatian deposits are interpreted as proximal upper fore-reef slope deposits developed along the margin of a carbonate platform. This interpretation is further supported by the abundance of reef-derived skeletal debris, the absence of significant coral framework development, and by the dominance of resedimented intraclasts. These deposits represent the equivalent of the third progradational reef cycle (late Alaunian–Sevatian) of the Dachstein Carbonate Platform described by Zöhrer et al. (2026).

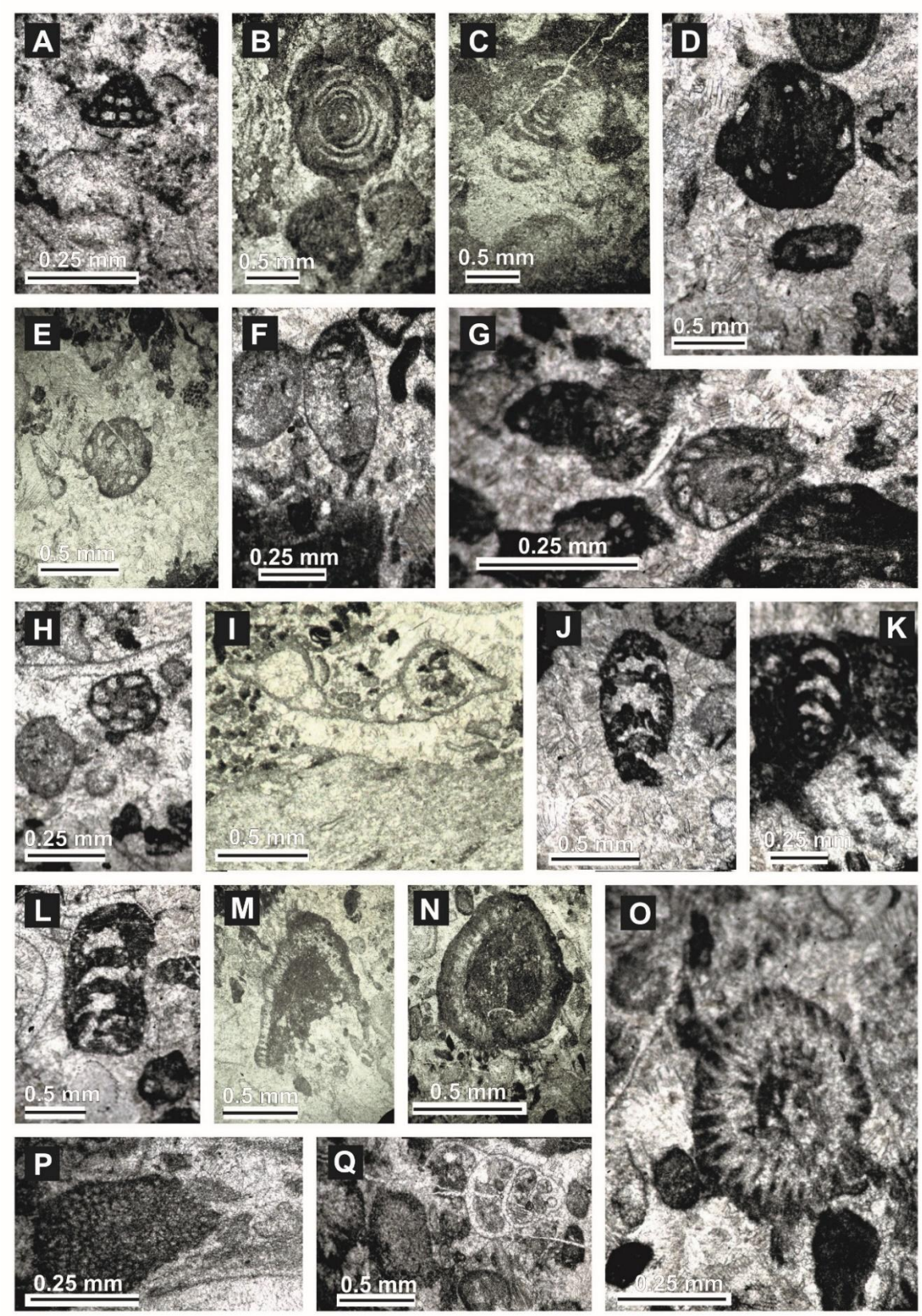


Fig. 31. (Stop no. 14). Microfossils from the Sevatian fore-reef limestones of the Road section near Câmp: A – *Kaeveria fluegeli*; B, C, F – *Aulotortus sinuosus*; D, E – *Parvalamella friedli*; G – *Duostomina biconvexa*; H – unidentified foraminifer; I, Q – gastropods; J, K, L – *Ammobaculites* sp.; M, N – *Griphoporella* sp.; O – *Pseudodiplopora* sp.; P – *Solenopora* sp.Q – Gastropod.

Stop no. 15 – Strâmtura Valley sections (Carnian)

The Strâmtura Valley sections (namely the House, River, Garden, and Quarry sections) represent a slightly proximal sequence of the Roșia Formation and document the early Carnian evolution and subsequent demise of a Wetterstein Carbonate Platform transitional to a basinal sequence along the western passive margin of the Neo-Tethys Ocean. The whole sequence records three progradational reef cycles, comprising two Cordevolian phases followed by a more pronounced Julian 1 phase. The latter is marked by the emplacement of the ***Strâmtura Limestone*** (cf. Patrulius et al., 1976), a huge reef-derived carbonate block preserving a hybrid framework dominated by calcified sponges, microbialites, microproblematic organisms, and early marine cements. Karst surfaces, displaced reef blocks, and siliciclastic-rich open-marine deposits indicate repeated reef exposure, a steep unstable platform margin, and downslope transport of carbonate debris during increased subsidence. Overall, the Strâmtura Valley succession provides important insights into Early Carnian Wetterstein reef evolution and carbonate platform dynamics in the western Tethyan realm. It records the development of the Wetterstein Carbonate Platform from its initiation to its final stages prior to its demise around the Julian 1/2 boundary, preceding the onset of the Carnian Pluvial Event (=Reingraben Turnover).

15.1 - House section ("Cordevolian") (Figs. 32, 34A)

This sub-section crops out on the right side of the DC220 road towards Beiuș, near an isolated house. It represents the lowermost part of the Strâmtura Valley succession and begins with massive, light-grey reefal dolomites (**Wetterstein limestones – first reef cycle**) containing recrystallized calcified sponges and diffuse microbial crusts. These shallow-water deposits are overlain by ~10 m of thick-bedded, medium-grey siliceous limestones with turbiditic material. The interval is dominated by fissured wackestone–packstone microfacies that grade upward into grainstone–packstone with shallow-water-derived bioclasts, peloids, and micritic intraclasts. It yields *Paragondolella polygnathiformis*, *P. inclinata*, and *P. tadpole*, suggesting an early Carnian age ("Cordevolian"). The succession is capped by 4 m of dm-bedded, dark-grey basinal dolomites with turbiditic material.

15.2 – River section ("Cordevolian") (Fig. 32)

This section starts with a two-meter-thick level of dolomitized shallow-water reefal carbonates (**Wetterstein limestones – second reef cycle**) overlain by 8 m of thick-bedded, medium-grey siliceous limestones with turbiditic material, dominated by fine-grained peloidal-bioclastic grainstone facies yielding *Paragondolella polygnathiformis*. These are followed by 1 m of marly carbonates containing *P. polygnathiformis* and rare juvenile ammonoid fragments, and by cm-bedded marly carbonates with turbiditic material. The succession continues with 5–6 m of dark limestones containing thin-shelled bivalves ("filaments") and the conodonts *P. polygnathiformis* and *Gladigondolella malayensis*.

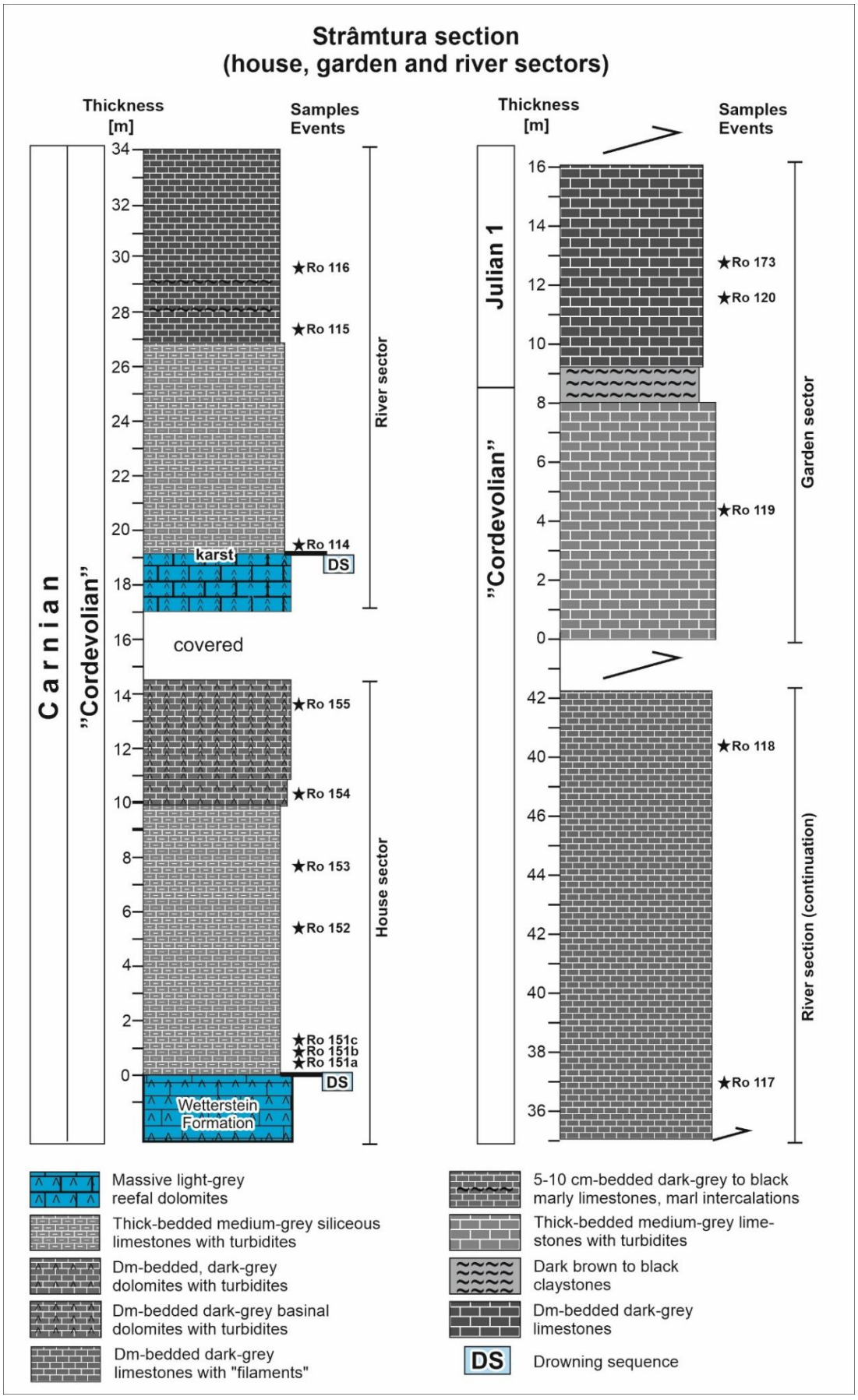


Fig. 32. (Stops 15.1, 15.2, 15.3). Strâmtura Valley section profile (Carnian).

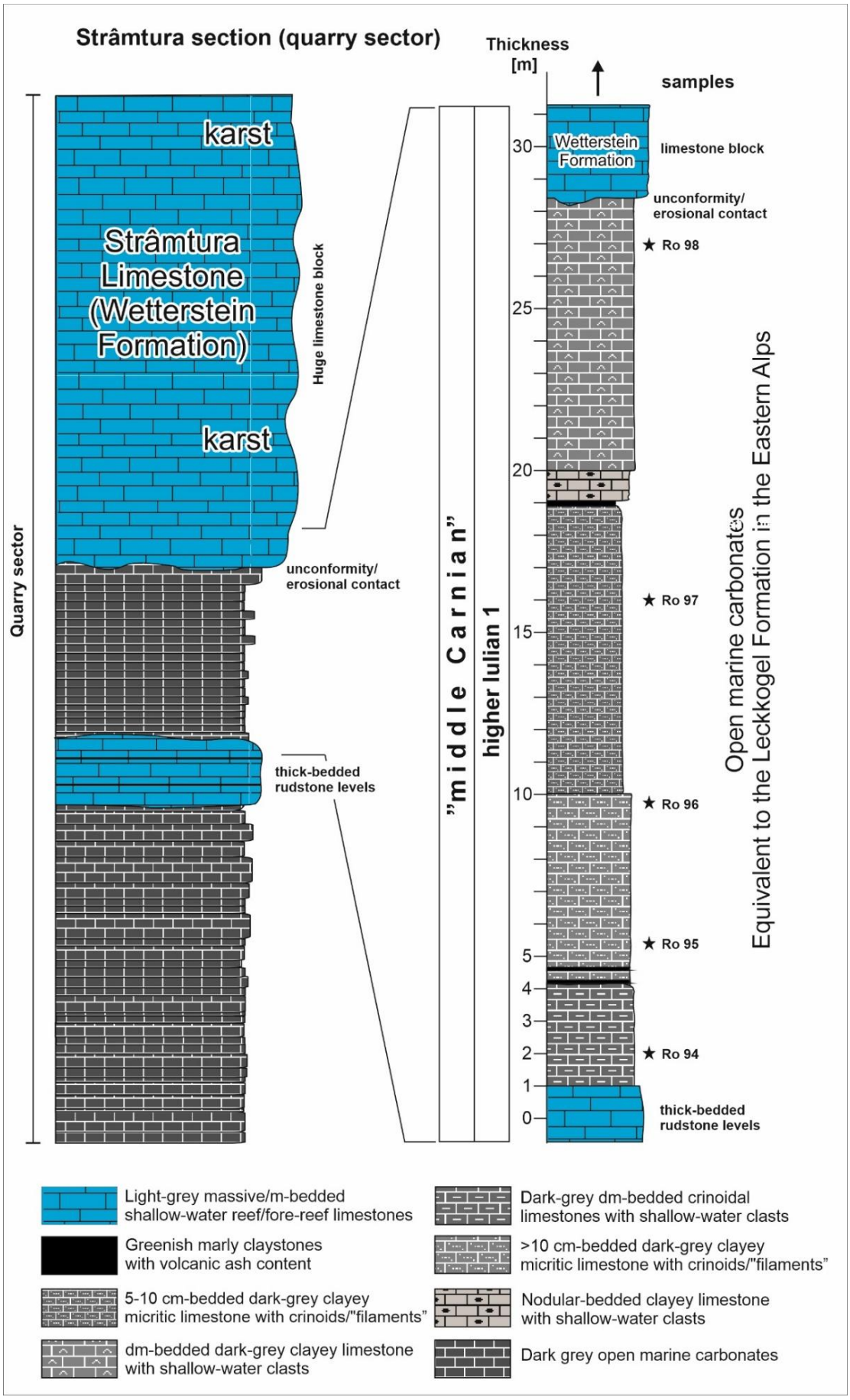


Fig. 33. (Stop 15.4). Quarry sector of the Strâmtura Valley section and the Strâmtura Limestone blocks (Carnian)

15.3 – Garden section ("Cordevolian"–Julian 1)

This section (Figs. 32, 34B) is composed of thick-bedded, medium-grey limestones intercalated with turbiditic deposits and characterized by fine- to medium-grained peloidal-intraclastic grainstone to packstone microfacies. These strata yielded the conodont species *Paragondolella polygnathiformis*, *P. inclinata*, and *Budurovignathus mostleri*. The limestones are overlain by a one-meter-thick claystone bed, followed by a seven-meter-thick succession of decimeter-bedded dark-grey micritic carbonates displaying a bioclastic wackestone microfacies with abundant "filaments" and rare benthic foraminifers. The conodont fauna recovered from this interval comprises *Paragondolella auriformis* and *Paragondolella* sp.

15.4 – Quarry section (Julian 1)

The upper part of the Strâmtura Valley succession is exposed in the abandoned Strâmtura limestone quarry (Figs. 33, 34C-D, 35A-H), representing the best-exposed sector of the area. It comprises an open-marine succession of dark-grey bedded limestones with abundant shallow-water resedimented material and siliciclastic input, overlain by reef-derived rudstone intervals and capped by a large, partly recrystallized Wetterstein reef block (***Strâmtura Limestone***) marking the third reef cycle of the Wetterstein Carbonate Platform.

The lower quarry section consists of centimeter-bedded peloidal–intraclastic grainstone to packstone microfacies containing platform-derived debris, benthic foraminifers, crinoids, and microproblematical organisms (*Tubiphytes*, *Isnella misiki*, *Muranella sphaerica*). The conodont assemblage includes *Paragondolella polygnathiformis* and *Gladigondolella* ME.

These deposits are overlain by coarse bio-intraclastic grainstone to rudstone facies with reefal intraclasts, calcified sponge–microencruster/microbialite boundstones, and microbialites. Up-section, turbiditic crinoidal limestones contain reef-derived debris and yield *Paragondolella polygnathiformis* and *P. auriformis*.

The succession ends with the >60 m thick light-grey fore-reef to reef carbonate block (***Strâmtura Limestone*** = Wetterstein Carbonate Platform) resting unconformably on the underlying open-marine limestones. Its main facies include calcified sponge–microencruster/microbialite boundstone and bio-intraclastic rudstone.

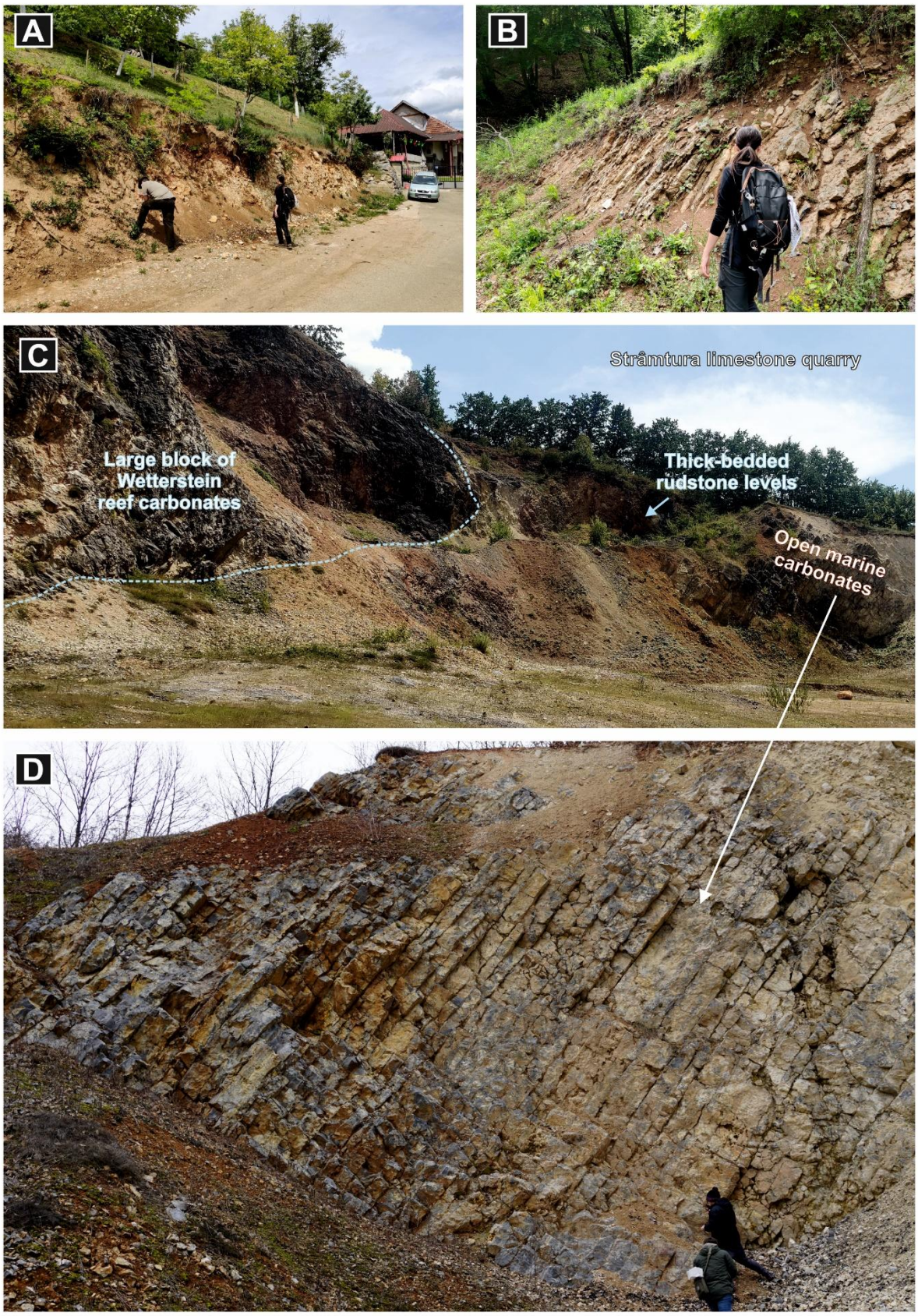


Fig. 34. (Stops 15.1-15.4). Strâmtura Valley sections (Carnian): A – The house sector; B – Garden section showing the well-bedded Julian 1 limestones; C - View of the Strâmtura quarry showing the large Wetterstein reefal/fore-reefal blocks on top of open marine dark carbonates (D).

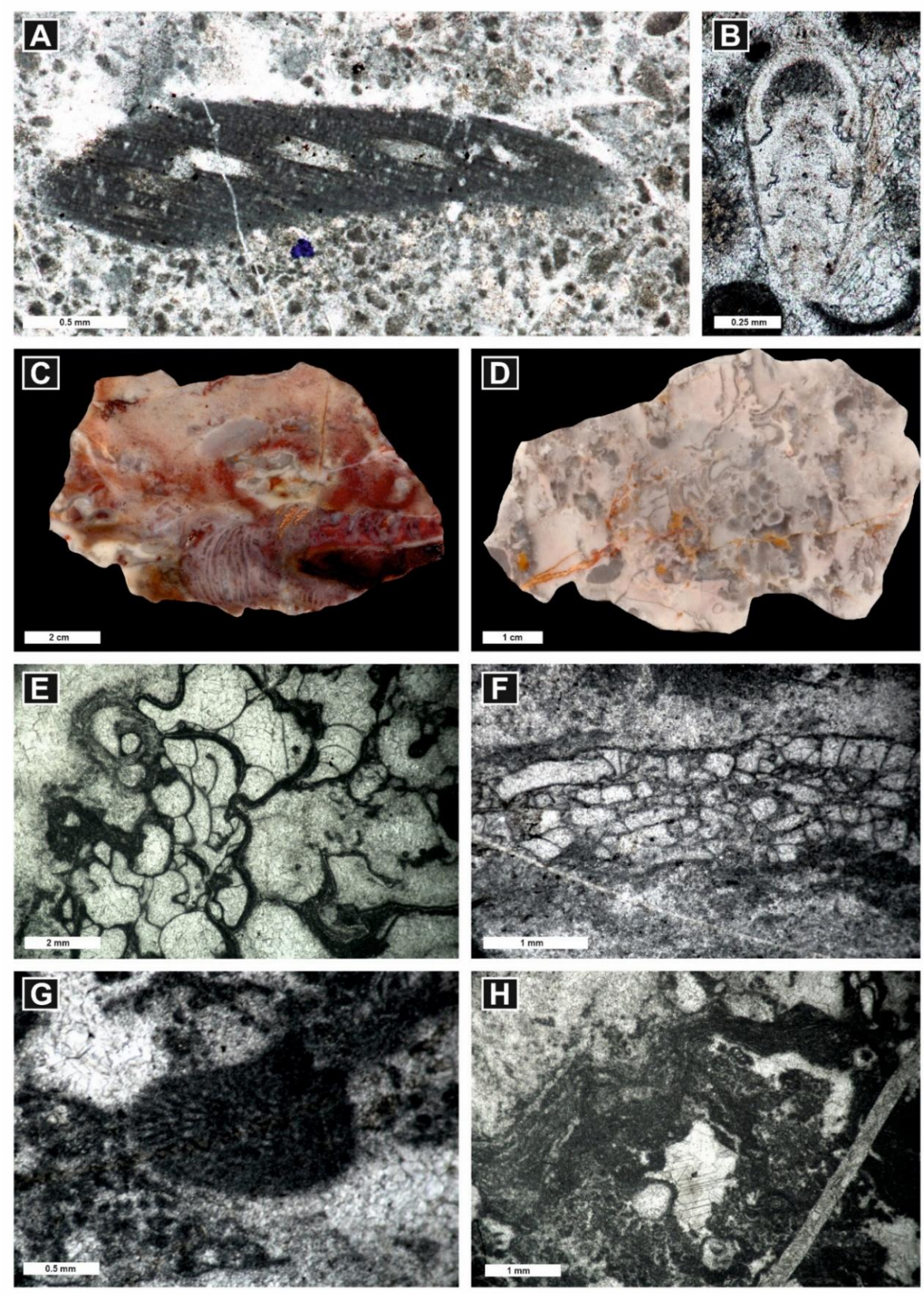


Fig. 35. (Stop no. 15.4). Microfacies and polished slabs from the Carnian limestones from the Strâmtura Valley section (quarry sector). A – Well beded hemipelagic limestones from the middle part of the Roșia river section; B – Nodosariid foraminifera; C-D – Polished slabs of calcified sponge-microencruster/microbialite boundstone from the Wetterstein Strâmtura Limestone; E – The calcified sponge *Jablonskyia* cf. *andrusovi*; F – *Bacinella ordinata*; G – *Ladinella porata*; H – Microbial crusts within a calcified sponge-microbialite boundstone.

Stop no. 16 – Roșia type-section (late Anisian to Norian)

The Roșia Limestone Formation (cf. Patrulius et al., 1976), the most important Mid-Late Triassic deep-water carbonate facies of the Codru Nappe System, has its type section exposed in two complementary outcrops: the Roșia River section and the quarry section (Figs. 36, 37A-E). The Roșia River section exposes the lower and upper parts of the succession, whereas the quarry section, located directly opposite the road, provides continuous access to the middle interval. Combining both sections allows reconstruction of a nearly complete stratigraphic record from the Pelsonian (middle Anisian) to the late Lacian (early Norian). Importantly, this sedimentary succession preserves the *Carnica* event (*M. carnica* conodont zone), marking the end of the Wetterstein Carbonate Platform and the dawn of the Reingraben Turnover (see Mrdak et al., 2023).

The succession begins with shallow-water dolomites of the Steinalm Formation (Sohodol Dolomite). These are abruptly overlain by a relatively condensed drowning sequence, marking the rapid termination of the Anisian Steinalm Carbonate Ramp. The drowning interval is constrained by conodonts, indicating a latest Illyrian age (Fig. 36).

Above the drowning surface, approximately 12 m of volcaniclastic deposits composed of volcanic ash, tuffs, volcanoclastic sandstones and siltstones, together with radiolarian-bearing sediments, document intense volcanic activity during the Fassanian (*Pietra Verde*). These deposits are succeeded by dm-bedded dark-grey pelagic limestones assigned to the Longobardian (Fig. 36).

The Carnian succession begins with thick-bedded rose-grey limestones with turbiditic material of Julian 1 age. Toward the end of this sequence the *Carnica* event is preserved, leading to the deposition of thin- to medium-bedded marly limestones with marl intercalations assigned to Julian 2, reflecting increased siliciclastic input (Fig. 36). A covered interval separates these deposits from overlying Tuvalian medium-grey hemipelagic limestones.

The quarry, located directly opposite the Roșia River section, exposes approximately 45 m of strata corresponding to the middle part of the succession, spanning the Tuvalian to early Lacian. It provides an exposure of the Carnian/Norian transition in hemipelagic environments and complements the river section. The lower part of the quarry is composed of approximately 20 m of Tuvalian medium-bedded marly limestones with marl intercalations and turbiditic material. Several *Halobia* lumachelles were identified around the Carnian/Norian transition. The Lacian 1 is characterized by the deposition of several horizons that contain abundant chert nodules, development of hemipelagic medium-grained carbonates with abundant conodonts. The marly interbeds become progressively less common upwards. The upper part of the succession is exposed along the Roșia River, above the quarry interval. It consists of approximately 40 m of thick-bedded to massive, light-grey limestones. Compared to the underlying Lacian 1 deposits, bedding becomes thicker and more uniform, while chert nodules and marl intercalations are absent. Conodont assemblages containing *Epigondolella rigoi* and *E. triangularis* indicate a middle to late Lacian (Lacian 2–3) age for this uppermost interval.

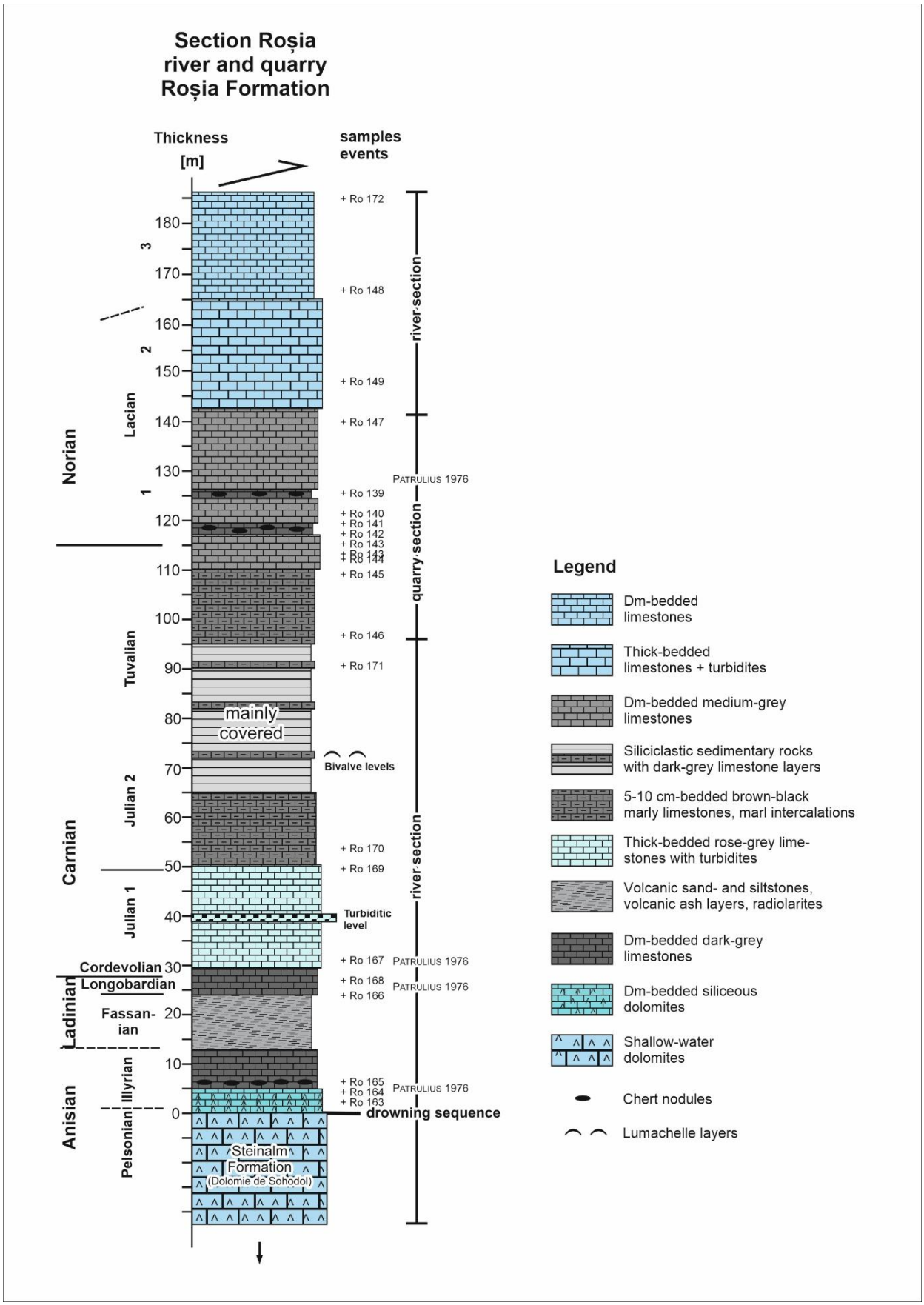


Fig. 36. (Stop 16). Roșia-type section profile (late Anisian to Norian).

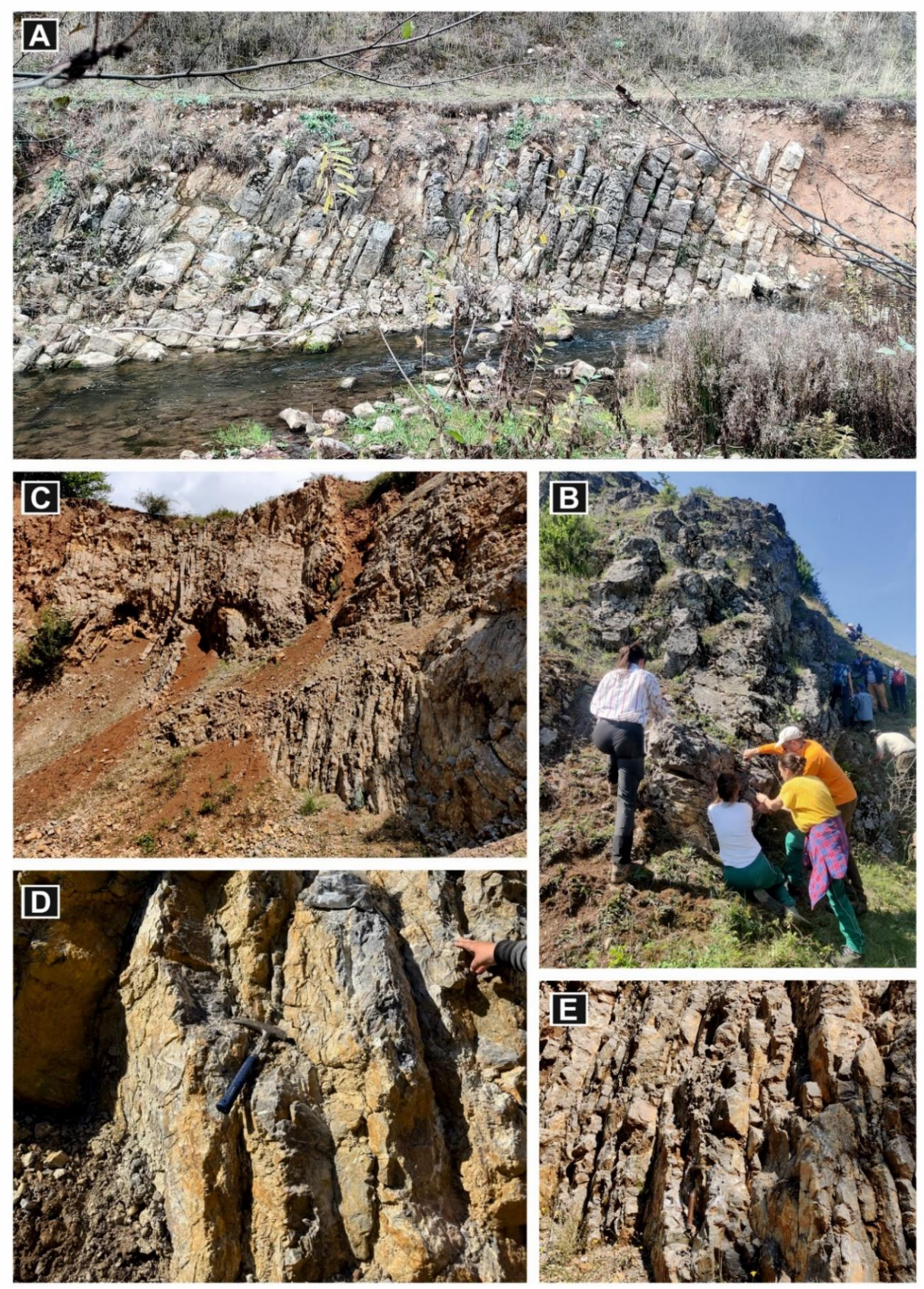


Fig. 37. (Stop no. 16). Outcrop view of the Roșia type section: A – Well beded hemipelagic limestones from the middle part of the Roșia river section; B – Upper part (Norian) of the Roșia river section; C – The quarry sector of the Roșia type section (Carnian-Norian); D-E – Well-bedded dark open-marine carbonates from the quarry section. In D, the approximate location of a *Halobia* level around the Carnan/Norian boundary.

Stop no. 17 – Cornet outcrop (Upper Jurassic-Early Cretaceous shallow-water platform carbonates)

Towards the end of the Late Jurassic, the Bihor-Pădurea Craiului carbonate platform was subaerially exposed and intensely karstified. The alteration of limestones and possibly exotic material led to the local accumulation of bauxite deposits that mark the Jurassic/Cretaceous boundary. This boundary is clearly visible within an outcrop in the Cornet area (Pădurea Craiului) that is the objective of Stop 17. The stop is located in the Central-northern part of Pădurea Craiului Mountains, on the left slope of Mnierăie valley, at the location of the 68-Cornet bauxite lens (see Fig. 8).

The outcrop (Fig. 38) exposes the terminal part of the Cornet Formation (Late Jurassic) and the lower part of the Blid Formation (Early Cretaceous) represented mainly by the Dobreşti Member (Berriasian?–Valanginian–Hauterivian) (Fig. 39).

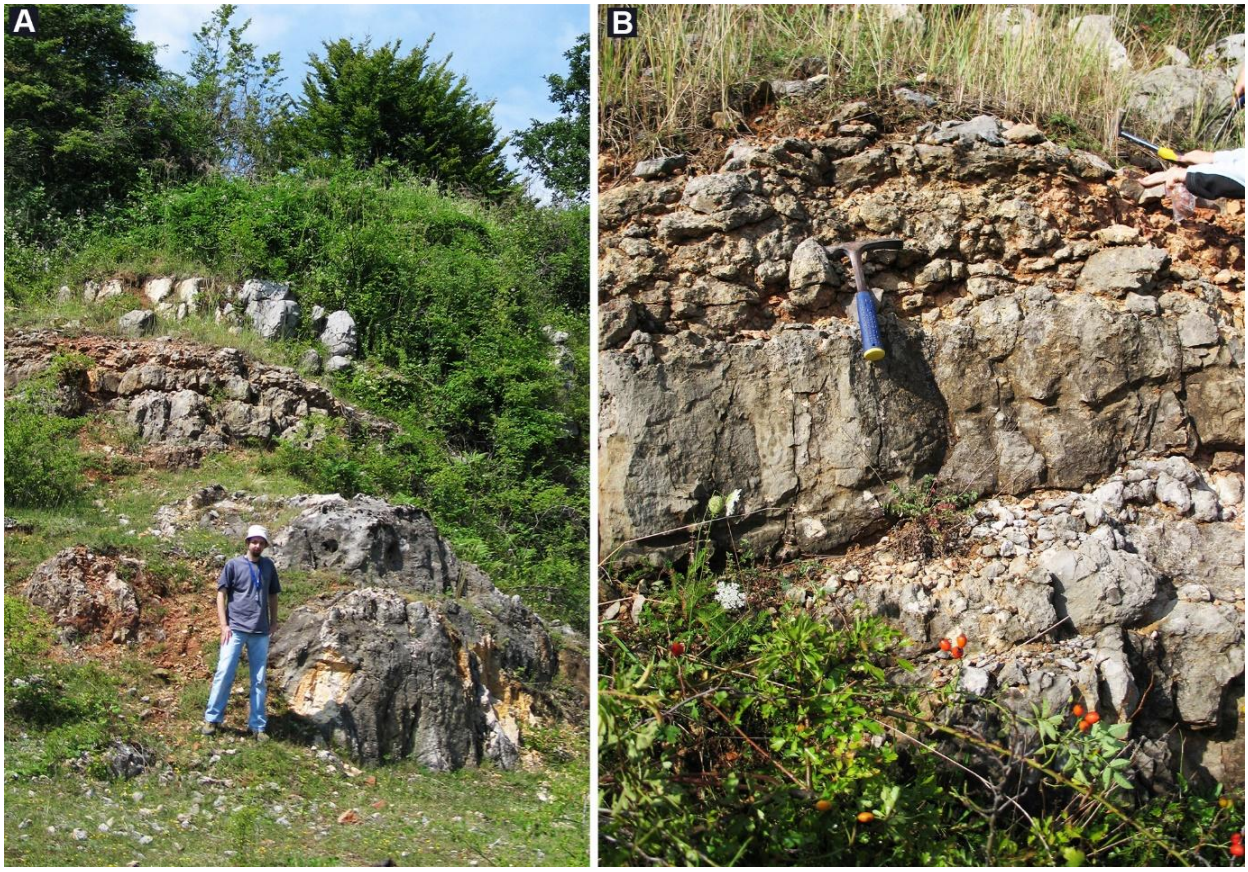


Fig. 38. (Stop no. 17). Cornet. A – Outcrop photograph of the lower part of the succession. B – Close-up view of the freshwater limestones containing charophytes.

Overlying the bauxites, the basal part of the Dobreşti Member consists of black limestones containing charophytes, intercalated with breccias. Between the charophyte-rich intervals, a limestone bed containing dasycladalean algae and small foraminifera (*Scythiolina* spp. and *Montsalevia salevensis*) is intercalated. Upsection, the limestones become grey and contain small gastropods and dasycladalean algae. The total thickness of the Dobreşti Member within the outcrop is about 15-20 m. The succession continues with limestones with rudists, foraminifers and dasycladalean algae (Urgonian facies) belonging to the Coposeni Member, of ?late Hauterivian-Barremian age.

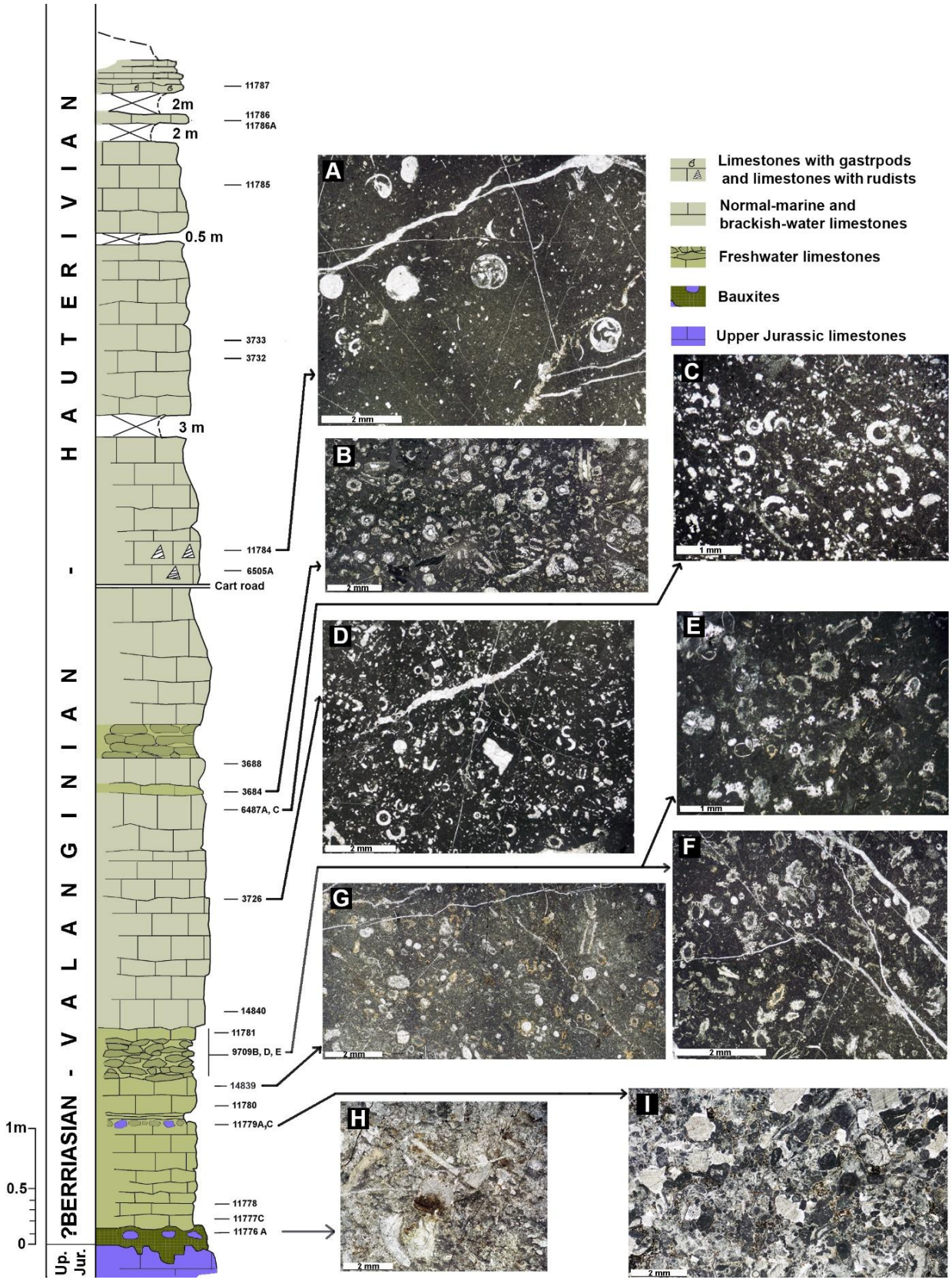


Fig. 39. (Stop no. 17). Cornet. Succession of the Lower Cretaceous deposits with the main microfacies. A – Wackestone; microgastropod-bearing limestones. B, E-F – Packstone; charophyte-bearing limestones. C-D – Packstone; limestones with dasycladalean algae, mainly *Salpingoporella annulata*. G – Wackestone; charophyte- and ostracod-bearing limestones. H-I – Grainstone; fragments of Upper Jurassic limestones reworked into bauxite rocks and freshwater limestones.

The charophyte limestones have typical characteristics of lacustrine deposits. During their formation, however, at least one marine imersion took place, which led to the replacement of the charophyte association with one of dasycladalean algae and foraminifera (Figs. 40-41). The lacustrine charophyte- and ostracod-bearing limestones occur as laterally continuous beds ranging from a few centimeters to several decimeters in thickness across the entire outcrop. The bioclastic assemblage consists of dispersed ostracod valves, charophytes, gastropod and thin-shelled bivalve fragments dispersed within the micritic matrix. Ostracods and charophytes are the dominant organisms in shallow freshwater environments (e.g., Freytet, 1973, 1974). They are commonly associated with marsh limestones, which form in shallow freshwater settings affected by pedogenetic processes. Evidence of subaerial exposure includes pseudomicrokarst and microkarst features, breccias, and pedogenic nodules (Freytet, 1974; Wright and Platt, 1995). The pedogenically altered intervals range from a few centimeters to several decimeters in thickness.

The charophyte-bearing limestones gradually grade into brackish-water limestones containing small gastropods and subsequently into normal-marine rudist-bearing limestones, marking the onset of the Urgonian facies. Within the Dobreşti Member, a micropaleontological assemblage composed of foraminifera and calcareous algae has been identified (see also Bucur, 2000; Bucur and Cociuba, 2001).

The benthic foraminifera assemblage is dominated by representatives of "small cuneolinids": *Scythiolina filiformae* (Fig. 40A), *S.* cf. *cuneata* (Fig. 40C), *S.* cf. *pileiformae* (Fig. 40H), and *Montsalevia salevensis* (Fig. 40D, G). Besides, *Haplophragmoide joukowsyi*, *Meandrospira favrei*, *Coscinoconus* sp., textulariids and rare miliolids have been noticed.

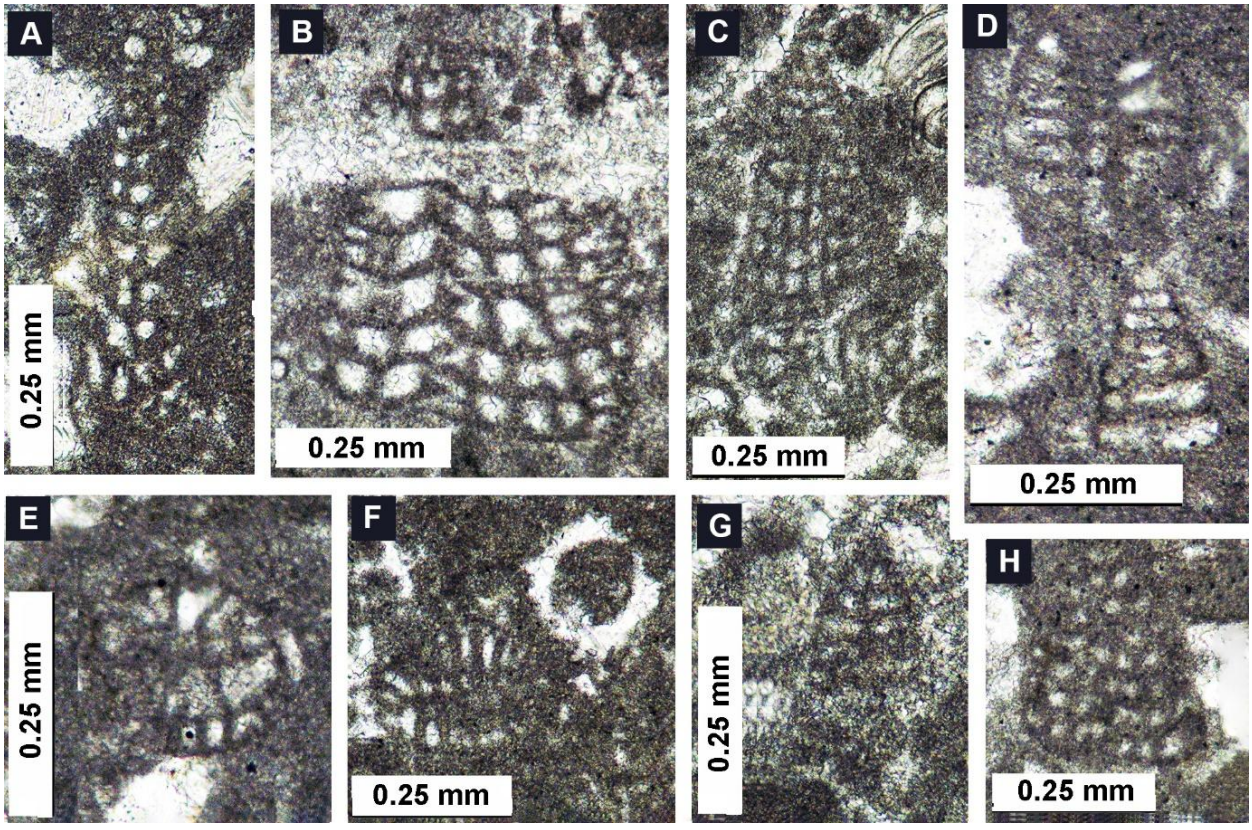


Fig. 40. (Stop no. 17) – Cornet. Foraminifers from the Valanginian-Hauterivian succession. A – *Scythiolina filiformae* Neagu, thin section 3688. B – *Scythiolina* sp., thin section 11785. C – *Scythiolina* cf. *cuneata* Neagu, thin section 11786. D – *Scythiolina* sp. and *Montsalevia salevensis* Charollais et al., thin section 6505A. E – *Scythiolina* sp., thin section 3726. F – *Scythiolina* sp. and *Salpingoporella annulata* Carozzi, thin section 6505A. G – *Montsalevia salevensis* Charollais et al., thin section 11786. H – *Scythiolina* cf. *pileiformae* Neagu, thin section 6505A.

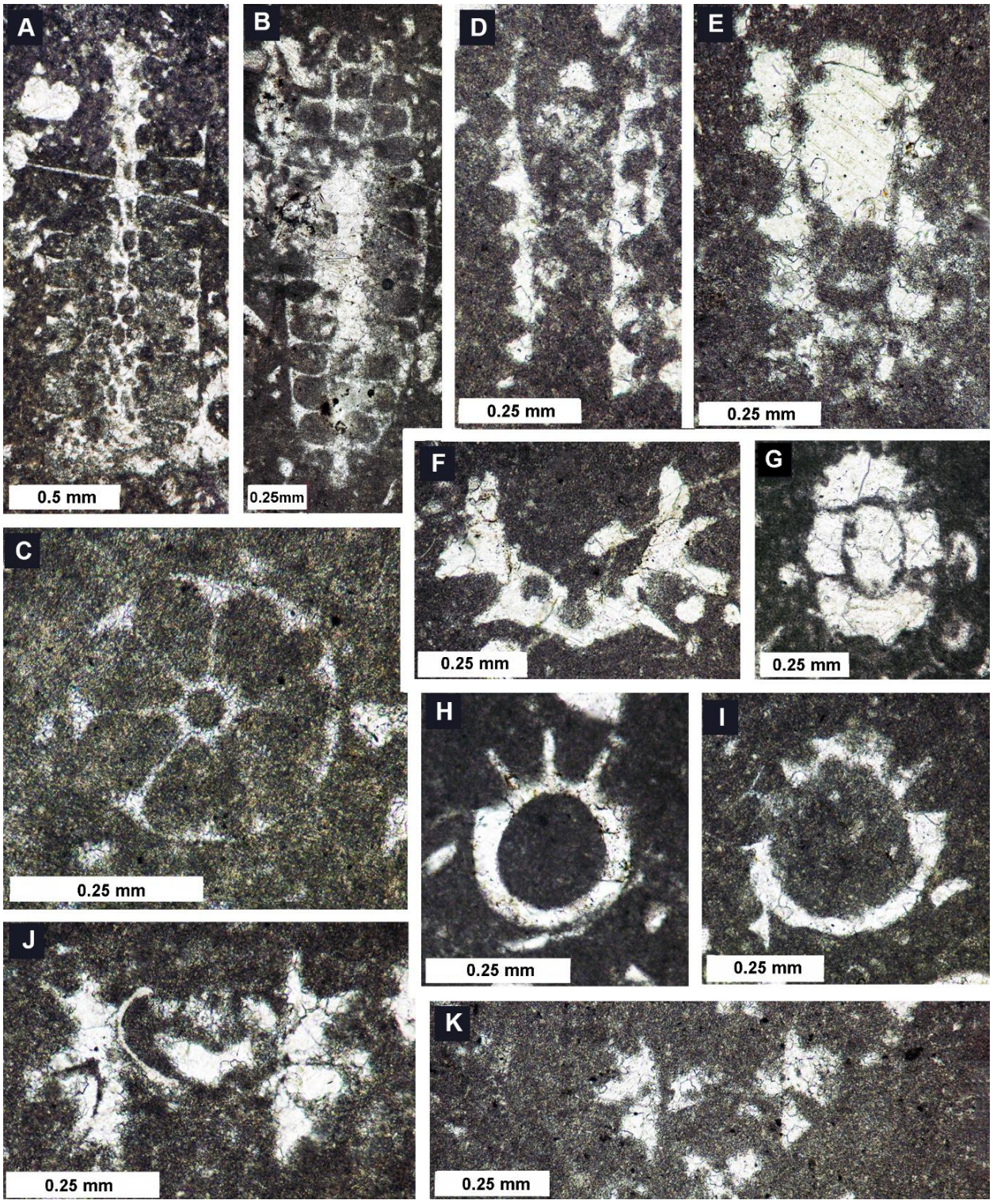


Fig. 41. (Stop no. 17) – Cornet. Dasycladalean algae from the Valanginian–Hauterivian succession. A-C – *Otternstella lemmensis*, thin section 6487C (A); 14840 (B, C). D-E – *Salpingoporella katzeri*, thin section 6505A (D); 3733 (E). F – *Clypeina solkani*, thin section 3726. G – *Salpingoporella annulata*, thin section 6505A-5. H-I – *Clypeina parasolkani*, thin section 3726 (H), 6487A-1 (I). J-K – *Falsolikanella nerae*, thin section 11786A (J), 3732-2(K).

The algal association of the Dobreşti Member is dominated by charophytes (Fig. 39B, E-G). Dragastan et al. (1966) described an association with *Atopochara trivolvis*, *Clavator harrisi, Porochara* sp. and *Atopochara* sp., belonging to the same formations but from different outcrops on the territory of the Pădurea Craiului Mountains. The dasycladalean association (Fig. 41) from the marine or brackish marine

intercalations is dominated by *Salpingoporella annulata* (Figs. 39C-D; 41G). In addition, *Otternstella lemmensis* (Fig. 41A-C), *Salpingoporella katzeri* (Fig. 41D-E), *Clypeina solkani* (Fig. 41F), *Clypeina parasolkani* (Fig. 41H-I), *Falsolikanella nerae* (Fig. 41J-K), and rare specimens of "*Cylindroporella*" sp. also occur. In addition to algae, ostracods and a macrofauna with small gastropods (Fig. 39A) occur within the Dobreşti Member. The rudist fauna within the Coposeni Member is composed of small requienids.

Stop no. 18 – Valea Măgurii quarry (Lower Cretaceous carbonates)

The stratigraphic succession of the Lower Cretaceous deposits in the Pădurea Craiului Mountains, overlying the Blid Formation, respectively above the Coposeni limestone Member (see Fig. 4) has been the subject of considerable debate in the geological literature (e.g., Patrulius in Ianovici et al., 1976; Dragastan et al., 1988; Cociuba, 1999, 2000; Avram et al., 2006). The stratigraphic succession proposed by Cociuba (1999, 2000) is considered to best reflect the observed field relationships and is therefore adopted in this guide. According to this interpretation, the Coposeni Limestone Member is overlain by the Ecleja Marls, which include the Valea Bobdei Limestone Member in their upper third and are, in turn, overlain by the Valea Măgurii Limestone Formation. This entire succession is assigned to the Bedoulian (early Aptian; see Fig. 4). The Vârciorog Formation (latest Bedoulian–Albian) unconformably overlies this succession.

This stop (Valea Măgurii quarry) is located north of Dobreşti, near the confluence of the Văsii Valley and the Măgurii Valley (Fig. 8). In the Valea Măgurii quarry (Fig. 42A, B) the upper part of the Valea Măgurii Limestone and the lower part of the Vârciorog Formation can be observed, separated by a ferruginous hardground.

The Valea Măgurii Limestone Formation comprises a succession of predominantly inner-platform facies, in which packstones and packstone–grainstones rich in foraminifera, particularly miliolids, are common (Fig. 42C, E). The succession generally develops an alternation of wackestone-packstone, packstone and packstone-grainstone with foraminifers, fragments of bivalves (mainly rudists) with coarse grainstones to intraclastic bioclastic grainstone-rudstone with foraminifers, dasycladalean algae and fragments of rudists, sometimes with a fenestrated appearance and often with meniscus cement. The entire succession contains a rich association of foraminifers and calcareous algae.

The foraminiferal assemblage includes: *Paracoskinolina maynci* (Fig. 43A), *Orbitolinopsis cuvillieri* (Fig. 43B-C), *Orbitolinopsis buccifer* (Fig. 43D), *Palorbitolina lenticularis*, *Paleodictyoconus actinostoma*, *Ovalveolina*? cf. *primigenita* (Fig. 2E), *Nezzazatinella macovei*, *Nezzazatinella* sp. (Fig. 43F), *Mayncina bulgarica* (Fig. 43G), *Derventina filipescui* (Fig. 43H), *Patelovalvulina patruliusi*, *Spiroloculina cretacea*, *Earlandia*? *conradi*, *Charentia cuvillieri*, *Melathokerion preasigali*, *Nautiloculina cretacea*, *Pseudolituonella gavonensis*, *Kamiskia* sp., *Arenobulimina* sp., *Glomospira urgoniana*, *Vercorsella scarsellai*, *Sabaudia minuta*, *Neotrocholina* sp., *Ichnusella* sp.

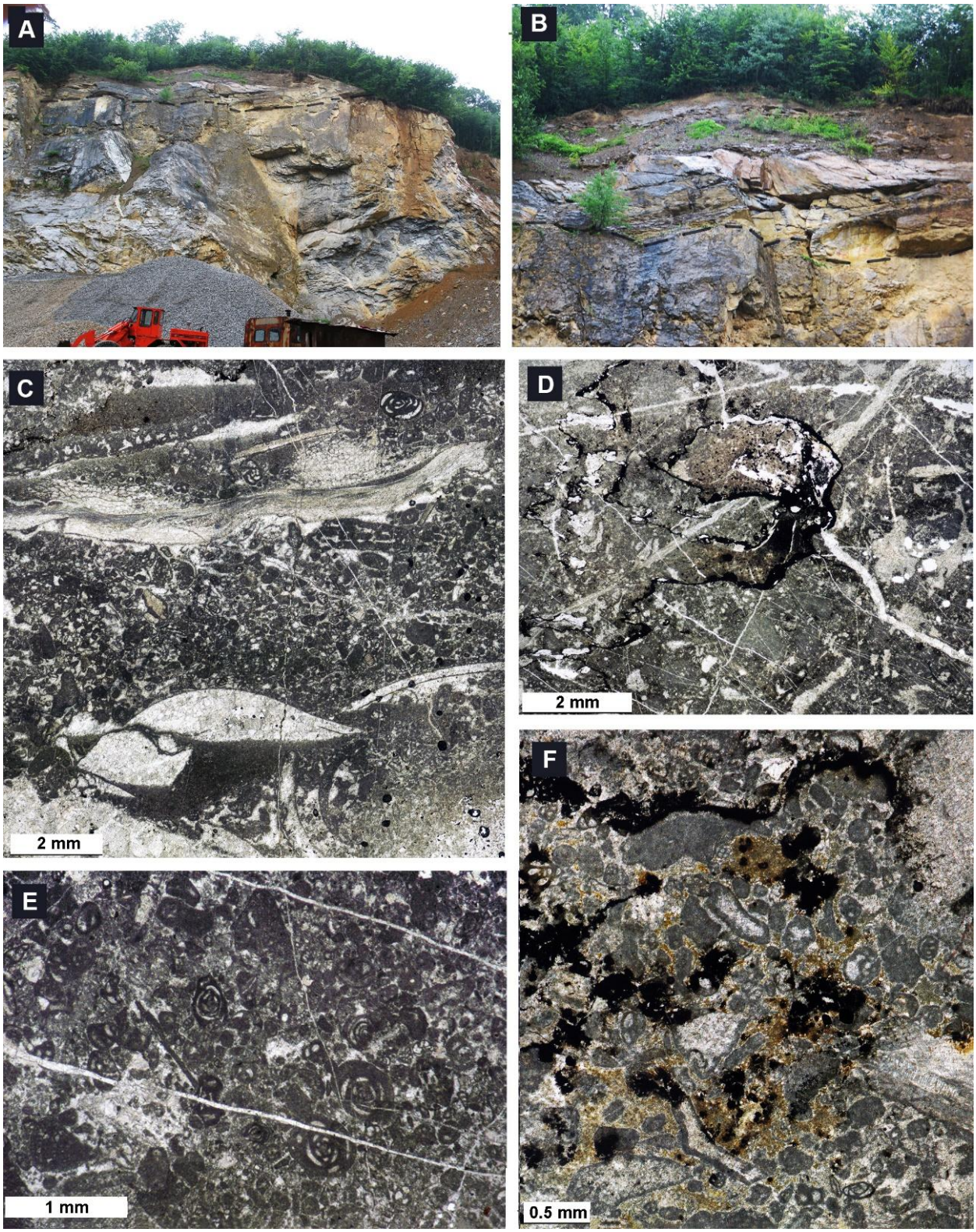


Fig. 42. (Stop no. 18) – Valea Măgurii quarry. Field and microfacies photographs. A – Field photograph of the Valea Măgurii quarry showing the discontinuity between the Valea Măgurii Formation (lower part) and Vârciorog Formation (black dashed line). B – Close-up view of the upper part in A. C, E – Peloidal and bioclastic packstone with frequent miliolids, one of the dominant microfacies within the Valea Măgurii Formation, thin section 11806B (C), 3159 (E). D, F – Packstone from the uppermost part of the Valea Măgurii Limestone (base of the discontinuity), with accumulation of ferruginous material, thin section 16541B (D), 11807B (F).

Calcareous algae are mainly represented by dasycladaleans: *Neomeris* sp. (Fig. 44A), *Salpingoporella muehlbergii* (Fig. 44B), *Salpingoporella melitae*, *Salpingoporella popgrigorei* (Fig. 44E), *Salpingoporella pygmaea*, *Biokoviella robusta*, "*Cylindroporella*" *lyrata* (Fig. 44D), "*Cylindroporella*" (*Korkyrella*) *texana*, *Suppiluliumaella* sp. Rare udoteaceans (*Arabicodium* sp., *Carpathocodium anae*), *Thaumatoporella parvovesiculifera, Rivularia*-type cyanobacteria, and *Lithocodium-Bacinella*-like structures also occur.

The foraminiferal association with *Orbitolinopsis cuvillieri*, *O. buccifer*, *Paracoskinolina maynci*, *Palorbitolina lenticularis*, *Paleodictyoconus actinostoma* indicates a Bedoulian (early Aptian) age.

The uppermost part of the Valea Măgurii Limestone is intensely recrystallized and affected by ferruginization (Fig. 42D, F). It is unconformably overlain by the sandy marls of the Vârciorog Formation, which contain abundant ammonites within the basal ~2 m of the succession. The ammonite assemblage includes, among others, the following species (Cociuba, 1999, 2000; Avram et al., 2006): *Toxoceratoides stefanescui*, *Helicancyclus aequicostatus*, *Acrioceras* sp. ex gr. *A. sarasini*, *Dufrenoya* sp., *Dufrenoya* cf. *lurensis*, *Colombiceras* (*C.*) cf. *tobleri*, *Colombiceras* (*C.*) cf. s*ubpeltoceratoides*, *Colombiceras* (*Egoianiceras*) cf. *multicostatum*, *Pseudohaploceras* cf. *matheroni*, and *Cheloniceras* sp. This assemblage indicates a latest Bedoulian–earliest Gargasian age.

Following the interpretation of Bordea et al. (1986), who considered the base of the Ecleja Marls above the "Middle Limestones with Pachyodonts" (i.e., the Valea Măgurii Limestone), Avram et al. (2006) assigned the ammonite assemblage to the base of the Ecleja Marls. However, this interpretation is inconsistent with both the biostratigraphic evidence and the observed stratigraphic relationships. The "Middle Limestones with Pachyodonts" (= Valea Măgurii Limestone) contain a foraminiferal assemblage with orbitolinid species whose stratigraphic ranges do not extend beyond the Bedoulian, including *Orbitolinopsis cuvillieri*, *Orbitolinopsis buccifer*, and *Palorbitolina lenticularis*. As demonstrated by Cociuba (1999, 2000), the Valea Măgurii Limestone (= "Middle Limestones with Pachyodonts" cf. Patrulius in Ianovici et al., 1976) overlies the Ecleja Marls. Moreover, the ammonite assemblage from the basal sandy marls exposed in the Valea Măgurii Quarry indicates a latest Bedoulian–early Gargasian age, which is younger than the age indicated by the foraminiferal assemblage of the Valea Măgurii Limestone.

The Vârciorog Formation continues in the Văsii Valley area and the tributaries of the Râului Valley, where it includes limestone intercalations referred to as the "Upper Limestones with Pachyodonts" (cf. Patrulius in Ianovici et al., 1976). These limestones contain the orbitolinids *Mesorbitolina texana* (Roemer) and *Mesorbitolina birmanica* (Sahni), whose stratigraphic ranges extend from the Gargasian to the Albian. Consequently, the ammonite-bearing marls exposed in the Valea Măgurii Quarry cannot represent the base of the Ecleja Marls; instead, they mark the base of the Vârciorog Formation (latest Bedoulian–Albian; Cociuba, 1999, 2000).

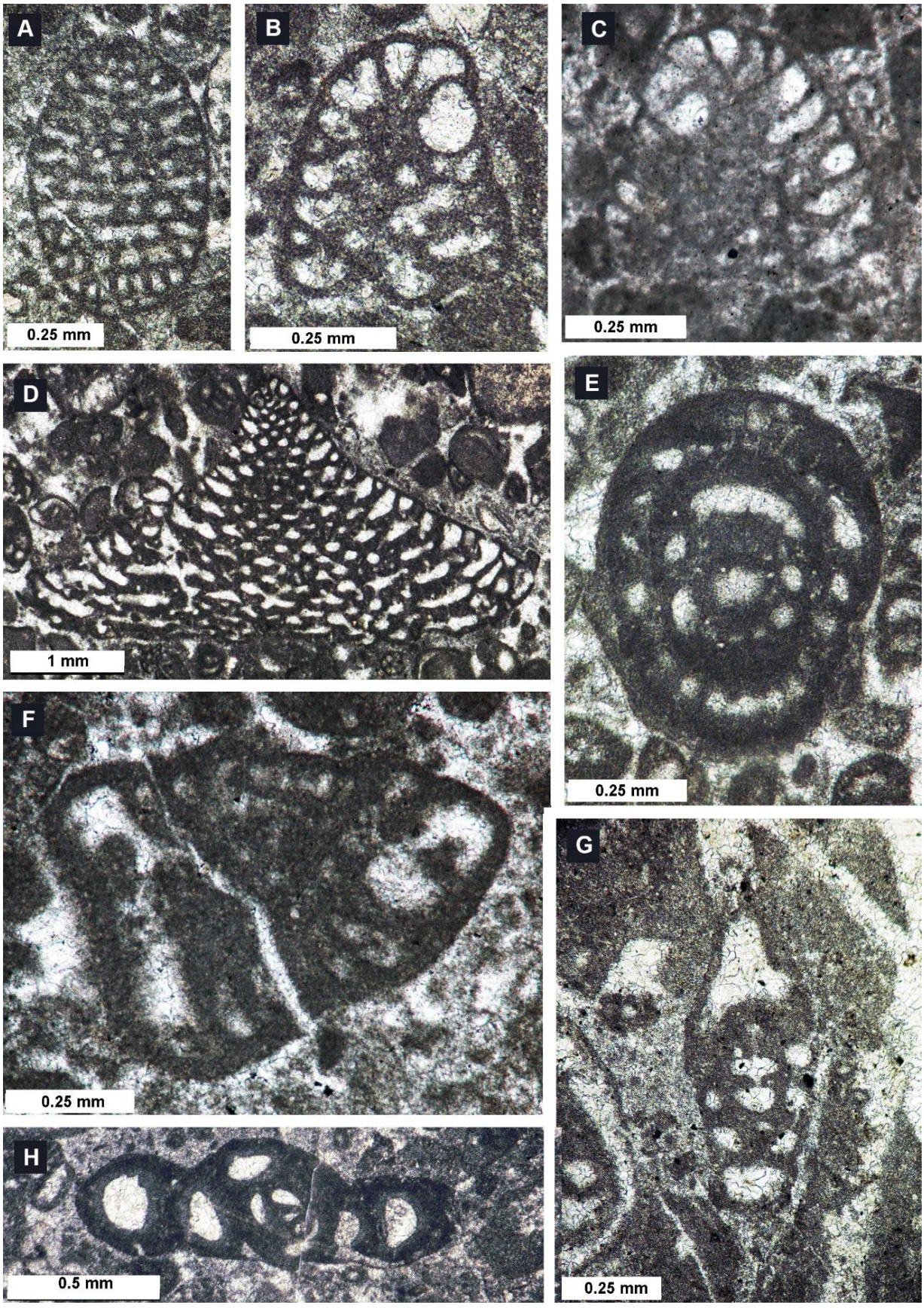


Fig. 43. (Stop no. 18) – Valea Măgurii quarry. Foraminifers from the Valea Măgurii Formation. A – *Paracoskinolina maynci*, thin section 3157. B, C – *Orbitolinopsis cuvillieri*, thin section 3159-4 (B), 3184 (C). D – *Orbitolinopsis buccifer*, thin section 5211. E – *Ovalveolina*? sp., thin section 3249-1. F – *Nezazatinella* sp., thin section 3183B. G – *Mayncina bulgarica*, thin section 3152. H – *Derventina filipescui*, thin section 4106.

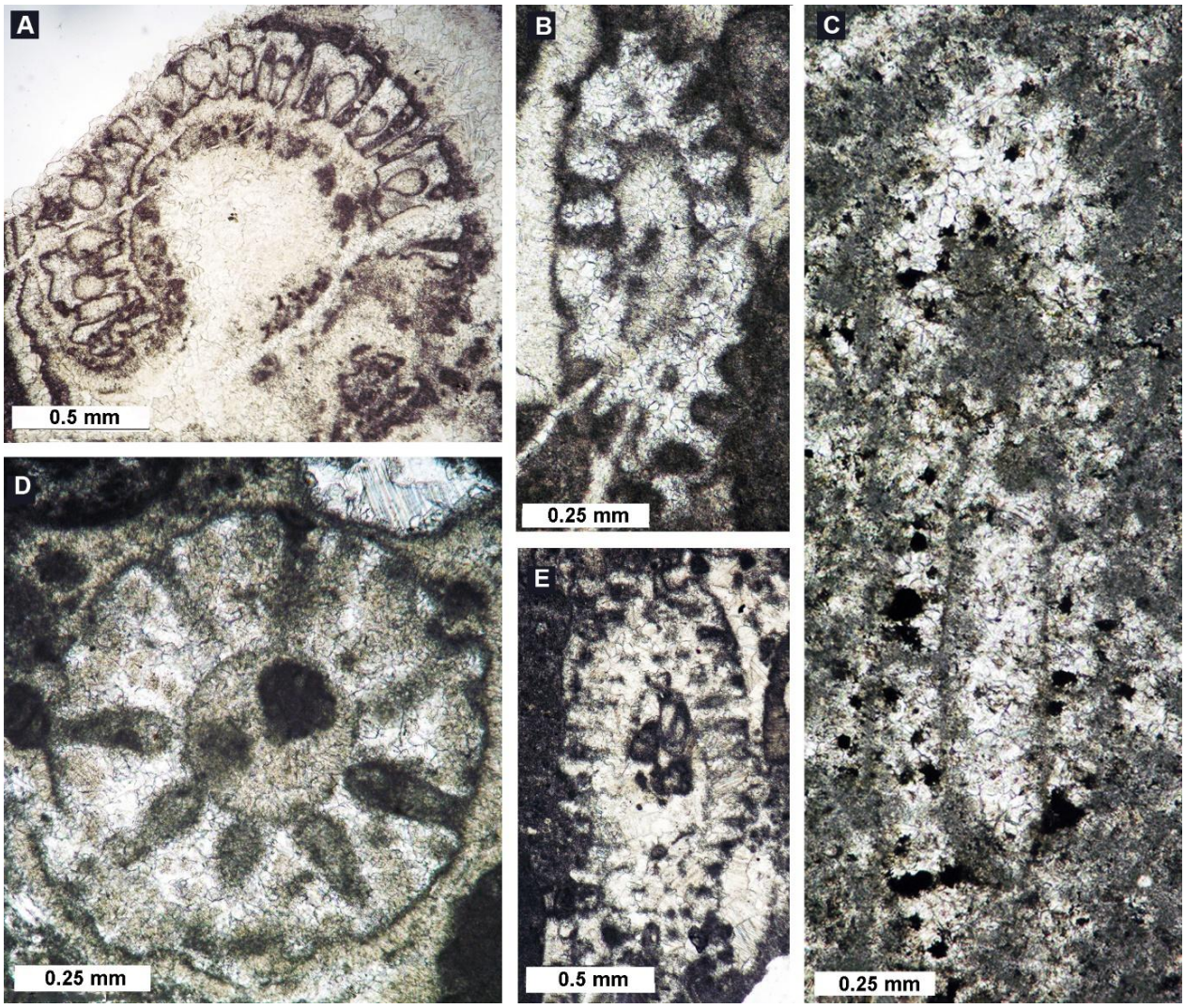


Fig. 44. (Stop no. 18). Valea Măgurii quarry. Calcareous algae from the Valea Măgurii Formation. A – *Neomeris* sp., thin section 3163. B – *Salpingoporella muehlbergii*, thin section 16486. C – *Salpingoporella* sp. from the uppermost part of the Valea Măgurii Limestone with ferruginous material, thin section 11806A. D – "*Cylindroporella*" lyrata, 3185-1. E – *Salpingoporella popgrigorei*, thin section 3180.

6. "MID-CRETACEOUS" THRUSTING AND SEALING

Stop no. 19 – Open marine Upper Triassic limestones in Sohodol area

The Sohodol river section exposes approximately 58 m of mainly Upper Triassic open-marine carbonates (Carnian). The succession consists mainly of dm-bedded grey limestones, locally containing turbiditic beds (Cordevolian-Julian1), crinoidal horizons, ammonites and siliceous layers (Tuvalian 3 and Lacian). A diverse conodont assemblage provides detailed biostratigraphic control.

The most important feature of this section is a stratigraphic gap between Julian 1 and Tuvalian 3 (Fig. 45). This is demonstrated by the presence of Tuvalian 3 conodonts species (e.g. *Norigondolella navicula* and *Paragondolella nodosa*) above those of Julian 1 age (e.g. *Gladigondolella malayensis*, *Paragondolella polygnathiformis*, and *P. tadpole*). Such a prolonged Carnian hiatus is characteristic of the Dinaridic realm, where the demise of the Wetterstein Carbonate Platform was commonly followed by a significant stratigraphic gap rather than by the thick siliciclastic successions related with the Carnian Pluvial Event (Reingraben turover) typical of the ALCAPA region (Missoni et al., 2012; Mrdak et al., 2023). Although these open-marine carbonates have been assigned to the Roșia Formation (cf. Patrulius et al., 1976), this Sohodol succession differs significantly from that at the Roșia type section (see Stop no. 16). At Roșia type section, the interval corresponding to the hiatus/gap in Sohodol is preserved within a comparatively continuous sedimentation (recording the *Carnica event*). The two successions also display different Conodont Alteration Index (CAI) values, indicating contrasting thermal histories. Together, these stratigraphic and thermal differences suggest that Sohodol may not simply represent another exposure of the Roșia Formation, but belong to a tectonically displaced unit from a different palaeogeographic position. The Carnian gap in Sohodol section suggest that this section represents a far-travelled tectonic unit with Dinaridic affinity. Importantly, it represents a tectonically displaced fragment of a more southerly palaeogeographic domain that was subsequently transported northward and incorporated onto the Jurassic nape stack of the Codru Nappe system during "Mid-Cretaceous" thrusting.

Stop no. 20 - Lower Cretaceous Urgonian-type carbonates with orbitolinids (Sohodol area)

The shallow-water carbonates from the western Sohodol Valley provides an excellent example to see the evolution of an Urgonian-type carbonate platform formed on the new relief related with the onset of the "Mid-Cretaceous" uplift. The Sohodol Valley section exposes approximately 27 m of shallow-water Urgonian limestones of late Barremian–early Aptian (Bedoulian) age (Fig. 46A-E). The succession is dominated by orbitolinid-rich carbonates deposited on a warm-water carbonate platform and records repeated fluctuations between low- and high-energy depositional environments. It consists mainly of bioclastic wackestones and packstones (MFT1), locally intercalated with orbitolinid grainstones (MFT2), a distinctive bacinellid bindstone horizon (MFT3), and coarse bioclastic grainstones to rudstones (MFT4) rich in rudist fragments and orbitolinids.

Dohan et al. (2026) identified a diverse assemblage of more than 30 species of benthic foraminifera, calcareous algae and microproblematic organisms. The most characteristic taxa include *Montseciella arabica, Palorbitolina lenticularis*, *Orbitolinopsis buccifer*, *Sabaudia minuta*, *Vercorsella scarsellai*, *Charentia cuvillieri*, *Debarina hahounerensis*, *Salpingoporella muehlbergii*, *S. pygmaea*, *Biokoviella robusta*, together with bacinellid and *Lithocodium*-like microstructures. This assemblage indicates a late Barremian–early Aptian (Bedoulian) age. The microfacies record deposition on a shallow-water carbonate platform, evolving from relatively restricted, low-energy lagoonal environments to more open-platform settings with locally increased hydrodynamic conditions.

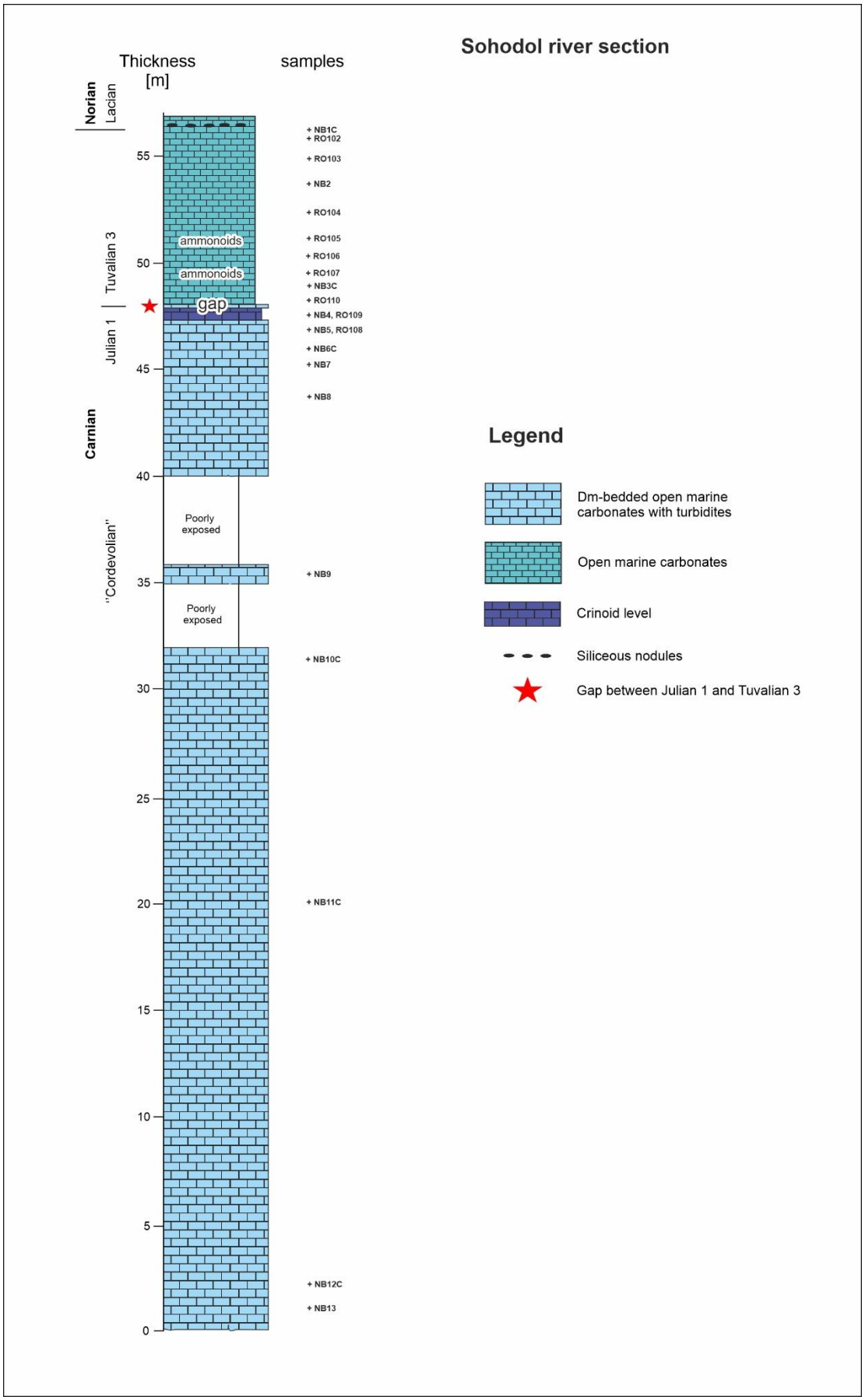


Fig. 45. (Stop no. 19). Sohodol river section profile (Carnian to Norian).

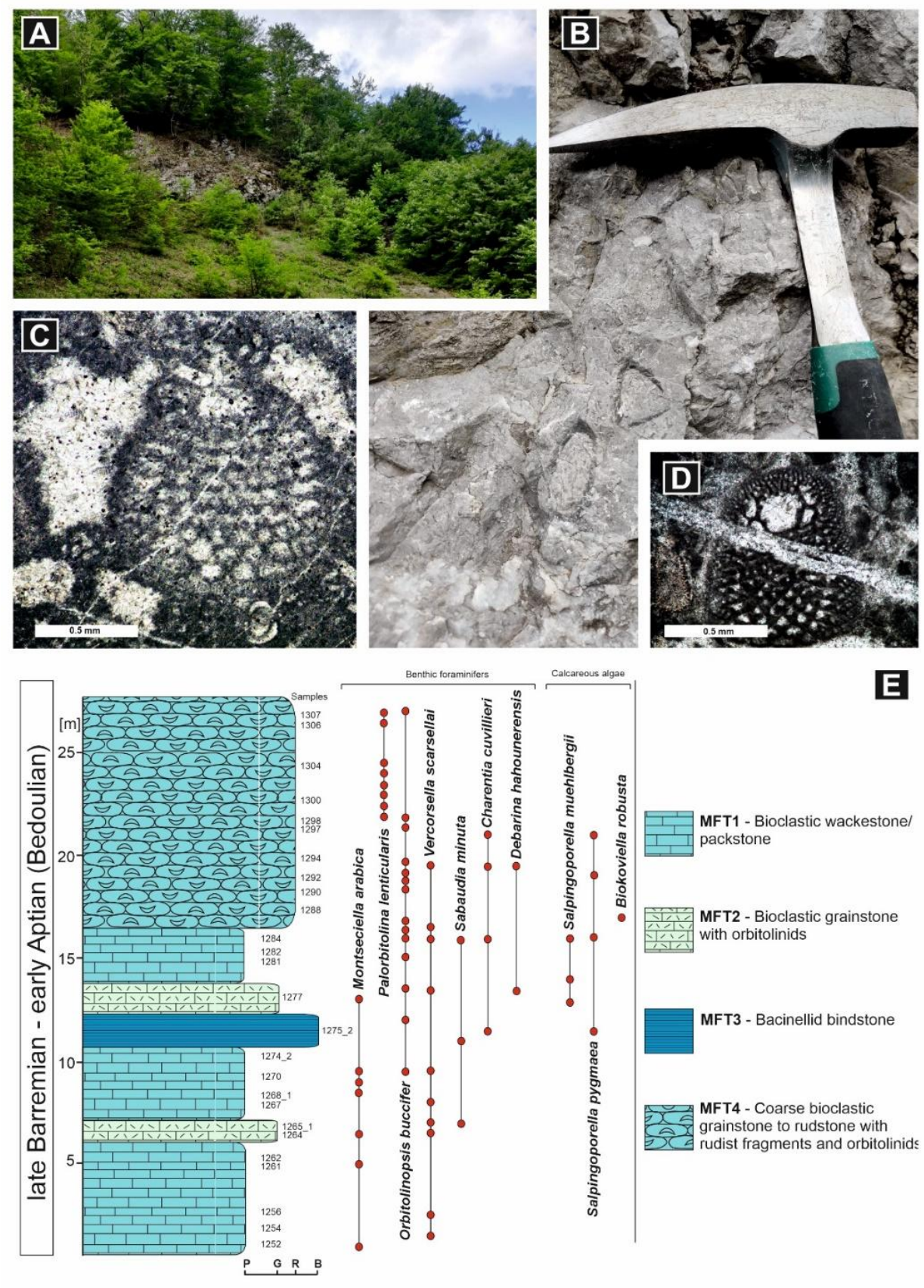


Fig. 46. (Stop no. 20). Lower Cretaceous Urgonian-type carbonates with orbitolinids (Sohodol area). A – View of the outcrop; B - Bioclastic carbonates with rudist fragments from the lower part of the section; C-D – The most common identified orbitolinid foraminifers: C – *Montseciella arabica*; D – *Palorbitolina lenticularis*; E – Profile of the late Barremian-early Aptian section.

Stop no. 21– Post tectonic cover (Gosau conglomerates)

This stop focuses on the redish, polymictic Gosau conglomerates (?Coniacian) of the Sohodol area. The conglomerates unconformably overlie the underlying Mesozoic units and record the sedimentation following the "Mid-Cretaceous" tectonic deformation, uplift, and erosion. The conglomerates contain poorly to moderately rounded clasts derived from the surrounding units. Particularly significant are clasts of Late Triassic open-marine limestones, which indicate that deeper-water Triassic successions were exposed and eroded during the development of the post-tectonic relief.

7. NEW CONCEPT OF THE NAPPE STRUCTURE OF THE NORTHERN APUSENI MOUNTAINS

In the new concept of the different tectonic units we follow strictly the Triassic-Jurassic arrangement of the facies belts, predominantly of the Triassic carbonate platform arrangement, that are the characteristic facies zones. The reconstruction of the Triassic facies belts is strictly in line with sedimentological/facies rules (Reading, 1996) and the carbonate platform facies belt arrangement (Wilson, 1975; Flügel, 2004), including carbonate sequence stratigraphy rules (Schlager, 2005), and the fundamentals of basin evolution (Einsele, 1992) in a plate tectonic setting (Frisch et al., 2011; 2022; Fossen and Teyssier, 2025). This reconstruction of facies belts during Triassic times and the subsequently deposited Early-Middle Jurassic deep-water sedimentary rocks is regardless of today´s superposition of tectonic units. However, the Jurassic hemipelagic sedimentary rocks, formed after the Triassic/Jurassic mass extinction show no facies characteristics in the sense of palaeogeographic provenance, they are similar elsewhere in the Western Tethys Realm (compare Gawlick et al., 2009 and references therein) except the shallow-water carbonates of the Adriatic Carbonate Platform and its basement (Vlahovic et al., 2005).

The time span between the late Middle Jurassic and the Late Cretaceous is characterized by two mountain building processes. The older Middle-Late Jurassic one is related to the obduction of ophiolites (Neo-Tethys derived ophiolites) forming a thin-skinned orogen in lower plate position as known from the Eastern Alps (Gawlick et al., 1999; Frisch and Gawlick, 2003), the Albanides (Gawlick et al., 2008), the Dinarides (Gawlick et al., 2017), or the Hellenides (Kostaki et al., 2024).

In the Tisza unit (Apuseni Mts.) the occurrence of (East) Vardar ophiolites (Gallhofer et al., 2017) improves this view together with the detection of a Middle to early Late Jurassic sedimentary mélange, which corresponds to the Jurassic mélanges known in the central Northern Calcareous Alps (Gawlick, 1996; Janauschek et al., 2003; Missoni and Gawlick, 2011a, b) or in The Rudabánya Mts. in Hungary (Gawlick and Missoni, 2019), the Dinarides (Gawlick et al., 2017, Gawlick and Missoni, 2019), the Albanides (Gawlick et al. 2008, Gawlick and Missoni, 2019), or the Hellenides (Kostaki et al., 2024). Jurassic carbonate platforms formed on top of the Apuseni Mts. obducted island-arc volcanics (Săsăran, 2006; Pleș et al., 2024) and other newly formed structural highs, i.e. nappe fronts resemble the situation as known in Albania (Schlagintweit et al., 2008) or the Northern Calcareous Alps (Gawlick et al. 2009, and references therein). Furthermore, the formation of latest Jurassic bauxites during the, or on top of the formation of the Late Jurassic shallow-water carbonate platforms is similar to age equivalent bauxites in the Northern Calcareous Alps or in parts of the Dinarides (Steiner et al., 2021, and references therein). During the Early Cretaceous the remaining foreland basins get filled by predominantly shallow-water limestones, and from the Aptian onwards new relief was formed in the frame of the "Mid-Cretaceous" mountain building process. This mountain building process was finally sealed by Gosau conglomerates.

Therefore, the tectonostratigraphic evolution of the Codru Nappe system records the progressive transformation of the passive northern Neotethyan margin into a Jurassic nappe stack, followed by a second phase of deformation during the "Mid-Cretaceous". The palaeogeography (Figs. 47 and 48) indicates that the original Late Triassic carbonate shelf was organized from proximal lagoonal environments in the northwest to progressively deeper shelf and basin settings toward the southeast.

The most proximal domain is represented by the Tărcăița Nappe (+ parts of Finiș B and Dieva) (Fig. 48), which corresponds to the parautochthonous Tisza basement. During the Late Triassic, this area was characterized by Keuper facies followed by Kössen lagoonal deposits, whereas Middle Carnian siliciclastic

deposits are absent. Instead, siliciclastic sedimentation occurred during the middle Norian, and continental siliciclastic deposits accumulated during the Early Jurassic in response to rifting and subaerial exposure.

Farther basinward, the Colești Nappe (parts of Diva, more distal facies) occupied a more distal position on the same parautochthonous basement. On top of this nappe the Colești mélange developed. The material incorporated into this mélange was derived predominantly from the overlying allochthonous Câmp Nappe System. The large stratigraphic and palaeogeographic differences between the Tărcăița and Colești successions indicate that a considerable amount of crust was shortened during both Jurassic and Mid-Cretaceous orogenies, explaining the missing original distance between these two depositional domains.

The Câmp Nappe System (+/- Vașcău and parts of Moma) represents the first truly allochthonous unit. Its sedimentary succession, extending from the Anisian to the Norian, records a more distal shelf environment than that preserved in the parautochthonous nappes. During Jurassic convergence, this nappe was emplaced onto the Colești Nappe, consequently supplying abundant blocks and debris to the developing Colești mélange.

The most distal parts of the original Triassic shelf are preserved within the Roșia/Strâmtura nappe. These units were transported over long distances during Jurassic tectonic shortening and represent the outermost portions of the former passive continental margin. Their original palaeogeographic position is supported by their sedimentary evolution and by the preservation of Late Jurassic carbonate-platform deposits. Jurassic deformation culminated during the Callovian to Late Oxfordian–Kimmeridgian with progressive ophiolite obduction and burial of Câmp and Colești nappes (Fig. 47).

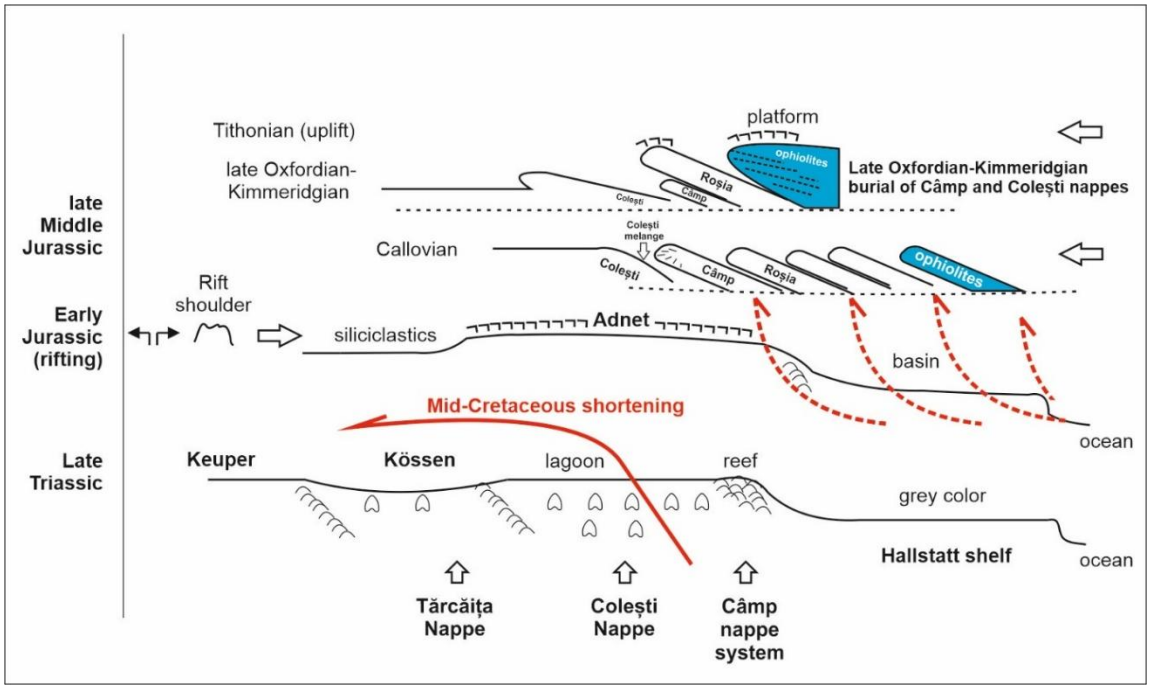


Fig. 47. Schematic tectono-sedimentary evolution of the Codru Nappe System from the Late Triassic to the Late Jurassic. Early Jurassic rifting (opening of the Central Atlantic and its continuation to the east, the Alpine Atlantic Ocean) resulted in development of rift shoulders, siliciclastic sedimentation, and the Adnet facies along the former Triaassic passive margin. This newly formed ocean in the north caused the Callovian to ?late Oxfordian–Kimmeridgian ophiolite obduction in the southern Neo-Tehys Ocean that cause the formation of nape stacks and initiated progressive burial and stacking of the Câmp, and Colești nappes, accompanied by mélange formation. Red dashed lines indicate major thrust faults related to Jurassic nappe stacking, and the red arrow marks the direction of "Mid-Cretaceous" shortening.

A second major tectonic event occurred during the Mid-Cretaceous, when renewed shortening affected the previously assembled Jurassic nappe stack. This event emplaced the Sohodol Unit, (probably representing far travelled Dinaridic nappes, above the Jurassic units). The onset of "Mid-Cretaceous"

deformation (uplift) is documented by the development of the orbitolinid-bearing limestones particularly in the Roșia area.

This reconstruction clears some of the inconsistencies present in earlier tectonic models by recognizing two distinct orogenic phases: (1) Jurassic nappe stacking, which assembled the Tărcăița, Colești, Câmp, and Roșia–Strâmtura nappes during Neo-Tethyan ophiolite obduction, and (2) "Mid-Cretaceous" shortening, which superimposed the Dinaridic (Sohodol) units onto the pre-existing Jurassic nappe pile. The resulting architecture closely resembles that of the Northern Calcareous Alps.

Concerning the Bihor Unit, Late Triassic sedimentary successions are not preserved (except the early Carnian of Mișid Valley considered by Dragastan, 1982). While the Early Jurassic consists of continental siliciclastic deposits deriving from the newly formed rift shoulder of the Alpine Atlantic rift system it can be concluded, that the Late Triassic deposits are completely eroded in Early Jurassic times. By the shedding of enormous amounts of siliciclastic material into the depositional realm of the later Bihor unit it can be concluded that the Late Triassic predominantly was consisting of siliciclastic sedimentary rocks, i.e. siliciclastics of the Lunz and Keuper facies. The Bihor unit was located south of that rift shoulder forming a continental sab-basin, which received the material from the north.

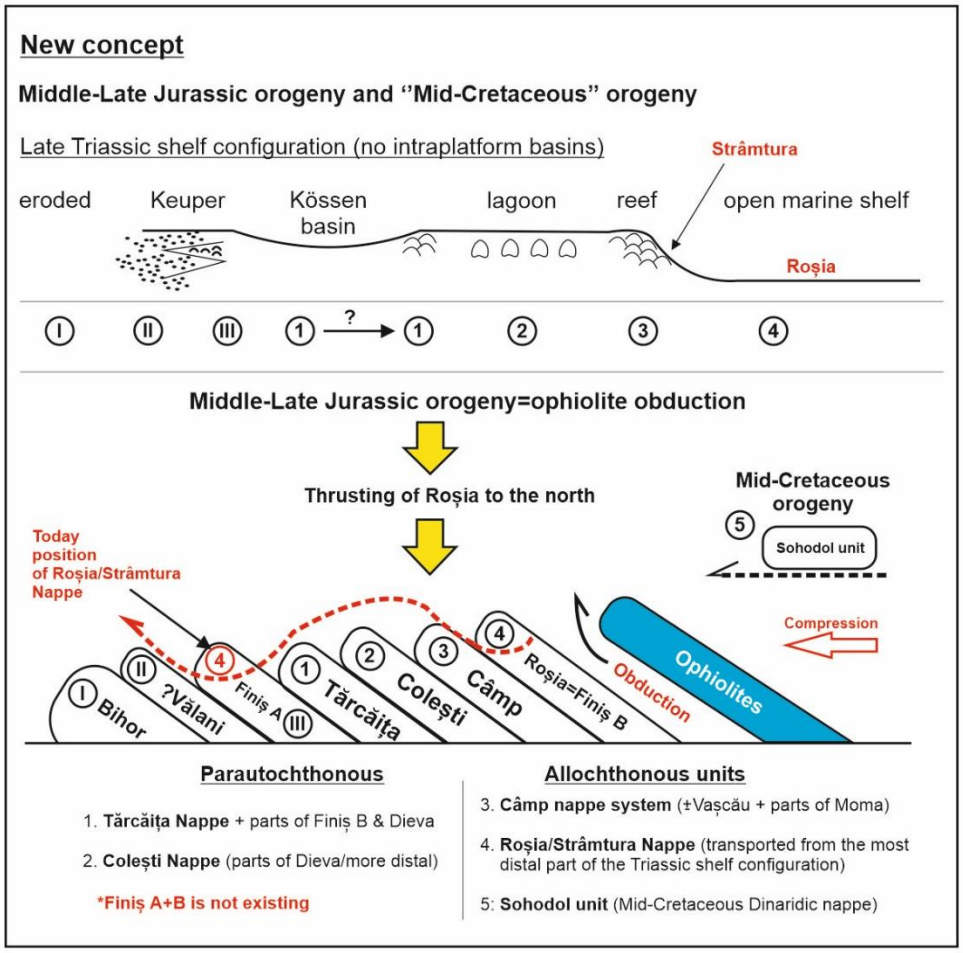


Fig. 48. New concept based on the two orogenic events. During the Middle Jurassic orogeny, the main nappe architecture of the codru Nappes was established, comprising (1) the Tărcăița Nappe, (2) the Colești Nappe, (3) the Câmp Nappe System, (4) the Roșia/Strâmtura Nappe. The Roșia/Strâmtura Nappe interpreted as having been transported from the distal part of the Triassic carbonate shelf during the Middle-Late Jurassic ophiolite obduction. During the "Mid-Cretaceous orogeny", the Sohodol unit (representing a Dinaridic unit) was emplaced onto this pre-existing Jurassic nappe stack.

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REFERENCES

Árkai, P., Bérczi-Makk, A., Balogh, K., 2000. Alpine low-T prograde metamorphism in the post-Variscan basement of the Great Plain, Tisza Unit (Pannonian Basin, Hungary). Acta Geologica Hungarica, 43(1), 43–63.

Aubouin, J., Blanchet, R., Cadet, J.-P., Celet, P., Charvet, J., Chorowicz, J., Cousin, M., Rampnoux, J.-P., 1970. Essai sur la géologie des Dinarides. Bulletin de la Société Géologique de France, 7e série, 12, 1060–1095.

Avram, E., Bordea, S., Cociuba, I., Huza, R., Preda, I., 2006. Ammonites assemblages of the Ecleja Formation (Northern Apuseni Mountains, Romania). Romanian Journal of Stratigraphy, 79 (2001), 13–20.

Bădescu, D., 1997. Tectono-thermal regimes and lithosphere behaviour in the External Dacides in the Upper Triassic and Jurassic Tethyan opening (Romanian Carpathians). Tectonophysics, 282(1–4), 167–188.

Balla, Z., 1984. The Carpathian loop and the Pannonian basin: a kinematic analysis. Geophysical Transactions, 30(4), 313–353.

Balintoni, I., 1994. Structure of the Apuseni Mountains. ALCAPA II Field Guidebook, Romanian Journal of Tectonics and Regional Geology, 75, Supplement no. 2, 51–58.

Balintoni, I., 1997. Geotectonica terenurilor metamorfice din România. Editura Carpatica, Cluj-Napoca, 176 pp.

Balintoni, I., Balica, C., Ducea, M. N., Zaharia, L., Chen, F., Cliveti, M., Hann, H.-P., Li, L.-Q., Ghergari, L., 2010. Late Cambrian–Ordovician northeastern Gondwanan terranes in the basement of the Apuseni Mountains, Romania. Journal of the Geological Society, 167(6), 1131–1145.

Balintoni, I., Balica, C., Ducea, M. N., Hann, H.-P., 2014. Peri-Gondwanan terranes in the Romanian Carpathians: A review of their spatial distribution, origin, provenance, and evolution. Geoscience Frontiers, 5(3), 395–411.

Balintoni, I., Puște, A., 2002. New lithostratigraphic and structural aspects in the southern part of the Bihor Massif (Apuseni Mountains). Studia Universitatis Babeș-Bolyai, Geologia, 47(2), 13–18.

Baltreș, A., 2000. Rhaetian carbonate cycles in the Northern Apuseni Mountains (Vașcău Plateau). Revue Roumaine de Géologie, 42, 125–130.

Bleahu, M., 1965. Harta geologică a R.P.R., scara 1:100.000, foaia Moneasa. Institutul Geologic, Bucharest.

Bleahu, M., 1976. Structural position of the Apuseni Mountains in the Alpine system. Revue Roumaine de Géologie, Géophysique et Géographie, Série de Géologie, 20, 7–19.

Bleahu, M., 1976. Structure géologique des Apuseni septentrionaux. Revue Roumaine de Géologie, Géophysique et Géographie, Série de Géologie, 20, 27–39.

Bleahu, M., Dimitrescu, R., 1957. Stratigrafia și tectonica Munților Apuseni (cu privire specială asupra cristalinului și Mezozoicului). Anal. Rom.-Sov. (Geol. Geogr.), Seria a 2-a, 2, 29–42.

Bleahu, M., Haas, J., Kovács, S., Péró, C., Mantea, G., Bordea, S., Panin, S., Bérczi-Makk, A., Ștefănescu, M., Konrád, G., Nagy, E., Rálisch-Felgenhauer, E., Sikić, K., Török, A., 1994. Triassic facies types, evolution and paleogeographic relations of the Tisza Megaunit. Acta Geologica Hungarica, 37, 187–234.

Bleahu, M., Istocescu, D., Diaconu, M., 1971. Formations prénéogènes de la partie occidentale des Monts Apuseni et leur position structurale. Dări de Seamă, Institutul de Geologie, 57, 5–12.

Bleahu, M., Lupu, M., Patrulius, D., Bordea, S., Ștefan, A., Panin, Șt., 1981. The structure of the Apuseni Mountains. Carpathian-Balkan Geological Association 12th Congress, Guide to Excursion B3, Guidebook Series 23, 106 pp., Bucharest.

Bleahu, M., Mantea, G., Bordea, S., Panin, Șt., Ștefănescu, M., Sikić, K., Haas, J., Kovács, S., Péró, C., Bérczi-Makk, A., Konrád, G., Nagy, E., Rálisch-Felgenhauer, E., Török, Á., 1994. Triassic facies types, evolution and paleogeographic relations of the Tisza Megaunit. Acta Geologica Hungarica, 37, 187–234.

Bleahu, M., Patrulius, D., Tomescu, C., Bordea, J., Panin, Șt., Rădan, S., 1970. Nouvelles données sur la stratigraphie des dépôts triasiques des Monts Apuseni. Dări de Seamă, Institutul Geologic, 56/4, 29–41.

Bleahu, M., Panin, Șt., Ștefănescu, M., Stan, N., Popescu, A., Tomescu, C., Ștefan, A., 1984. Geological map of R. S. Romania, sheet 55a, Dumbrăvița, scale 1:50,000. Institutul de Geologie și Geofizică, Bucharest.

Bleahu, M., Tomescu, C., Panin, Șt., 1972. Contribution à la biostratigraphie des dépôts triasiques du Plateau de Vașcău (Monts Apuseni). Dări de Seamă, Institutul Geologic, 58/3, 5–25.

Bordea, S., Bleahu, M., Bordea, J., 1975. Date noi stratigrafice şi structurale asupra Bihorului de vest. Unitatea de Următ şi Unitatea de Vetre. Dări de Seamă ale Ședințelor, Institutul de Geologie și Geofizică, 61(5), 61–83.

Bordea, S., Bleahu, M., Bordea, J., 1975. Nouvelles données stratigraphiques et structurales sur le Bihor de l'Ouest. L'Unité d'Următ et l'Unité de Vetre. Dări de Seamă ale Institutului de Geologie și Geofizică, 61(5), 61–83.

Bordea, S., Bordea, J., 1973. Noi date stratigrafice şi structurale în vestul Munţilor Bihor. Dări de Seamă ale Institutului de Geologie și Geofizică, 59(5), 5–12.

Bordea, S., Bordea, J., 1987. Note préliminaire sur la présence des Orbitolinidés primitifs du Calcaire d'Albioara (au sud de Pădurea Craiului, Monts Apuseni). Dări de Seamă ale Institutului de Geologie și Geofizică, 72–73/4, 45–53.

Bordea, S., Mantea, G., Costea, C., 1986. Geological map of Romania, 1:50,000, sheet 40b, Zece Hotare. Geological Institute of Romania, Bucharest.

Bucur, I. I., 2000. Lower Cretaceous dasyclad algae from the Pădurea Craiului massif (Northern Apuseni Mountains, Romania). Acta Palaeontologica Romaniae, 2 (1999), 53–72.

Bucur, I. I., 2001. Upper Triassic deposits of Vașcău Plateau. In: Bucur, I. I., Filipescu, S., Săsăran, E. (eds), Algae and Carbonate Platforms in the Western Part of Romania, 4th Regional Meeting of IFAA, Cluj-Napoca, August 29–September 5, 2001, Field Trip Guidebook, pp. 18–23.

Bucur, I. I., Bruchental, C., Cociuba, I., Granier, B., Hebrișțean, A.-M., Lazăr, D. F., Marian, A. V., Săsăran, E., 2013. Representatives of the genus Triploporella (Dasycladales, calcareous algae) in the Lower Cretaceous limestones of Romania. Facies, 59, 193–206.

Bucur, I. I., Cociuba, I., 1998. La plate-forme carbonatée du Crétacé inférieur des Monts Pădurea Craiului (Monts Apuseni, Roumanie). Biostratigraphie et configuration. Studia Universitatis Babeș-Bolyai, Geologia, 43(2), 89–100.

Bucur, I. I., Cociuba, I., 2001. Lower Cretaceous algae of Pădurea Craiului. In: Bucur, I. I., Filipescu, S., Săsăran, E. (eds), Algae and Carbonate Platforms in the Western Part of Romania. Field Trip Guidebook, pp. 119–127. Cluj University Press, Cluj-Napoca.

Bucur, I. I., Cociuba, I., 2001. Upper Jurassic–Lower Cretaceous deposits from Pădurea Craiului. In: Bucur, I. I., Filipescu, S., Săsăran, E. (eds), Algae and Carbonate Platforms in the Western Part of Romania. 4th Regional Meeting of IFAA, Field Trip Guidebook, pp. 40–49. Cluj University Press, Cluj-Napoca.

Bucur, I. I., Cociuba, I., Cociuba, M., 1993. Microfacies and microfossils in the Upper Jurassic–Lower Cretaceous limestones in the southern part of the Pădurea Craiului Mountains. Romanian Journal of Stratigraphy, 75, 33–40.

Bucur, I. I., Cociuba, I., Császár, G., Koch, R., Nowak, M., Săsăran, E., 2010. Development of Lower Cretaceous deposits from Bihor–Pădurea Craiului unit (Apuseni Mountains, Romania): Comparisons with Villány region in Hungary. Geologica Balcanica, 39(1–2), 59–60.

Bucur, I. I., Granier, B., Săsăran, E., 2008. Upper Aptian calcareous algae from Pădurea Craiului (Northern Apuseni Mountains, Romania). Geologia Croatica, 61(2–3), 297–309.

Bucur, I. I., Granier, B., Săsăran, E., 2010. Zittelina massei n. sp., a new dasycladacean alga from the Lower Cretaceous strata of Pădurea Craiului (Apuseni Mountains, Romania). Facies, 56, 445–457.

Bucur, I. I., Săsăran, E., Balica, C., Beleș, D., Bruchental, C., Chendeș, C., Chendeș, O., Hosu, A., Lazăr, D. F., Lăpădat, A., Marian, A. V., Mircescu, C., Turi, V., Ungureanu, R., 2010. Mesozoic Carbonate Deposits from Some Areas of the Romanian Carpathians—Case Studies. Presa Universitară Clujeană, Cluj-Napoca, 203 pp.

Chablais, J., Martini, R., Samankassou, E., Onoue, T., Sano, H., 2010a. Microfacies and depositional setting of the Upper Triassic mid-oceanic atoll-type carbonates of the Sambosan Accretionary Complex (southern Kyushu, Japan). Facies, 56, 249–278.

Chablais, J., Onoue, T., Martini, R., 2010b. Upper Triassic reef-limestone blocks of southwestern Japan: New data from a Panthalassan seamount. Palaeogeography, Palaeoclimatology, Palaeoecology, 293, 206–222.

Cociuba, I., 1999. Studiul stratigrafic al depozitelor mezozoice din sud-vestul Pădurii Craiului. Unpublished PhD Thesis, 235 pp., 28 figs., 56 pls., Cluj-Napoca.

Cociuba, I., 2000. Upper Jurassic–Lower Cretaceous deposits in the south-western part of Pădurea Craiului. Formal lithostratigraphic units. Studia Universitatis Babeş-Bolyai, Geologia, 45(2), 33–61.

Csontos, L., Vörös, A., 2004. Mesozoic plate tectonic reconstruction of the Carpathian region. Palaeogeography, Palaeoclimatology, Palaeoecology, 210, 1–56.

Dercourt, J., Ricou, L. E., Vrielynck, B. (eds), 1993. Atlas Tethys palaeoenvironmental maps and explanatory notes. Gauthier-Villars, Paris, 307 pp., maps 1–14.

Djerić, N., Jach, R., Goričan, Š., Reháková, D., Uchman, A., Gawlick, H.-J., Schlögl, J., Stojadinovic, U., 2026. Jurassic–Early Cretaceous depositional history of the Alpine Atlantic southern passive margin: Inferences from the Serbian Carpathians. Global and Planetary Change, 259, 105372.

Dohan, D., Hegedüs, A., Pleș, G., Bucur, I. I., Mircescu, C. V., Ciuclea, A., 2025. Lower Cretaceous micropaleontological assemblages from the Urgonian-type carbonates of the Vălani Unit (northern Apuseni Mountains, Romania). Acta Palaeontologica Romaniae, 21(2), 53–71.

Dragastan, O., Coman, M., Știucă, E., 1988. Bauxite-bearing formations and facies in the Pădurea Craiului and Bihor Mountains (Northern Apuseni). Revue Roumaine de Géologie, Géophysique et Géographie, Série de Géologie, 32, 67–81.

Dragastan, O., Diaconu, M., Popa, E., Damian, R., 1982. Biostratigraphy of the Triassic formations in the east of the Pădurea Craiului Mountains. Dări de Seamă ale Institutului de Geologie și Geofizică, 67(4) (1979–1980), 29–61.

Dragastan, O., Istocescu, D., Diaconu, M., 1966. Etude du niveau a charophytes d'âge Crétacé inférieur des Monts Pădurea Craiului. Revue de Micropaléontologie, 9(1), 23–28.

Dragastan, O., Marinescu, M., Gheorghe, D., Ținteanu, C., 1989. Upper bauxite sensu D. Patrulius and some new algae of Pădurea Craiului Mountains. Revue Roumaine de Géologie, Géophysique et Géographie, Série de Géologie, 33, 55–67.

Dragastan, O., Purecel, R., Brustur, T., 1986. The Upper Jurassic and Lower Cretaceous formations from the Bihor Mts. – Central-southern sector/Northern Apuseni. Analele Universității București, Geologie, 35, 57–70.

Ebner, F., Vozárová, A., Kovács, S., Kräutner, H. G., Krstić, B., Jamičić, D., Balen, D., Belak, M., Trajanova, M., 2008. Devonian–Carboniferous pre-flysch and flysch environments in the Circum-Pannonian Region. Geologica Carpathica, 59, 159–195.

Ebner, F., Vozárová, A., Kovács, S., Kräutner, H. G., Krstić, B., Jamičić, D., Balen, D., Belak, M., Trajanova, M., 2010. Devonian–Carboniferous pre-flysch and flysch environments in the Circum-Pannonian Region. In: Vozár, J., Ebner, F., Vozárová, A., Haas, J., Kovács, S., Sudar, M., Bielik, M., Péró, C. (eds), Variscan and Alpine terranes of the Circum-Pannonian Region. Slovak Academy of Sciences, Geological Institute, pp. 13–49.

Ebner, F., Vozárová, A., Kovács, S., 2007. Die variszische Orogenese im Circum-Pannonischen Raum – reflektiert an Devon-Karbon-Sedimenten. Jahrbuch der Geologischen Bundesanstalt, 147, 315–329.

Einsele, G., 1992. Sedimentary Basins: Evolution, Facies, and Sediment Budget. Springer-Verlag, Berlin–Heidelberg, 628 pp.

Fischer, A. G., 1964. The Lofer cyclothems of the Alpine Triassic. In: Merriam, D. F. (ed.), Symposium on Cyclic Sedimentation. Kansas Geological Survey Bulletin, 169, 107–149.

Flügel, E., 1978. Mikrofazielle Untersuchungsmethoden von Kalken. Springer-Verlag, Berlin, 454 pp.

Flügel, E., 1982. Microfacies Analysis of Limestones. Springer-Verlag, Berlin, 633 pp.

Flügel, E., 2004. Microfacies of Carbonate Rocks: Analysis, Interpretation and Application. Springer, Berlin–Heidelberg, 976 pp.

Fossen, H., Teyssier, C., 2025. Plate Tectonics. Cambridge University Press, 450 pp.

Fourcade, E., Azéma, J., Bassoullet, J.-P., Cecca, F., Dercourt, J., Enay, R., Guiraud, R., 1995. Paleogeography and Paleoenvironment of the Tethyan Realm During the Jurassic Breakup of Pangea. In: Nairn, A. E. M., Ricou, L.-E., Vrielynck, B., Dercourt, J. (eds), The Tethys Ocean, pp. 191–214. Springer, Boston.

Freytet, J. E., 1973. Petrography and paleo-environment of continental carbonate deposits with particular reference to the Upper Cretaceous and Lower Eocene of Languedoc (Southern France). Sedimentary Geology, 10, 25–60.

Freytet, P., 1984. Les sédiments lacustres carbonatés et leurs transformations par émersion et pédogenèse. Importance de leur identification pour les reconstitutions paléogéographiques. Bulletin des Centres de Recherche Exploration-Production Elf-Aquitaine, 8(1), 223–247.

Frisch, W., Gawlick, H.-J., 2003. The nappe structure of the central Northern Calcareous Alps and its disintegration during Miocene tectonic extrusion—a contribution to understanding the orogenic evolution of the Eastern Alps. International Journal of Earth Sciences, 92, 712–727.

Frisch, W., Meschede, M., 2005. Plattentektonik: Kontinentverschiebung und Gebirgsbildung. Wissenschaftliche Buchgesellschaft, Darmstadt, 196 pp.

Frisch, W., Meschede, M., Blakey, R. C., 2011. Plate Tectonics: Continental Drift and Mountain Building. Springer, Berlin–Heidelberg, 212 pp.

Frisch, W., Meschede, M., Blakey, R. C., 2022. Plate Tectonics: Continental Drift and Mountain Building. 2nd ed. Springer, 241 pp.

Gallhofer, D., von Quadt, A., Schmid, S. M., Guillong, M., Peytcheva, I., Seghedi, I., 2017. Magmatic and tectonic history of Jurassic ophiolites and associated granitoids from the South Apuseni Mountains (Romania). Swiss Journal of Geosciences, 110(2), 699–719.

Gawlick, H.-J., 1996. Die früh-oberjurassischen Brekzien der Strubbergschichten im Lammertal – Analyse und tektonische Bedeutung (Nördliche Kalkalpen, Österreich). Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten in Österreich, 39–40, 119–186.

Gawlick, H.-J., Djerić, N., Missoni, S., Bragin, N. Y., Lein, R., Sudar, M., Jovanović, D., 2017. Age and microfacies of oceanic Upper Triassic radiolarite components from the Middle Jurassic ophiolitic mélange in the Zlatibor Mountains (Inner Dinarides, Serbia) and their provenance. Geologica Carpathica, 68(4), 350–365.

Gawlick, H.-J., Frisch, W., Hoxha, L., Dumitrica, P., Krystyn, L., Lein, R., Missoni, S., Schlagintweit, F., 2008. Mirdita Zone ophiolites and associated sediments in Albania reveal Neotethys Ocean origin. International Journal of Earth Sciences, 97, 865–881.

Gawlick, H.-J., Frisch, W., Vecsei, A., Steiger, T., Böhm, F., 1999. The change from rifting to thrusting in the Northern Calcareous Alps as recorded in Jurassic sediments. Geologische Rundschau, 87, 644–657.

Gawlick, H.-J., Missoni, S., 2019. Middle-Late Jurassic sedimentary mélange formation related to ophiolite obduction in the Alpine-Carpathian-Dinaridic Mountain Range. Gondwana Research, 74, 144–172.

Gawlick, H.-J., Missoni, S., Schlagintweit, F., Suzuki, H., 2009. Jurassic tectonostratigraphy of the Austroalpine Domain. Journal of Alpine Geology, 50, 1–152.

Gawlick, H.-J., Sudar, M., Jovanović, D., Lein, R., Missoni, S., Bucur, I. I., 2023. From shallow-water carbonate ramp to hemipelagic deep-marine carbonate deposition: Part 1. General characteristics, microfacies and depositional history of the Middle to Late Anisian Bulog sedimentary succession in the Inner Dinarides (SW Serbia). Geološki anali Balkanskoga poluostrva, 84(2), 1–39.

Gawlick, H.-J., Sudar, M., Missoni, S., Aubrecht, R., Schlagintweit, F., Jovanović, D., Mikuš, T., 2020. Formation of a Late Jurassic carbonate platform on top of the obducted Dinaridic ophiolites deduced from the analysis of carbonate pebbles and ophiolitic detritus in southwestern Serbia. International Journal of Earth Sciences, 109, 2023–2048.

Gawlick, H.-J., Sudar, M., Missoni, S., Suzuki, H., Lein, R., Jovanović, D., 2017. Triassic–Jurassic geodynamic history of the Dinaridic Ophiolite Belt (Inner Dinarides, SW Serbia). Journal of Alpine Geology, 55, 1–167.

Gawlick, H.-J., Sudar, M., Mrdak, M., Đerić, N., Jovanović, D., Đaković, M., 2026. Triassic–Jurassic intraplatform basins in the Dinarides: Myth or reality? The Neo-Tethys geodynamic history along a cross-section through the Inner to Outer Dinarides (Serbia–Montenegro). Geološki anali Balkanskoga poluostrva, 87, 93–177.

Haas, J., Kovács, S., Gawlick, H.-J., Grădinaru, E., Karamata, S., Sudar, M., Péró, C., Mello, J., Polák, M., Ogorelec, B., Buser, S., 2011. Jurassic Evolution of the Tectonostratigraphic Units of the Circum-Pannonian Region. Jahrbuch der Geologischen Bundesanstalt, 151(3–4), 281–354.

Haas, J., Kovács, S., Krystyn, L., Lein, R., 1995. Significance of Late Permian–Triassic facies zones in terrane reconstructions in the Alpine–North Pannonian domain. Tectonophysics, 242, 19–40.

Haas, J., Péró, C., 2004. Mesozoic evolution of the Tisza Mega-unit. International Journal of Earth Sciences, 93, 297–313.

Handy, M. R., Schmid, S. M., Paffrath, M., Friederich, W., AlpArray Working Group, 2021. Orogenic lithosphere and slabs in the greater Alpine area – interpretations based on teleseismic P-wave tomography. Solid Earth, 12, 2633–2669.

Ianovici, V., Borcoş, M., Bleahu, M., Patrulius, D., Lupu, M., Dimitrescu, R., Savu, H., 1976. Geologia Munţilor Apuseni. Editura Academiei RSR, Bucharest, 631 pp.

Istocescu, D., 1970. Stratigrafia și fauna depozitelor cretacice din zona Vîrciorog–Copăcel (Nord-vestul Pădurii Craiului, Munții Apuseni). Dări de Seamă ale Institutului Geologic, 54(4), 161–164.

Janák, M., Froitzheim, N., Vrabec, M., Krogh Ravna, E. J., De Hoog, J. C. M., 2006. Ultrahigh-pressure metamorphism and exhumation of garnet peridotite in Pohorje, Eastern Alps. Journal of Metamorphic Geology, 24, 19–31.

Kostaki, G., Gawlick, H.-J., Missoni, S., Kilias, A., Katrivanos, E., 2024. New stratigraphic and palaeontological data from carbonates related to the Vourinos–Pindos ophiolite emplacement: implications for the provenance of the ophiolites (Hellenides). Journal of the Geological Society, 181(2).

Kovács, S., Sudar, M., Grădinaru, E., Gawlick, H.-J., Karamata, S., Haas, J., Péro, C., Gaetani, M., Mello, J., Polák, M., Aljinović, D., Ogorelec, B., Kolar-Jurkovšek, T., Jurkovšek, B., Buser, S., 2011. Triassic Evolution of the Tectonostratigraphic Units of the Circum-Pannonian Region. Jahrbuch der Geologischen Bundesanstalt, 151(3–4), 199–280.

Kovács, S., Sudar, M., Karamata, S., Haas, J., Péro, C., Grădinaru, E., Gawlick, H.-J., Gaetani, M., Mello, J., Polák, M., Aljinović, D., Ogorelec, B., Kolar-Jurkovšek, T., Jurkovšek, B., Buser, S., 2014. Triassic environments in the Circum-Pannonian Region related to the initial Neotethyan rifting stage. In: Vozár, J., Ebner, F., Vozárová, A., Haas, J., Kovács, S., Sudar, M., Bielik, M., Péro, C. (eds), Variscan and Alpine terranes of the Circum-Pannonian Region, 2nd edn. Slovak Academy of Sciences, Geological Institute and Comenius University, Faculty of Natural Sciences, Bratislava, pp. 89–158.

Kozur, H., 1991. The evolution of the Meliata-Hallstatt ocean and its significance for the early evolution of the Eastern Alps and Western Carpathians. Palaeogeography, Palaeoclimatology, Palaeoecology, 87, 109–135.

Krystyn, L., 2008. The ammonoid zones of the Hallstatt Limestone in the Salzkammergut (Northern Calcareous Alps). In: Krystyn, L., Mandl, G. (eds), The Hallstatt Triassic of the Salzkammergut. Berichte der Geologischen Bundesanstalt, 66, 1–11.

Kurz, W., Fritz, H., Wölfler, A., 2024. Tectonic Evolution of the Eastern Alps. In: Geodynamics of the Alps 1: Present-Structure and Regional Alpine Studies from Extension to Collision, pp. 211–292. Wiley.

Lazăr, I., Săsăran, E., Grădinaru, M., Bucur, I. I., 2015. Lower and Middle Jurassic deposits from Vadu Crișului (Apuseni Mountains). 10th Romanian Symposium on Paleontology, Cluj-Napoca, 16–17 October 2015, Field Trip Guidebook, pp. 23–36. Presa Universitară Clujeană, Cluj-Napoca.

Lein, R., Krystyn, L., Richoz, S., Lieberman, H., 2012. Middle Triassic platform/basin transition along the Alpine passive continental margin facing the Tethys Ocean – The Gamsstein: the rise and fall of a Wetterstein Limestone Platform (Styria, Austria). Journal of Alpine Geology, 54, 471–498.

Linzer, H.-G., Decker, K., Peresson, H., Dell'Mour, R., Frisch, W., 2002. Balancing lateral orogenic float of the Eastern Alps. Tectonophysics, 354(3–4), 211–237.

Lupu, M., 1984. Problems of the European continental margin in the Transylvanian-Pannonian area. Annuaire de l'Institut de Géologie et de Géophysique Bucharest, XLV, 323–332.

Marcoux, J., Baud, A., 1995. Late Permian to Late Triassic, Tethyan Paleoenvironments. Three snapshots: Late Murgabian, Late Anisian, Late Norian. In: Nairn, A. E. M., Ricou, L. E., Vrielynck, B., Dercourt, J. (eds), The Tethys Ocean, pp. 153–190. Springer, Boston.

Merten, S., Matenco, L., Foeken, J. P. T., Andriessen, P. A. M., 2011. Toward understanding the post-collisional evolution of an orogen influenced by convergence at adjacent plate margins: Late Cretaceous–Tertiary thermotectonic history of the Apuseni Mountains. Tectonics, 30, TC6008.

Missoni, S., Gawlick, H.-J., 2011. Jurassic mountain building and Mesozoic–Cenozoic geodynamic evolution of the Northern Calcareous Alps as proven in the Berchtesgaden Alps (Germany). Facies, 57, 137–186.

Missoni, S., Gawlick, H.-J., 2011. Evidence for Jurassic subduction from the Northern Calcareous Alps (Berchtesgaden; Austroalpine, Germany). International Journal of Earth Sciences, 100, 1605–1631.

Missoni, S., Gawlick, H.-J., Sudar, M., Jovanović, D., Lein, R., 2012. Onset and demise of the Wetterstein Carbonate Platform in the mélange areas of the Zlatibor Mountain (Sirogojno, SW Serbia). Facies, 58, 95–111.

Mrdak, M., Đaković, M., Gawlick, H.-J., Djerić, N., Bucur, I. I., Sudar, M., Milić, M., Čađenović, D., 2024. Middle Triassic stepwise deepening and stratigraphic condensation associated with Illyrian volcanism in the Durmitor Mountain, Montenegro. Facies, 70(3), 10–31.

Mrdak, M., Djerić, N., Gawlick, H.-J., Đaković, M., 2025a. Late Anisian extension evidenced by mass-transport deposits and overlying deep-water carbonates and radiolarites in the Dinarides of northern Montenegro (Brvenica, East Bosnian–Durmitor megaunit). Neues Jahrbuch für Geologie und Paläontologie – Abhandlungen, 314(3), 229–252.

Mrdak, M., Gawlick, H.-J., Djerić, N., Bucur, I. I., Wegerer, E., Đaković, M., Sudar, M., 2025b. From deep-marine stratigraphic condensation to mass-transport deposition: Illyrian stepwise extension recorded in a red nodular limestone drowning sequence (Bulog Formation) of the Ravni Carbonate Ramp (Seljani area, Montenegro). Geologia Croatica, 78(3), 185–204.

Mrdak, M., Wegerer, E., Sudar, M., Đerić, N., Đaković, M., Gawlick, H.-J., 2023. Demise of the Wetterstein Carbonate Platform and onset of the Dachstein Carbonate Platform recorded in deep-water successions of the East Bosnian–Durmitor megaunit (Plješevina, northern Montenegro, Dinarides). Geologica Carpathica, 74(6), 443–458.

Muttoni, G., Tartarotti, P., Chiari, M., Marieni, C., Rodelli, D., Dallanave, E., Kirscher, U., 2015.Paleolatitudes of Late Triassic radiolarian cherts from Argolis, Greece: Insights on the paleogeography of the western Tethys. Palaeogeography, Palaeoclimatology, Palaeoecology, 417, 476–490.

Neumayr, M., 1885. Die geographische Verbreitung der Juraformation. Denkschriften der Akademie der Wissenschaften Wien, Mathematisch-naturwissenschaftliche Klasse, 50, 57–86.

Panin, Ș., Bleahu, M., Tomescu, C., Mirăuță, E., Ștefănescu, M., 1982. Structure of the Vașcău Plateau. Dări de Seamă ale Ședințelor Institutului de Geologie și Geofizică, 67(5), 109–124.

Panin, Ș., Tomescu, C., 1974. Stratigrafia Triasicului și geneza fierului din Platoul Vașcău. Dări de Seamă ale Ședințelor Institutului de Geologie și Geofizică, 62(2), 31–58.

Patrulius, D., 1971. Unitatea de Vălani: un nou element structural al sistemului pânzelor de Codru (Munții Apuseni). Dări de Seamă ale Ședințelor, 57, 155–171.

Patrulius, D., 1976. Les formations mésozoïques des Monts Apuseni septentrionaux: corrélation chronostratigraphique et faciale. Revue Roumaine de Géologie, Géophysique et Géographie, Série Géologie, 20(1), 49–57.

Patrulius, D., 1996. Ammonites hétéromorphes et autres Parkinsoniidés du Bathonien–Callovien inférieur de Vadu Crișului (Monts Apuseni–Roumanie). Mémoires de l'Institut Géologique de Roumanie, 36, 13–19.

Patrulius, D., Bleahu, M., Antonescu, E., Baltreș, A., Bordea, S., Bordea, J., Gheorghian, D., Iordan, M., Mirăuță, E., Panin, Șt., Popa, E., Tomescu, C., 1979. The Triassic Formations of the Bihor Autochthon and Codru Nappe-System (Apuseni Mountains). 3rd Triassic Colloquium, Carpatho-Balkan Geological Association, Guidebook to Field Trips, 31 pp., Bucharest.

Patrulius, D., Bordea, S., Avram, E., 1982. La brèche de Gugu. Un exemple de contrôle tectonique de la sédimentation sur une plate-forme carbonatée barremo-bédoulienne (Pădurea Craiului, Monts Apuseni). Dări de Seamă ale Institutului de Geologie și Geofizică, 66(4), 109–117.

Patrulius, D., Gheorghian, D., Mirăuță, E., 1976. Corrélation biochronologique du Calcaire de Roșia, formation triasique du Système des Nappes de Codru (Monts Apuseni). Dări de Seamă ale Ședințelor, 62, 121–133.

Patrulius, D., Istocescu, D., 1967. Câteva fosile oxfordiene din Pădurea Craiului (Munții Apuseni). Dări de Seamă ale Ședințelor, Institutul Geologic, 53(2), 27–32.

Patrulius, D., Popa, E., Popescu, Il., Săndulescu, J., Lupu, D., 1972. R. S. Romania, Atlas lithofacial, III. Jurassique, 1:200.000. Institutul Geologic, Bucharest.

Patrulius, D., Popa, E., Tomescu, C., Popescu, E., Iordan, M., Pop, G., Panin, S., Bordea, S., 1982. Cercetări biostratigrafice pentru corelarea formațiunilor mezozoice. Jurasicul și Neocomianul din Munții Apuseni de Nord. Raport, Arhiva I.G.R., București.

Patrulius, D., Popa, E., Pope scu, Il., Săndulescu, J., Lupu, D., 1972. R. S. Romania, Atlas lithofacial, III. Jurassique, 1:200.000. Institutul Geologic, Bucharest.

Patrulius, D., Popa, E., Cîmpeanu, St., Orăşanu, Th., 1973. Geological Map Remeţi, scale 1:50,000. Institutul de Geologie și Geofizică, București.

Pleș, G., Bucur, I. I., Săsăran, E., 2016. Lower Cretaceous shallow-water carbonates and a new lituolid foraminifer (Bulbobaculites felixi n. sp.) from the Northern Apuseni Mountains (Romania). Facies, 62, 24.

Pleș, G., Schlagintweit, F., Kołodziej, B., Bucur, I. I., Gawlick, H.-J., Mircescu, C. V., Săsăran, E., Lazăr, I., 2024. Upper Jurassic–lowermost Cretaceous hybrid build-ups of the Western Tethys Realm: Cement-rich microencruster–microbialite–calcified sponge framework. Palaeogeography, Palaeoclimatology, Palaeoecology, 639, 112035.

Pleș, G., Bucur, I. I., Săsăran, E., Bindiu-Haitonic, R., Balica, C., Mircescu, C. V., Magdaș, D. A., Vulpoi, A., 2025. Late Aptian–middle Albian bacinellid oncoid event, Apuseni Mountains, Romania: A possible link to OAE1b? Palaeogeography, Palaeoclimatology, Palaeoecology, 664, 112807.

Plašienka, D., 2018. Continuity and Episodicity in the Early Alpine Tectonic Evolution of the Western Carpathians: How Large-Scale Processes Are Expressed by the Orogenic Architecture and Rock Record Data. Tectonics, 37, 2029–2079.

Rampnoux, J.-P., 1974. Contribution à l'étude géologique des Dinarides : un secteur de la Serbie méridionale et du Monténégro oriental (Yougoslavie). Mémoires de la Société géologique de France, nouvelle série, 52(119), 1–99.

Ratschbacher, L., Frisch, W., Linzer, H. G., Merle, O., 1991. Lateral extrusion in the Eastern Alps, Part 2: Structural analysis. Tectonics, 10, 257–271.

Reading, H. G. (ed.), 1996. Sedimentary Environments: Processes, Facies and Stratigraphy. 3rd ed. Blackwell Science, Oxford.

Reiser, M. K., Schuster, R., Tropper, P., Fügenschuh, B., 2017. Constraints on the depositional age and tectonometamorphic evolution of marbles from the Biharia Nappe System (Apuseni Mountains, Romania). Geologica Carpathica, 68(2), 147–164.Ricou, L.-E., 1996. The plate tectonic history of the past Tethys ocean. In: Nairn, A. E. M., Ricou, L. E., Vrielynck, B., Dercourt, J. (eds), The Ocean Basins and Margins. The Tethys Ocean, vol. 8, pp. 3–70. Plenum Press, New York, London.

Robertson, A. H. F., 2012. Late Palaeozoic-Cenozoic tectonic development of Greece and Albania in the context of alternative reconstructions of Tethys in the Eastern Mediterranean region. International Geology Review, 54, 373–454.

Săndulescu, M., 1984. Geotectonica României. Editura Tehnică, București, 334 pp.

Săsăran, E., 2006. Calcarele Jurasicului superior–Cretacicului inferior din Munții Trascău. Presa Universitară Clujeană, Cluj-Napoca, 249 pp.

Schlagintweit, F., Gawlick, H.-J., Missoni, S., Hoxha, L., Lein, R., Frisch, W., 2008. The eroded Late Jurassic Kurbnesh carbonate platform in the Mirdita Ophiolite Zone of Albania and its bearing on the Jurassic orogeny of the Neotethys realm. Swiss Journal of Geosciences, 101, 125–138.

Schlager, W., 2005. Carbonate Sedimentology and Sequence Stratigraphy. SEPM, Concepts in Sedimentology and Paleontology, 8, 200 pp.

Schmid, S. M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski, K., 2008. The Alpine-Carpathian-Dinaride-orogenic system: correlation and evolution of tectonic units. Swiss Journal of Geosciences, 101, 139–183.

Schmid, S. M., Fügenschuh, B., Kounov, A., Mațenco, L., Nievergelt, P., Oberhänsli, R., Pleuger, J., Schefer, S., Schuster, R., Tomljenović, B., Ustaszewski, K., van Hinsbergen, D. J. J., 2020. Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey. Gondwana Research, 78, 308–374.

Schuller, V., Frisch, W., Danišík, M., Dunkl, I., Melinte, M. C., 2009. Upper Cretaceous Gosau deposits of the Apuseni Mountains (Romania) – similarities and differences to the Eastern Alps. Austrian Journal of Earth Sciences, 102(1), 133–145.

Şengör, A. M. C., 1984. The Cimmeride orogenic system and the tectonics of Eurasia. Geological Society of America Special Paper, 195, 1–82.

Şengör, A. M. C., 1985. Die Alpiden und die Kimmeriden: die verdoppelte Geschichte der Tethys. Geologische Rundschau, 74, 181–213.

Şengör, A. M. C., 1998. Die Tethys: vor hundert Jahren und heute. Mitteilungen der Österreichischen Geologischen Gesellschaft Wien, 89, 5–177.

Stampfli, G. M., Borel, G. D., 2004. The TRANSMED transects in space and time: constraints on the paleotectonic evolution of the Mediterranean domain. In: Cavazza, W., Roure, F. M., Spakman, W., Stampfli, G. M., Ziegler, P. A. (eds), The TRANSMED Atlas, The Mediterranean Region From Crust to Mantle, pp. 53–80. Springer.

Stampfli, G. M., Kozur, H. W., 2006. Europe from Variscan to the Alpine cycles. In: Gee, D. G., Stephenson, R. A. (eds), European Lithosphere Dynamics. Geological Society Memoir, 32, 57–82.

Steiner, P., Gawlick, H.-J., Missoni, S., et al., 2021. Ophiolite derived material as parent rocks for Late Jurassic bauxite: evidence for Tithonian unroofing in the Northern Calcareous Alps (Eastern Alps, Austria). International Journal of Earth Sciences.

Suciu, T., Pleș, G., Tămaș, T., Bucur, I. I., Săsăran, E., Cociuba, I., 2021. New insights into the depositional environment and stratigraphic position of the Gugu Breccia (Pădurea Craiului Mountains, Romania). Carnets de Géologie, 21(11), 215–233.

Suess, E., 1888. Das Antlitz der Erde. II. F. Tempsky, Prag and Wien; G. Freytag, Leipzig, IV + 704 pp.

Suess, E., 1901. Abschieds-Vorlesung. Beiträge zur Paläontologie und Geologie Österreich-Ungarns und des Orients, 14, 2–8.

Sudar, M., Gawlick, H.-J., Jovanović, D., Lein, R., Missoni, S., Bucur, I. I., 2023. From shallow-water carbonate ramp to hemipelagic deep-marine carbonate deposition: Part 1. General characteristics, microfacies and depositional history of the Middle to Late Anisian Bulog sedimentary succession in the Inner Dinarides (SW Serbia). Geološki anali Balkanskoga poluostrva, 84(2), 1–40.

Sudar, M., Gawlick, H.-J., Bucur, I. I., Jovanović, D., Missoni, S., Lein, R., 2023. From shallow-water carbonate ramp to hemipelagic deep-marine carbonate deposition: Part 3. Lithostratigraphy and formations of the Middle to Late Anisian Bulog sedimentary successions (Bulog Group) in the Dinarides (Bosnia and Herzegovina, Serbia, Montenegro). Geološki anali Balkanskoga poluostrva, 84(2), 71–?.

Sudar, M., Gawlick, H.-J., Skopljak, F., 2025. The Bulog Formation in the type area (Sarajevo) and related Middle and Late Triassic open-marine sedimentary successions in the Dinarides of Bosnia and Herzegovina. Geološki anali Balkanskoga poluostrva, 86(1), 1–67.

Sudar, M., Gawlick, H.-J., Lein, R., Missoni, S., Jovanović, D., 2013. Depositional environment, age and facies of the Middle Triassic Bulog and Rid formations in the Inner Dinarides (Zlatibor Mountain, SW Serbia): evidence for the Anisian break-up of the Neotethys Ocean. Neues Jahrbuch für Geologie und Paläontologie – Abhandlungen, 269(3), 291–320.

Tollmann, A., 1976. Analyse des klassischen nordalpinen Mesozoikums. Deuticke, Wien, 580 pp.

Vlahović, I., Tišljar, J., Velić, I., Matičec, D., 2005. Evolution of the Adriatic Carbonate Platform: Paleogeography, main events and depositional dynamics. Palaeogeography, Palaeoclimatology, Palaeoecology, 220, 333–360.

Vörös, A., 1977. Provinciality of the Mediterranean Lower Jurassic brachiopod fauna: causes and plate-tectonic implications. Palaeogeography, Palaeoclimatology, Palaeoecology, 21, 1–16.

Vörös, A., 1993. Jurassic microplate movements and brachiopod migrations in the western part of the Tethys. Palaeogeography, Palaeoclimatology, Palaeoecology, 100, 125–145.

Wilson, J. L., 1975. Carbonate Facies in Geologic History. Springer-Verlag, Berlin, 471 pp.

Wright, V. P., Platt, N. H., 1995. Seasonal wetland carbonate sequences and dynamic catenas: a re-appraisal of palustrine limestones. Sedimentary Geology, 99, 65–71.

Zankl, H., 1967. Die Karbonatsedimente der Obertrias in den nördlichen Kalkalpen. Geologische Rundschau, 56, 128–139.

Zöhrer, O., Pleș, G., Mrdak, M., Gawlick, H.-J., 2026. Development of reef facies during the latest Carnian–earliest Rhaetian Dachstein Carbonate Platform of the Dinaridic realm (northern Montenegro) in the context of the Late Triassic geological events. Facies, 72, 20.

FIELD TRIP 6

FT6. Petroleum system of the Eastern Carpathians Bend Zone

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INTRODUCTION

The Eastern Carpathians Bend Zone (ECBZ) in Romania represents an 80-km-long segment of the thin-skinned fold-and-thrust belt, situated where the north-south-trending Eastern Carpathians meet the east-west-trending Southern Carpathians (Schléder *et al.*, 2019).

Historically, the ECBZ and the broader Romanian Carpathians are recognised as among the oldest oil- and gas-producing areas in the world, with industrial activities formalised in the mid-nineteenth century (Tulucan *et al.*, 2018; Tămaș *et al.*, 2018; Krézsek *et al.*, 2023). The year 1857 is particularly significant, as Romania became the first country with crude oil production formally recorded in international statistics, totalling 275 tonnes (Tulucan *et al.*, 2018; Krézsek *et al.*, 2023). In that same year, the world's first industrial petroleum refinery was established in Ploiești, and Bucharest became the first city globally to use lamp oil for public street lighting (Tulucan *et al.*, 2018). Over a 150-year period, more than 9 billion barrels of oil equivalent have been found in the Romanian Carpathians, much of which is centred in the structurally complex ECBZ (Boote *et al.*, 2018; Krézsek *et al.*, 2023).

Beyond its relevance to the petroleum industry, the area is also of great scientific importance. It is the type locality for the geological term *diapir*, coined in 1907 by Ludovic Mrazec (1910). Mrazec used the term diapir to describe folds with a salt core and the discordant nature of the salt, in which salt had pierced the overlying sedimentary strata (Mrazec, 1910, 1926; Tămaș *et al.*, 2018, and references therein).

This region is also an exceptional outdoor laboratory for understanding subsurface challenges, offering analogue exposures of reservoir, source, seal, and trap elements. For geologists working in clastic systems globally, the ECBZ provides a critical surface analogue for validating seismic interpretations, understanding complex reservoir geometries, and better managing exploration and production risks associated with structurally complex systems.

GEOLOGICAL SETTING

The Carpathians represent a highly arcuate segment of the Alpine orogen in Central and Eastern Europe (e.g. Săndulescu, 1984; Schmid *et al.*, 2008; Krézsek *et al.*, 2023). This mountain belt records the complex tectonic history of the closure of the Alpine Tethys from the latest Jurassic through the Middle Miocene (Săndulescu, 1984, 1988; Krézsek *et al.*, 2023). Structurally, the Carpathians are divided into two main zones. The internal zone is basement-dominated and characterised by thick-skinned deformation. The external zone consists mainly of deep-marine sedimentary rocks (flysch) and is characterised by thin-skinned tectonics (Săndulescu, 1984, 1988; Matenco, 2017; Schléder et al., 2019; Krézsek et al., 2023). The external nappes were emplaced during several contractional phases: the Convolute Flysch during the Cretaceous; the Black Flysch, Audia, Macla and part of the Tarcău Nappe during the Late Oligocene–Early Miocene; and the Tarcău, Marginal Folds and Subcarpathian nappes during the Middle Miocene (e.g. Săndulescu 1984). During the Sarmatian (middle Miocene), the Subcarpathian Nappe was thrusted over the undeformed foreland (Băncilă 1958; Săndulescu 1984, 1988; Matenco & Bertotti 2000; Merten et al. 2010; Matenco 2017). The Moesian Platform serves as the lower plate of the Carpathian orogen in this sector (e.g.

Săndulescu, 1984, 1988). In the ECBZ, the Moesian plate dips northward at approximately 5° to 10° beneath the external thin-skinned nappes, reaching depths of up to 10 km beneath the hinterland (Schléder *et al.*, 2019). Seismic data indicate that the lower plate is relatively stable beneath the thin-skinned belt, showing no major brittle faulting that correlates directly with surface salt structures, confirming the thin-skinned nature of the regional tectonics (Fernandez *et al.*, 2016; Schléder *et al.*, 2019).

THE TECTONOSTRATIGRAPHIC FRAMEWORK OF THE ECBZ

This field trip focuses on the external sector of the Eastern Carpathian Bend Zone, covering the Tarcău Nappe, the Subcarpathian Nappe and the post-tectonic foreland deposits. The stratigraphy is described in a tectonostratigraphic framework relative to the Middle Miocene compressional event, during which most regional shortening occurred.

The pre-kinematic sequence begins with Lower Cretaceous deep-marine black shales and sandy turbidites (Ștefănescu, 1978; Roban *et al.*, 2020), followed by Upper Cretaceous variegated shales and calcareous turbidites (Krézsek *et al.*, 2023). The Eocene is marked by the deposition of the Tarcău Formation, a 600 m thick deep-marine turbiditic sandy unit sourced from uplifted internal units to the west (Băncilă, 1958; Schléder *et al.*, 2019; Krézsek *et al.*, 2023). During the Oligocene to lowermost Miocene, the region was part of the Paratethys basin (e.g. Rögl, 1998; Palcu and Krijgsman, 2021). The Oligocene–Lower Miocene deep-marine deposits of the Tarcău Nappe comprise two main lithofacies. The internal Pucioasa–Fusaru facies is of Carpathian origin, whereas the external facies is sourced from the European craton and includes organic-rich shales deposits and quartz-rich sandstones (Kliwa sandstones). An interbedded transition zone separates the two (Pătruț, 1955; Conțescu *et al.*, 1966; Săndulescu *et al.*, 1995; Sylvester and Lowe, 2004; Răbăgia *et al.*, 2011; Szabo, 2012). The organic-rich shales, known as the lower dysodiles and menilites, act as primary hydrocarbon source rocks (Ștefănescu *et al.*, 2006; Melinte-Dobrinescu and Brustur, 2008; Miclăuș *et al.*, 2009; Schléder *et al.*, 2019; Bercea *et al.*, 2023). This succession is overlain by a regionally continuous Lower Burdigalian evaporite succession that forms the principal salt horizon in the ECBZ (Albu and Balteș, 1983). Halite dominates across most of the Eastern Carpathians, passing laterally into gypsum and anhydrite towards the west and northwest (Ștefănescu, 1978). The evaporites are overlain by up to 900 m of Lower–Upper Burdigalian shallow-marine siliciclastic deposits, locally containing anhydrite and gypsum.

The Lower Burdigalian salt acted as a primary detachment horizon during contraction (Schléder *et al.*, 2019; Tămaș *et al.*, 2020a, 2021; Krézsek *et al.*, 2023). The total shortening in the fold-belt wedge is estimated at 37 km, though this depends on the interpreted ages of the frontal thrust slices (Schléder *et al.*, 2019).

The syn-kinematic Middle Miocene (Badenian–Middle Sarmatian) succession is c. 500 m thick and was deposited in NE–SW-trending piggyback basins during compression. It comprises tuffs, marls, breccias, pebbly mudstones, locally developed Badenian salt, radiolarian shales and minor sandstones and capped by lowermost Sarmatian marls and thin-bedded sandstones (Schléder *et al.*, 2019 and references therein).

The post-kinematic succession consists of Middle Sarmatian to Recent deposits with a total thickness of 1.5–3 km. The Middle Sarmatian is dominated by marls with thin sandstone interbeds, whereas the Upper Sarmatian contains thicker sandstone intervals. The overlying Meotian comprises shallow-marine calcareous sandstones, sands, silts and marls. Pontian deposits are mainly marls and silts with minor sand bodies, while the Dacian–Quaternary succession consists of shallow-marine to continental siliciclastic deposits with local coal beds (Pătruț *et al.*, 1973; Ștefănescu *et al.*, 2000). These units are themselves deformed by the ongoing Wallachian phase (Pliocene to Recent), which involved regional uplift and the

reactivation of the fold belt (Hippolyte and Săndulescu, 1996; Merten *et al.*, 2010; Schléder *et al.*, 2019). During this phase, the Lower Burdigalian salt was further remobilised, rising through 2–3 km of post-tectonic cover to reach the surface (Tămaș *et al.*, 2018, 2020a; Schléder *et al.*, 2019). This created a 30-km-long NE–SW structural lineament, including localities such as Moreni and Băicoi (Tămaș *et al.*, 2018; Schléder *et al.*, 2019, and references therein). This phase was characterised by north–south compression that produced gentle to open folds and reactivated basement faults at a crustal scale, accompanied by several kilometres of uplift and erosion (e.g. Hippolyte and Săndulescu, 1996; Sanders *et al.*, 1999; Merten *et al.*, 2010; Schléder *et al.*, 2019; Bercea *et al.*, 2023).

THE PETROLEUM SYSTEM

Source

The hydrocarbons of the ECBZ are sourced primarily from the Oligocene–early Miocene (Oligocene s.l.) dysodiles and menilites (Slaczka *et al.*, 2014; Negru and Roban, 2015; Sachsenhofer *et al.*, 2015, 2018; Schléder *et al.*, 2019; Tulan *et al.*, 2020; Krézsek *et al.*, 2023). Within this succession, the Lower Dysodile Formation forms the principal regional source rock. These organic-rich shales contain 1–>10% total organic carbon and are dominated by oil-prone Type II kerogen (Sachsenhofer *et al.*, 2015, 2018; Krézsek *et al.*, 2023).

A secondary source interval is provided by Lower Cretaceous (Neocomian–lower Albian) deep-marine black shales. These contain 2–4% total organic carbon but are generally gas-prone or overmature and are considered less significant than the Oligocene–Lower Miocene source system (Krézsek *et al.*, 2023).

Reservoir

Reservoir units are found throughout the Paleogene and Neogene successions (see Table 1).

The most prolific reservoirs are the Oligocene–Lower Miocene Kliwa Sandstones, which are quartz arenites sourced from the European craton (Săndulescu *et al.*, 1981; Krézsek *et al.*, 2023). Their reservoir quality is also attributed to the development of secondary dissolution porosity, which provides well-connected pore spaces (Krézsek *et al.*, 2023). The architecture of these reservoirs, specifically the Oligocene and Lower Miocene Kliwa successions, is profoundly modified by sand injectites (Tămaș *et al.*, 2020b). These structures, comprising interconnected networks of sandstone dykes and sills, were formed by the fluidisation and remobilisation of overpressured sand possibly during the mid-Miocene contractional phase (Tămaș *et al.*, 2020b).

Table 1. Reservoir properties (after Butac *et al.*, 1997).

Reservoir intervals	Age	Tarcău Nappe		Subcarpathian Nappe & Inner Foredeep	
		Por. (%)	Perm. (mD)	Por. (%)	Perm. (mD)
Romanian	Pliocene	–	–	25–32	150–1500
Dacian		–	–	25–40	100–2500
Meotian	Miocene	20–29	7–300	20–40	20–1400
Sarmatian		–	–	18–33	100–350
Burdigalian		20–25	100–300	20–25	50–80
Upper Kliwa	Lower Miocene	22–29	100–400	–	–
Lower Kliwa	Oligocene	12–18	25–150	12–21	100–300

Seals

The Eastern Carpathian Bend Zone contains both regional and local sealing units. In the sub-salt petroleum system, the Lower Miocene salt represents the primary regional seal, while the organic-rich shales provide additional intraformational sealing. In the supra-salt succession, sealing is primarily provided by multiple interbedded Miocene to Pliocene shale intervals that compartmentalise the reservoirs and host numerous hydrocarbon accumulations. In parts of the foredeep, the fine-grained Pontian deposits may also function as a sub-regional seal.

Traps

Structural traps are the dominant trapping style in the Eastern Carpathian Bend Zone. The Tarcău nappe is characterised by faulted anticlines and hanging wall anticlines associated to the imbricate thrust faults aligned parallel to the Carpathian bend. In the Subcarpathian Nappe, hydrocarbon accumulations are primarily controlled by diapiric anticlines formed during Miocene salt tectonics and subsequent halokinetic reactivation. Traps, such as those found at the Moreni and Băicoi fields, are intimately related to the folding and truncation of sediments along salt diapirs (Popescu *et al.*, 1973; Tămaș *et al.*, 2018; Schléder *et al.*, 2019). These structures initiated during the Middle Miocene (Badenian to Middle Sarmatian) contractional phase as upright, tight detachment folds (Schléder *et al.*, 2019; Tămaș *et al.*, 2020a). The cores of these folds were occupied by thickened Lower Burdigalian salt and an Oligocene s.l. duplex system (Schléder *et al.*, 2019; Tămaș *et al.*, 2020a). Seismic data reveal that these salt structures were subsequently breached, either by out-of-sequence thrusts cutting up from the Lower Dysodilic level or by slip along the Burdigalian salt level itself (Schléder *et al.*, 2019).

Charge history and preservation risks

The Oligocene–Lower Miocene source rocks exhibit variable thermal maturity (0.4–1.25% Ro), entering the oil window at burial depths greater than ~4.5 km. Hydrocarbon generation began during Miocene tectonic burial, although the timing of peak generation varied across the belt (Butac *et al.*, 1997). The Tarcău Nappe reached maximum burial before the Middle Miocene, whereas the Marginal Folds Nappe attained peak oil generation and expulsion after nappe emplacement (Schléder *et al.*, 2019; Krézsek *et al.*, 2023). Preservation of hydrocarbon accumulations was subsequently controlled by the Wallachian tectonic phase, with post-tectonic burial favouring trap preservation and uplift causing leakage and active hydrocarbon seeps (Merten *et al.*, 2010; Krézsek *et al.*, 2023).

FIELD TRIP ITINERARY

This four-day pre-conference field trip examines the petroleum system of the Eastern Carpathian Bend Zone (ECBZ) through a series of key outcrops spanning the Tarcău Nappe, the Subcarpathian Nappe and the post-tectonic foreland succession. A distinctive feature of the ECBZ is that the same lithological units that host the producing petroleum system in the subsurface are extensively exposed at the surface, allowing direct observation of the source rocks, reservoirs, seals, traps and active seepage systems.

Participants will examine the principal source rocks and sub-salt reservoirs, the Lower Miocene salt acting as both the regional seal and the main detachment horizon, the supra-salt reservoir succession, and examples of structural trapping or seal failure. Most stops are located in the proximity of the producing fields, providing direct analogues for the subsurface petroleum system. Tables 2 and 3 summarise the petroleum system elements examined during the field trip and the four-day itinerary, respectively.

Table 2. Elements of the petroleum system of the Eastern Carpathians Bend Zone and the localities at which each is examined during the field trip.

Element	Expression in the Bend Zone	Field trip locality
Source rock	Oligocene to lower Burdigalian dysodiles, menilites and diatomites.	Day 2: Sibiciu de Sus, Colți
Reservoir (sub-salt)	Upper and Lower Kliwa sandstones; quartz arenites locally fluidised and cut by networks of sand injectites.	Day 2: Sibiciu de Sus, Colți
Reservoir (supra-salt)	Meotian, Pontian and Dacian sands and calcareous sandstones of the post-tectonic cover.	Day 3: Slănicul de Buzău transect
Seal and detachment	Lower Miocene salt: efficient top seal in the Carpathians and the principal detachment during nappe emplacement.	Day 3: Mânzălești diapir
Trap	Detachment folds, duplexes and triangle zones above multiple detachment levels; faulted anticlines in the cover.	Days 2 and 3: structural stops
Seal failure	Evaporitic top seal fully eroded; gas escaping along fractures.	Day 3: burning gas seeps
Seal failure	Methane and formation water rising along the fault system.	Day 3: Pâclele Mari and Pâclele Mici

Table 3. Summary of the four-day field trip programme, based at Berca in the Buzău region.

Day	Route	Themes
1	Cluj-Napoca to Siriu Dam to Berca, or Bucharest to Berca by train	Travel; regional structure of the thick-skinned and thin-skinned Carpathian fold and thrust belt; Eocene Tarcău Sandstone
2	Berca – Sibiciu de Sus – Colți – Berca	Reservoir and source rock exposures and structures in the sub-salt stratigraphic units
3	Berca – Slănicul de Buzău – Mânzălești – Pâclele mud volcanoes – Berca	Reservoirs and seals in the supra-salt units; salt as a petroleum system element; seal failure and active seepage
4	Berca to Viscri to Cluj-Napoca	Return travel

Day 1: travel to Berca

Two travel options are available. The first is departure from Cluj-Napoca by coach at 08:00, included in the field trip cost. Crossing the Carpathians, a short stop is made at the Siriu Dam to discuss the regional structure of the thick-skinned and thin-skinned Carpathian fold and thrust belt. The Siriu locality also offers an excellent introduction to the Eocene Tarcău Sandstone in the Tarcău nappe, where low-density turbidites interbedded with bioturbated green marls build submarine channel and levee complexes tens of metres thick, alternating with chaotic mass transport deposits (Krézsek *et al.*, 2023).

The expected arrival at Berca is around 17:00.

The second option is the train from Bucharest to Berca, which takes approximately three hours; tickets are not included in the field trip cost. Participants using this option should aim to arrive at Berca around 17:00. An icebreaker and dinner follow from about 19:00.

Day 2: Berca – Colți – Sibiciu de Sus – Berca

The aim of the second day is to observe the reservoir, source rock exposures and structures in the sub-salt stratigraphic units. Participants will examine the Oligocene and Lower Miocene deep-water siliciclastic rocks of the bituminous Kliwa facies, specifically the lower (fig. 1) and upper Kliwa (fig. 2) sandstones, which are among the best hydrocarbon reservoirs in the ECBZ (Tămaș et al., 2020b). These quartz-rich sandstones, with more than 90% quartz, and their interbedded dysodilic shales, the primary source rock in the region (figs 1 and 2).



Fig. 1. Digital outcrop model of the Lower Kliwa sandstone from Colti.

The outcrops also illustrate the factors that control reservoir heterogeneity across a range of scales. Variations in reservoir architecture result from structural deformation, including folding, faulting and fracturing, as well as post-depositional fluidisation, sandstone remobilisation and the development of sand intrusions (Tămaș *et al.*, 2020b).

Colți outcrop

Colți outcrop is c. 100 m wide and displays folded and back-thrusted lower Kliwa formation (fig. 1). The beds are steeply dipping towards the SE and comprise metre- to cm-thick poorly cemented sandstones interbedded with organic-rich shales (fig. 1). Most of the sandstone beds were fluidised and remobilised, hence the primary sedimentary structures are rarely visible. A network of sand intrusions emerges from remobilised units, significantly increasing vertical and horizontal connectivity (Tămaș *et al.*, 2020b). In such sill-dominated areas, the net:gross ratio can reach 35–50%, explaining subsurface challenges such as inconsistent log correlations and compartmentalisation (Tămaș *et al.*, 2020b).

Sibiciu de Sus

Sibiciu de Sus locality exposes the Upper Kliwa formation to the north (fig. 2) and the Upper Dysodiles and Diatomites formation to the east in an abandoned quarry.



Fig. 2. Digital outcrop model Upper Kliwa sandstone from Sibiciu de Sus.

At this location, an excellent exposure of the Upper Kliwa Formation can be observed, where sandstone beds up to c.10 m thick are interbedded with organic-rich shales (fig. 2). The succession is folded into a recumbent anticline and crosscut by a low-angle thrust fault, illustrating the complex structural style of the ECBZ. The sandstones are locally remobilised, forming an interconnected network of sand intrusions. A dense array of deformation bands is also exposed at the base of the outcrop, offering an exceptional example of small-scale structures that influence reservoir heterogeneity and fluid flow.

Towards the east, the Upper Dysodile and Diatomite formations are exposed in one of the largest diatomite outcrops in the Carpathians. The succession comprises organic-rich dysodiles, menilitic shales interbedded with diatomites (Tulan *et al.*, 2020). Geochemical analysis of these diatomites reveals good to very good hydrocarbon potential, with an average total organic carbon content of 3.77 wt%, reaching up to 9.57 wt%, and oil-prone Type II–III kerogen (Tulan *et al.*, 2020). Although the organic matter at this specific outcrop is thermally immature, with a maximum pyrolysis temperature below 424 °C, a high production index of 0.1–0.3 proves the presence of migrated hydrocarbons, confirming the efficiency of the broader petroleum system (Tulan *et al.*, 2020).

Day 3: Berca – Slănicul de Buzău – Mânzălești – Pâclele – Berca

The third day, also running from c. 08:00 to 17:00, addresses reservoirs and seals in the supra-salt stratigraphic units, the role of salt as a petroleum system element, and the surface expressions of seal failure and active seepage.

The route follows the structural framework of the Foredeep, from Quaternary deposits downward into Miocene successions, and continues into the Subcarpathian nappe until the limit with the Tarcău nappe. Along this transect, progressively older stratigraphic units are exposed, allowing observation of the transition from mildly deformed Quaternary and Miocene strata within the Foredeep into the Miocene sedimentary sequences of the Subcarpathian unit, which are involved in nappe tectonics (Săndulescu, 1988; Krézsek *et al.*, 2023).

Mânzălești salt outcrop

At the Mânzălești salt diapir stop, participants can observe one of the largest rock salt outcrops in Europe, an 80 m high relief feature covering an area of approximately 2.7 by 1.3 km (Tămaș *et al.*, 2021; fig. 3). This location is geologically unique because its internal fabric consists of sub-horizontal foliation and isoclinal folds, contrasting sharply with the sub-vertical, domal fabrics typically found in other Romanian diapirs (Tămaș *et al.*, 2021). This unusual geometry is interpreted as a low-angle tectonic shear zone formed by the decapitation of a deep-seated salt structure by the eastward-propagating Tarcău nappe (Tămaș *et al.*, 2021).



Fig. 3. Aerial photograph of the Mânzălești salt diapir.

The salt is impure, containing a high volume of clastic inclusions such as sandstones, limestones and volcanic rocks, which exhibit a power-law size distribution due to intense tectonic reworking (Tămaș *et al.*, 2021, 2025). These impurities are hosted in a matrix of halite porphyroclasts surrounded by finer-grained recrystallised halite (Tămaș *et al.*, 2021). Beyond its geological tectonic history, the diapir is a site of active modern deformation. Near-horizontal white bands cross-cutting the salt, originally interpreted as shear zones (Tămaș *et al.*, 2021), have been re-identified as sediment-filled dissolution notches or palaeo-river terraces (Tămaș *et al.*, 2025).

Radiocarbon dating of vegetal fragments found within these notches, with wood and leaves dated to approximately 720 years ago, indicates remarkable relative salt uplift rates of 10.5 ± 0.8 mm/year to 29.8 ± 4.2 mm/year (Tămaș *et al.*, 2025). These historical rates are corroborated by modern velocities derived from persistent scatterer interferometry, which show average vertical movements of 10 mm/year, peaking at 55 mm/year in the south-western part of the diapir (Tămaș *et al.*, 2025). This rapid rise, driven by both gravitational loading and ongoing compression, suggests that the present surface exposure of the diapir may be very young; extrapolating these rates indicates that the top of the diapir may not have reached the surface 17,000 years ago (Tămaș *et al.*, 2025). Participants can also explore the surface geomorphology of the

Meledic Plateau, which features a unique salt-karst landscape. This stop thus provides a comprehensive view of salt dynamics, from Miocene nappe-driven decapitation to modern-day millimetric uplift in a humid continental climate.

Burning gas seeps at Lopătari (optional stop, subject to time and weather)



Fig. 4. Lit gas seeps from Lopătari.

Not very far from the Mânzălești diapir, analogue reservoir rocks of the lower Kliwa, stratigraphically situated beneath the Lower Miocene evaporites, are locally exposed at the surface. At these sites, natural gas escapes continuously through fractures, creating the so-called eternal flames (fig. 4). These burning seeps provide a striking field example of a missing or breached seal. The original evaporitic top seal has been completely eroded here, allowing gas to migrate from the underlying reservoirs to the surface.

Pâclele mud volcanoes

The Pâclele Mari and Pâclele Mici mud volcanoes formed by the escape of gas and fluids from deep, overpressured hydrocarbon-bearing layers (Baciu *et al.*, 2007; Brustur *et al.*, 2015). Methane-rich emissions drive mud and water to the surface, creating small cones and flow structures that resemble volcanic activity (fig. 5). The seeps are located on the Berca–Arbănași structure, an approximately 18 km long faulted anticline within the Subcarpathian nappe whose fault system provides the migration pathways for hydrocarbons and formation waters towards the surface (Ciocârdel, 1949; Butac *et al.*, 1997; Soto and Hudec, 2023). Gas geochemistry confirms a thermogenic origin, with methane contents typically above 95% and carbon isotope signatures that differ between the two fields (Etiope *et al.*, 2004, 2009; Baciu *et al.*, 2018). The site provides insight into an active subsurface petroleum system and into fluid overpressure,

while also illustrating the hazards of surface and subsurface instability associated with overpressured zones (Tingay *et al.*, 2018).

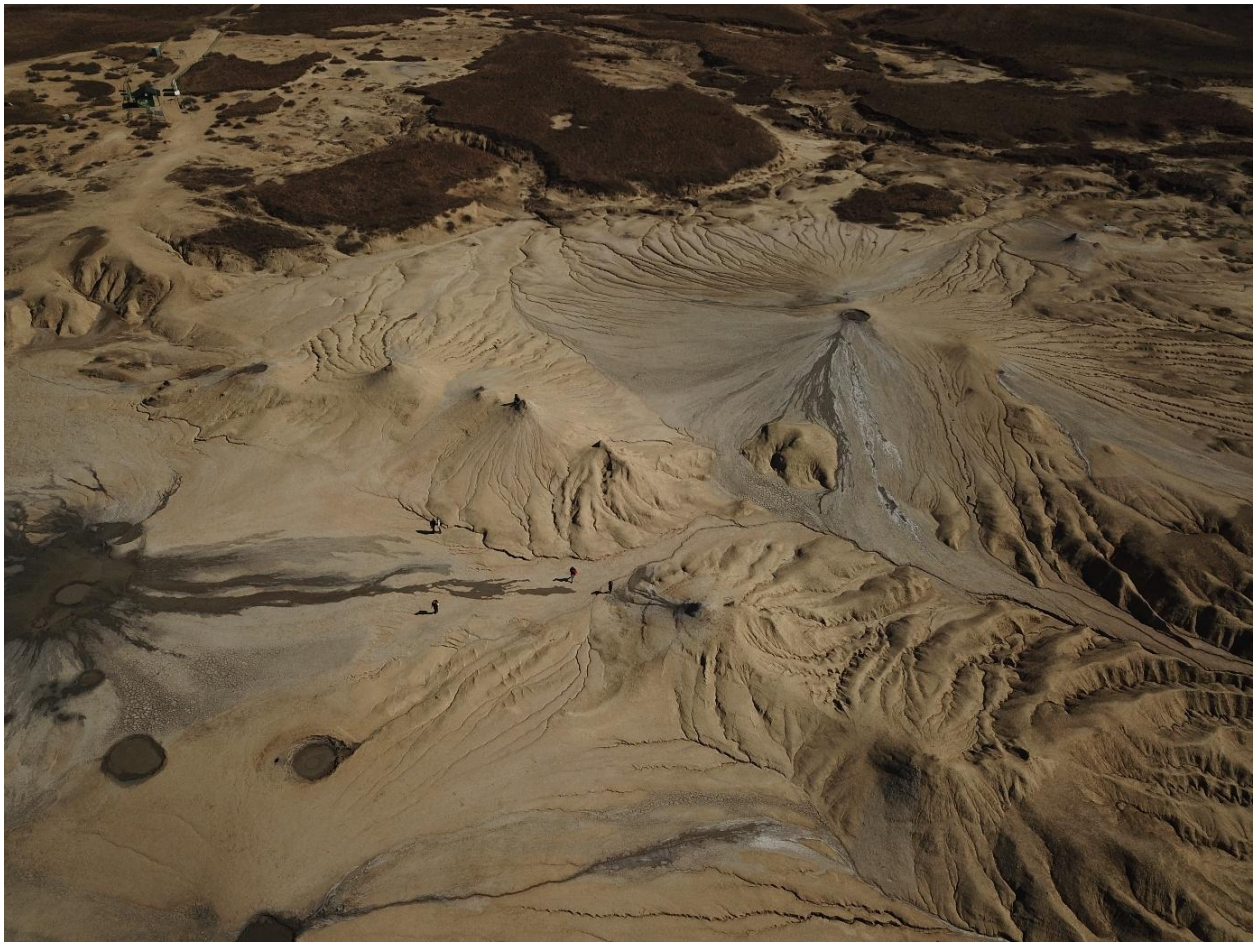


Fig. 5. Aerial photograph of the Pâclele Mari mud volcanoes.

Day 4: Berca to Cluj-Napoca

Departure from Berca is at 08:00, with a lunch stop at Viscri and expected arrival in Cluj-Napoca around 19:00.

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REFERENCES

Albu, E. and Baltes, N. 1983, Considerations sur l'age du sel dans la zone des plis diapirs attenues et incipients de la Muntenie et ses implications sur la genese et la repartition des gisements d'hydrocarbures: Carpathian-Balkan Geological Association, 12th Congress, Bucharest, Romania, September 8–13, 1981, *Anuarul Institutului de Geologie si Geofizica, Tectonica, Petrol si Gaze* 60, p. 257–264.

Baciu, C., Caracausi, A., Etiope, G., Italiano, F. 2007. Mud volcanoes and methane seeps in Romania: main features and gas flux. *Annals of Geophysics* 50 (4), 501–511.

Baciu, C., Ionescu, A., Etiope, G. 2018. Hydrocarbon seeps in Romania: gas origin and release to the atmosphere. *Marine and Petroleum Geology* 89, 130–143.

Băncilă, I. 1958. Geology of the Eastern Carpathians. Editura Științifică, Bucharest, 367 pp. (in Romanian).

Bercea, R.-I., Bălc, R., Tămaș, A., Filipescu, S., Tămaș, D.M., Guillong, M., Szekely, S.F., Lukács, R. 2023. Insights into the palaeoenvironments, structure and stratigraphy of the lower Miocene of the Eastern Carpathians Bend Zone, Romania. *Geological Quarterly* 67 (2), 22.

Boote, D.R.D., Sachsenhofer, R.F., Tari, G., Arbouille, D. 2018. Petroleum provinces of the Paratethyan region. *Journal of Petroleum Geology* 41, 247–298.

Brustur, T., Stănescu, I., Măcăleț, R., Melinte-Dobrinescu, M.C. 2015. The mud volcanoes from Berca: a significant geological patrimony site of the Buzău Land Geopark (Romania). *Geo-Eco-Marina* 21, 73–96.

Butac, A., Desanu, D., Dobre, S., Georgescu, C., Grecu, D., Ghiran, M., Popescu, M., Serini, V., Sindilar, V., Ștefănescu, M., Zaharescu, P. 1997. Trip 10: Romania East Carpathian Bend. Field-trip guide, AAPG International Conference and Exhibition, Vienna, 43 pp.

Ciocârdel, R. 1949. The Berca–Beciu–Arbănași petroliferous region. Comitetul Geologic, Studii tehnico-economice A1, Bucharest, 32 pp. (in Romanian).

Contescu, L., Jipa, D., Mihailescu, N., Panin, N., 1966. The internal Paleogene flysch of the Eastern Carpathians: paleocurrents, source areas and facies signifcance. *Sedimentology*, 7, 307–321.

Etiope, G., Baciu, C., Caracausi, A., Italiano, F., Cosma, C. 2004. Gas flux to the atmosphere from mud volcanoes in eastern Romania. *Terra Nova* 16 (4), 179–184.

Etiope, G., Feyzullayev, A., Baciu, C.L. 2009. Terrestrial methane seeps and mud volcanoes: a global perspective of gas origin. *Marine and Petroleum Geology* 26, 333–344.

Fernandez, O., Aristizabal, J.J., Garcia-Craviotto, A., Iusco, G. 2016. Structural framework, evolution and structural style of the Southern Carpathians in the Getic Depression and their impact on prospectivity. AAPG European Regional Conference and Exhibition, Bucharest, Abstract Book, 80.

Hippolyte, J.-C., Săndulescu, M. 1996. Paleostress characterization of the Wallachian phase in its type area, southeastern Carpathians, Romania. *Tectonophysics* 263, 235–248.

Krézsek, C., Schléder, Z., Olaru-Florea, R., Tămaș, A., Oteleanu, A., Stoicescu, A., Ungureanu, C., Dudus, R., Tari, G. 2023. Structure and petroleum systems of the Eastern Carpathians, Romania. *Marine and Petroleum Geology* 151, 106179.

Mațenco, L. and Bertotti, G. 2000. Tertiary tectonic evolution of the external East Carpathians (Romania). *Tectonophysics*, 316, 255–286. https://doi.org/10.1016/S0040-1951(99)00261-9

Matenco, L. 2017. Tectonics and exhumation of Romanian Carpathians: inferences from kinematic and thermochronological studies. In: Rădoane, M., Vespremeanu-Stroe, A. (Eds), Landform Dynamics and Evolution in Romania. Springer, Berlin, 15–56.

Melinte-Dobrinescu, M.C., Brustur, T. 2008. Oligocene–Lower Miocene events in Romania. *Acta Palaeontologica Romaniae* 6, 203–215.

Merten, S., Mațenco, L., Foeken, J.P.T., Stuart, F.M., Andriessen, P.A.M. 2010. From nappe stacking to out-of-sequence post-collisional deformations: Cretaceous to Quaternary exhumation history of the SE Carpathians assessed by low-temperature thermochronology. *Tectonics* 29, TC3013.

Miclăuș, C., Loiacono, F., Puglisi, D., Baciu, D. 2009. Eocene–Oligocene sedimentation in the external areas of the Moldavide basin (Marginal Folds Nappe, Eastern Carpathians, Romania): sedimentological, palaeontological and petrographic approaches. *Geologica Carpathica* 60 (5), 397–417.

Mrazec, L. 1910. On the formation of the Romanian petroleum deposits. Third International Petroleum Congress (1907), Bucharest, Compte Rendu 2, 80–134 (in German).

Mrazec, L. 1926. Diapir folds and diapirism in general. Institutul Geologic al României, Compte Rendu 6 (1914–1915), 215–255 (in French).

Negru, F.-A., Roban, R.-D. 2015. Evaluation of the hydrocarbon potential for Lower Cretaceous deposits from the Marginal Folds Nappe, Romania. 77th EAGE Conference and Exhibition, Madrid, 1–3.

Palcu, D.V., Krijgsman, W. 2021. The Dire Straits of Paratethys: gateways to the anoxic giant of Eurasia. Geological Society, London, Special Publications 523.

Patrut, I., 1955. Geology and tectonics of the Vălenii de Munte–Cosminele–Bustenari region (in Romanian). *Anuarul Comitetului Geologic*, 28: 7–99.

Pătruț, I., Paraschiv, D., Dicea, O. 1973. Considerations on the mode of formation of diapiric structures in Romania. *Petrol și Gaze* 24 (9), 533–542 (in Romanian).

Popescu, G., Ciupagea, D., Georgescu, C., Baltes, N., Motas, C. 1973. General overview of the geology of the saliferous formations of Romania. *Petrol și Gaze* 24 (9), 525–532 (in Romanian).

Rabagia, T., Roban, R.D., Tarapoanca, M. 2011. Sedimentary records of Paleogene (Eocene to Lowermost Miocene) deformations near the contact between the Carpathian thrust belt and Moesia. *Oil & Gas Science and Technology, Revue d'IFP Energies Nouvelles*, (66) 931–952.

Roban, R.D., Ducea, M.N., Matenco, L., Panaiotu, G.C., Profeta, L., Krezsek, C., Melinte-Dobrinescu, M.C., Anastasiu, N., Dimofte, D., Apotrosoaiei, V., Francovschi, I. 2020. Lower Cretaceous provenance and sedimentary deposition in the Eastern Carpathians: inferences for the evolution of the subducted oceanic domain and its European passive continental margin. *Tectonics* 39 (7), e2019TC005780.

Rögl, F. 1998. Palaeogeographic considerations for Mediterranean and Paratethys seaways (Oligocene to Miocene). *Annalen des Naturhistorischen Museums in Wien* 99A, 279–310.

Sachsenhofer, R.F., Hentschke, J., Bechtel, A., Ćorić, S., Gross, D., Horsfield, B., Rachetti, A., Soliman, A. 2015. Hydrocarbon potential and depositional environments of Oligo-Miocene rocks in the Eastern Carpathians (Vrancea Nappe, Romania). *Marine and Petroleum Geology* 68, 269–290.

Sachsenhofer, R.F., Popov, S.V., Bechtel, A., Ćorić, S., Francu, J., Gratzer, R., Grunert, P., Kotarba, M., Mayer, J., Pupp, M., Rupprecht, B.J., Vincent, S.J. 2018. Oligocene and Lower Miocene source rocks in the Paratethys: palaeogeographic and stratigraphic controls. In: Simmons, M.D., Tari, G.C., Okay, A.I. (Eds), Petroleum Geology of the Black Sea. Geological Society, London, Special Publications 464, 267–306.

Sanders, C.A.E., Andriessen, P.A.M., Cloetingh, S.A.P.L. 1999. Life cycle of the East Carpathian orogen: erosion history of a doubly vergent critical wedge assessed by fission-track thermochronology. *Journal of Geophysical Research* 104, 29095–29112.

Săndulescu, M. 1984. Geotectonics of Romania. Editura Tehnică, Bucharest, 335 pp. (in Romanian).

Săndulescu, M. 1988. Cenozoic tectonic history of the Carpathians. In: Royden, L., Horváth, F. (Eds), The Pannonian Basin: A Study in Basin Evolution. AAPG Memoir 45, 17–25.

Săndulescu, M., Popescu, G., Mărunțeanu, M. 1995. Facies and stratigraphy of the Lower and Middle Miocene formations of the Slanic Syncline. *Romanian Journal of Stratigraphy* 76, 3–11.

Săndulescu, M., Ștefănescu, M., Butac, A., Pătruț, I., Zaharescu, P. 1981. Genetical and structural relations between flysch and molasse (the Eastern Carpathians model). Guide to Excursion A5, Guidebook Series 19, Institute of Geology and Geophysics, Bucharest.

Schléder, Z., Tămaș, D.M., Krézsek, C., Arnberger, K., Tulucan, A. 2019. Salt tectonics in the Bend Zone segment of the Carpathian fold and thrust belt, Romania. *International Journal of Earth Sciences* 108, 1595–1614.

Schmid, S.M., Bernoulli, D., Fügenschuh, B., Mațenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski, K. 2008. The Alpine–Carpathian–Dinaridic orogenic system: correlation and evolution of tectonic units. *Swiss Journal of Geosciences* 101 (1), 139–183.

Slaczka, A., Golonka, J., Oszczypko, N., Cieszkowski, M., Słomka, T., Matyasik, I. 2014. Occurrence of Upper Jurassic–Lower Cretaceous black organic-rich pelitic sediments as targets for unconventional hydrocarbon exploration in the Outer Carpathians and adjacent part of the Alps. *AAPG Bulletin* 98, 1967–1994.

Soto, J.I., Hudec, M.R. 2023. Mud volcanoes guided by thrusting in compressional settings. *Geology* 51 (8), 779–784.

Ștefănescu, M. 1978. Stratigraphy and structure of Cretaceous and Palaeogene flysch deposits between the Prahova and Ialomița valleys. PhD thesis, University of Bucharest, Bucharest.

Ștefănescu, M., Dicea, O., Tari, G. 2000. Influence of extension and compression on salt diapirism in its type area, East Carpathian Bend area, Romania, in B. C. Vendeville, Y. Mart, and J. L. Vigneresse, eds., Salt, shale and igneous diapirs in and around Europe. *Geological Society, London, Special Publications* 174, 131–147.

Ștefănescu, M., Dicea, O., Butac, A., Ciulavu, D. 2006. Hydrocarbon geology of the Romanian Carpathians, their foreland, and the Transylvanian Basin. In: Golonka, J., Picha, F.J. (Eds), The Carpathians and Their Foreland: Geology and Hydrocarbon Resources. AAPG Memoir 84, 521–567.

Sylvester, Z., Lowe, D.R. 2004. Textural trends in turbidites and slurry beds from the Oligocene flysch of the East Carpathians, Romania. *Sedimentology* 51, 945–972.

Szabo, B., 2012. Reconstruction of the Paleogene and Neogene marine paleoenvironments in the southernmost part of the Tarcau Nappe (East Carpathians) based on fossil foraminifera assemblages. Ph.D. Thesis, Babes-Bolyai University, Cluj-Napoca, Romania.

Tămaș, A., Tămaș, D.M., Krézsek, C., Schléder, Z., Palladino, G., Bercea, R. 2020b. The nature and significance of sand intrusions in a hydrocarbon-rich fold and thrust belt: Eastern Carpathians Bend Zone, Romania. *Journal of the Geological Society* 177, 343–356.

Tămaș, D.M., Schléder, Z., Krézsek, C., Man, S., Filipescu, S. 2018. Understanding salt in orogenic settings: the evolution of ideas in the Romanian Carpathians. *AAPG Bulletin* 102 (6), 941–958.

Tămaș, D.M., Schléder, Z., Tămaș, A., Krézsek, C., Copoț, B., Filipescu, S. 2020a. Middle Miocene evolution and structural style of the Diapir Fold Zone, Eastern Carpathian Bend Zone, Romania: insights from scaled analogue modelling. In: Hammerstein, J.A., Di Cuia, R., Cottam, M.A., Zamora, G., Butler, R.W.H. (Eds), Fold and Thrust Belts: Structural Style, Evolution and Exploration. Geological Society, London, Special Publications 490, 249–266.

Tămaș, D.M., Tămaș, A., Barabasch, J., Rowan, M.G., Schléder, Z., Krézsek, C., Urai, J.L. 2021. Low-angle shear within the exposed Mânzălești diapir, Romania: salt decapitation in the Eastern Carpathians fold-and-thrust belt. *Tectonics* 40, e2021TC006850.

Tămaș, D.M., Tămaș, A., Hajdas, I., Sava, G.O., Poncoș, V., Teleagă, D. 2025. Quaternary to recent uplift rates of salt diapirs in the Romanian Carpathians determined from radiocarbon dating and PSInSAR data. *Scientific Reports* 15 (1), 23379.

Tingay, M., Manga, M., Rudolph, M.L., Davies, R. 2018. An alternative review of facts, coincidences and past and future studies of the Lusi eruption. *Marine and Petroleum Geology* 95, 345–361.

Tulan, E., Sachsenhofer, R.F., Tari, G., Witkowski, J., Tămaș, D.M., Horvat, A., Tămaș, A. 2020. Hydrocarbon source rock potential and palaeoenvironment of lower Miocene diatomites in the Eastern Carpathians Bend Zone (Sibiciu de Sus, Romania). *Geologica Carpathica* 71 (5), 424–443.

Tulucan, A., Soveja-Iacob, L.E., Krézsek, C. 2018. History of the oil and gas industry in Romania. In: Craig, J., Gerali, F., Macaulay, F., Sorkhabi, R. (Eds), History of the European Oil and Gas Industry. Geological Society, London, Special Publications 465, 191–200.

FIELD TRIP 9

FT9. Late Cretaceous and Neogene magmatism in the Northern Apuseni Mountains

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1. GENERAL OUTLOOK ON THE STRUCTURE OF THE APUSENI MOUNTAINS

The field trip crosses the Apuseni Mountains (Fig. 1.1). The Apuseni Mountains structure, as described in different synthesis papers (e.g., Ianovici et al., 1976, Săndulescu, 1984, Balintoni, 1997, Schmid et al., 2008, 2020), owes its configuration to different tectonic events of the Alpine Orogeny. This orogen is presently located between the Pannonian basin to the west and the Transylvanian basin to the east (Fig. 1.2), and it is classically divided into two large structural domains: the South Apuseni Mountains (also known as the Metaliferous Mountains) and the North Apuseni Mountains (Fig.1.3). Each of these domains has a different origin, lithostratigraphic composition, and geological history. However, both structural areas are fold and thrust structures generated by the mid- and upper-Cretaceous tectonic events, which defined the South Apuseni architecture (e.g. Balintoni, 1994), and, respectively, the intra-Turonian tectonic phase that produced the final stacking in the Northern Apuseni (e.g. Balintoni, 1994, Schuller, 2004, Schmid et al., 2008, 2020).



Fig. 1.1. Location of the field trip stops

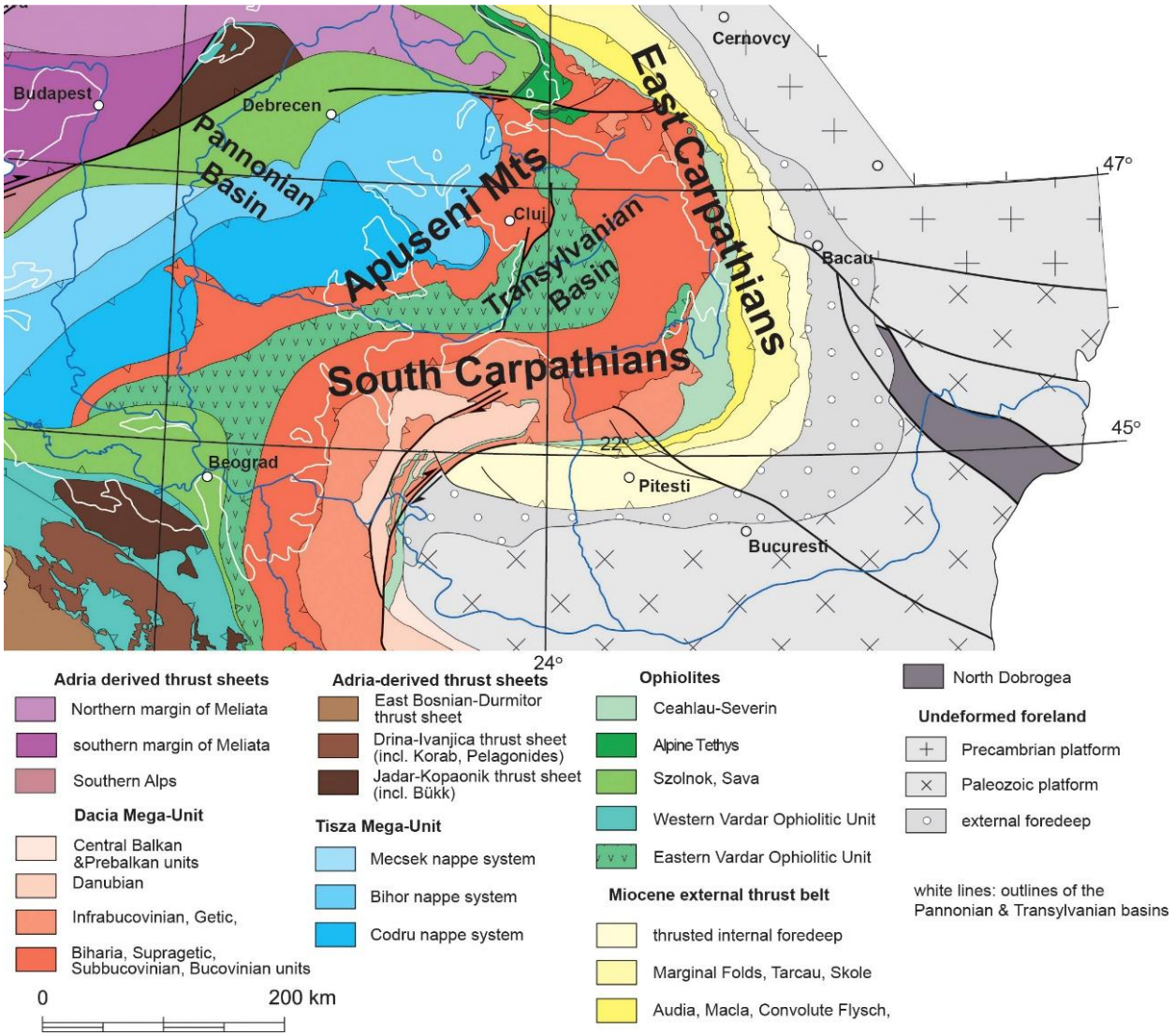


Fig. 1.2. Major tectonic units of the Carpathians and adjacent areas. Map adapted from Schmid et al. (2008), Kounov and Schmid (2013), and Schmid et al. (2020).

The provenance of the tectonic units comprising the two structural areas is still a matter of debate. However, according to the latest model proposed by Schmid et al. (2008, 2020), it is agreed to some extent that the tectonic units stacked in the northern domain (commonly referred to as the Apusenides) are crustal fragments representing two continental blocks, rifted off from Europe: Tisza and Dacia mega-units. The tectonic units separated in the southern area (referred to as the Transylvanides) represent the expression of the East Vardar oceanic domain (i.e., the Northern branch of the Neotethys ocean, Schmid et al., 2020).

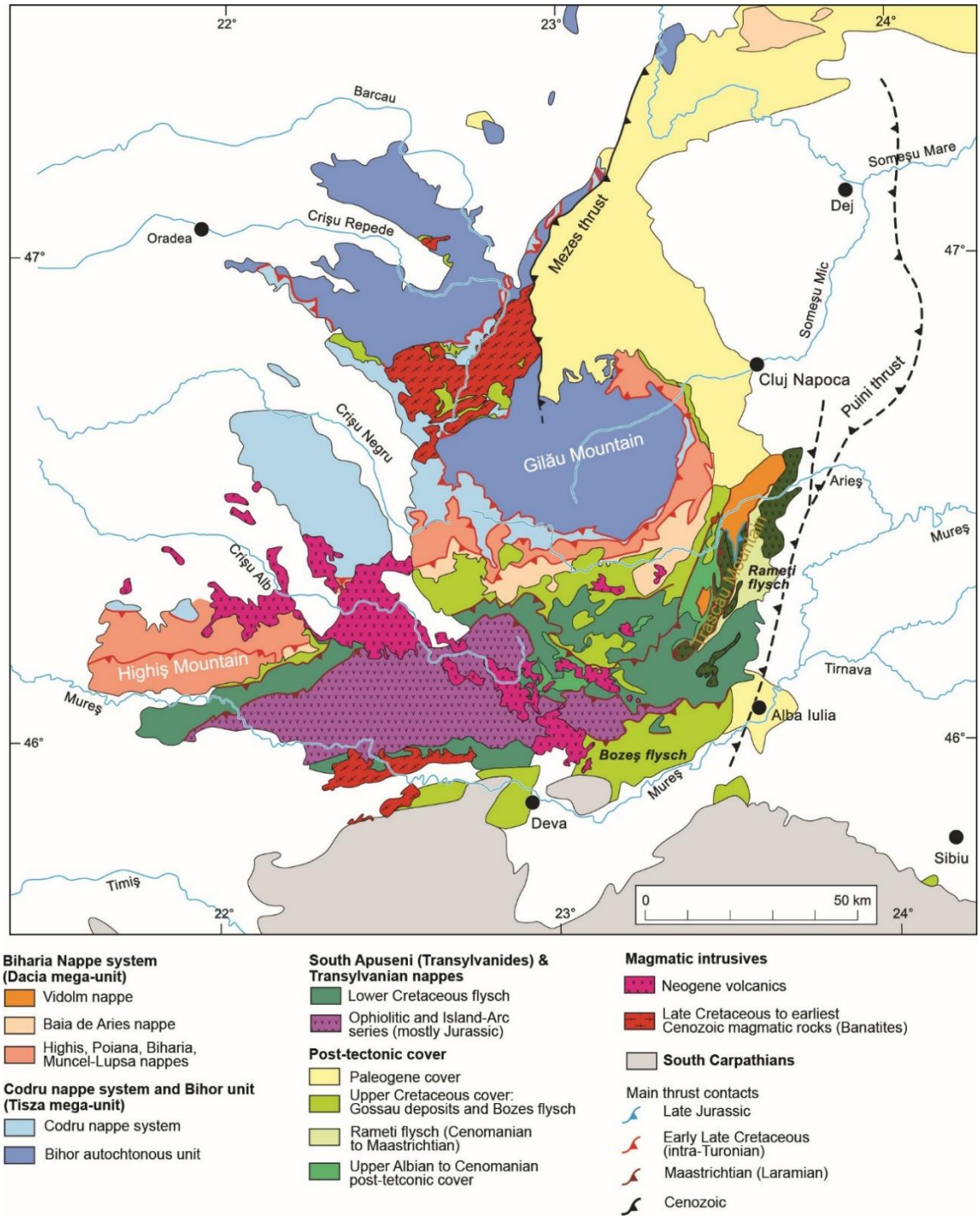


Fig. 1.3. The main Alpine tectonic units in the Apuseni Mountains. Map compiled after Bleahu et al., 1981; Sandulescu, 1984; Krautner et al., 1997; Balintoni and Puste, 2002; Balintoni et al., 2010; and Kounov et al., 2013.

North Apuseni Domain

The tectonic units that build this segment of the Apuseni Mountains are traditionally termed the ***Apusenides*** and expose, among others, the largest and most coherent outcropping parts of the Tisza mega-unit. These tectonic units are grouped according to their provenance, lithological content and geological histories, in two nappe systems: the Codru nappe system and the Biharia nappe system (Fig. 1.3). Both these nappe systems are thrust over the Bihor dome (i.e. Bihor unit or Bihor autochtonous unit), whose provenance is still disputed (e.g. Săndulescu, 1984;Balintoni, 1997; Schmid et al., 2008, 2020). Older reconstructions (e.g., Săndulescu, 1984; Balintoni, 1997) assumed that the tectonic units of both systems came from the

same crustal block, and each nappe system originates in different areas of this craton. Thus, the tectonic units comprising the Biharia nappe system originate in the Penninic active margin of the fore-Apulian (i.e., pre-Apulian, Săndulescu, 1984) Craton bordered by the Transilvanides rift, while the tectonic units making the Codru nappe system originate in the Meliatic passive margin of the fore-Apulian Craton (e.g., Săndulescu, 1984; Balintoni, 1997). However, Schmidt et al., 2008 and 2020 (and references therein) resolve the Alpine evolution differently. Firstly, the authors proposed that the Codru tectonic units and the Bihor unit have their origin within the Tisza mega-unit, a continental block rifted off main Europe during the Jurassic through a system of rifts connected to the main Alpine Tethys rift (Schmid et al., 2008). Secondly, the Biharia tectonic units are far-traveled nappes that originate in a different continental block, the Dacia mega-unit, together with other tectonic segments from the Romanian Carpathians (e.g., Getic, Infrabucovinian, etc, Schmid et al., 2008).

The Bihor unit is represented by a crystalline basement formed by medium-grade metamorphic rocks. The lithological association, largely known as the Somes series, comprises micaschists, quartzites, orthogneises, amphibolites and migmatites. Main features of this series (e.g. Balintoni, 1997), are given by the presence of frequent pegmatite bodies, large-scale migmatization (i.e. the Aries migmatites), and the presence of large Variscan granitic batholiths (i.e. Codru and Muntele Mare granites). It is worth mentioning that Somes series fragments have been identified in the basements of some tectonic units, both from the Codru nappe system (i.e. Finiș nappe) and the Biharia nappe system (i.e. Gârda nappe). The crystalline basement of the Bihor unit is conformably covered by Permian to lower Cretaceous sedimentary sequence (Pana et al. 2002; Balintoni et al. 2009, 2010), followed by unconformably post-tectonic late Albian to Cenomanian clastic sediments and by Turonian to Maastrichtian Gosau sediments (Sandulescu 1984; Balintoni 1994; Schuller 2004; Schuller et al. 2009).

Biharia nappe system. This nappe stack system occupies the tectonically highest position amongst the continentally derived tectonic units (i.e. the *Apusenides*), and was considered an integral part of the Tisza mega-unit by almost all authors working in the area, partly because of the Garda nappe, which was traditionally attributed to this system (e.g. Sandulescu, 1984, Balintoni, 1994, 1997, etc). However, more recent studies (i.e., Schmid et al., 2008, 2020) attribute the provenance of the Biharia nappe system to the Dacia mega-unit, based on the apparent involvement of the Biharia nappe system in the Early Cretaceous E-facing nappe stacking, which is typical for the East Carpathians basement nappes as parts of the Dacia continental block. The Biharia nappe system contains, from bottom to top, the following tectonic units (Fig. 1.3, 1.4): the Gârda nappe, the Poiana nappe, the Piatra Graitoare scale, the Highiș-Muncel nappe and the Baia de Arieș nappe (Balintoni, 1997). The Poiana and Highis-Muncel nappes are also known as the Highiș-Poiana and Muncel-Lupșa nappes (e.g. Săndulescu, 1984, Pană, 1998, Pană et al., 2002) However, the Gârda nappe has a basement represented by the Someș series and a Permo-Triassic cover similar to that of the Finiș nappe from the Codru nappe system, which makes it more likely part of this system (see discutions in Schmid et al 2008 and 2020 for instance), rather than of the Biharia system, as previously described by Balintoni, 1997. The Biharia nappe has, on its eastern part, a low-grade metamorphosed Triassic sedimentary cover, Vulturese Belioara series (Marza, 1969), formed of metasandstones, metaconglomerates and low-grade marbles. The Biharia nape basement is featured by particular lithologies, dominated by the presence of meta-igneous rocks represented mainly by mafic associations and subordinate metagranitoids, meta-ultramafics, as well as rare carbonate rocks, black quartzites and meta-terrigenous associations (Giușcă, 1960, Ianovici et al., 1976, Marza, 1969) These “Biharia type” lithologies has been described in the basements of Poiana, Highis-Muncel and Biharia nappes.

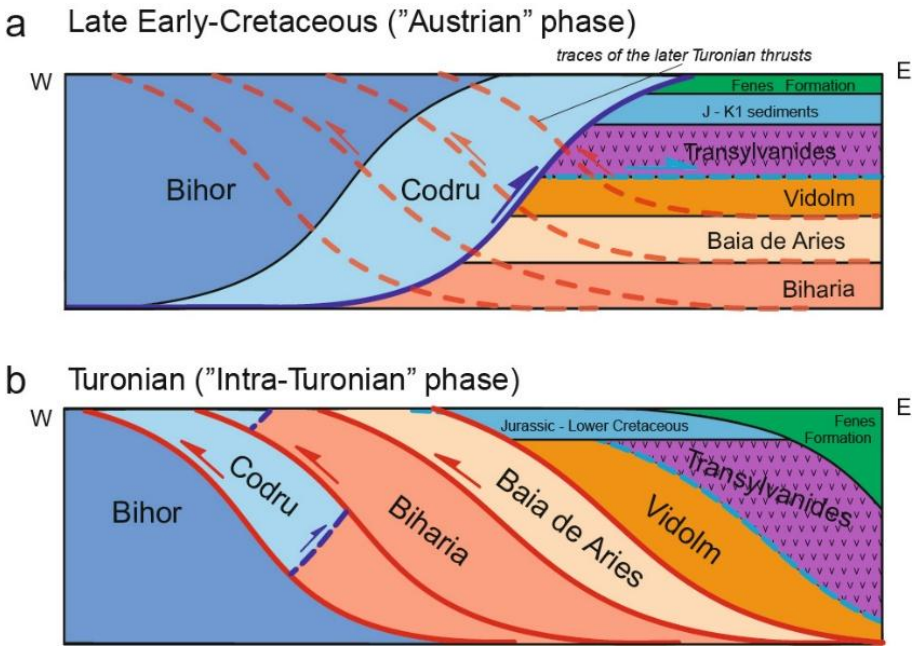


Fig. 1.4. Schematic depiction of an idealized cross section through the Eastern part of the Apuseni Mountains. Note that the intra-Turonian tectonic phase affected the Apusenides largely. Adapted from Kounov and Schmid, 2013.

The Baia de Aries nappe (e.g., Ianovici et al., 1976; Krautner, 1980; Balintoni, 1994, 1997) is exclusively a basement nappe and structurally occupies the topmost position in the Biharia nappe system. However, Pană (1998), separated at the uppermost part of this unit the Vidolm nappe, which tends to be frequently used in the more recent studies involving the structure of the Apuseni Mountains (e.g., Kounov and Schmid, 2013; Reiser, 2015; Reiser et al., 2017; Schmid et al., 2020). However, both units share the same basement, the Baia de Aries series. This series is largely defined by the presence of medium-to-high grade metamorphic rocks (garnet and staurolite-bearing micaschists, paragneisses, marbles, etc), as well as by the presence of Variscan granitoid bodies (e.g. Vința granite, Muncel granite, etc).

The structurally highest unit from this continental-derived nappe system, the Baia de Arieș nappe (or Vidolm unit), is overlain by the ophiolite-bearing South Apuseni nappes (or the *Transylvanides*).

The Codru nappe system. This nappe stack (Fig. 1.3) has an areal distribution restricted to the western part of the Bihor Mountains (i.e., Codru-Moma Mountains), and some patches in the northern border of the Highiș massif. The sequence of tectonic units is given by (from bottom to top, Ianovici et al., 1976, Balintoni, 1997): the Vălani nappe, Finiş-Ferice nappe, Următ nappe, Vetre nappe, Dieva-Batranescu nappe, Moma nappe, Vaşcau nappe and Colești nappe. In the Codru Mountains, the most comprehensive nappes are Dieva, Moma, Vascau and Colesti nappes. Except for the Finiș (or Finiș-Gârda, Schmid et al., 2008) unit that has a crystalline basement, the rest of the units are essentially cover units made up of Permo-Triassic sedimentary formations. Structurally, this nappe sequence is located between the Bihor unit and the Biharia nappe system (Fig. 1.4b; additionally see plate 3, profile 3 in Schmid et al., 2008 for a detailed section through the Apuseni Mountains). The Codru nappe system, along with the other nappe succession that forms the Tisza mega-unit (i.e. Mecsek, Bihor), was thrusted during the Turonian, predating the latest Turonian deposition of the post-tectonic Gossau sediments (e.g., Schuller, 2004)

The Southern Apuseni Mountains

Most of the review papers refer to these units as *the Transylvanides* (e.g. Sandulescu, 1984; Balintoni, 1997). The Transylvanides (Fig. 1.2, 1.3) are antitethic ophiolite-bearing tectonic units (Balintoni, 2007), and are grouped with ophiolitic nappes that occur beneath the Neogene sediments of the Transylvanian Basin, and with those that are exposed in the Transylvanian nappes of the East Carpathians (Fig. 1.2; e.g. Schmid et al., 2008, 2020). According to Schmid et al. (2008, 2020), are remnants of the Eastern Vardar Ocean (as part of the larger Neotethys ocean) obducted over the margin of the Dacia mega-unit. Parts of

these ophiolites show MORB signatures (Nicolae, 1994), while the other parts of these generally called ophiolites represent remnants of a Late Jurassic intra-oceanic island arc which includes basalts, andesites, rhyolites and some granites, slightly younger than the surrounding MORB-type basalts (Bortolotti et al. 2002; Nicolae and Saccani 2003; Bortolotti et al. 2004). These particular arc-type sequences are widespread in the Trascau Mountains, South of Cluj. These South Apuseni ophiolites are unconformably covered by Late Jurassic (Late Oxfordian) - Early Cretaceous limestones (e.g. Sasaran, 2006) which also step over the contact between the ophiolites and the underlying Baia de Aries nappe (Sasaran, 2006). This suggests that the Transylvanides were thrusted over (obducted) the topmost unit of the Biharia Nappe system before the Late Oxfordian. Generally, the sedimentary sequences are dominated by thick Late Jurassic – Early Cretaceous limestones, followed by Barremian – Aptian turbidite deposits (flysch deposits) followed by Aptian – Albian wildflysch (Bleahu et al. 1981; Săndulescu 1984). This wildflysch formation marks the second and main ("Austrian") deformational event that affected the South Apuseni sector. This event produced a set of tectonic units represented by: Izvoarele, Valea Muntelui, Colţu Trascaului, and Bedeleu nappes. A third, Late Campanian – Maastrichtian compressional event, known as "Laramian" tectogenesis (e.g., Balintoni, 1997), is responsible for the top-ESE thrusting. This event produced the high-angle pop-up in the Trascau Mountains (Schmid et al., 2008), and also affected the South Apuseni ophiolites and their Jurassic to late Cretaceous sedimentary cover. It is worth mentioning that this "Laramian" thrusting was also reported from the Mures valley area, where the most frontal tectonic fragments of the South Apuseni units were indented towards N and NW and thrusted onto the sedimentary cover of the eastern part of the Biharia nappe system (Fig. 1.3, Balintoni, 1994).

Cenozoic evolution of the Apuseni Mountains and Neogene volcanism

Post-Cretaceous compressional events and up to Miocene the Apuseni Mountains and Transylvanian basin experienced a complex tectonic evolution (see Merten et al., 2011 for a review). The last compressional event recorded during the early Miocene is related to thrusting north of the Transylvanian basin (Tischler et al., 2007). Subsidence of the Transylvanian basin started during early to mid-Miocene, in the back-arc area of the eastward retreating Carpathian arc (Cloeting et al., 2006), coeval with the ongoing clockwise rotation of the Tisza and Dacia mega-units by up to 70º (Panaiotu, 1999), rotation that started probably earlier (Oligocene or earlier, e.g. Rosu et al., 2004, Fuegenschuh and Schmid, 2005). This rotation was combined with indentation of these two blocks (i.e., Tisza and Dacia) into the Carpathians embayment, while the Apuseni Mts remained highland during most of the Cenozoic. The Neogene evolution of the area is mostly a combined effect of these rotational and extensional events with the continental collision and possibly continental subduction, that trigered widespread calcalkaline and alkaline magmatism (Fig. 1.3), which reached maxima between 14.7 and 7.4 Ma and waned out around 1.6 Ma (Roșu et al., 1997, 2004).

According to Roșu et al (2004), the Neogene magmatism in the South Apuseni Mountains follow two apparent lineaments (without any genetic connotation): (i) – WNW – ESE lineament, between Miniș in the west and Zlatna in the east (approx 100 km), containing Zarand, Brad and Zlatna volcano-intrusive structures, and (ii) – NNE – SSW lineament, containing (1) Baia de Aries – Rosia Montana – Bucium, (2) Sacaramb and (3) Deva volcano-intrusive structures. Deva volcano-intrusive structure also contains the youngest marker of volcanic activity at Uroi (1.6 Ma). Generally, it is believed that the protracted subduction combined with the extensional regime due to the post-Miocene roll-back was the main contributor for the enrichment of lithospheric sourced melts as well as for the calc-alkaline to alkaline variability, while the rotation induced the lower crust – lithosphere melting and facilitated the pathways for calc-alkaline to alkaline magmas, after the rotation ceased (see Roșu et al., 2004 and Ene et al., 2024 for an updated review on Neogene magmatism in the South Apuseni Mountains).

2. ALPINE MAGMATIC ACTIVITY IN THE APUSENI MOUNTAINS

The magmatic activity associated with the Alpine orogenesis took place on the territory of Romania in several stages, closely related to the tectonic evolution of the Carpathian-Pannonian region during the Mesozoic and Cenozoic. The associations of Alpine magmatic rocks are predominantly characteristic of subduction and post-collisional geostructural conditions. A special situation occurred in the Apuseni Mountains during the Neogene due to the setup of an extensional regime of the back-arc type in relation to the subduction in the northern part of the Eastern Carpathians. This tectonic context, corroborated with the clockwise rotation and the eastward migration of the Tiszia and Dacia adjacent unit (acc. Schmid et al. 2008), controlled the distribution of Neogene magmatic rocks within the Apuseni Mountains, which generally corresponds to the development of alignments of tectonic Neogene basins.

Earlier, during Jurassic – Lower Cretaceous, two distinct extensional oceanic basins were active: the Alpine Tethys ocean branch, which separated Tiszia and Dacia units, and the Cehlău-Severin Ocean, respectively (Schmid et al. 2008). The magmatic basic rocks of ocean-floor type are associated with sediment outcrops on large areas in the Apuseni (South Ophiolite of Apuseni Mountains according to Schmid et al. 2008), and the Eastern Carpathians, respectively (Transylvanian Ophiolites, according to Schmid et al. 2008). Similar rocks are also present in the Southern Carpathians (Severinides nappes, according to Balintoni, 1994).

The ophiolites are in tectonic position, and those located in the South Apuseni Mountains belong to the Transylvanide nappes (according to Balintoni, 1997).

On the Romanian territory, the Alpine-related magmatic rocks are found today in the inner part of the accretion prism of the Eastern Carpathians, in the western Southern Carpathians (Poiana Ruscă and Banat) and Apuseni Mountains, respectively.

The Late Cretaceous (– Paleogene?) magmatic activity determined mainly the formation of calc-alkaline products, and the final phases being marked by subordinate alkaline rocks. The magmatic products of this stage are found both north and south of the "ophiolitic suture" (Mureș zone) of the Apuseni Mountains. The magmatic rocks are of continental–margin arc, those located north of the ophiolitic suture being generated by the subduction of the oceanic plate in the western basin (Alpine Tethys branch according to Schmid et al., 2008), and those in Poiana Ruscă and Banat following the subduction in the eastern basin (acc. Rădulescu and Săndulescu, 1973) or Ceahlău-Severine ocean (according to Schmid et al., 2008).

Regarding the distribution of the Late Cretaceous magmatic rocks in the Carpathian-Balkan orogen, Gallhofer et al. (2015) show that the Apuseni-Banat-Timok-Srednogorie Late Cretaceous magmatic arc is a unitary one in the Carpathian-Balkan orogen formed on the European margin during closure of the Neotethys Ocean.

Referring to the spatial distribution of Banatitic magmatic rocks in relation to the subduction in the western and eastern basins respectively, Rădulescu and Dimitrescu (1982) consider that a major separation can be made first based on differences in the magma sources. They state: "*...this separation - the area to the N and W of the ophiolitic region of the Apuseni Mountains and the area between this region and the ophiolitic region of the Southern Carpathians - is not obvious at first sight because, for reasons unknown to us, the two areas with linear development are arranged in continuity, giving the impression of a single rectilinear area*."

Subsequent results of structural geology studies, corroborated with paleomagnetism data on the tectonic evolution of the Carpathian-Pannonian area during the Tertiary, established that the Tisia Block and the Getic Carton underwent a clockwise rotation process around the corner of the Moesian Plate in the Middle Miocene (Ratschbacher et al., 1992) followed by an eastward translation (Csontos, 1995).

In the Apuseni Mountains, paleomagnetic determinations on Neogene volcanics identified a 60-70o clockwise rotation (Pătraşcu et al., 1994). Thus, it can be concluded that the current position of the Banatites located north of the ophiolitic region of the Apuseni Mountains is allochthonous; initially, these were

developed in an approximately NW - SE direction. The distinct evolution of the Upper Cretaceous - Paleogene magmatism in the northern and southern parts of the ophiolites in the Apuseni Mountains is also emphasized by Jankovic and Jelenkovic (1998), considering that the two petrographic provinces are independent and formed under separate geotectonic conditions.

Late Cretaceous magmatic activity from the North Apuseni Mountains. The Late Cretaceous -Paleogene magmatic rocks from the Apuseni Mountains are located north of the ophiolite suture and are tectonically related to the subduction from the Alpine Tethys branch according to Schmid et al. (2008).

It represents an important segment of the Banatitic Magmatic and Metallogenetic Belt (BMMB) extended on Romania, Serbia and Bulgaria and belongs to a complex calc-alkaline magmatic arc of Late Cretaceous age, hosting a variety of magmatic-hydrothermal Cu, Au, Mo, Zn, Pb and Fe deposits, including Europe's only world-class porphyry-copper deposits. (Ciobanu et al. 2002).

Following the compressional regime, the subduction of the oceanic plate of the western basin (Neotethys Ocean as defined by Gallhofer et al. (2015), under the pre-Apulian craton takes place; the magmatism generated by this process develops in two main phases (Giuşcă et al., 1966; Savu, 1976; Rădulescu and Dimitrescu, 1982; Ştefan et al, 1988):

- as a result of the Mesocretaceous and pre-Gosau movements, the first phase of magmatic processes occurred in the Turonian - Senonian interval, determining the formation of rocks in predominantly extrusive facies (andesites, dacites, rhyolites and associated pyroclastics);

- following the Laramian movements, a second phase of magmatic processes occurred in the Paleogene, characterized by the replacement of abyssal and hypabyssal intrusions (granodiorites, diorites, quartz diorites, granites, monzonites, porphyry granodiorites, porphyry granites, microgranites, microdiorites as well as associated aplites and lamprophyres). Mârza and Mészáros (1987) mention, for the north-eastern border of the Gilău massif and the eastern part of the Transylvanian depression, the existence of a third phase, defined as post-Laramian, whose products (pyroclastics and geysers) were identified in Eocene and Oligocene sedimentary formations. The magmatic manifestations within this phase are of lower intensity and are associated with the Pre-Pyrenean, Pyrenean and Savic tectonic movements. Later, Har (2001) determined the Bartonian age (40.6 ± 2.4 Ma) of the olivine-bearing calc-alkaline basalts from Cionca Hill (on the eastern rim of Gilau Mountains), which belongs to the same third stage described by Mârza and Mészáros (1987).

The issue of the evolution of the Upper Cretaceous - Paleogene magmatism and the associated metallogenesis in the Apuseni Mountains has been the subject of study of a very large number of scientific works that have outlined the spatial and temporal development of the Banatites, the geological - structural conditions in which the generating magmatism functioned and the petrogenetic and metallogenetic processes characteristic of it.

Ştefan et al. (1988, 1992) delimit the evolution of calc-alkaline Banatitic magmatism on the territory of the Apuseni Mountains, within two main phases:

- *phase I,* characterized by the presence of lava flows, sometimes accompanied by pyroclastics (Vlădeasa, Meseş - Valea Chioarului). Simultaneously with these manifestations, small subvolcanic bodies were emplaced (Vlădeasa, Gilău, Bihor). The magmatism of the first phase is very well represented in the Vlădeasa Mountains and with a lower extension in the Gilău, Meseş and Valea Chioarului Mountains. The manifestations began with lava flows of andesitic composition (quartz andesites with pyroxenes, with hornblende, with biotite) which in the Vlădeasa Mountains have the greatest extension and are located on fracture lines that border the graben of this massif. The andesites are followed by dacites that cut them and trap andesites as xenoliths. The dacites constitute intrusive sheets, dykes, and lava flows that cover Lower Coniacian - Lower Maastrichtian deposits (Dragoş, 1971). The Vlădeasa Mountains constitute the typical area of Upper Cretaceous - Paleogene first phase volcanics, represented by a large volume of rhyolites, a part of the plutono-volcanic complex developed in this massif. The Vlădeasa rhyolites, developed in ignimbrite facies, cut through and include as xenoliths the previously formed andesites, dacites and

rhyolites and, upon contact with them, determine the formation of breccias. Absolute age datings performed by the K-Ar method on the rhyolites from Vlădeasa indicate 61 ± 3.0 Ma and 61.5 ± 5.0 Ma (Bleahu et al., 1984). Banatitic volcanism in this region ends before Middle Eocene, and fragments of andesites, dacites, and rhyolites occur as boulders in conglomerates that appear at the base of the lower banded complex (Paleocene - Ypresian).

In the Bihor Mountains, the products of the first phase are represented by rhyodacites and subordinately dacites. The rhyodacites are developed as sills and irregular bodies, intruded into the crystalline schists of the Biharia series, and the dacites are arranged in the form of small subvolcanic bodies. In the NE part of the Gilău Mountains, sills, dykes, and irregular bodies of rhyodacites are also present. Rhyolites developed in ignimbrite facies, like those in Vlădeasa, are present in the northernmost occurrences of this type, to the NE of Zalău, in the Măguricea and Puguiorul hills. The bentonitized rhyolite dyke from Valea Chioarului also belongs to the first phase of the manifestations of the Upper Cretaceous - Paleogene stage.

- *phase II,* characterized by the emplacement of intrusive bodies, developed in abyssal and hypabyssic facies, consisting mainly of granodiorites, granites and quartziferous diorites which are accompanied by their porphyry varieties developed on the periphery of plutonic bodies or as their apophyses. The last Banatitic magmatic rocks occur as differentiated alkaline products and dykes, i.e., basalts, basaltic andesites and lamprophyres. Banatitic magmatism in phase II begins with quartz diorites, porphyritic microdiorites, porphyritic diorites and andesites which, in Valea Ţoha (south of Arieşul Mic in Bihor) cross the rhyolites of the first cycle (Jude and Ştefan, 1967). In the southern part of the Bihor Mountains, at Hălmăgel and Obârşia, the quartz diorites are crossed by granodiorites and granites, and at Stânişoara, the porphyry rocks of dioritic composition are thermally affected by bodies of granodioritic and granitic composition. Also, in the Bihor Mountains (Hălmăgel, Obârşia, Muntele Găina, and Valea Seacă) the rocks of dioritic composition and the porphyry varieties are arranged on the periphery or in the roof of the granitic plutons. In the Valea Seacă area, the magmatic rocks have a quartz - monzodiorite composition, being similar to those from Măgureaua Vaţei - Valea Birtinului.

At Pietroasa, Budureasa and the western part of the Vlădeasa massif, rocks of quartz-diorite composition are known, developed as independent bodies or on the periphery of bodies of granodioritic, granitic and monzogranitic composition. Porphyritic microdiorites are also known in the north-eastern part of the Vlădeasa massif, north of Crişul Repede, developed on the periphery of porphyritic granodiorite bodies. In the Gilău Mountains, south of the Băişoara locality, Banatitic bodies of granodioritic composition are present, which in the marginal facies pass into quartz diorites, monzodiorite and their porphyritic varieties. Monzodiorites are frequently encountered as a transitional lithology between granodiorites and quartz diorites. In the region, small bodies consisting of porphyritic microdiorites, quartz diorites, porphyritic quartz andesites, basaltic andesites and rhyolites are also common. Microdiorite bodies, with small dimensions, are also known in the Borod area. In the Meseş, Trascău, Măgureaua Vaţei - Valea Birtinului area, porphyritic quartz andesites and microdiorites occur. The second phase of the Upper Cretaceous - Paleogene magmatism on the territory of the Apuseni Mountains ends with the formation of differentiated alkaline products represented by aplites, porphyritic microgranites, micropegmatites, etc., developed as dykes.

Neogene - Quaternary volcanism from Apuseni Mountains. The Neogene - Quaternary volcanism has the highest complexity in terms of the geological and structural conditions. During the Neogene, an extensional regime of the back-arc type in relation to the subduction in the northern part of the Eastern Carpathians, corroborated with the clockwise rotation and the eastward migration of the Tisia – Dacia Unit block (Csontos, 1995; Seghedi et al., 2004) controlled the distribution of Neogene magmatic rocks on the territory of the Apuseni Mountains, which generally corresponds to the development alignments of the Neogene basins of tectonic nature.

Based on spatial distribution of the Neogene magmatism in the Carpathian – Pannonian, Seghedi et al. (2004) defined four segments, three of them being partly or totally developed on the Romanian territory:

(1) the Western Segment that includes the West Carpathians and Pannonian basin (North Hungary and Central Slovakia); (2) a Central Segment from Tokaj-Slanské – Vihorlat to the Călimani Mountains; (3) the South-Eastern Segment from Călimani (north) to the Harghita Mountains (south) and (4) the Interior Segment, whose dominantly intermediate volcanic activity occurred mostly at 15 –8 Ma in the Apuseni Mountain area. Alkalic basaltic and shoshonitic volcanism post-dated the calc-alkaline magmatism (2.5–1.5 Ma).

Regarding the spatial distribution of the products of Neogene - Quaternary volcanism, on the territory of the Apuseni Mountains, Har (2001) separated five areas where they outcrop: Mureş Valley, Brad - Săcărâmb, Zarand (on the course of the Crişului Alb), Zlatna - Stănija and Roşia Montană - Bucium - Baia de Arieş. From a geochemical point of view, the calc-alkaline character (acid and intermediate) of the products generated in the Lower Badenian - Pliocene interval is notable (Mureş Valley, Brad - Săcărâmb, Zarand, Zlatna - Stănija and Roşia Montană - Bucium - Baia de Arieş) and an alkaline (shoshonitic) character of the products of Quaternary age (Mureş Valley - Uroi).

The Neogene - Quaternary volcanism in the Apuseni Mountains is further systematized based on chemical character: calc-alkaline volcanism, with an initial acidic phase, followed by an intermediate phase and alkaline (shoshonitic) volcanism that ends the magmatism. Overall, the following main characteristics for the Neogene - Quaternary volcanism in the Apuseni Mountains can be noticed:

- magmatic activity begins in the lower Badenian, with the formation of acidic products, represented by rhyolites and rhyodacites, in some situations these being developed in an ignimbrite facies;
- the acidic phase is followed by calc-alkaline volcanism with a much wider representation both in terms of the volume of resulting rocks and the areas of spread. The products of intermediate volcanism are andesitic rocks (quartzite andesites with biotite, quartzite andesites with amphiboles and pyroxenes, quartzite andesites with pyroxenes, andesites with biotite, andesites with biotite and amphiboles, andesites with amphiboles, andesites with pyroxenes) and associated pyroclastics;
- the paroxysm of calc-alkaline volcanism took place in Sarmatian, during which volcanic activity was present in all volcanic areas of Apuseni (Mureşului Valley, Brad - Săcârâmb, Zarand, Zlatna - Stănija and Roşia Montană - Bucium - Baia de Arieş). The volcanic structures formed are very varied, with mixed stratovolcanoes predominating (lava flows alternating with pyroclastic products), and situations are also known in which volcanic effusions (lava flows) are the manifestations that led to the formation of the volcanic apparatus (Haneş). Post-Sarmatian, the intermediate volcanic activity gradually narrows and ends towards the end of the Pannonian;
- the youngest calc-alkaline intermediate products are formed in the Northern Apuseni, the Roșia Montană - Bucium - Baia de Arieș volcanic zone, towards the end of the Pannonian, these being the basaltic andesites from Detunata (7.4 Ma, Roșu et al., 1997);
- the final stage of the evolution of the Neogene - Quaternary volcanism in the Apuseni Mountains takes place in the Mureş Valley through an alkaline magmatic activity, with punctiform development, and determines the emplacement of the shoshonitic andesites from Magura Uroiului. These rocks formed in the Quaternary (1.6 Ma, Csontos et al., 1995).

The South Apuseni Mountains host the most important Neogene-related ore deposits in Romania. There are porphyry Cu-Au (Deva, Roșia Poieni; Ivascanu et al., 2019) and Au-Cu deposits (Bolcana; Ivascanu et al., 2019), the whole range of epithermal deposits (Ivascanu et al., 2019; Tămaș et al., 2021), i.e., low-sulfidation (e.g. Baia de Arieș, Roșia Montană), intermediate-sulfidation (e.g., Certej, Roșia Montană), high-sulfidation (Larga, Pârâul lui Avram), as well as replacement deposits (e.g., Baia de Arieș; Borcoș et al., 1984).

The field trip no. 9 will cover areas in the North Apuseni Mountains where different magmatic rocks formed in connection with the Alpine tectono-magmatic evolution: the ophiolites from Trascau Mountains, Neogene volcanics from Roșia Montană- Roşia Poieni area, and Late Cretaceous magmatic rocks from

Băişoara-Surduc area, Jidovina Massif (Aries Valley), Budureasa and North of Vlădeasa Mountains (Valea Lungii, Poieni and Bologa).

3. BĂIŞOARA – MAŞCA – CACOVA IERII AREA

Băișoara Quarry is located at the confluence of Ierii and Sacelului Valleys, at the contact of the orogen of Apuseni Mountains with the sedimentary deposits of the Transylvanian Basin. Magmatic dykes intruded into the metamorphic rocks of the Baia de Aries unit, which are open into the quarry used for raw materials for road construction.



Fig. 3.1. Băișoara quarry open into the metamorphic rocks of Baia de Arieș pierced by Late Cretaceous dacite dykes; photo N. Har.

Geological framework. The geological structure of the Băișoara – Mașca - Cacova Ierii area (Fig. 3.2) consists of (1) crystalline schists, (2) sedimentary formations and (3) igneous rocks (Intorsureanu and Lazar, 1992).

(1) The crystalline schist in the quarry from Băișoara belongs to the Baia de Arieș unit. Stan (2006) describes three sub-units of the Baia de Arieș: (a) Lower part - paragneiss and micaschists with intercalations of migmatized amphibolites, and characteristic quartzites, black graphitic schists, meta-porphyroids and meta-granitoids; (b) Middle part - formed by thick carbonate levels characteristic of the Baia de Arieș unit; (c) Upper part - paragneiss, micaschists, white quartzites and micaceous quartzites, and amphibolites.

The metamorphic rocks in the Băișoara quarry consist of micaschists and black graphitic schists of the lower part of the Baia de Arieș unit.

(2) The sedimentary formations in the Băișoara-Mașca-Cacova Ierii area belong to the Permian, Senonian, Tertiary and Quaternary. In the area of interest, there are Senonian sedimentary deposits represented by carbonate rocks and flysch deposits formed of Santonian – Maastrichtian microconglomerates, sandstones, marls, and clays.

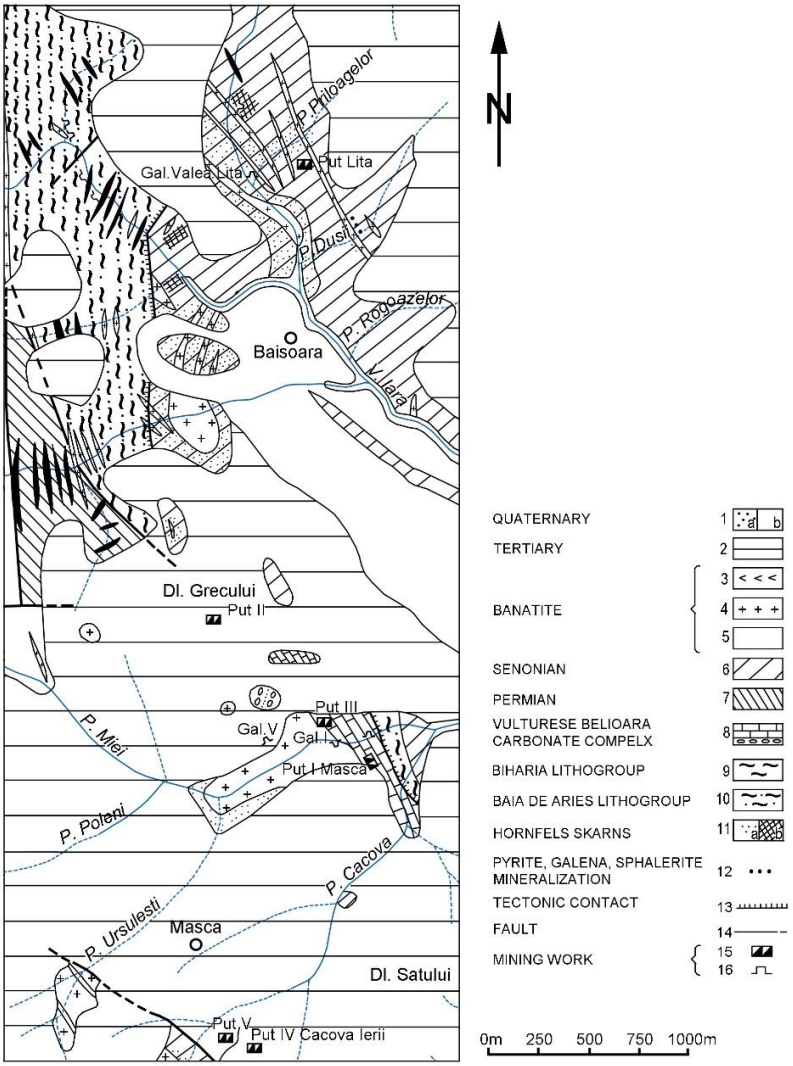


Fig 3.2. Geological sketch of the Băișoara- Mașca – Cacova Ierii area; from Intorsureanu and Lazar, 1992.

(3) Banatitic igneous rocks form an intrusive complex consisting of numerous bodies, apophyses and veins oriented predominantly NNW-SSE, suggesting the existence of an intrusive pluton at depth. Banatitic rocks are represented by granodiorites, porphyritic granodiorites, microgranodiorites. quartz diorites, porphyritic diorites, granites, hornblende andesites, dacites (Fig. 3.3), rhyolites, granitic aplite, etc. (Intorsureanu and Lazar, 1992).

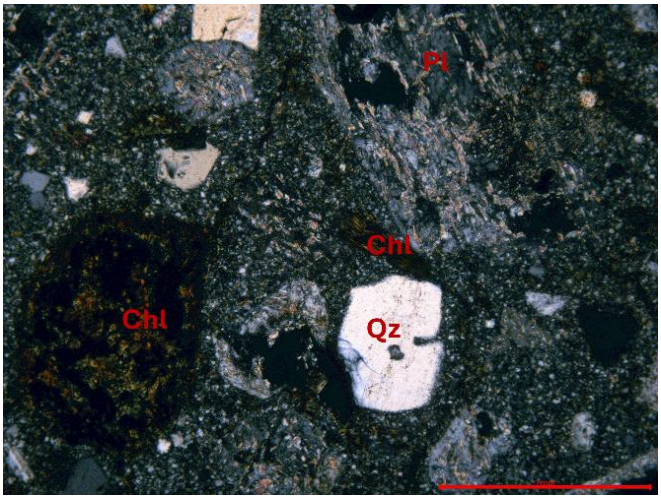


Fig. 3.3. Microphotograph under the microscope at crossed polars of dacite from Băișoara quarry. Pl- plagioclase feldspars, Qz – Magmatic corroded quartz, Chl- chlorite replacing phenocrysts of biotite; Scale bar = 1 mm.

The contact metamorphism generated by the Banatitic intrusions determined the formation of a contact aureola composed of hornfelses, marbles, skarns, and metallic mineralization, up to a hundred meters into the surrounding rocks, etc.

Depending on preexisting rocks, under the influence of temperature, hornfels with diopside, epidote, and actinolite, with biotite, etc. were formed. The crystalline limestone and dolomites recrystallized, and the presence of quartz impurities led to the formation of dolomite with forsterite±serpentinite minerals, brucite, etc.

The thermal metasomatic metamorphism took place at the contact of the Banatitic intrusions and the Paleozoic carbonate complex of Vulturese – Belioara crystalline limestone and dolomites (Maşca – Băişoara and Cacova Ierii deposits) and Senonian flysch-like marls and sandstones at Valea Lita deposit, and different types of skarns were generated. On the eastern border of the Gilău Mountains, in the Săcelului Valley- Baişoara - Maşca - Cacova Ierii area, there are typical occurrences of magnetite and sulfide skarn ore deposits with magnetite and sulfides.

Intorsureanu and Lazar (1992) carry out a synthesis of the geology of the skarn deposits from the mentioned area and present their genetic conditions and associated mineralization.

Different types of skarns are known according to the paleosome (exo- and endoskarns), chemistry (magnesian and calcic skarns) and mineral composition. The exoskarns are magnesian (MgO/CaO > 1) with spinel, forsterite, diopside, phlogopite and clinohumite, and calcic skarn (MgO/CaO < 1) with salite-hedenbergite, garnets, epidote, wollastonite, vesuvianite and ilvaite (Fig. 3.4 and 3.5).

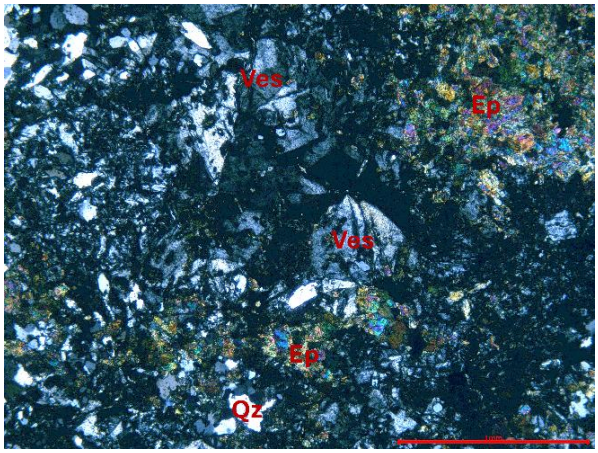


Fig. 3.4. Microphotograph under the microscope at crossed polars of vesuvianite (Ves) and epidote (Ep) in skarn from Valea Săcelului. Qz- quartz. Scale bar = 1 mm.

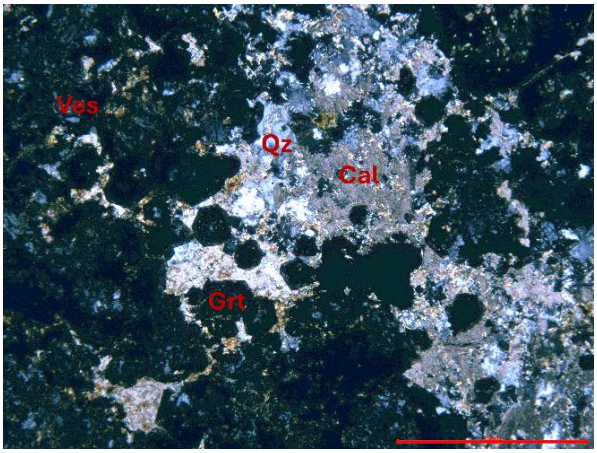


Fig. 3.5. Microphotograph under the microscope at crossed polars of vesuvianite (Ves) and garnet (Grt) in skarn from Valea Săcelului. Cal – calcite, Qz – quartz. Scale bar = 1 mm.

Three important ore deposits are related to the metasomatic-hydrothermal activity associated with the Late Cretaceous-Paleogene magmatic intrusions in this area: Maşca Băişoara, Cacova Ierii and Valea Lita. There is a high similarity between the deposits at Maşca – Baişoara and Cacova Ierii, formed by the substitution of the same carbonate paleosome, while Valea Lita is formed based on marls and marly sandstones and presents a different mineralization.

Intorsureanu and Lazar (1992) identified four mineralization types related to the skarn deposits: (1) the iron ore occur in Maşca-Băişoara and Cacova Ierii consisting of oxides (magnetite ± hematite ± maghemite) and iron sulfides (pyrrhotite ± pyrite ± marcasite; (2) the zinc mineralization (sphalerite ± galena ± pyrite ± chalcopyrite) is present in Valea Lita ore deposit; (3) the base metal ore (galena ± sphalerite ± pyrite ± chalcopyrite ± mispickel ± molybdenite occurs in peripheral areas and (4) the boron mineralization (ludwigite ± szaibelyite).

The iron ore deposit was exploited for more than 20 years in the underground Mașca Băișoara mine, which is presently closed. The primary iron minerals were extracted, milled, and separated using physical methods (magnetic procedure), and the resulting waste material was deposited in the tailings pond (Fig. 3.6).

The tailings pond of Mașca – Băișoara mine has been subjected to the biological remediation conducted in 2004-2006 in the frame of a research project within PNCDI – BIOTECH.



Fig. 3.6. The tailings pond of Masca Mine

4. SURDUC QUARRY

The Surduc dolomite quarry is located on the left slope of the Iara Valley, about 3 km downstream of Surduc and 4 km upstream of Buru, and is currently not in operation, although underground mining of the rock was attempted in the past. The crystalline dolomites in the Valea Ierii quarry, downstream of the Surduc village, embedded in biotite micaschists with garnets and microblastic gneisses, are traversed by dioritic vein bodies (metadiorites), which cause both contact mineralization and hydrothermal manifestation. The dioritic dyke (Fig. 4.1), probably the apophyses of a magmatic intrusion, is small (tens of meters long, maximum 2 m thick) and is intruded on the contact between crystalline dolomite and micaschists. The thickness varies within the same vein, presenting irregularities and constrictions, and the magmatic rock contains numerous dolomite enclaves, with centimetric or millimetric dimensions.

In the Surduc quarry, magmatic and metamorphic (dolomite and skarn) rocks are present.

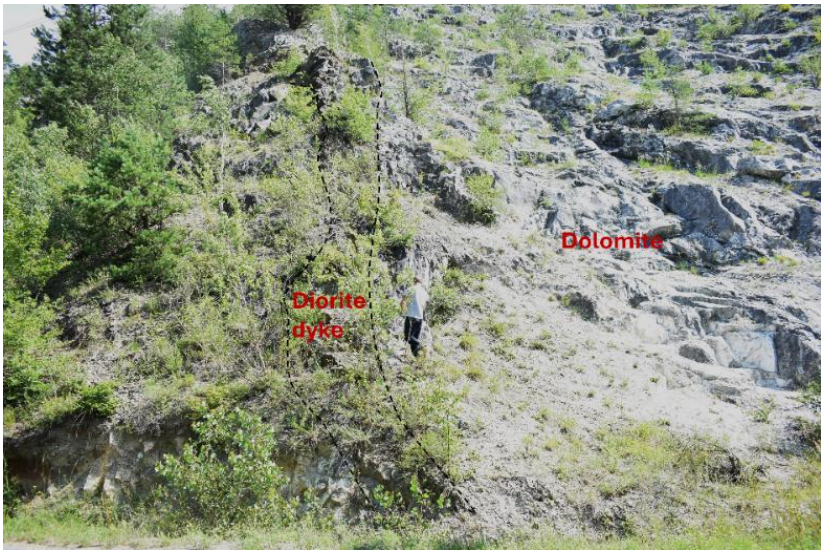


Fig. 4.1. Diorite dyke from Surduc intruded on the contact between crystalline dolomite and micaschists of Baia de Arieș units.

1. The magmatic rocks are represented by porphyritic diorites (metadiorites) of Upper Cretaceous. Paleogene age, developed as dyke. Their maximum observable length in the outcrop is of the order of several tens of meters. The igneous rock constituting the Surduc dykes is dark gray in color, with a phaneritic, holocrystalline, sometimes slightly porphyritic structure and massive texture. According to the relative size of the crystals, the structure is slightly inequigranular. The rock is weakly metamorphosed (metadiorite), and macroscopically, hornblende, plagioclase feldspars, biotite, and pink garnets are distinguished. In the eastern part of the quarry, the phenomenon of metadiorite argillization is observed on a fracture zone. As metallic minerals, sulfides occur as impregnations and veinlets in the contact zone; as mineral species, pyrite is found in paragenesis with pyrrhotite and supergene sulfides (covellite, bornite).

The magmatic dyke hosted by the crystalline dolomite in the Surduc quarry contains orthoclase, plagioclase feldspars, and subordinate quartz, hornblende, and biotite. Secondary minerals are represented by magnesium chlorite, epidote, calcite, sericite, and clay minerals. These were formed on the primary minerals in the pneumatolytic and hydrothermal stages. Accessory minerals are present in small quantities and consist of titanite and scarce apatite.

2. Crystalline dolomite. The characteristic of the Baia de Arieş unit is the presence of intercalations of limestones and crystalline dolomites within the micaschists and gneisses with garnets. The Baia de Arieş unit of the Trascău Mountains consists of an upper complex formed by crystalline limestones and a lower complex formed by micaschists and amphibolites. In the Surduc perimeter, two main bodies of dolomites, with lenticular shapes are known. The first dolomite body extends on the northwestern and southeastern sides of the Iara Valley. The width of the body on the northwestern slope of the Iara Valley is 180 m (along the valley line), and on the southeastern slope, the thickness of the body in the valley is 120 m. Downstream, at about 80 m from the first body, the second dolomite lens with a thickness of 50 m is developed only on the left slope of the Iara Valley.

The dolomites from the Surduc quarry are generally grayish white in color, sometimes with a striped appearance (alternating gray bands with white bands), with a heteroblastic structure, massive texture, and are crossed by calcite-filled fissures. Mineralogically, they are predominantly formed by dolomite in a proportion of 97-99%, the rest of the minerals being represented by calcite, quartz, muscovite and chlorite. In the mass of the dolomites, there are intercalations of small metadiorites and quartzite-sericite schists with thicknesses of 0.5-4 m, with a lenticular shape. The Surduc dolomites were used in the manufacture of lime, silica glass, in the soda industry, and as raw stone for road foundations and pavements.

3. Skarns. The skarns are macrogranular rocks with a massive texture and complex mineralogical composition, consisting of calcium silicates (garnets, pyroxenes, amphiboles, epidote, vesuvian, wollastonite, etc.) along with which calcite, dolomite, quartz, etc. may be present. Skarns represent the main products of pyrometasomatic processes. These products and associated mineralizations are usually located in the dome areas of intrusive bodies, in the vicinity of apophyses and veins, where they have crossed carbonate rocks, which show a high susceptibility to substitution processes.

In the Surduc quarry, at the contact between a diorite dyke and crystalline dolomitic rocks, neoformation minerals are formed, both on the dolomitic rock support (exoskarn) and on the igneous rock support (endoskarn). Hydrothermal-metasomatic processes have changed the primary structural characters, including those of the skarns. The skarns have heteroblastic structures, the granoblastic structure being of

a more restricted development. At the contact of metadiorites with dolomite, a reaction zone with a well-defined zonality appears from the less affected metadiorite; there is a transition to a metadiorite with garnets (Fig. 4.2), followed by hornblende (locally with phlogopite), which makes the transition to a zone with tremolite. The latter is either disposed in direct contact with the dolomite or is separated from it by a strip (1-3 cm thick) of talc.

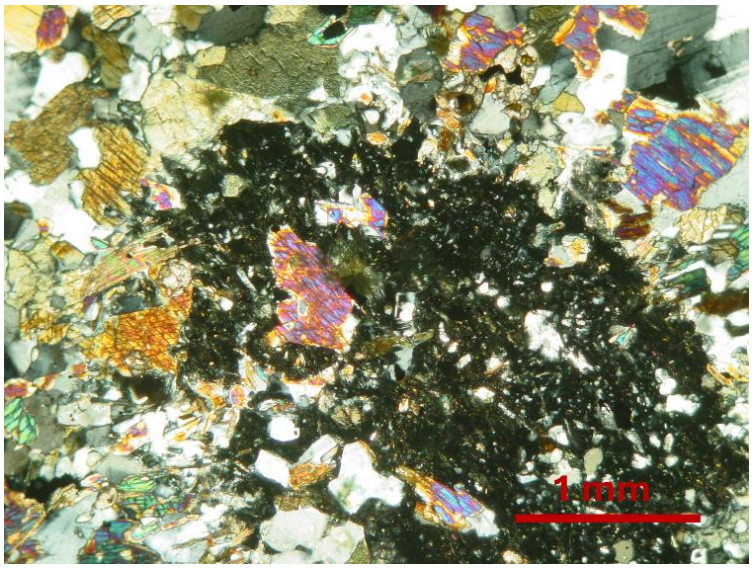


Fig. 4.2. Microphotograph under the microscope at crossed polars of garnet and tremolite metadiorite from Surduc. Scale bar = 1 mm.

Giușcă and Mârza (1976) describe the contact paragenesis in the dolomites in the immediate vicinity of the metadiorite vein from Surduc. This is made up of: forsterite, chondrodite, phlogopite, diopside, in association with hydrothermal minerals: tremolite, talc, serpentinite, brucite, epidote-zoisite. Forsterite occurs extremely rarely in a fresh state; usually it is fully transformed into serpentinite (chrysotile – antigorite). Chondrodite occurs in colorless isometric granular crystals with barely perceptible yellowish pleochroism, clear contour, high relief, and very low interference color, good cleavage often as simple twins.

Phlogopite occurs in isolated crystals and is frequently concentrated in nests; the crystals are very pure, free of inclusions, except for some calcite grains they contain, and the pleochroism varies from colorless to yellowish brown. In addition to the intimate tremolite crystals associated with contact minerals, centimetric-thick veins containing large crystallized massive tremolite (3 x 7 cm) are observed. The observations in the thin sections show that the serpentine minerals, so abundant, do not result exclusively from magmatic metamorphic magnesian nesosilicates, but are also formed by the substitution of dolomite under the action of hydrothermal solutions, in which case there is a diffuse arrangement of serpentine aggregates in the carbonate mass and the remaining dolomite as non-silicate relicts in serpentine. Associated with serpentine, lamellae and fibrous aggregates of brucite can be noticed. Boron-rich hydrothermal solutions are responsible for the formation of fibrous-radial ascharite, with a fasciculate arrangement, in fans and rosettes, the length of the needles being around 0.5-1 mm. The talcification of dolomite under the effect of siliceous hydrothermal solutions occurs both in the rock mass and directed along cracks with the source in the magmatic body; the talc is intimately associated with carbonate or present in compact masses of light gray color, containing microscopic relics of dolomite, often accompanied by fasciculate tremolite

Sulfides occur as veinlets in the contact zone, rarely at greater distance and as disseminations in the diorite.

5. DACITE FROM JUDOVINA MASSIF (OCOLIȘ - ALBA COUNTY)

The Jidovina massif (907 m) is located within the perimeter of the Ocoliş locality (Alba County), on the left slope of the Arieş Valley. It is delimited by the Arieş Valley to the SE, the Runcului Valley to the NE, the Coşegii stream to the SW and the Craca stream to the north. In the southeastern part of the massif, along the Arieş Valley, is DN 75.

The dacite massif from Jidovina is an object of quarrying the magmatic rock developed in the central-upper part of the eruptive body. The extracted material is used as aggregates in road construction. The magmatic rock at Jidovina appears today in the form of two bodies: a main one developed in the highest area of the Jidovina massif, and which represents an old feeding channel of the volcano and a secondary one, developed as a dyke, with N-S orientation. The main body has well-marked edges by a rugged relief (especially in the southern and eastern parts) which, together with the quality of the material, has favored the opening of some quarries since the last century.

From geological point of view, the Jidovina massif is located in the southeastern part of the Muntele Mare massif. Within the perimeter of the Jidovina massif, metamorphic, sedimentary and magmatic rock formations are present (Fig. 5.1).

In the Jidovina area, these formations have a local development at the confluence of Runcului valley with the Arieş valley and are represented by micaschist of the upper part of Baia de Arieș unit as defined by Stan (2006). However, these formations appear to the surface, with a wide development, on the right slope of the Arieş as well as to the north and north-west of the perimeter of the Jidovina massif (to the NW of the Craca stream).

The sedimentary rocks are of Upper Cretaceous (Senonian) and Quaternary age. The Cretaceous sediments were deposited in the neocretaceous tectonic basin in the Arieş Valley corridor developed on the Baia de Arieş – Iara alignment. The Senonian transgression begins with conglomerates and sandstones overlain by limestones (with *Hippurites* and *Corals*). There are also known Gosau facies sediments consisting of marls, clays, sandstones, conglomerates, etc., with a typical flysch character in which the clayey or marly material is predominant. In the perimeter of the Jidovina massif, there are Senonian sediments in flysch facies in which violet and greenish clays, marls and sandstone levels are present. The clayey and marly material predominates and presents obvious stratification. The position of the stratification planes in the eastern part of the Jidovina massif (access road cut) is 275º/12 º. The sandstone intercalations are consistent with the clay stratification and have variable thicknesses (from a few centimeters to 30 cm). On the eastern slope of the Jidovina massif as well as in the Baciului hill up to the vicinity of the Ocoliş locality, a dacite dyke with NS orientation develops. In the vicinity of the dike there are outcrops of Senonian sediments thermally affected by the dacitic intrusion (cornification phenomena of the clayey sediments are present).

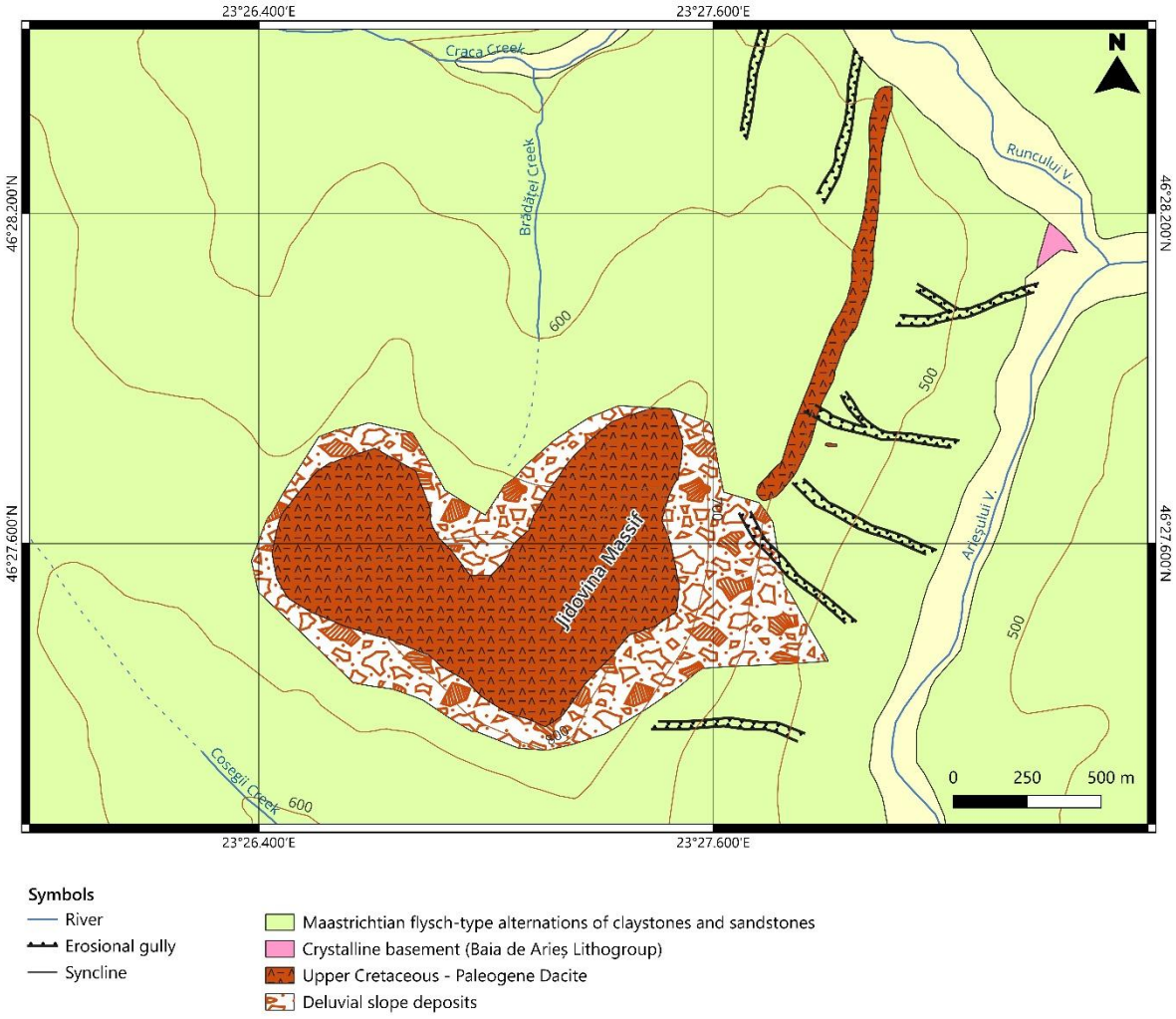


Fig. 5.1. Geological map of the Jidovina area

Quaternary sedimentary deposits are represented by two types of formations: terrace alluvial and slope deluvial deposits. The alluvial deposits are developed in the terraces (terrace I) of Arieş, the Runcul valley and the Craca stream. They have a limited development, with widths of the order of meters and follow the course of the valleys that deposited them. They are represented by blocks (more common in the Arieş terrace), gravel and sand, with different degrees of rolling. The slope deluvial deposits are developed in the immediate vicinity of the dacitic intrusion (the body exposed in the top of the Jidovina massif). They are represented by blocks and fragments of dacite, with angular to slightly rounded shapes, frequently trapped in a sandy - clayey matrix. This matrix represents dacite material disaggregated under the influence of exogenous factors (precipitation, freezing - thawing phenomena). Part of the fragmentary material near the main intrusion is the result of the activities of exploitation and processing of dacite material, which in the last century, was used to make cubic stone for paving.

The magmatic rocks are represented by volcanic rocks of dacite composition. Dacite developed in the form of two bodies: a main one developed in the central part of the Jidovina massif and represents a volcanic neck, resulting from the consolidation of magma in the supply conduit of an old volcano. The second body represents a dyke that appears on the surface from the eastern slope of the Jidovina massif and extends northwards through Dealul Baciului to the right slope of the Runcului valley. It has a length of approx.

1200 m and a width of max. 50 – 60 m, with a N-S orientation. It is connected to the main body, probably at a shallow depth (today the direct connection between the two bodies is not observed) and represents the filling of a radial crack formed during the volcanic eruption that generated the main body. The magmatic activity that generated the igneous rocks at Jidovina belongs to the Upper Cretaceous – Paleogene magmatic activity and the two bodies cross Senonian sedimentary formations, which they thermally affect. The main body has an elliptical – reniform shape, with the long axis-oriented NE – SW, with dimensions of 830 x 1500 m (Treiber et al., 1967). From a morphological point of view, the body is contrasting in relation to the neighboring rocks and presents planar cooling cracks that delimit polyhedral columns visible only in the apical part of the body. The intense cracking of the apical part of the main dacite body is the cause of the presence of rock blocks from the slope diluvial deposits developed around it.

Compositional characteristics: from a petrographic point of view, the two igneous rock bodies are similar, but the rock in the dacite dyke is more intensely altered than that in the main body. Overall, the rock is fine-medium grained. Microscopically, it has a porphyritic holocrystalline structure with a microgranular groundmass and a massive texture (Fig 4.2 and 5.3). The rock is composed of phenocrysts (40%) of plagioclase feldspar, quartz, biotite and former hornblende (replaced by secondary minerals), embedded in a microgranular groundmass (Fig 4.2 and 4.3). The mineralogical composition includes:

- primary minerals: plagioclase feldspar, quartz (magmatic corroded), orthoclase (rare), biotite (partially transformed into magnetite), hornblende (pseudomorphosed by chlorite, opaque minerals, epidote etc.), apatite.

- secondary minerals: chlorites, clay minerals, calcite, epidote, iron oxy-hydroxides, zeolites.

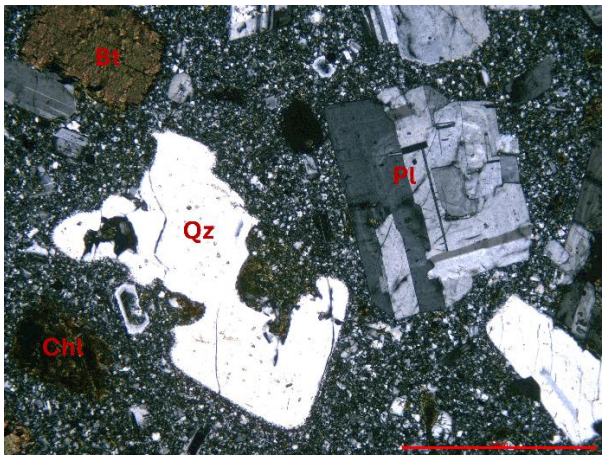


Fig. 5.2. Microphotograph under the microscope at crossed polar of Jidovina dacite with phenocryst of plagioclase feldspar (Pl), quartz (Qz), biotite (Bt), and chlorite (Chl) replacing hornblende, into a microcrystalline groundmass. Scale bar = 1 mm

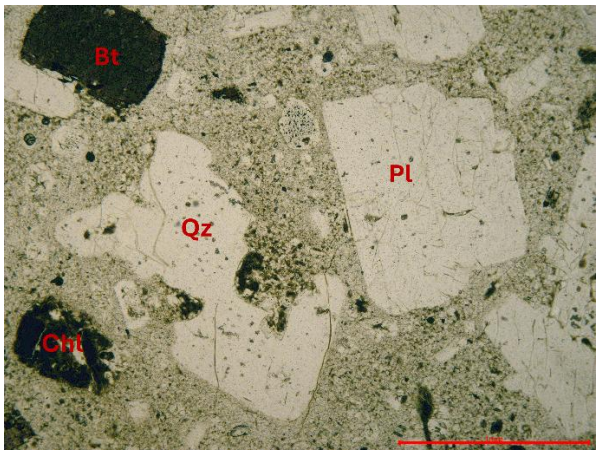


Fig. 5.3. Microphotograph under the microscope at one polar of Jidovina dacite with phenocryst of plagioclase feldspar (Pl), quartz (Qz), biotite (Bt), and chlorite (Chl) replacing hornblende, into a microcrystalline groundmass. Scale bar = 1 mm

Note: *The symbols of the mineral name are according to War (2021).*

The estimated participation of minerals determined under the microscope is presented in *Table 5.1*.

Table 5.1

	Minerals	%	Microscopic features
Phenocrysts (40 %)			
1.	Plagioclase feldspars	20	Fresh of partly affected by secondary alteration
2.	Quartz	10	Magmatic corroded
3.	Biotite	5	Sometime with a rim of iron oxides
4.	Chlorite	5	Replacing hornblende
Groundmass (60 %)			
5.	Plagioclase feldspars	14	Very fined grains (< 0.1 mm) forming together the groundmass of the rock. Chlorite is formed on the mafic minerals (e.g. hornblende). The alteration of the plagioclase feldspars leads to formation of clay minerals, epidote and zeolites. Iron oxi-hydroxides are formed on the biotite.
6.	Quartz	25	
7.	Biotite	5	
8.	Pyroxene	1	
9.	Orthoclase	5	
10.	Apatite	<0.5	
	Chlorite, clay minerals, Calcite, epidote, zeolites, iron oxi-hydroxides	9.5	

An important petrographic feature of the Jidovina dacite is represented by the presence of xenoliths, well delimited in the magmatic rock and with tabular shape (Fig. 4.4). These xenoliths are hornfels generated by thermal metamorphism of Senonian clays, with recrystallization under the influence of temperature and without metasomatic exchange. They were formed in the pyroxene hornfels facies, and from systematic point of view, they can be classified as silicate-oxide hornfels.



Fig. 5.4. Xenolith in de Dacite of Jidovina

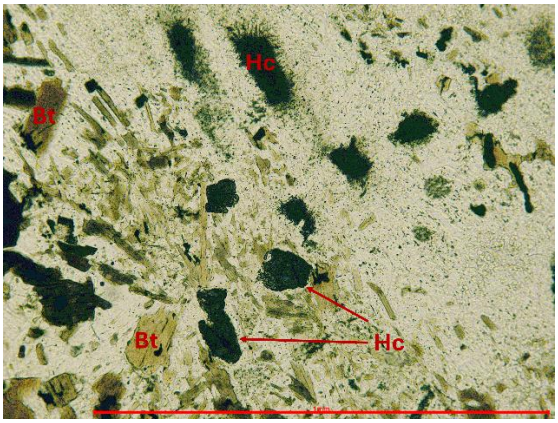


Fig. 5.5. Microphotograph under the microscope at one polar with hercynite (Hc) in biotite (Bt) hornfels from Jidovina dacite. Scale bar = 1 mm

The mineralogical composition of hornfels consists of garnet, biotite, hercynite (Fig. 4.5), chlorite, quartz, plagioclase feldspars (albite), K-feldspars. phlogopite, magnetite etc.

The Jidovina dacite is extracted and processed as raw material for aggregates used in the road construction industry.

6. THE ROȘIA POIENI PORPHYRY COPPER-GOLD DEPOSIT

The Roșia Poieni is the largest Cu–Au porphyry deposit in Romania. It is located in the South Apuseni Mountains at about 3 km northeast of the Roșia Montană epithermal Au-Ag deposit. The Roșia Poieni porphyry is hosted by Miocene volcanics (Ionescu, 1974; Ionescu et al., 1975; Borcoș et al., 1984). First

drillings and surface studies carried out in the 1960s identified a porphyry copper system (Ionescu, 1974). The deposit extends vertically for more than 1200 m from the surface and reaches a maximum diameter of approximately 500 m. Mining began in 1986, and the open pit currently reaches +805 m ASL, over 400 m below the former surface at +1210 m ASL (Fig. 6.1). The Roșia Poieni ore deposit contains about 60% of Romanian Cu reserves (https://cuprumin.ro/). Published resource estimates include 350 Mt at 0.36% Cu and 0.29 g/t Au (Borcoș et al., 1998), 431 Mt at 0.55% Cu and 0.25 g/t Au (Kouzmanov et al., 2005), and >1 billion tonnes at 0.36% Cu (https://cuprumin.ro/). The mining pit operations and ore processing are carried out by the State mining company Cupru Min S.A. Abrud.



Fig. 6.1. View heading south of the Roșia Poieni open pit (Photo C.G Tămaș).

The mineralization at Roșia Poieni is hosted by a subvolcanic body named Fundoaia andesite by Ionescu et al. (1975), Fundoaia microdiorite by Milu et al. (2004), and Poieni diorite by Kouzmanov et al. (2005). Based on fieldwork and petrographic studies, Rey (2004) and Wallier (2004) demonstrated that the so-called Fundoaia microdiorite corresponds to the potassic-altered part of the Poieni diorite, an interpretation later adopted by Wallier et al. (2006). However, recent work in the open pit revealed multiple intrusive phases spanning from early mineralization to post-mineralization timing in the Roșia Poieni license area.

The volcanic complex at Roșia Poieni (Fig. 6.2) is formed of rooted bodies, lava flows, and pyroclastics (Bordea et al., 1979). The succession of volcanic units proposed by Bordea et al. (1979) is (1) Poieni (quartz) amphibole andesite; (2) Fundoaia (quartz) amphibole–pyroxene andesite; (3) Ruginiș (quartz) pyroxene–amphibole andesite; (4) Dealul Melciului (quartz) amphibole–biotite andesite; and (5) Rotunda amphibole–pyroxene andesite. The Poieni andesite was dated by Kouzmanov et al. (2005) at 9.42 ± 0.14 Ma, and the Rotunda andesite was dated by Roşu et al. (1997) at 9.3 ± 0.47 Ma. According to these data, the Roșia Poieni volcanic structure was active for approximately 120 ky.

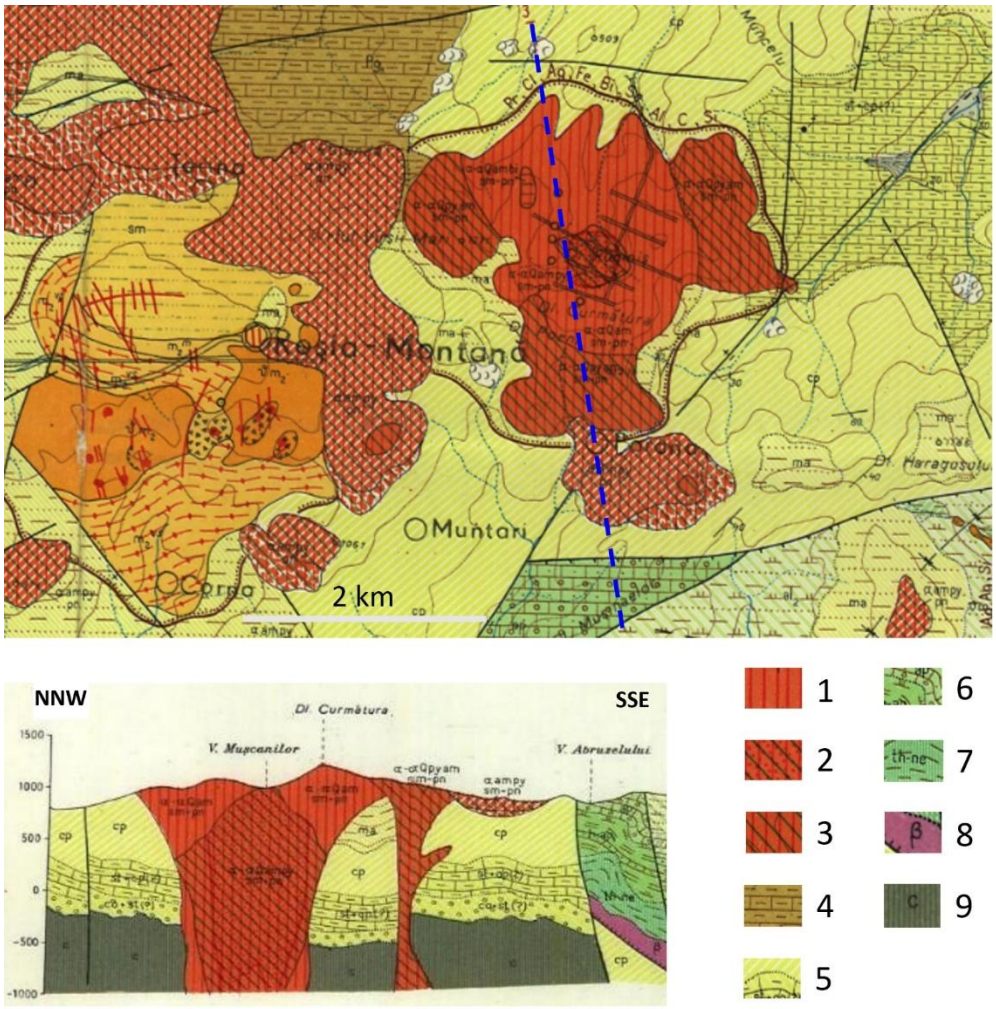


Fig. 6.2. The geology of the Roșia Poieni ore deposit (Bordea et al., 1979). The cross-section is along the blue dotted line shown on the map. 1. Poieni andesite (host rock), 2. Fundoaia andesite (ore), 3. Ruginis andesite (post ore), 4. Paleogene sedimentary rocks, 5. Upper Cretaceous sedimentary rocks, 6. Lower Cretaceous sedimentary rocks, 7. Jurassic sedimentary rocks, 8. Jurassic basalts, 9. Palaeozoic marbles

The Miocene volcanism at Roșia Poieni pierced a metamorphic basement formed of Paleozoic Sohodol marbles belonging to the Baia de Arieș unit (Balintoni, 1996). The marbles are covered by Jurassic basalts and a sedimentary succession of Jurassic, Cretaceous, and Palaeocene age (Fig. 6.2; Bordea et al., 1979). The Jurassic volcanic rock suite consists of basalts, which are covered by a Late Jurassic–Early Cretaceous (Tithonian to Albian) flysch sequence, part of the Bucium Unit (Bordea et al., 1979). This flysch sequence is thrusted over a post-tectonic sedimentary cover of Late Cretaceous age (Santonian–Maastrichtian), which passes into a Palaeocene flysch sequence (Bordea et al., 1979).

The hydrothermal alteration related to the porphyry mineralization was mapped early during the initial exploration of the deposit (Fig. 6.3) by Ionescu et al. (1975). The hydrothermal alteration zonality was also recognized by Ionescu et al. (1975), who identified a strict correlation between alteration and mineralization. The deposit has an intense K-altered core enveloped by phyllic, argillic, and propylitic alteration. These authors noticed a vertical grading, with secondary biotite more abundant in the lower part of the K-altered zone and K-feldspar more abundant in the upper part of the potassic alteration core. These alterations were confirmed by Milu et al. (2004), who identified potassic, phyllic, advanced argillic, and propylitic alterations (Fig. 6.4). The potassic alteration zone is overprinted by a phyllic and argillic overprint along the borders and internally by faults. The potassic alteration has the common mineralogy, with

secondary magnetite, K-feldspar, and secondary biotite. The remaining hydrothermal alteration assemblages were detailed by Milu et al. (2004), i.e., phyllic alteration with quartz, illite, illite–smectite mixed layers, phengite, minor smectite, kaolinite, and pyrite; advanced argillic alteration with alunite, kaolinite, dickite, pyrophyllite, diaspore, aluminum–phosphate–sulfates (woodhouseite–svanbergite series, zunyite, minamyite), and pyrite; propylitic alteration with chlorite, epidote, albite, and carbonates.

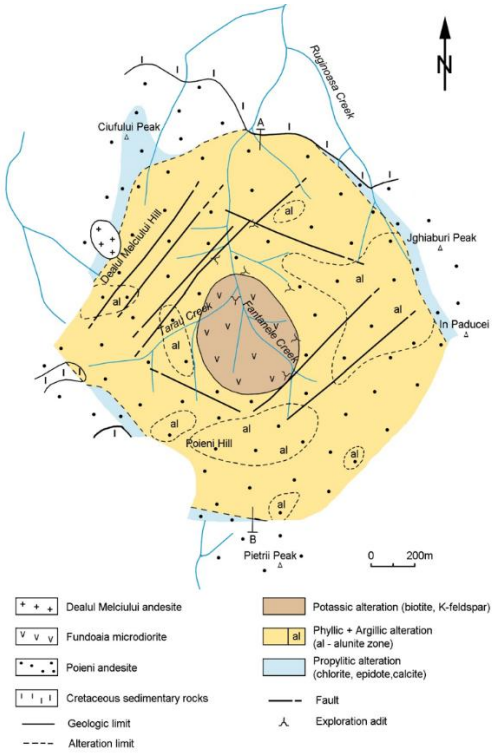


Fig. 6.3. Pre-mining surface alteration and lithology map of the Roșia Poieni ore deposit (Ionescu et al., 1975). The A-B cross-section is shown on **Fig. 6.4.**

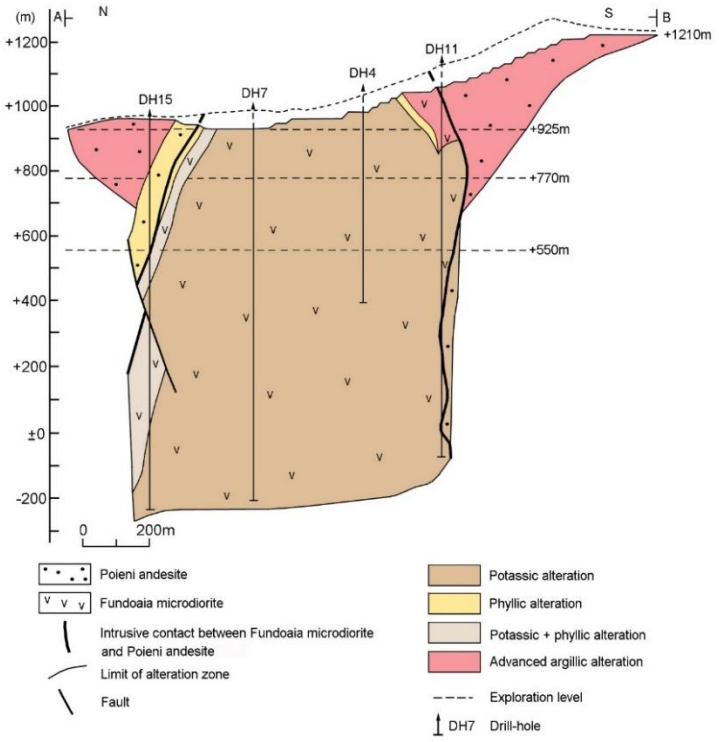


Fig. 6.4. Cross-section showing the hydrothermal alteration of the Roșia Poieni ore deposit, following the line A-B in **Fig. 6.3**. (Milu et al., 2004).

The mineralization consists of dense stockwork and disseminations. The stockwork is formed of massive quartz-magnetite A-veins, straight quartz B-veins with centerlines, and C-veins/paint veins. Chalcopyrite is by far the most abundant Cu-sulfide, being followed by bornite. Enargite was identified by Milu et al. (2004) as small-scale inclusions in pyrite.

The porphyry ore hosts epithermal mineralization. High sulfidation veins with luzonite/enargite, covellite, and pyrite with an advanced argillic alteration halo were noticed by Milu et al. (2004). Enargite-cemented hydrothermal breccias were recently observed in the lower part of the open pit.

Late intermediate-sulfidation veins cut the porphyry ore. These veins are dominated by sphalerite with subordinate participation of galena, chalcopyrite, tetrahedrite, and native gold. The host rock of these veins, which is the porphyry ore, shows a phyllic overprint on the K-alteration zone.

The age of the porphyry mineralization was determined by Kouzmanov et al. (2005) by U–Pb dating of mineralized volcanic units, i.e., a dyke with secondary biotite alteration of 9.23 ± 0.15 Ma and a late intra-mineralization dyke of 9.16 ± 0.10 Ma, indicating at least 70ky of porphyry mineralization. Following porphyry ore deposition, mineralization continued and consisted of telescoped high-sulfidation and intermediate sulfidation stages.

7. ROȘIA MONTANĂ Au–Ag DEPOSIT

Roșia Montană is located northeast of Abrud, approximately 7 km upstream along the Roșia Valley. Alburnus Maior is the ancient Roman name for what is today Roșia Montană (Fig. 7.1). Roșia Montană is a world-class Au–Ag deposit (Manske et al., 2006), hosted by dacite plugs and volcaniclastic vent breccias. It occupies the northwestern sector of a NW–SE-oriented extensional basin (Roșia Montană–Bucium), which—together with the Stănija–Zlatna and Brad–Săcărâmb basins—contains most of the Neogene volcanic formations and associated Au–Ag and Cu ore deposits of the Southern Apuseni Mountains.



Fig. 7.1. Panoramic image of the Cârnic massif (left) and the Cetate quarry (right) (Photo S. Drăgușanu)

The sedimentary cover comprises an Upper Cretaceous flysch and a poorly developed Upper Badenian–Lower Sarmatian succession, interlayered with volcaniclastic units of the so-called Vent Breccia (Leary et al., 2004). The volcanic assemblage includes dacites (Cetate dacite) and andesites (Rotunda andesite), together with their associated volcaniclastics. The crystalline basement does not outcrop in the Roșia Montană area.

Cetate dacite is found in the Cetate, Cârnic, Coș, and Văidoaia massifs, which are remnants of two dacitic domes that intruded through the Vent Breccia. The dacite displays a characteristic porphyritic texture, with magmatic quartz and feldspar phenocrysts set in a microcrystalline groundmass. Abundant bipyramidal quartz crystals, reaching up to 2 cm in length, are a distinctive feature of the rock. The feldspar phenocrysts are also common, though they typically measure less than 1 cm in length. These feldspars are white, but often display a pinkish hue due to adularia replacement. Overall, the Cetate dacite is whitish, with colour variations controlled by the degree of alteration. The rock is strongly altered, characterized by pervasive adularia–sericite assemblages. The silicification is closely associated with the ore bodies (veins, breccias, stockworks), imparting grayish tones to the dacite host rock and significantly increasing its hardness. Along the road leading to the Cetate open pit, at the southwestern edge of the Cârnic massif, the Cetate dacite outcrops on large surfaces. This place is commonly referred to as the “white rocks” due to the pale colour and high friability of the intensely altered rock. Well-formed bipyramidal quartz crystals can be readily collected here.

The Rotunda andesites, together with their associated pyroclastic deposits, extend across the northern and northeastern sectors of the Roșia Montană area.

The volcanic activity at Roșia Montană began with the emplacement of the Cetate dacite (13.5 ± 1.1 Ma) and continued with the Rotunda andesite (9.3 ± 0.47 Ma) (Pécskay et al., 1995; Roșu et al., 1997).

Significant phreatomagmatic activity (maar–diatreme) occurred before, during, and after the intrusion of the Cetate dacite, contributing, among other effects, to the formation of the Vent Breccia. The youngest phreatomagmatic breccia identified to date has an age of 11.0 ± 0.8 Ma (Manske et al., 2006). Roșu et al. (2004) reported an age of 13.6 Ma for the altered and mineralized dacite from the Cârnic massif, while adularia associated with quartz veins in the Cetate massif yielded ages of 12.7–12.8 Ma (Manske et al., 2006).

Roșia Montană was recognized as a low-sulfidation deposit (Mârza et al., 1997; Tămaș and Bailly, 1998, 1999; Sillitoe and Hedenquist, 2003; Leary et al., 2004). Later on, Tămaș et al. (2006) proved that an early low-sulfidation Au-dominated mineralization was followed by an intermediate sulfidation Ag-dominated one. The ore bodies consist of veins, breccias, disseminations, stockworks, and paleo-placers. The ore bodies are hosted by dacite (Fig. 7.2), phreatomagmatic breccias (e.g., Cetate Breccia), and the Vent Breccia (Drăgușanu, 2017).

The mineralogy of the low-sulfidation ore stage is quite simple, with native gold, pyrite, tetrahedrite, and minor amounts of sphalerite, galena, and sphalerite and an abundant quartz-adularia gangue. The mineralogy of the intermediate-sulfidation ore is dominated by Ag-sulfosalts, hessite, tetrahedrite, galena, sphalerite, chalcopyrite, minor native gold, and other less frequent minerals like altaite, sylvanite, petzite, argyrodite, cervelleite, and alburnite hosted by a rhodochrosite-rich gangue (Tămaș et al., 2006; 2014).

Brecciation at Roșia Montană is complex, with several genetically distinct types of mineralized breccias identified (Tămaș, 2002; Minuț et al., 2004; Tămaș, 2007). These include phreatomagmatic breccias (Cetate Breccia, Black Breccia, Corhuri Breccia, Găuri Breccia, Piatra Corbului Breccia, Cănţăliște Breccia, among others), hydrothermal breccias (numerous bodies distributed throughout the deposit), and tectonic breccias, such as the Zeus Breccia from the Cetate massif (Tămaș, 2007). The Cetate Breccia – Black Breccia relationship was solved by Tămaș (2002; 2007) who recognized that Black Breccia is the fluidisation conduit of Cetate Breccia.

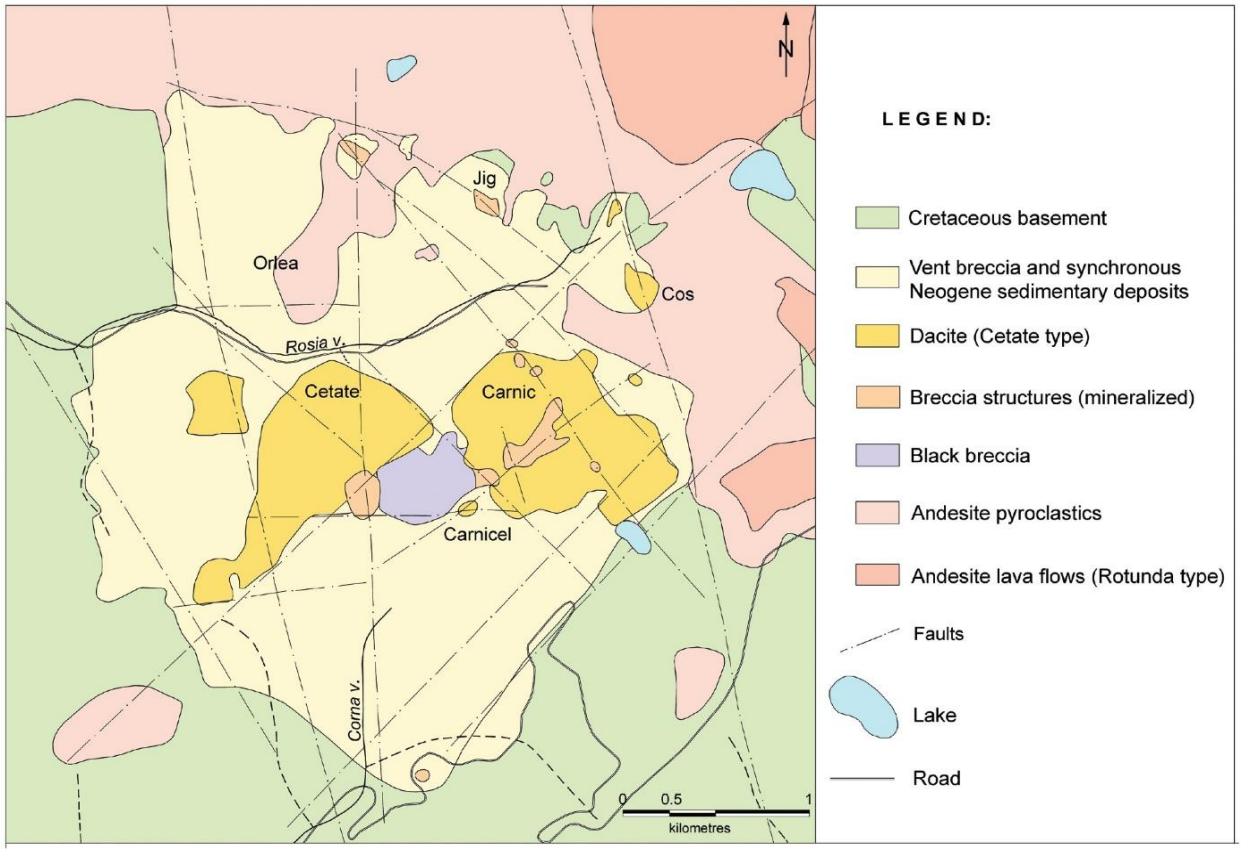


Fig. 7.2. Geology of the Roșia Montană ore deposit (data from Gabriel Resources – RMGC).

The Mining Museum in Roșia Montană is marked by the tourist sign "Galeriile Romane Roșia Montană", indicating the Roman galleries. The underground section of the Mining Museum comprises nearly 200 m of Roman workings. Access from the surface is through a 53-m inclined shaft with 157 steps, which leads into a 42-m modern adit before reaching the Roman workings. The contrast between the modern and Roman excavations is striking: modern passages are reinforced with concrete bricks, whereas the Roman galleries remain entirely unsupported. Tool marks created by iron chisels and hammers are still visible on the walls. The geometry of the workings also differs markedly. Modern adits and inclined shafts have rounded ceilings, while the Roman galleries display a trapezoidal cross-section with a flat roof. In the southern sector, the Roman adit maintains relatively consistent dimensions, with a height of 1.7–1.8 m, a ceiling width of 0.87–1.05 m, and a base width of 1.2–1.4 m.

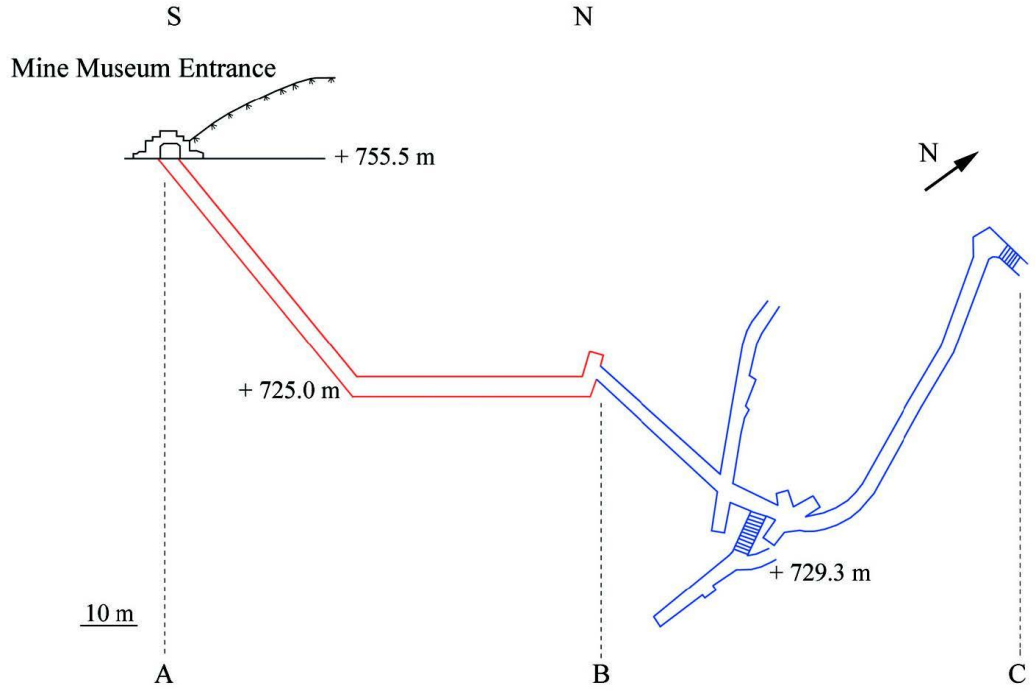


Fig. 7.3. Map of the Roșia Montană Underground Mining Museum. A–B (red): vertical cross-section of the modern workings, showing the access from the surface. B–C (green): plan view of the Roman galleries (Benea and Tămaș, 2010, simplified after Sîntimbrean, 1989).

Roșia Montană was exploited until 2006 by the state-owned mining company Minvest Deva. Towards the end of the 1990s, a new mining project was initiated by the Canadian–Romanian joint venture Roșia Montană Gold Corporation. At present, the project is suspended due to disagreements between the company and the Romanian state.

8. THE BASALTIC ANDESITE FROM DETUNATA

The youngest calc–alkaline rocks of the Neogene – Quaternary volcanism from Apuseni Mountains are the basaltic andesites from Detunata (7,40 ± 0,4 Ma; Pécskay et al. 1995). They belong to the Roșia Montană - Bucium - Baia de Arieș volcanic district and outcrop in two distinctive bodies: Detunata Goală and Detunata Flocoasă.

The morphology of the two magmatic bodies is different. For the basaltic andesites from Detunata Goală, polygonal columns (3, 4 or 5 sides) with centimetric dimensions of their sides (between 20 - 50 cm) are characteristic. The basaltic andesite columns from Detunata Goală show, in spatial terms, two different positions: the columns in the lower part have a vertical position and are banded at the upper part by the columns that have an oblique position, with an inclination of 30^{o} - 45^{o}. This spatial arrangement of the columns and the existence of the natural opening in the form of a vertical-concave wall, with a height of 35 - 40 m, determined by the arching of the columns, give the Detunata Goală massif a unique and spectacular form of presentation (Fig. 8.1). The basaltic andesites from Detunata Flocoasă have a different development, the columnar shape being very poorly outlined due to the irregularity of the planes that delimit them. There are also planes with a position perpendicular to the elongation of the columns, which fragment them and form massive blocks with metric dimensions (1-5 m in diameter).



Fig. 8.1. Banded basaltic columns from Detunata Goală (photo N. Har)

Geological framework. The basaltic andesites from Detunata Goală and Detunata Flocoasă are intruded into the sedimentary formations of the Bucium Unit (Fig. 8.2), which belongs to the Laramian Transylvanides (Balintoni, 1997), the last term in the stratigraphic succession being represented by the Maastrichtian-micaceous sandstone flysch. The stratigraphic succession of the Bucium Unit from the Tithonic(?) - Lower Albian interval is the following (Balintoni, 1997): the Valea Ciuruleasa Formation (Tithonic - Neocomian), the Valea Povernei Formation (Hauterivian - Lower Aptian), the calcareous flysch - schist formation (Aptian), and ends with the locally developed wild-grey flysch Formation (south of Buninginea) and the Soharu Formation (Upper Aptian - Lower Albian).

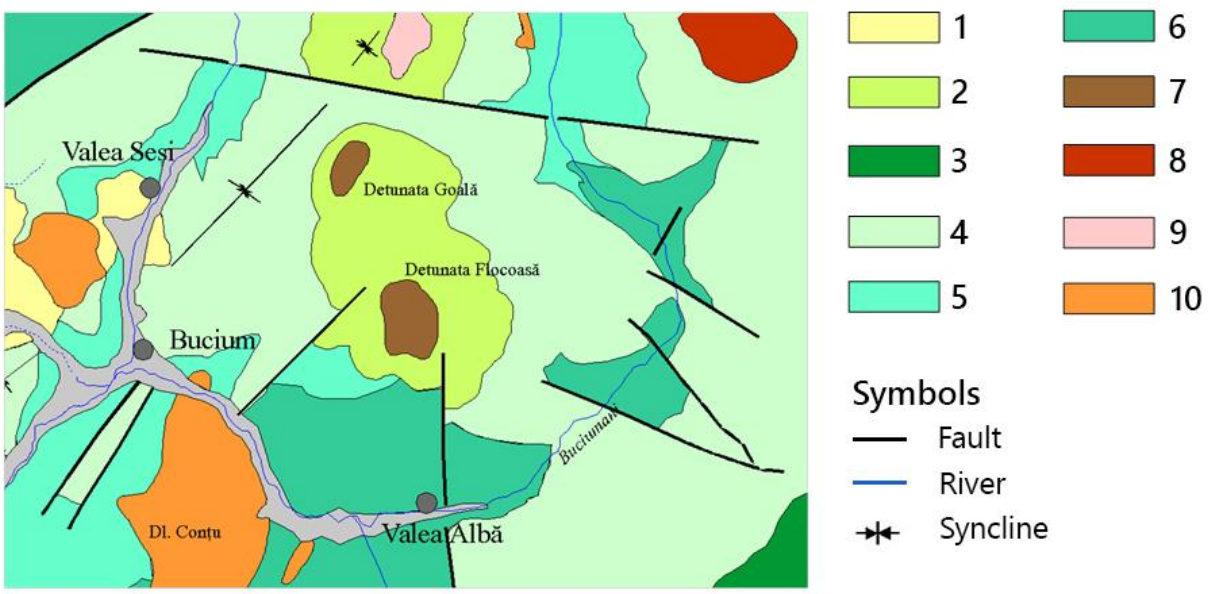


Fig. 8.2. Geological map of Detunata area acc. Bordea at al. (1979) with changes. 1. Marls, clays, sandstones and gypsum (Badenian), 2. Grey calcareous sandy flysch (Maastrichtian), 3. Negrileasa conglomerates (Vraconian - Cenomanian), 4. Pârâul Izvorului Beds - sandy shaly flysch (Upper Albian), 5. Soharu Beds – grey argillaceous flysch with sandy and calcareous interbeds (Upper Aptian - Lower Albian), 6. Sandy-shaly flysch with calcarenites and rare ophiolites (Aptian), 7. Basaltic andesites (Pannonian), 8. Rotunda and Șurligata-type amphibole-pyroxene andesites (Pannonian), 9. Amphibole-pyroxene andesites - lava flows (Pannonian), 10. Roșia Montană-type dacites (Badenian).

Petrographic and mineralogic features. The basaltic andesite from Detunata has a porphyritic texture with intergranular – intersertal groundmass, locally with ophitic aspects (Fig. 8.3). Specific mineralogical features can be noticed. Minerals of igneous genesis are present, and on the other hand, quartz xenocrysts and pyroxene of reaction are frequently observed (Har, 2001).

The primary assemblage is dominated by plagioclase feldspar, pyroxene (diopside), olivine (chrysotile), and beside them, magnetite, apatite, and opacitized hornblende are present (*Table 8.1*).

Table 8.1.

Minerals	Compositional features
Plagioclase feldspar:	
- phenocrysts	Bytownite (83,6 % An) - Labradorite (51,9 % An)
- microlites	Bytownite (70,2% An) – Labradorite (58,6 % An)
Primary pyroxene	Diopside
Olivine	Chrysotile (75 % Fs)*
Amphibole	Opacitized hornblende
Opaque minerals	Magnetite
Accessory minerals	Apatite
Quartz	Xenocrysts, magmatic corroded
Minerals of neoformation	
- pyroxene of reaction	Augite
- SiO_2 variety	Tridymite

* from Măldărescu (1978)

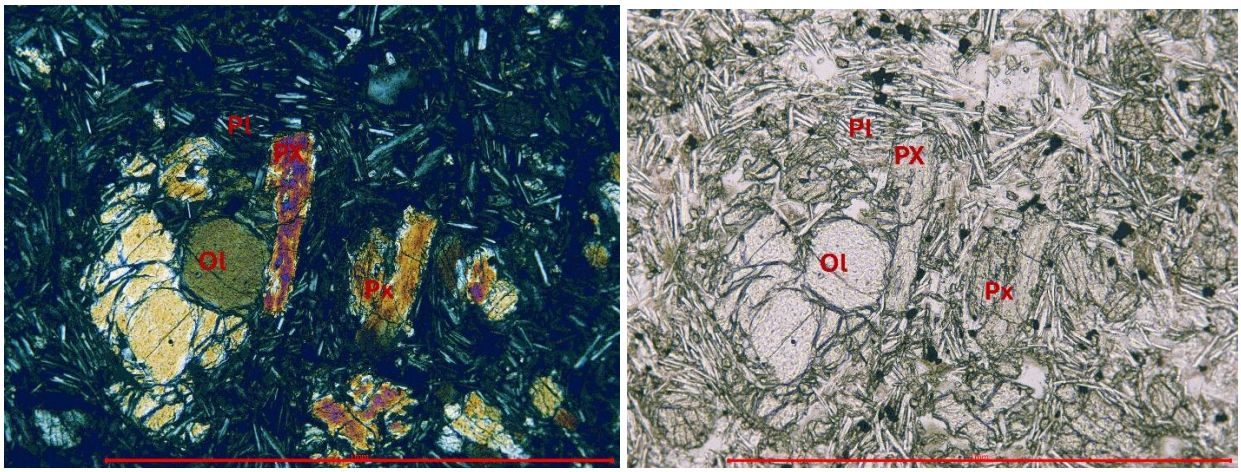


Fig. 8.3. Microphotograph under the microscope at crossed polars (left) and one polar (right) of the olivine-bearing andesite basalt from Detunata. Plagioclase feldspar (Pl), pyroxene (Px), and olivine (Ol) phenocrysts into a intergranular-intersertal groundmass. Scale bar = 1 mm

In the southeastern part of the Detunata Flocoasă massif, the basaltic andesite contains enclaves of quartz – micaceous sandstone. The size of the enclaves varies between 2 – 5 cm and originates in the flysch of Santonian - Maastrichtian age. Most of the enclaves were partly fractured and assimilated by the basaltic melt, and thus isolated xenocrysts of quartz occur in the basaltic andesite (Fig 8.4). The millimetric (1-10 mm) quartz xenocrysts are randomly distributed in the rock.

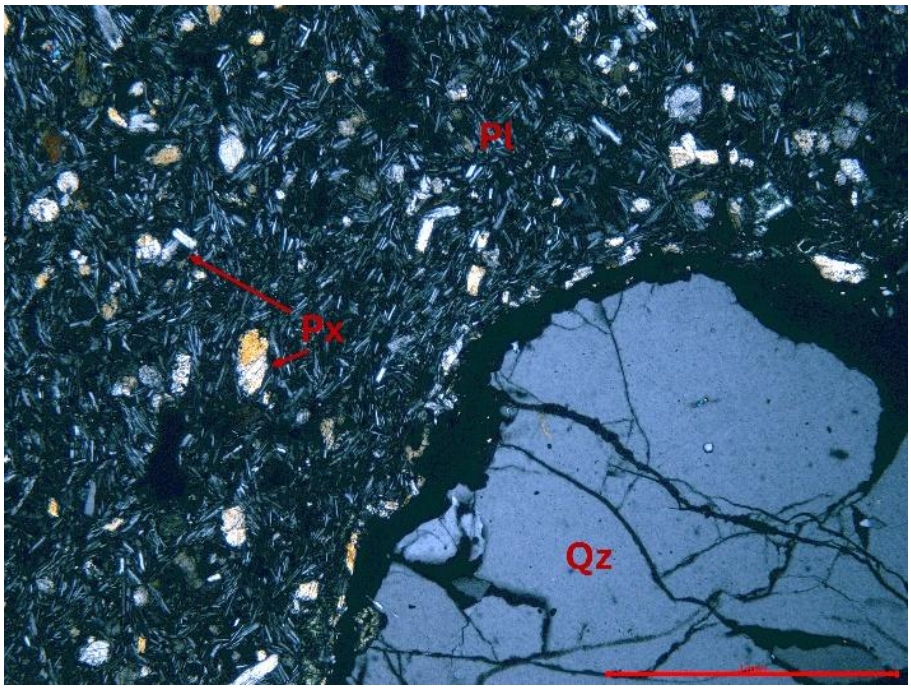


Fig. 8.4. Microphotograph under the microscope at crossed polars of the quartz (Qz) xenocrysts into basaltic andesite from Detunata. Pl-plagioclase feldspars, Px – pyroxene. Scale bar = 1 mm

Har (2005) described the reaction coronas consisting of pyroxene, tridymite, quartz fragments and glass developed around quartz xenocrysts, as a result of interaction between the xenoliths and host basaltic magma.

9. BUDUREASA BRUCITE DEPOSIT

The Finiș (- Ferice-Gârda) Nappe is a major nappe within the Codru Nappe System. It contains a metamorphic basement belonging to the polymetamorphic Codru Series. These basements rocks are intruded by de Codru migmatites and various bodies of granitoids and they are covered by a continuous Permian–Upper Jurassic succession (Balintoni 1994; Bordea et al. 2019). The Finiș Nappe covers a large territory extending from the northern part of the Highiș Mountains to the southern part of the Pădurea Craiului Mountains and from the basement of the Pannonian Basin/Codru Mountains to the eastern part of the Apuseni Mountains (Ianovici et al. 1976) (Fig. 1). The Permian-Mesozoic succession is well exposed on the southern margin of the Pădurea Craiului Mountains, in the Codru Mountains and in the Bihor Mountains (Pietroasa, Budureasa, Ferice, Băița-Bihor and Gârda areas) (Ianovici et al. 1976) (Fig. 1.3).

In the Pietroasa-Ferice-Budureasa area, the sedimentary succession consists of Permian, Triassic and Jurassic formations. Siltites, quartzitic sandstone and shales form the bulk of the Permian succession. The Triassic contains Werfenian quartzitic sandstones, dolomites and shales, Anisian dolomites, Ladinian black limestones, Carnian black limestones with silica nodules (Roșia Limestone), Norian dolomitic limestones/limestones and Rhaetian limestones (Kössen limestone), sandstones, conglomerates and black shales (Ianovici et al. 1976; Bleahu et al. 1985; Bordea et al. 2019). On the other hand, the Jurassic succession (Fig. 9.1) contains Lower Jurassic deep-water facies (calcareous sandstones, marly limestones, black shales) and Upper Jurassic conglomerates (Ianovici et al. 1976; Bleahu et al. 1985; Bordea et al. 2019).

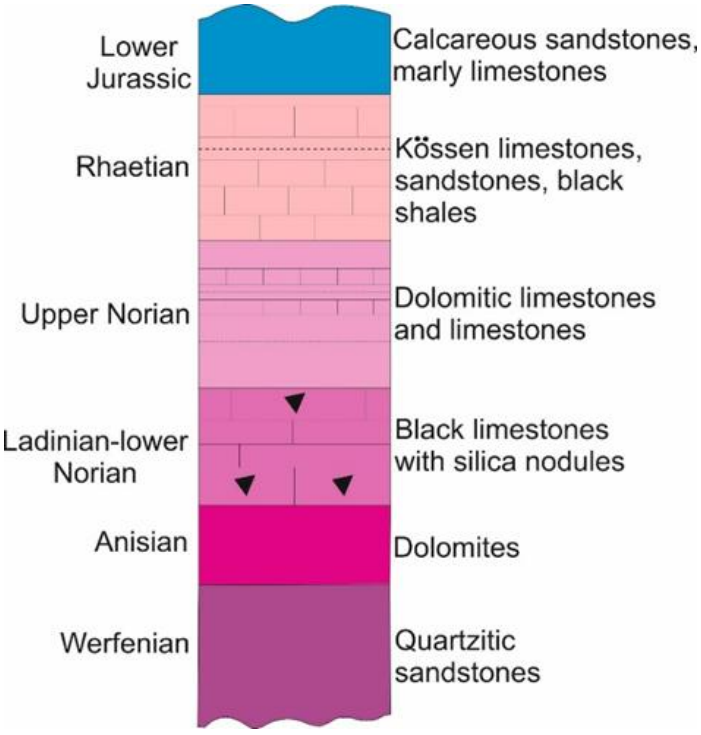


Fig. 9.1. Synthethic lithological column of the sedimentary succession of the Finiș (- Ferice-Gârda) Nappe in the Pietroasa-Ferice-Budureasa area (from Bleahu et al. 1985, with changes, not at scale).

Brucite bearing deposits from Budureasa and Pietroasa

In the Pietroasa and Budureasa areas, the laramic (banatitic) igneous intrusions (granodiorites, rhyolites, rhyodacites) took contact with Anisian dolomites and Ladinian limestones from the Finiș (- Ferice-Gârda) Nappe (Savu 1976; Ionescu and Har 2001). This contact has generated the following zones with distinct petrographic characteristics (Ionescu and Ghergari 2000): a) endoskarns (with pyroxenes, epidote and garnets); b) areas with magnetite and serpentinic minerals; c) magnesian and calcitic skarns; d) dolomitic marbles with phylosilicates and brucite; e) dolomitic marbles with brucite, f) dolomitic marls.

In the Budureasa area, at Valea Mare, the magnesian skarn area has a total thickness of 2-6 km. The Anisian dolomites of the Finiș Nappe are transformed and they have a white or white-grey colour (Istrate and Udubașa 1980; Ionescu 1987). They contain abundant brucite developed as nestles less than 1 mm into the crystalline limestone (Fig. 9.2).

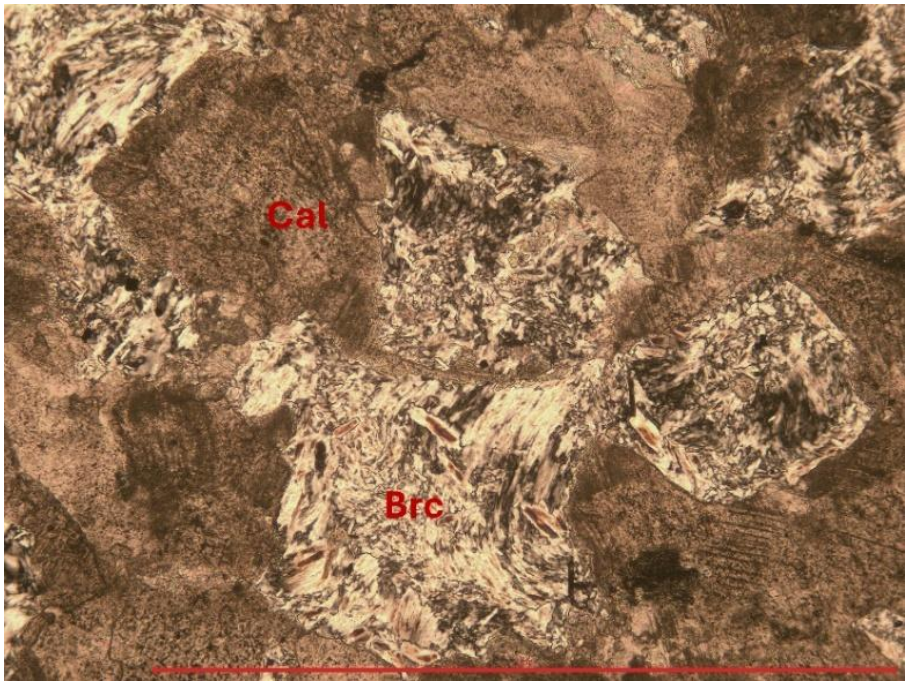


Fig. 9.2. Microphotograph under the microscope at crossed polars of nestles of burcite (Brc) in calcite (Cal)

In the Pietroasa area, the contact between the granodiorites and the Anisian dolomites has an irregular shape. The brucite content is lower than that observed in the Budureasa deposit (Ionescu and Ghergari 2001). Well known occurences are present at Dealul Dâncoasa, Măgura Guranilor, Crișul Pietros-Valea Galbenei and Valea Bohodei-Vârful Tisa (Ionescu and Ghergari 2000).

10. VLĂDEASA MASSIF - NORTHERN AUSENI MOUNTAINS

Vladeasa massif is an important segment of the Banatitic Magmatic and Metallogenetic Belt (BMMB) situated south of Europe during the Late Cretaceous, within a rigid block (Tisza–Dacia block), aligned with other segments of the BMMB parallel to the Vardar subduction front Ciobanu et al. (2002). The complex alpine evolution of the Apuseni Mountains, especially during Laramide tectonic events, led to the emplacement of significant volumes of Banatitic magmas as plutonic and subvolcanic intrusive bodies as well as massive lava extrusions, which in their entirety, form the Vladeasa massif.

The magmas were located on a system of faults with a predominantly NE-SW orientation (Istrate,1978) that affected the crystalline – Mesozoic basement (Fig. 10.1). The Late Cretaceous igneous rocks of the Apuseni Mountains are mainly calc-alkaline, with variably high-K to locally shoshonitic character (Ștefan et al. 1992). Istrate (1978) carried out a synthesis study on the Banatitic magmatism in the Apuseni

Mountains and demonstrated that the Banatitic rocks in the Vladeasa massif represent a complex volcano-plutonic structure, whose formation was controlled by caldera collapses and tectonics.

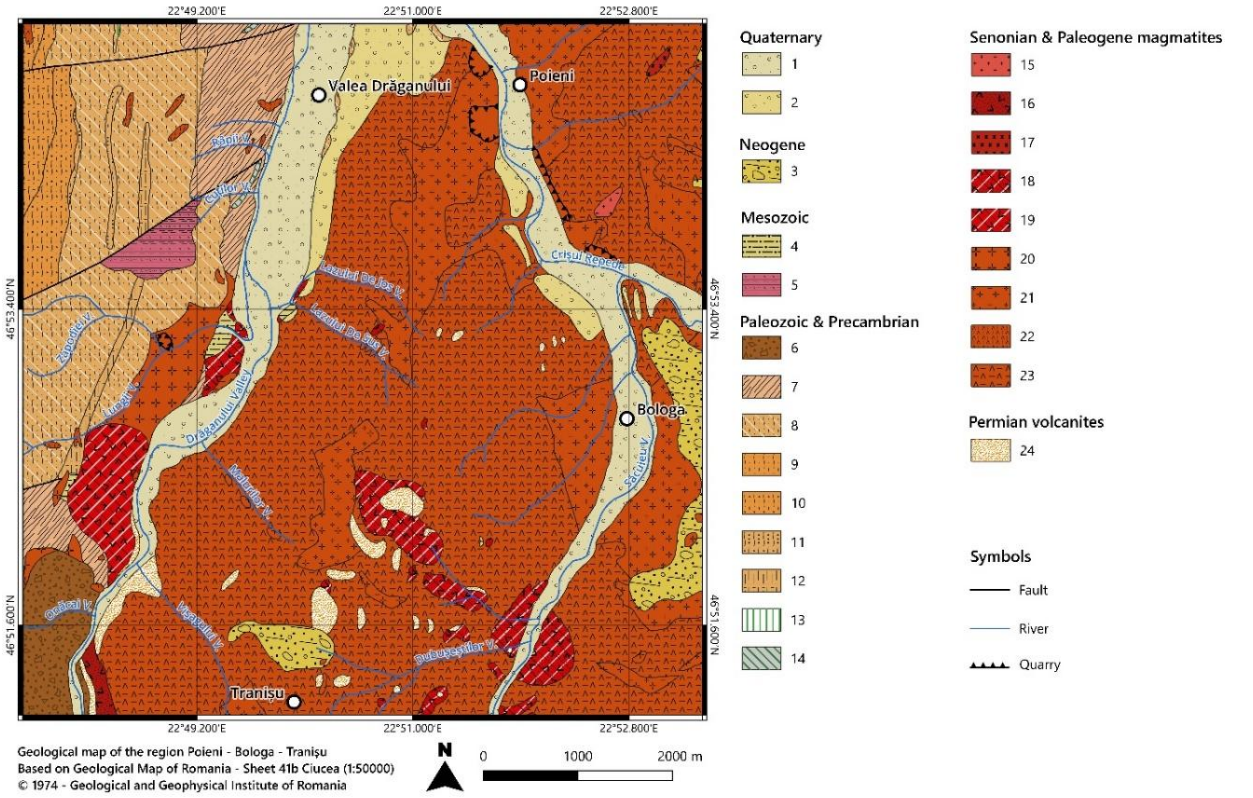


Fig. 10.1. The geological map of nortern part of Vlădeasa massif (Poieni-Bologa- Traniș area). Legend: 1. Gravels and sands of first terrace, 2. Gravel and sands belonging to the 25 m terrace, 3. Sands, gravels and silty clays 4. Sandstones, clay shales, 5. Siliceous sandstones and conglomerates, clay shales, 6. Breccias, conglomerates, and sandstones, 7. Chlorite-sericite quartzitic schists, 8. Micaceous quartzitic schists, quartzitic micaschists 9. Muscovite-biotite micaschists, 10. Garnet-bearing muscovite-biotite micaschists, 11. Micaceous quartzites 12. Paragneisses. 13. Paramphibolites, 14. Chlorite-epidote schists with albite porphyroblasts, 15. Microgranites 16. Quartz-bearing andesites, 17. Quartz-bearing microdiorites, 18. Andesitic lavas, 19. Pyroxene-bearing andesites, 20. Granodiorites 21. Porphyritic Granodiorite, 22. Microgranitic rhyolites, 23. Dacites, 24. Rhyolitic tuffs.

The emplacement of the Banatites in the Vladeasa massif was carried out in several stages (Istrate, 1978). The first stage is characterized by the deposition of pyroclastics, the formation of andesites and the first dacite lava flows. These are followed by violent eruptions that represent a paroxysmal stage of the magmatic manifestations in Vladeasa, with massive deposits of rhyolite ignimbrites and rhyodacites occupying extensive areas of the massif.

The plutonic (intrusive) phase follows, occurring after volcanic collapses, and deep magmas generated intrusions of granodiorites, granite and diorites, which penetrated both the crystalline basement and the pre-existing volcanic rocks. The last stage of magmatic manifestations is represented by the emplacement of dykes, veins and lamprophyres.

South of the Vlaseasa massif, two Banatitic bodies are known: monzogranite – granodorite from Pietroasa and laccolite from Budureasa with a similar composition. The latter is accompanied by a quart-diorite body with development up to Stâna de Vale.

The field trip no. 9 will cover the eastern, northeastern and northern part of the Vlădeasa Mountains with the quarries from Valea Lungii, Poieni and Bologa (Fig. 10.1).

VALEA LUNGII QUARRY

On the north - western part of Vlădeasa Mts., in Drăganului Valley – Lungii Valley area, both volcanic and plutonic – subvolcanic rocks belonging to Upper Cretaceous – Paleogene magmatic activity are known. The granodiorite from Lungii Valley, well exposed in a quarry at the confluence of the Lungii Valley and Zăpodiei Valley, belongs to the plutonic episode (the second cycle of magmatic activity from Vlădeasa). The magmatic rock has a holocrystalline-porphyritic texture with a fine to medium grained - microgranulare groundmass. The phenocrysts consist of plagioclase feldspars, biotite, and hornblende, while in the groundmass, besides these minerals, K-feldspar, quartz, opaque minerals, titanite, and apatite are present (Fig. 10.2). Sericite, chlorite, calcite, and epidote can be noticed as secondary minerals. The last crystallization products in the Valea Lungii granodiorite are represented by the intergrowth of K-feldspars (orthoclase) and quartz, forming a granophyric texture (Fig. 10.3).

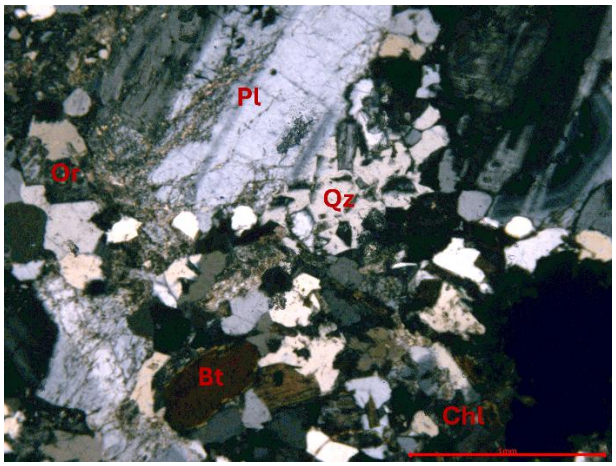


Fig. 10.2. Microphotograph under the microscope at crossed polars of porphyritic granodiorite from Valea Lungii quarry. Pl- plagioclase feldspars, Or – orthoclase, Qz –quartz, Bt – biotite Chl- chlorite partly replacing biotite. Scale bar = 1 mm.

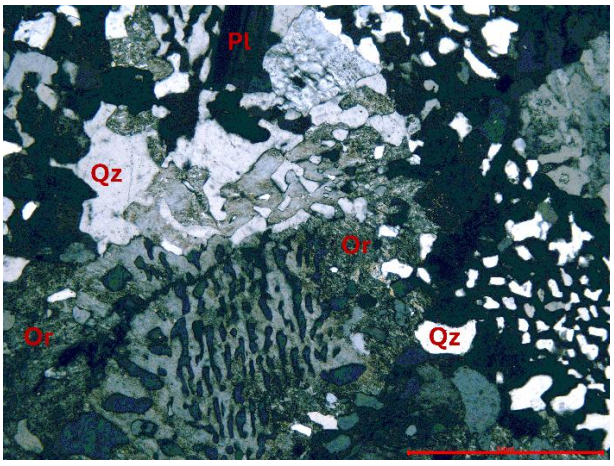


Fig. 10.3. Microphotograph under the microscope at crossed polars of granophyric texture with orthoclase (Or) and quartz (Qz) in granodiorite from Valea Lungii quarry. Pl- plagioclase feldspars.

During upward movement of the granodioritic magma, fragments of previous magmatic rocks as well as of Senonian clays were included. Thus, xenoliths of magmatic and sedimentary origin are embedded by the granodiorite from Valea Lungii. They are well visible due to their different colors and texture as compared with the host rock.

Usually, the magmatic xenoliths are rounded in shape with very net contact with the host granodiorite. They are very well preserved in terms of their mineralogy and petrography.

On the other hand, the xenoliths of sedimentary origin underwent thermic metamorphism. They are entirely recrystallized with the formation of hornfels. They are lenticular in shape, up to 30 cm in length and 10 cm thick. They are mostly black in color, having also a net external limit. Very often, but especially in the case of the larger ones (more than 20 cm in length), a layered aspect consisting of thin layers (up to 0.5 cm thickness) of light- gray granodioritic material intruded into the black metamorphic material can be noticed.

The mineralogical composition of the hornfels consists of quartz, biotite, plagioclase feldspars (albite), andalusite, sillimanite, hercynite (Fig. 10.4), magnetite, phlogopite, garnet, etc.

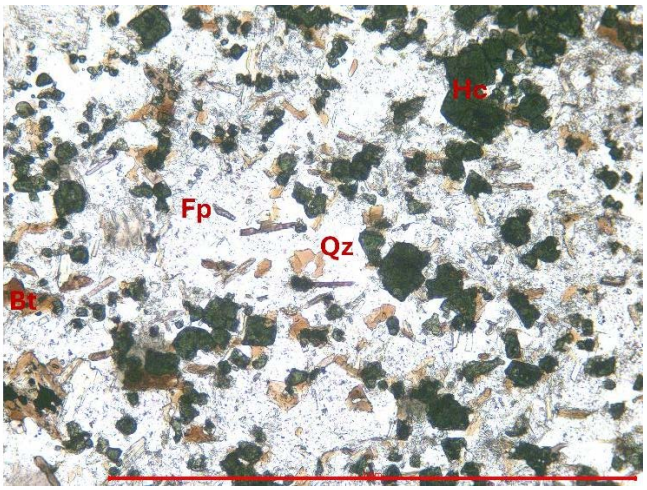


Fig. 10.4. Microphotograph under the microscope at one polar with hercinite (Hr) in horfels from granodiorite from Valea Lungii. Fp – feldspars, Bt – biotite, Qz – quartz.

POIENI AND BOLOGA QUARRIES

Poieni (Cluj County – Romania), represents the "*locus tipicus*" for the petrographic type of volcanic facies known in the literature as ***dacite***. It represents the volcanic rock corresponding to granodioritic and tonalitic rocks. Dacite was first described in the literature by Hauer & Stache (1863). The authors describe two groups of volcanic rocks from the Vlădeasa area (Vlegyásza-Gebiert): with oligoclase ("Quatrztrachyte") and with orthoclase ("Rhyoliten"). They propose the name "Dacite" for the first category of rocks ("Quartztrachyte"), after the name of Dacia, an ancient province that also extended to the territory of Transylvania, where these rocks have an important distribution[1]. Later, Schafarzik (1909) mentions the quarrying of dacite from Poieni ("Kis-Sebes"), in the Cluj County ("Komitat Kolozs"), emphasizing that the name of the rock comes from the ancient Roman province of Dacia. Dacite generally presents a porphyritic texture in which the phenocrysts are made up of plagioclase feldspar (oligoclase, andesine), magmatic corroded hexagonal quartz, biotite, green hornblende, pyroxenes (diopside, augite, enstatite, hypersthene). The groundmass is structurally varied: felsitic, microcrystalline, hyalopilitic or vitreous. The mineralogical composition of the groundmass is identical to that of the phenocrysts, to which volcanic glass is added in variable quantities. The accessory minerals consist of apatite, garnet, allanite, titanite, metallic minerals, etc.

Porphyritic granodiorite/dacite is extracted from Poieni quarry and dacite from Bologa quarry, both rocks as row materials for aggregates (Fig. 10.5) used in road and railway constructions.



Fig. 10.5. Processing aggregates in Bologa quarry

[1] "*Soll jedoch entsprechent der Sonderbezeichnung für die jüngere Gruppe, auch für die ältere Gruppe der Quartztrachyte ein besonderer Name eingeführt werden, so möchte der Name "Dacit" vielleicht entsprechend sein, da die Gruppe im alten Dacien eine besonders hervorragende Rolle zu spielen scheint*" (Hauer & Stache,1863; p. 72)

Porphyritic granodiorite/dacite from Poieni has porphyritic texture with microgranular groundmass (Fig. 10.6). The phenocrysts consists of plagioclase feldspars, quartz, and biotite. The former hornblende phenocrysts are replaced by secondary minerals (chlorite, calcite and opaque minerals). The groundmass consists of quartz, plagioclase feldspars, orthoclase, biotite, chlorite, calcite, opaque minerals, zeolite etc.

The dacite from Bologa has porphyritic texture with phenocrysts of plagioclase feldspar, magmatic corroded hexagonal quartz, biotite, green hornblende, pyroxenes entirely replaced by chlorite (Fig. 10.7). The groundmass is microcrystalline, sometime oriented, having roughly a similar composition with the phenocrysts but secondary minerals as calcite, clay minerals, chlorite, and epidote are also present. The Bologa dacite contains a high variety of xenoliths of the previous volcanics (e.g. andesite, rhyolite), rocks from the basement (crystalline schists, marble etc.) or of sedimentary origin (clayey schists).

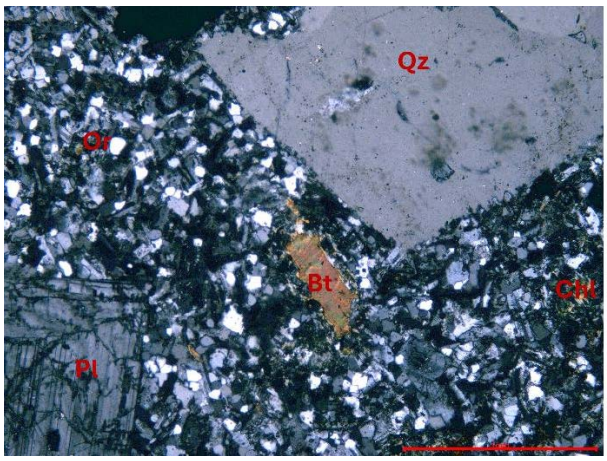


Fig. 10.6. Microphotograph under the microscope at crossed polars of porphyritic granodiorite/dacite from Poieni with phenocysts of plagioclase feldspars (Pl), biotite (Bt), and quartz (Qz).Chl- chlorite, Or – orthoclase. The ground mass is microgarnualre.

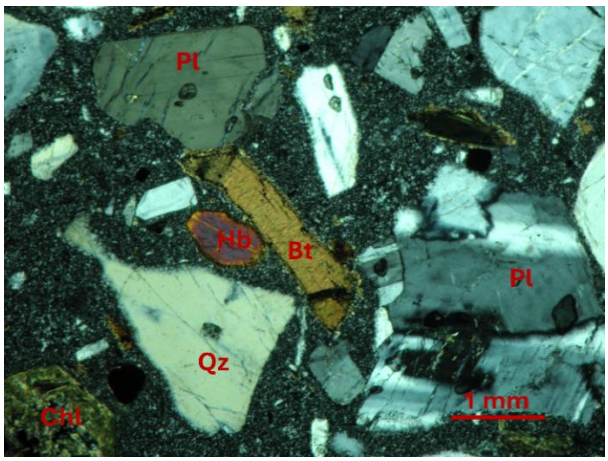


Fig. 10.7 Microphotograph under the microscope at crossed polars of dacite from Bologa with phenocysts of plagioclase feldspars (pl), biotite (Bt), Hornblende (Hb), quartz (Qz) and chlorite replacing pyroxene. The ground mass if microcrystalline.

References

Balintoni, I., 1994. Structure of the Apuseni Mountains. ALCAPA II Field Guidebook, Romanian Journal of Tectonics and Regional Geology, 75, Suppl. 2.

Balintoni, I., 1997. Geotectonica terenurilor metamorfice din România. Editura Carpatica, Cluj-Napoca, 176 p.

Balintoni, I., Puste, A., 2002. New lithostratigraphic and structural aspects in the southern part of the Bihor Massif (Apuseni Mountains). Studia Universitatis Babeș-Bolyai, Geologia, XLVII, 13–18.

Balintoni, I., Ghergari, L., Babut, T., 2002. The Arieseni nappe, or the Moma and Poiana nappes. Studia Universitatis Babeș-Bolyai, Geologia, XLVII, 19–26.

Balintoni, I., Balica, C., Ducea, M.N., Zaharia, L., Fukun Chen, Cliveti, M., Hann, H.P., Li-Qiu Li., Ghergari, L., 2010. Late Cambrian-Ordovician northeastern Gondwanan terranes in the basement of the Apuseni Mountains, Romania. Journal of the Geological Society, London, 167, 1131–1145.

Benea, M., Tămaș, C.G., 2010. Neogene volcanics in the Apuseni Mts.: historical mining, and gold deposits. IMA Field Trip Guide RO3, Acta Mineralogica-Petrographica, Field Guide Series, 21, 24 p.

Bleahu, M., Lupu, M., Patrulius, D., Bordea, S., Ștefan, A., Panin, S., 1981. The structure of the Apuseni Mountains. In: Carpatho-Balkan Geological Association, XII Congress (Bucharest, Romania). Guide to Excursion B3, 103 p., Bucharest.

Bleahu, M., Soroiu, M., Catalina, R., 1984. On the Cretaceous tectonomagmatic evolution of the Apuseni Mountains as revealed by K-Ar dating. Rev. Roum. Phys., 29, 1, 123–130.

Borcoș, M., Krautner, H.G., Udubașa, G., Săndulescu, M., Năstăseanu, S., Bițoianu, C., 1984. Atlas geologic 1:1 000 000. Harta substanțelor minerale utile. Notă explicativă, ediția a II-a. București, Romania, Ministerul Geologiei, Institutul de Geologie și Geofizică, 132 p.

Bordea, S., Ștefan, A., Borcoș, M., 1979. Harta geologică 1:50 000, foaia Abrud. Inst. Geol. Geofiz., București.

Borcoș, M., Krautner, H.G., Udubașa, G., Săndulescu, M., Năstăseanu, S., Bițoianu, C., 1984. Map of the mineral resources. 2nd edn. Explanatory note. Institute of Geology and Geophysics, Bucharest.

Bortolotti, V., Marroni, M., Ionel, N., Pandolfi, L., Principi, G.F., Saccani, E., 2002. Geodynamic implications of Jurassic ophiolites associated with island-arc volcanics, South Apuseni Mountains, Western Romania. International Geology Review, 44, 938–955.

Bortolotti, V., Marroni, M., Ionel, N., Pandolfi, L., Principi, G.F., Saccani, E., 2004. An update of the Jurassic ophiolites and associated calc-alkaline rocks in the South Apuseni Mountains (Western Romania). Ophioliti, 29/1, 5–18.

Ciobanu, C.L., Cook, N.J., Stein, H., 2002. Regional setting and geochronology of the Late Cretaceous Banatitic Magmatic and Metallogenetic Belt. Mineralium Deposita, 37, 541–567.

Cloetingh, S., Bada, G., Matenco, L., Lankreijer, A., Horváth, F., Dinu, C., 2006. Modes of basin (de)formation, lithospheric strength and vertical motions in the Pannonian-Carpathian system: inferences from thermo-mechanical modelling. In: Gee, D.G., Stephenson, R.A. (eds), European Lithosphere Dynamics. Geological Society, London, Memoirs, 32, 207–221.

Csontos, L., 1995. Tertiary tectonic of the Intra-Carpathian area: a review. Acta Vulcanologica, 7 (2), 1–13.

Dragoș, I., 1971. Fauna și flora cretacică din regiunea Vlădeasa (Munții Apuseni). Rezumatul tezei de doctorat, Univ. București.

Drăgușanu, S., 2017. Gold-silver mineralizations in the northern part of the Roșia Montană deposit, Apuseni Mountains, Romania. Unpublished thesis, 173 p. (in Romanian).

Ene, V., Tapster, S., Smith, D.J., Panaiotu, C., Roșu, E., Naden, J., Munteanu, M., 2024. Spatiotemporal distribution of magmatism and crustal inheritance within an extensional–rotational environment: an updated geochronology of the Miocene and Quaternary magmatism of the South Apuseni Mountains. Journal of the Geological Society, 181.

Fuegenschuh, B., Schmid, S.M., 2005. Age and significance of core complex formation in a very curved orogen: evidence from fission track studies in the South Carpathians (Romania). Tectonophysics, 404, 33–53.

Gallhofer, D., von Quadt, A., Peytcheva, I., Schmid, S.M., Heinrich, C.A., 2015. Tectonic, magmatic, and metallogenic evolution of the Late Cretaceous arc in the Carpathian-Balkan orogen. Tectonics, 34.

Giușcă, D., 1960. Asupra unui corp de ultrabazite metamorfozate din cristalinul Bihorului. Analele Universității București, 23, 7–15, București.

Giușcă, D., Cioflică, G., Savu, H., 1966. Caracterizarea petrologică a provinciei Banatitice. An. Com. Geol., XXXV, 13–45.

Giușcă, D., Mârza, I., 1976. Mineralizări de contact în dolomitele cristaline din Valea Ierii (Munții Apuseni). St. Cercetări de Geologie, Geofizică și Geografie, 21, 21–30.

Har, N., 2001. The alpine basaltic andesites from Apuseni Mountains. Casa Cărții de Știință, Cluj-Napoca, 214 p.

Har, N., 2005. Reaction coronas around quartz xenocrysts in the basaltic andesite from Detunata (Apuseni Mountains, Romania). Geologica Carpathica, 56, 4, 369–378.

Hauer, F., Stache, G., 1863. Geologie Siebenbürgens. Wien, 636 p.

Ianovici, V., Borcoș, M., Bleahu, M., Patrulius, D., Lupu, M., Dimitrescu, R., Savu, H., 1976. Geologia Munților Apuseni. Ed. Acad. RSR, 631 p., București.

Intorsureanu, I., Lazăr, C-tin, 1992. Zăcămintele de skarn și sulfuri din zona Băișara (Munții Apuseni). Romanian Journal of Mineral Deposits, 75, 65–75.

Ionescu, O., 1974. Mineralizația cupriferă de tip diseminat de la Roșia-Poieni (Jud. Alba). Studii și Cercetări de Geologie, Geofizică, Geografie, Seria Geologie, 19, 77–84.

Ionescu, O., Soare, C., Gheorghiu, M., 1975. Contribuții la cunoașterea zăcământului cuprifer Roșia-Poieni. Alterații hipogene. Studii și Cercetări de Geologie, Geofizică, Geografie, Seria Geologie, 20, 2, 159–170.

Istrate, Gh., 1978. Petrologic Study of the Vlădeasa Massif (Western Part). An. Inst. Geol. Geofiz., LIII, 177–311, București.

Ivășcanu, P., Baker, T., Lewis, P., Kulcsar, Z., Denes, R., Tamas, C., 2019. Bolcana, Romania: Geology and discovery history of a gold rich porphyry deposit. 2019 NewGenGold Conference, Perth, 12–13 November 2019, 145–160.

Jude, R., Ștefan, A., 1967. Contribuții la studiul petrografic al banatitelor din partea de sud a Munților Bihor (Munții Apuseni). D.S. Com. Geol., LIII/1, 74–94, București.

Kounov, A., Schmid, S.M., 2013. Fission track constraints on the thermal and tectonic evolution of the Apuseni Mountains (Romania). International Journal of Earth Sciences, 10, 207–233.

Kräutner, H.G., 1996. Alpine and pre-Alpine terranes in South Carpathians and equivalents of South of Danube. In: Knežević, V., Krstić, B. (eds), Terranes of Serbia, 53–58, Belgrad.

Kouzmanov, K., von Quadt, A., Peytcheva, I., Harris, C., Heinrich, C.A., Roșu, E., O'Connor, G., 2005. Roșia Poieni porphyry Cu–Au and Roșia Montană epithermal Au–Ag deposits, Apuseni Mts., Romania: Timing of magmatism and related mineralisation. Au–Ag–Te–Se Deposits, IGCP Project 486, 2005 Field Workshop, Kiten, Bulgaria, 14–19 September 2005, Proceedings, 113–117.

Leary, S., O'Connor, G., Minuț, A., Tămaș, C., Manske, S., Howie, K., 2004. The Roșia Montană deposit. In: Cook, N.J., Ciobanu, C.L. (eds), Gold-Silver-Telluride Deposits of the Golden Quadrilateral, South Apuseni Mts., Romania: Guidebook of the International Field Workshop of IGCP Project 486, Alba Iulia, Romania, August–September 2004. IAGOD Guidebook Series, 12, 89–98.

Măldărescu, I., 1978. Contribuții la cunoașterea bazaltelor cu xenolite de cuarț de la Detunata. St. și Cerc. de Geol., Geofiz. și Geogr., 23, 2, 167–334.

Manske, S.L., Hedenquist, J.W., O'Connor, G., Tămaș, C., Cauuet, B., Leary, S., Minuț, A., 2006. Roșia Montană, Romania: Europe's largest gold deposit. Society of Economic Geologists Newsletter, 64 (1), 9–15.

Mârza, I., 1969. Evoluția unităților cristaline din estul Muntelui Mare. Ed. Acad. Române, 166 p., București.

Mârza, I., Mészáros, 1987. La relation géochronologique du magmatisme laramique (banatitique) et postlaramique (Paléogène) avec les formations Sénoniennes–Paléogènes de la bordure nord-est des Monts Gilău. The Eocene from the Transylvanian Basin, Cluj-Napoca, 241–246.

Mârza, I., Tămaș, C., Ghergari, L., 1997. Low sulfidation epithermal gold deposits from Roșia Montană, Metaliferi Mountains, Romania. Studii și Cercetări de Geologie, 42, 3–12.

Merten, S., Matenco, L., Foeken, J.P.T., Andriessen, P.A.M., 2011. Towards understanding the post-collisional evolution of an orogen influenced by convergence at adjacent plate margins: Late Cretaceous–Tertiary thermo-tectonic history of the Apuseni Mountains. Tectonics, 30, TC6008.

Milu, V., Milési, J.-P., Leroy, J.L., 2004. Roșia Poieni copper deposit, Apuseni Mountains, Romania: Advanced argillic overprint of a porphyry system. Mineralium Deposita, 39, 173–188.

Minuț, A., Leary, S., Szentesy, C., O'Connor, G., 2004. A new style of mineralization identified at Roșia Montană. Romanian Journal of Mineral Deposits, 81, Special Issue, 147–148.

Nicolae, I., 1994. The ophiolitic rocks from Mureș Valley. ALCAPA II Field Guide-Book, Romanian Journal of Tectonic and Regional Geology, 75, 2, 136–14, Bucharest.

Nicolae, I., Saccani, E., 2003. Late Jurassic calc-alkaline series in the South Apuseni Mountains. Schweizerische Mineralogisch-Petrographische Mitteilungen, 83, 81–96.

Panaiotu, C., 1999. Paleomagnetic studies in Romania. Tectonophysics implications. PhD thesis, University of Bucharest, 265 pp.

Pană, D., Heaman, L., Creaser, R., Erdmer, P., 2002. Pre-alpine crust in the Apuseni Mountains, Romania: insights from Sm–Nd and U–Pb data. Journal of Geology, 110, 341–354.

Pătrașcu, S., Panaiotu, C., Șeclăman, M., Panaiotu, C.E., 1994. Timing of rotational motion of Apuseni Mountains (România): paleomagnetic data from Tertiary magmatic rocks. Tectonophysics, 233, 163–176.

Pécskay, Z., Edelstein, O., Seghedi, I., Szakács, A., Kovacs, M., Crihan, M., Bernad, A., 1995. K–Ar datings of Neogene-Quaternary calc–alkaline volcanic rocks in Romania. In: Downes, H., Vaselli, O. (eds), Neogene and Related Magmatism in the Carpatho-Pannonian Region. Acta Vulcanologica, 7 (2), 53–61.

Ratschbacher, L., Linzer, H.G., Moser, F., Strusievicz, R.O., Bedelean, H., Har, N., Mogoș, P., 1992. Cretaceous to Miocene thrusting and wrenching along the Central South Carpathians due to a corner effect during collision and orocline formation. Tectonics, 12, 855–873.

Rădulescu, D., Dimitrescu, R., 1982. Petrologia endogenă a teritoriului R.S. România. Universitatea București, 120 p.

Reiser, M.K., 2015. The tectonometamorphic evolution of the Apuseni Mountains during the Cretaceous: Investigations on the interplay between tectonics and surface processes in the build-up of a source area. PhD thesis, University of Innsbruck, 156 pp.

Reiser, M.K., Schuster, R., Spikings, R., Tropper, P., Fügenschuh, B., 2017. From nappe stacking to exhumation: Cretaceous tectonics in the Apuseni Mountains (Romania). International Journal of Earth Sciences, 106, 659–685.

Rey, R., 2004. Roșia Poieni and Roșia Montană: Neighbouring porphyry Cu–Au and epithermal Au–Ag deposits in the South Apuseni Mountains, Romania, with special focus on fluid inclusions trapped in hydrothermal quartz from Roșia Montană. M.Sc. thesis, Swiss Federal Institute of Technology (ETH Zürich), Zurich, Switzerland, 146 p.

Roșu, E., Pécskay, Z., Ștefan, A., Popescu, Gh., Panaiotu, C., Panaiotu, C.E., 1997. The evolution of the Neogene volcanism in the Apuseni Mountains (Romania): constraints from new K–Ar data. Geologica Carpatica, 48, 6/1997, 353–359.

Roșu, E., Seghedi, I., Downes, H., Alderton, D., Szakacs, A., Pecskay, Z., Panaiotu, C., Nedelcu, L., 2004. Extension-related Miocene calcalkaline magmatism in the Apuseni Mountains, Romania: origin of magmas. Schweizerische Mineralogische und Petrographische Mitteilungen, 84, 153–172.

Savu, H., 1976. Evolutions du magmatisme laramien dans les Monts Apuseni et la métallogénie associée. Rev. Roum. de Géol., Géoph. et Géogr., s. Géol., 20/1, 77–84.

Săndulescu, M., 1984. Geotectonica României. Ed. Tehnica, 336 p., București.

Săsăran, E., 2006. Calcarele Jurasicului superior–Cretacicului inferior din Munții Trascău. Unpublished PhD thesis, University Cluj-Napoca. Presa Universitară Clujeană, 249 pp.

Sîntimbrean, A., 1989. Mining Museum in Roșia Montană. Editura Sport-Turism, Bucharest, 220 p. (in Romanian).

Schafarzik, Fr., 1909. Detaillierte Mitteilungen über die auf dem Gebiet des ungarischen Reiches befindlichen Steinbrecher. Publikationen d. kgl. ung. geol. R.A., Budapest.

Schmid, S.M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski, K., 2008. The Alpine-Carpathian-Dinaridic orogenic system: correlation and evolution of tectonic units. Swiss Journal of Geosciences, 101 (1), 139–183.

Schmid, S.M., Fügenschuh, B., Kounov, A., Matenco, L., Nievergelt, P., Oberhänsli, R., Pleuger, J., Schefer, S., Schuster, R., Tomljenović, B., Ustaszewski, K., van Hinsbergen, D.J.J., 2020. Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey. Gondwana Research, 78, 308–374.

Schuller, V., 2004. Evolution and geodynamic significance of the Upper Cretaceous Gosau basin in the Apuseni Mountains (Romania). Tübinger Geowissenschaftliche Arbeiten, Reihe A, 70, 112 pp.

Schuller, V., Frisch, W., Danisik, M., Dunkl, I., Melinte, M.C., 2009. Upper Cretaceous Gosau deposits of the Apuseni Mountains (Romania)—similarities and differences to the Eastern Alps. Austrian Journal of Earth Sciences, 102, 133–145.

Seghedi, I., Downes, H., Szakacs, A., Mason, P.R.D., Thirlwall, M.F., Rosu, E., Pecskay, Z., Márton, E., Panaiotu, C., 2004. Neogene-Quaternary magmatism and geodynamics in the Carpathian-Pannonian region: a synthesis. Lithos, 72, 117–146.

Sillitoe, R.H., Hedenquist, J.W., 2003. Linkages between volcanotectonic settings, ore-fluid compositions, and epithermal precious-metals deposits. In: Simmons, S.F., Graham, I.J. (eds), Volcanic, Geothermal and Ore-Forming Fluids: Rulers and Witnesses of Processes within the Earth. Society of Economic Geologists Special Publication, 10, 315–343.

Stan, R., 2006. Studii mineralogice și de petrologie asupra litozonei Gârda și litogrupului Biharia, cuprinse între Valea Someșului și cursul superior al Arieșului. Teza de doctorat. Universitatea Babeș–Bolyai, Cluj-Napoca, 290 p.

Ștefan, A., Lazăr, C., Berbeleac, I., Udubașa, Gh., 1988. Evolution of banatitic magmatism in the Apuseni Mountains and associated metallogenesis. D.S. Inst. Geol., 72–73/2, 195–213.

Ștefan, A., Roșu, E., Andăr, A., Robu, L., Robu, N., Bratosin, I., Grabari, G., Stoian, M., Vâjdea, Colios, E., 1992. Petrological and geochemical features of banatitic magmatites in northern Apuseni Mountains. Romanian Journal of Petrology, 75, 97–115.

Tămaș, C.G., 2002. Breccia pipe structures associated to some hydrothermal ore deposits from Romania [Structuri de "breccia pipe" asociate unor zăcăminte hidrotermale din România]. PhD thesis, Babeș–Bolyai University, Cluj-Napoca, Romania, 336 p. (in Romanian).

Tămaș, C.G., 2007. Endogene breccia structures (breccia pipe–breccia dyke) and the petrometallogeny of Roșia Montană ore deposit (Metalliferous Mountains, Romania). Cluj-Napoca: Casa Cărții de Știință, 230 p. (in Romanian).

Tămaș, C.G., Bailly, L., 1998. Fluid inclusion study for Roșia Montană ore deposit. Romanian Journal of Mineral Deposits, 78, Suppl. 1, 97–98.

Tămaș, C.G., Bailly, L., 1999. Roșia Montană low-sulfidation ore deposit – evidence from fluid inclusion study. Studia Universitatis Babeș–Bolyai, Geologia, 44 (1), 49–56.

Tămaș, C.G., Bailly, L., Ghergari, L., O'Connor, G., Minuț, A., 2006. New occurrence of tellurides and argyrodite at Roșia Montană, Apuseni Mountains, Romania and their metallogenetic significance. Canadian Mineralogist, 44 (2), 689–705.

Tămaș, C.G., Grobety, B., Bailly, L., Bernhardt, H.-J., Minut, A., 2014. Alburnite, Ag8GeTe2S4, a new mineral species from the Roșia Montană Au-Ag epithermal deposit, Apuseni Mountains, Romania. American Mineralogist, 99, 57–64.

Tischler, M., Gröger, H.R., Fügenschuh, B., Schmid, S.M., 2007. Miocene tectonics of the Maramureș area (Northern Romania): implications for the Mid-Hungarian fault zone. International Journal of Earth Sciences (Geologische Rundschau), 96, 473–496.

Treiber, I., Ghergari, Lucreția, Mârza, I., Ionescu, Georgeta, 1967. Cercetări microtectonice în masivul dacitc Jidovina (V. Arieșului). Studia Geologia–Geographia, 1967/2.

Tămaș, C.G., Andrii, M.P., Kovács, R., Drăgușanu, S., Cauuet, B., 2021. Sphalerite composition in low and intermediate-sulfidation epithermal ore bodies from the Roșia Montană Au-Ag ore deposit, Apuseni Mountains, Romania. Minerals, 11, 634.

Wallier, S., 2004. Roșia Poieni and Roșia Montană: Neighbouring porphyry Cu–Au and epithermal Au–Ag deposits in the South Apuseni Mountains, Romania, including analysis of fluid inclusions trapped in quartz phenocrysts from Roșia Montană. M.Sc. thesis, Swiss Federal Institute of Technology (ETH Zürich), Zurich, Switzerland, 145 p.

Wallier, S., Rey, R., Kouzmanov, K., Pettke, T., Heinrich, C.A., Leary, S., O'Connor, G., Tămaș, C.G., Vennemann, T., Ullrich, T., 2006. Magmatic fluids in the breccia-hosted epithermal Au–Ag deposit of Roșia Montană, Romania. Economic Geology, 101, 923–954.

Warr, N. Laurence, 2021. IMA–CNMNC approved mineral symbols. Mineralogical Magazine, 85, 291–320.

FIELD TRIP 10

FT10. A geological transect across the Transylvanian Basin and the Eastern Carpathians: insights into their tectono-sedimentary evolution

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INTRODUCTION

The Romanian Carpathians and the Transylvanian Basin preserve one of the most complete records of Alpine tectonic and sedimentary evolution in the Central and Eastern Europe. Their geological architecture reflects the progressive closure of several branches of the Alpine Tethys Ocean, the interaction between continental blocks, oceanic domains and foreland basins, and the subsequent development of one of Europe's most complex fold-and-thrust systems (Săndulescu, 1984, 1988; Schmid *et al*., 2008). As a result, the region preserves an exceptional sedimentary archive spanning from the Jurassic to the Miocene, recording the evolution of these oceanic basins, passive continental margins, carbonate platforms, deep-water turbidite deposits and foreland basins.

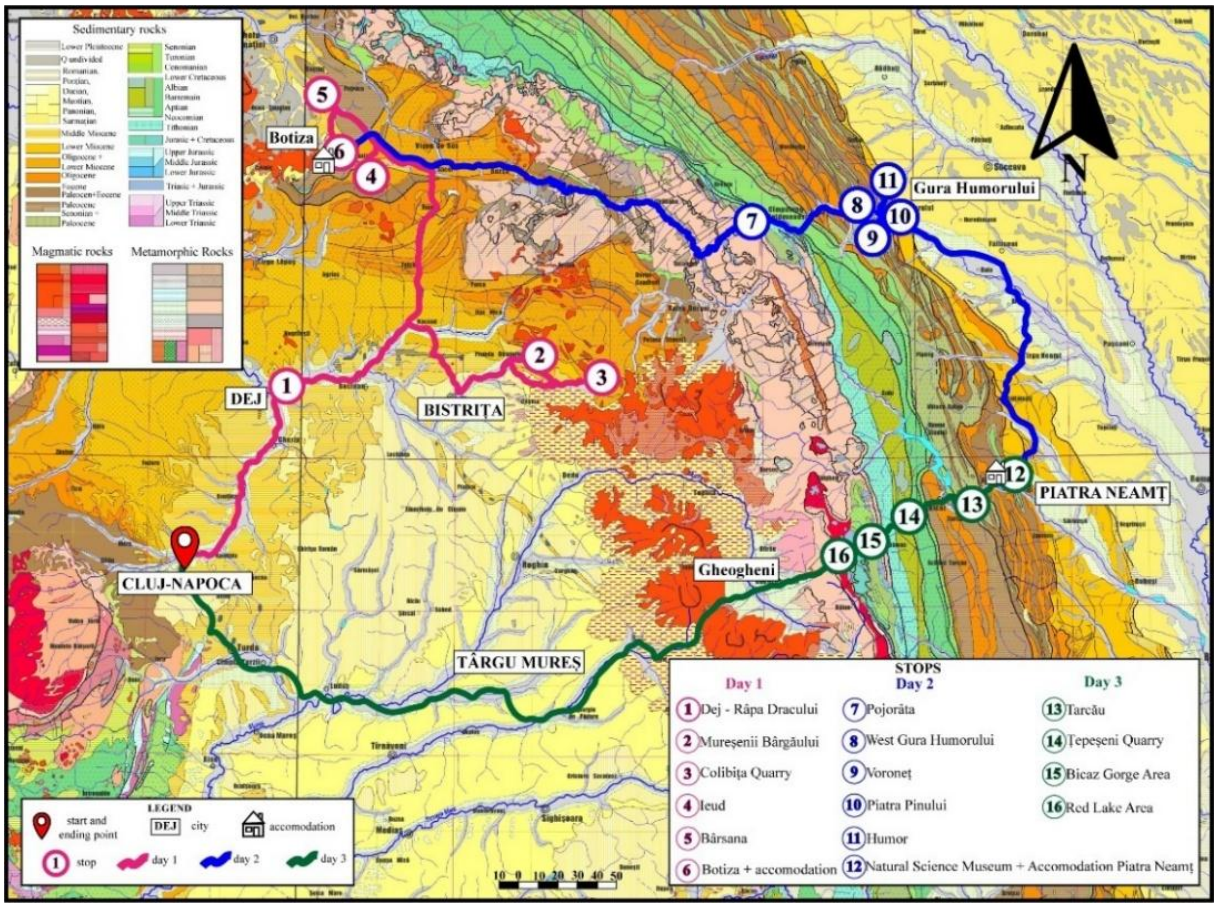


Fig. 1. Geological map of the northern Romania showing the itinerary of the three-day field excursion (modified after the Geological Map of Romania, scale 1:1.000.000; Săndulescu *et al*., 1978).

This field excursion follows a west-to-east geological transect across the Transylvanian Basin and the Eastern Carpathians, providing a comprehensive overview of the principal tectonic units that characterize the northern sector of the East Romanian Carpathians (Fig. 1). Over the course of three days, participants will examine representative outcrops within the Transylvanian Basin, the Transcarpathian Basin, the Pienides, the Median Dacides, the Outer Dacides, and the Moldavides.

A distinctive feature of the excursion is the integrated application of sedimentology, stratigraphy, and biostratigraphy to reconstruct a part of the Carpathian evolution. Throughout the itinerary, sedimentological observations are combined with lithostratigraphic and biostratigraphic data to constrain the age of sedimentary successions-and reconstruct depositional environments.

REGIONAL GEOLOGICAL FRAMEWORK

The Romanian Carpathians constitute a segment of the Alpine–Carpathian orogenic chain and represent the result of a long tectonic evolution. Their present-day architecture is the consequence of interaction and progressive convergence of three major continental units: the Tisza Block, represented by the Inner Dacides; the Dacia Block, represented by the Median Dacides; and the European foreland, including the East-European, Scythian, Moesian platforms and North Dobrogea Orogen (e.g., Săndulescu, 1980, 1984, 1988; Csontos & Vörös, 2004; Matenco, 2017). During the Mesozoic, these continental blocks were separated by several oceanic and thinned continental domains that originated during the extensional evolution of the Neotethys and Alpine Tethys (Fig. 2). Subsequent convergence led to progressive closure of these basins during the Cretaceous and Miocene, producing the complex nappe architecture that characterizes the Romanian Carpathians today (e.g., Săndulescu, 1984, 1988; Schmid *et al*., 2008; Matenco, 2017).

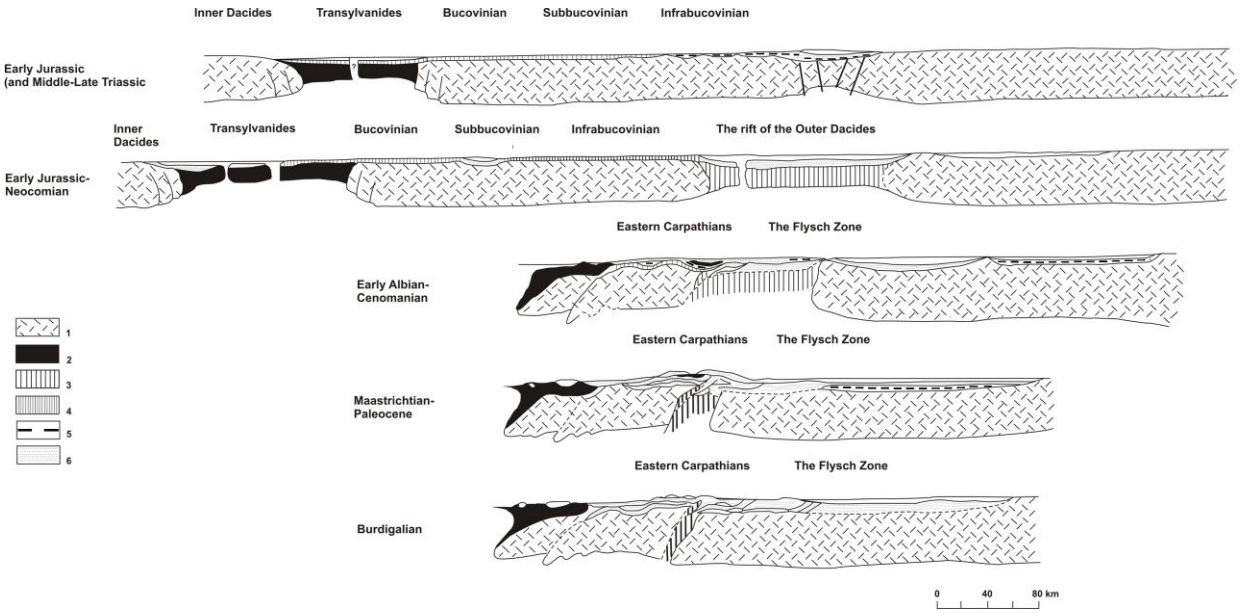


Fig. 2. The geo-tectonic evolution of Carpathians (Săndulescu, 1984, 1988): 1 – continental crust; 2 – oceanic crust; 3 – thinned crust; 4 – pelagic deposits; 5 – flysch deposits.

The Northern and Central compartments of Eastern Carpathians constitute key segments for understanding the overall geology of the Eastern Carpathians (Fig. 3), offering outcrops of paramount importance for the evolution of the Pienides, Median Dacides, Outer Dacides, and Moldavides. The Pienides represent a former oceanic domain of the Alpine Tethys, formed between the ALCAPA and Tisza-Dacia continental blocks. They consist of a series of nappes forming a continuous belt that extends from the Vienna Basin, in the West, through Slovakia, Poland, and Ukraine, to their easternmost occurrence at

Poiana Botizei in Northern Romania (Săndulescu, 1984; Săndulescu *et al.*, 1982). In the North-Eastern Carpathians, particularly in the Maramureș region, the Pienides are represented by individual nappes outcropping in two distinct sectors, separated by the Bogdan-Vodă transcrustal strike-slip fault system. The Pienides are divided into internal (Botiza Nappe and Pieniny Klippen-type units) and external (Petrova, Leordina, and Wildflysch) nappes (Aroldi, 2003; Tischler *et al.*, 2008). The external Pienides show similarities with flysch deposits of the Magura Group in Slovakia and Poland (Săndulescu *et al.*, 1981; Săndulescu, 1994; Aroldi, 2003). Their sedimentary successions span from the Jurassic to Miocene (Săndulescu, 1984; Aroldi, 2001; Golonka *et al.*, 2003) and were folded during the Late Cretaceous and thrust onto the Dacia margin in Burdigalian (Tischler *et al.*, 2008). An important role in the way the Pienides are displayed today must have been played by two major strike-slip faults, namely the Bogdan-Vodă and Dragoș-Vodă Faults, linked to the Mid-Hungarian fault zone (Tischler *et al.*, 2008).

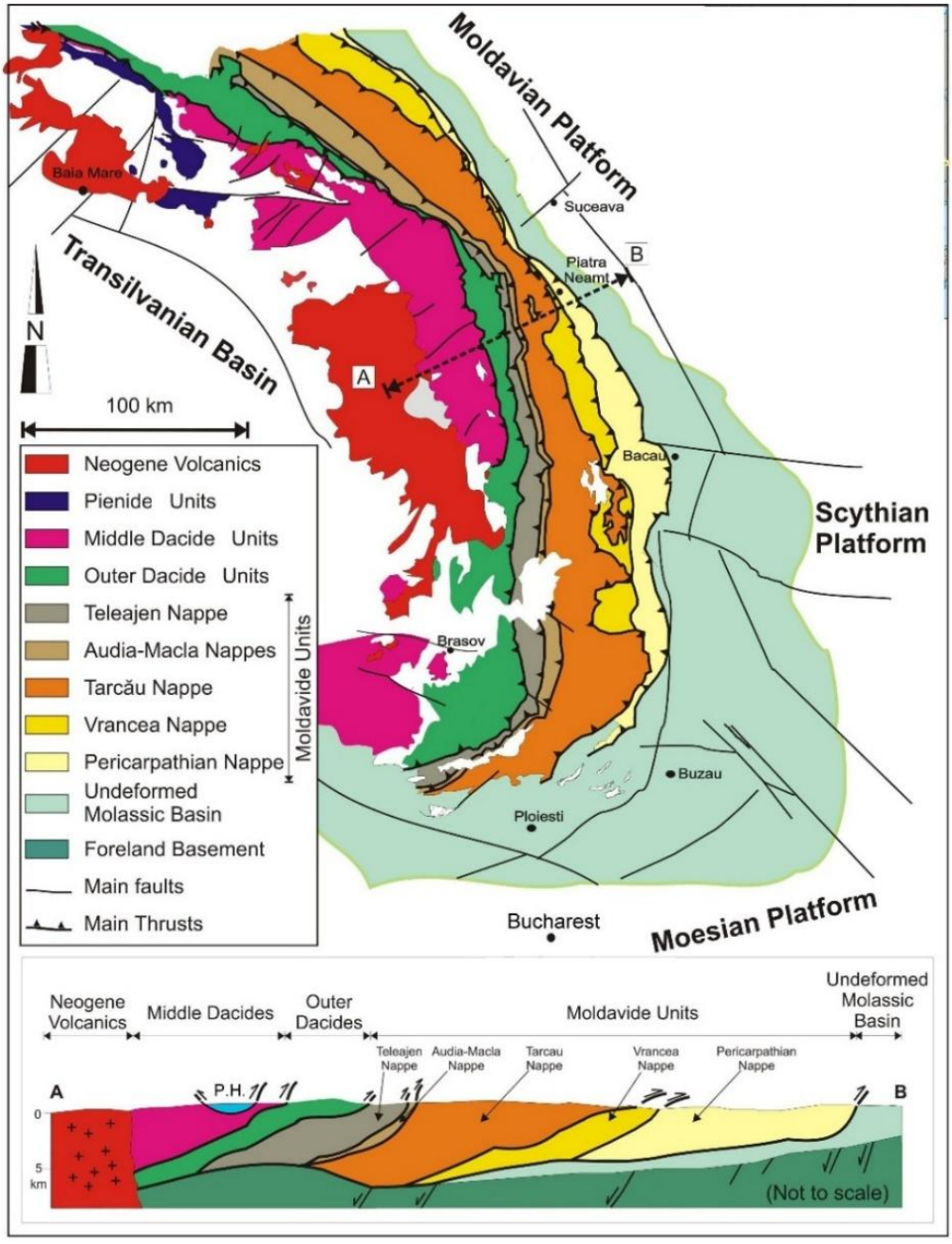


Fig. 3. Geological sketch of the East Carpathians (modified after Bădescu, 2005): BHw – Bistriţa Half-window; P.H. – Hăşmaş Transylvanian Nappe.

South of the Pienides, the Transylvanide (Vardar–Mureș) Ocean, situated between the Tisza and Dacia blocks, represented one of the branches of the Neotethys. It opened during the Triassic and was consumed during the Cretaceous convergence events, leading to the emplacement of the Transylvanide nappes (Săndulescu, 1984; 1988).

Outward of the Median Dacides evolved the Ceahlău–Severin Ocean, generally regarded as the easternmost branch of the Alpine Tethys (Săndulescu, 1984, 1988; Schmid *et al.*, 2008). This oceanic domain most likely opened during the Middle Jurassic between the Dacia continental block and the European foreland. Several authors have suggested that it represented either the eastern continuation of the Silesian Basin or part of the Magura Ocean system of the Western Carpathians (e.g., Csontos & Vörös, 2004; Golonka *et al.*, 2006). Oceanic crust developed locally within its internal sector, where Middle Jurassic–Lower Cretaceous black flysch was deposited together with basic volcanics, preserved today within the Black Flysch Nappe, Ceahlău Nappe, and Severin Nappe (Săndulescu, 1980, 1984). According to Bădescu (2005), the Ceahlău–Severin domain may have been connected with the Transylvanide Ocean prior to its final closure, implying that the Median Dacides behaved as a narrow continental ribbon during Alpine convergence.

Following the progressive closure of the Ceahlău–Severin Ocean, its external margin evolved into the Moldavide foreland basin (Săndulescu, 1984; Grasu *et al.*, 1999; Bădescu, 2005). The emplacement of the Median Dacide nappes during the Early Cretaceous generated a forebulge along the peri-Moldavian margin, which became an important source of clastic sediment for the basin (Săndulescu, 1984; Grasu *et al.*, 1999). Continued tectonic loading caused the basin depocentre to migrate progressively eastward, from the Convolute Flysch Nappe domain during the Cretaceous, to the Tarcău Nappe domain during the Paleogene, and finally to the Pericarpathian Basin during the Miocene (Ionesi, 1971; Grasu *et al.*, 1999; Bădescu, 2005).

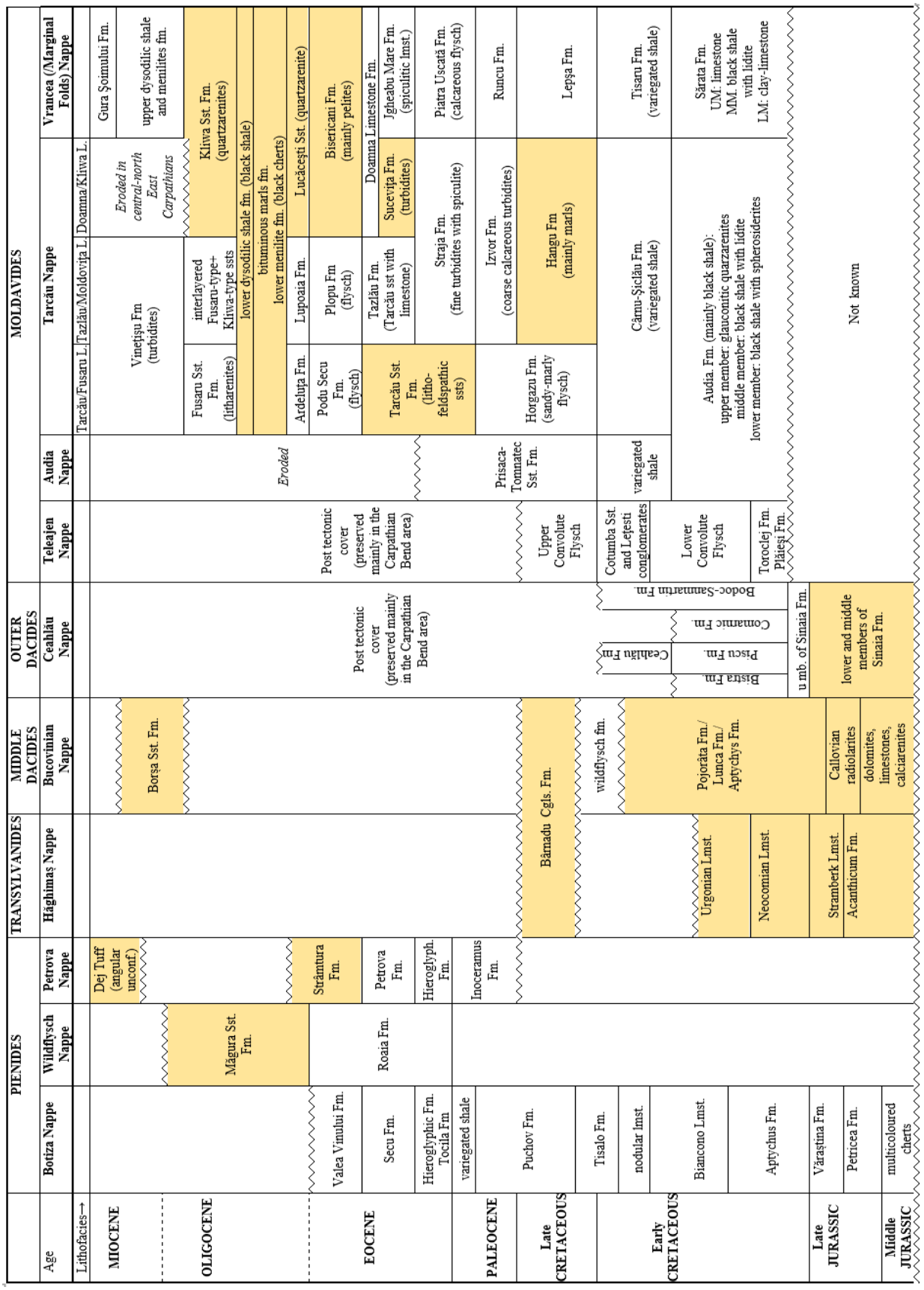
The Eastern Carpathian Flysch Belt represents a thin-skinned fold-and-thrust system developed through the progressive closure of the Moldavide Basin and the subsequent incorporation of its sedimentary fill into the Carpathian orogenic wedge. It is composed predominantly of Lower Cretaceous to Lower Miocene marine sedimentary successions deposited along the margin of the European Platform, being conventionally subdivided into two major structural domains according to the age of tectonic deformation. The internal domain comprises ?Middle Jurassic–Lower Cretaceous successions belonging to the former Ceahlău–Severin Ocean, whereas the external domain consists of Lower Cretaceous–Lower Miocene flysch deposits accumulated within the Moldavide Basin on the thinned continental crust of the European passive margin (Săndulescu, 1984, 1988; Bădescu, 2005).

These two domains record the two principal tectonic stages responsible for the present-day architecture of the Eastern Carpathians. The internal flysch nappes, related to the Ceahlău–Severin Ocean, were emplaced during the Cretaceous tectogeneses, when the Dacia unit was sutured back to Europe. In contrast, the Moldavide units were progressively incorporated into the fold-and-thrust belt during the Miocene tectogeneses. The Moldavide nappe stack comprises, from the internal to the external part of the belt, the Teleajen (Convolute Flysch), Macla, Audia, Tarcău, Vrancea (Marginal Folds), and Pericarpathian nappes. Their emplacement occurred successively during three major compressional phases: the intra-Burdigalian event, responsible for the overthrusting of the Teleajen, Macla and Audia nappes; the intra-Badenian event, during which the Tarcău and Vrancea (Marginal Folds) nappes were emplaced and folded, respectively; and the lower Sarmatian event, which resulted in the emplacement of the Pericarpathian Nappe together with the previously stacked internal units (Săndulescu, 1984, 1988) onto the foreland. This sequential nappe emplacement produced the present-day structural framework of the Outer Eastern Carpathians.

Variations in sediment supply from the uplifting Dacides and the European foreland, respectively, controlled the development of several characteristic Paleogene lithofacies within the Tarcău Nappe domain of Moldavide Basin. These include the internal Tarcău-Fusaru lithofacies, the mixed Tazlău–Moldovița lithofacies, and the external Doamna-Kliwa lithofacies (Băncilă, 1958; Ionesi, 1971; Grasu *et al.*, 1988). Together, these lithofacies document changes in sediment provenance, dispersal pathways, and foreland basin evolution during the Paleogene.

Our field trip traverses several of the Moldavide nappes, providing the opportunity to examine representative lithostratigraphic successions ranging from the Lower Cretaceous to the Oligocene, together with their structural relationships and the evolution of sedimentary environments within the Eastern Carpathian Flysch Basin.

Table 1. Lithostratigraphic units of the Eastern Carpathian included in the field trip (based on Ionesi, 1971; Săndulescu, 1984; Grasu *et al.*, 1988; Grasu *et al*., 1996). Units examined during the excursion are highlighted in yellowish beige.



DESCRIPTION OF THE STOPS

DAY 1 (6th September): Cluj-Napoca – Dej – Bistrița – Mureșenii Bârgăului – Colibița Quarry – Bistrița – Ieud – Bârsana – Botiza (342 km)

The first day of the excursion (Fig. 1) introduces the geological evolution of northern Romania, beginning with the Neogene sedimentary successions related to the Central Paratethys (Transylvanian Basin) and continuing eastwards through the Transcarpathian Basin (Bârgău Mountains) and into the Pienides (Pienidian Units) from the Northeastern Carpathians, finally ending the day with the overnight accommodation at the Botiza village.

Stop 1. Dej (Râpa Dracului) – the Hida and Dej formations (Early-Middle Miocene)

The Râpa Dracului outcrop near Dej exposes one of the most complete successions across the Early–Middle Miocene transition in the northwestern Transylvanian Basin. The section comprises the upper part of the Hida Formation and the overlying Dej Formation, recording the evolution from a prograding fan-delta system to a transgressive deep-marine basin strongly influenced by contemporaneous volcanism (Krézsek and Bally, 2006; Beldean *et al*., 2013). Within the Lower–Middle Miocene stratigraphic framework of the Transylvanian Basin, the Hida Formation represents the upper part of the Lower Miocene megasequence, whereas the Dej Formation marks the onset of the Badenian marine transgression and widespread volcaniclastic sedimentation (Fig. 4).

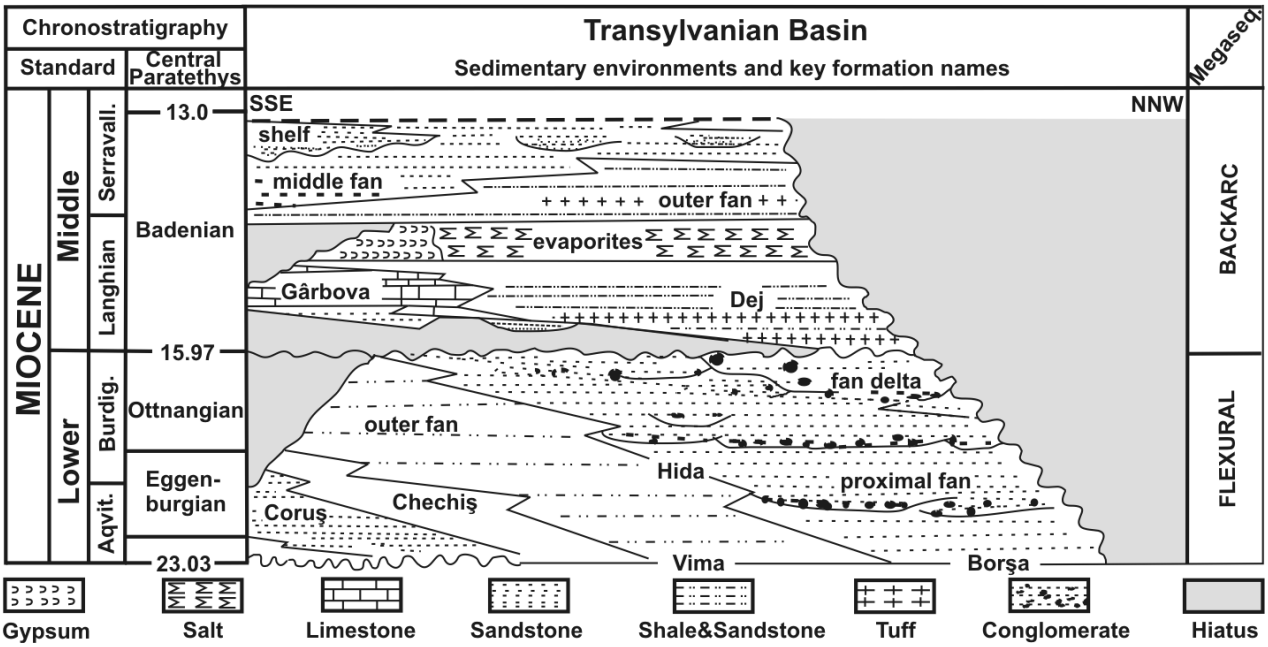


Fig. 4. Lithostratigraphic units in the Transylvanian Basin during the Lower and Middle Miocene (Beldean *et al*., 2013, modified after Krézsek and Bally, 2006).

The Hida Formation (Fig. 5) consists predominantly of mudstones, siltstones, sandstones, and conglomerates arranged in a pronounced coarsening-upward succession, reflecting the progradation of a distal fan-delta system. Four sedimentary facies associations have been distinguished, representing depositional environments ranging from prodelta to delta-front settings dominated by sediment gravity flows, including turbidity currents and hyperconcentrated flows (Beldean *et al.*, 2013).



Fig. 5. General view of the Râpa Dracului, showing the upper member of the Hida Formation and its contact with the Dej Formation (left), and the Dej Formation with channel-fill deposits (right).

The overlying Dej Formation (Fig. 5) comprises mixed siliciclastic and volcaniclastic deposits, including the regionally extensive Dej Tuff. The succession contains submarine channel fills, volcaniclastic turbidites, reworked tuffs and primary ash-fall deposits recording intense volcanic activity during the early Badenian marine transgression. Three facies associations document the transition from deep-marine lobe deposits to volcaniclastic submarine channels and finally to low-energy ash-fall sedimentation (Seghedi and Szakács, 1991; Szakács *et al*., 2012; Beldean *et al*., 2013). The sedimentary architecture of both formations exposed at the Râpa Dracului is illustrated by the measured sedimentary log shown in the Figure 6.

The sedimentological evolution is supported by both planktonic foraminifera and calcareous nannofossils. The Hida Formation belongs to the *Streptochilus–Bolivina* Biozone, characterized by abundant *Streptochilus pristinum* associated with rare benthic foraminifera (*Bolivina*, *Bulimina* and *Cibicidoides*), whereas the overlying Dej Formation is assigned to the *Orbulina suturalis* Biozone, containing typical early Badenian planktonic foraminifera, including *Praeorbulina*, *Orbulina*, *Globigerinoides* and *Globorotalia*. These faunal turnover records the transition from eutrophic conditions, associated with the initial stage of relative sea-level rise, to oligotrophic conditions established during the main Badenian transgression (Popescu, 1975; Beldean *et al*., 2013).

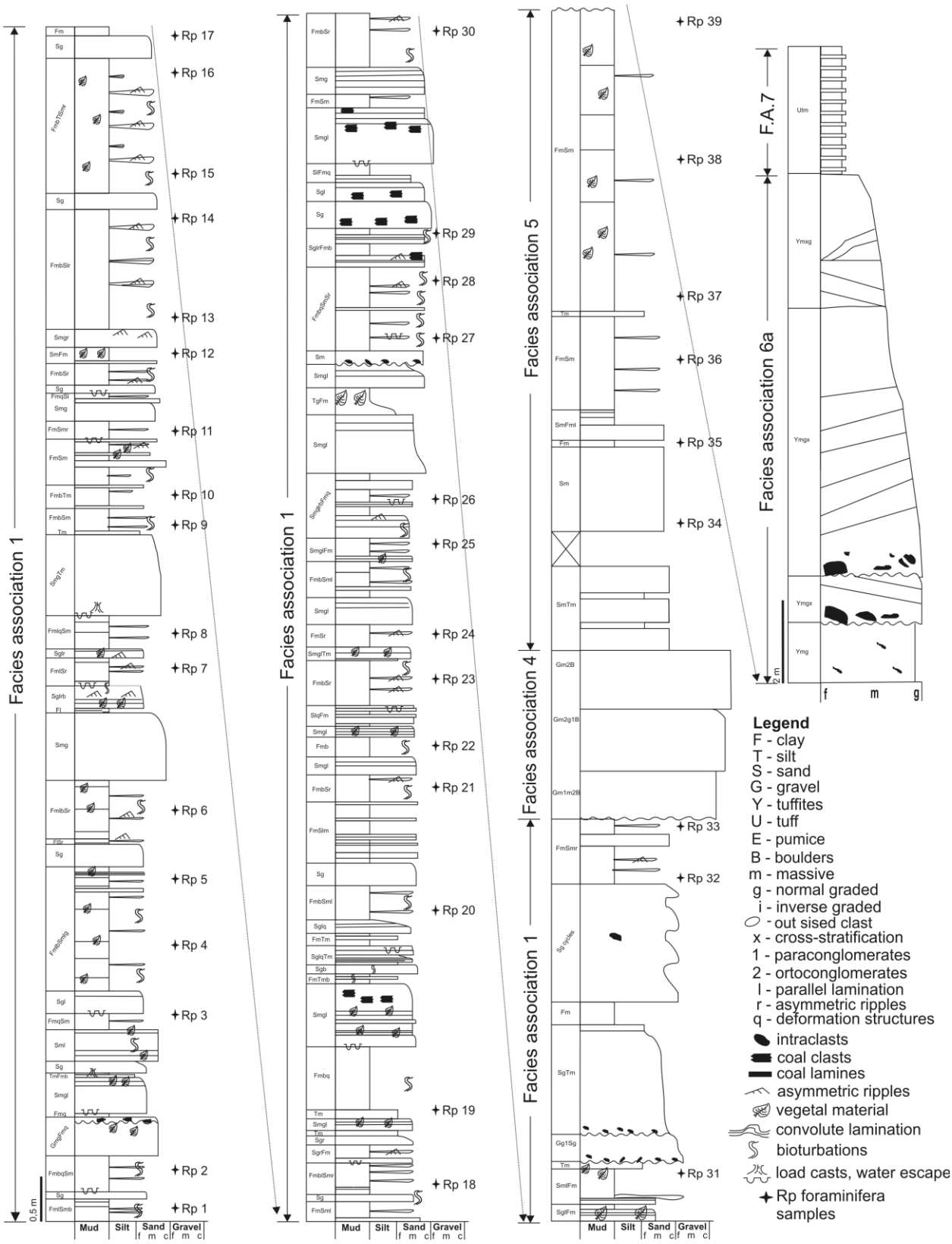


Fig. 6. Sedimentary log for the Dej and Hida formations at Dej (Râpa Dracului) (Beldean *et al*., 2013).

The Burdigalian–Langhian boundary is approximated by the first occurrence (FO) of *Praeorbulina*, corresponding to the M4–M5 planktonic foraminiferal zonal boundary (Berggren *et al*., 1995). Calcareous nannofossil assemblages provide additional chronostratigraphic control, with the upper Hida Formation assigned to the NN4 Biozone and the Dej Tuff to the NN5 Biozone, confirming its early Badenian age (Martini, 1971; Dumitrică *et al*., 1975; Mészáros and Filipescu, 1991; Beldean *et al*., 2013).

Overall, the Râpa Dracului section documents the transition from a prograding distal fan-delta system to a volcaniclastic deep-marine basin established during the Badenian transgression. The combination of sedimentological observations, planktonic foraminifera, and calcareous nannofossils makes this locality one of the key reference sections for the Early–Middle Miocene evolution of the northwestern Transylvanian Basin.

Stop 2. Colibița Quarry – the lower Borșa Formation (Oligocene)

The Colibița Quarry (Fig. 7), located in the eastern part of the Bistrița-Năsăud County near the Colibița and Mureșenii Bârgăului villages, provides an exceptional "seismic-scale" outcrop of the lower part of the Borșa Formation (Oligocene–Lower Miocene), belonging to the Transcarpathian Basin (Mészáros and Hosu, 1989). The approximately 50 m thick succession is composed of laterally continuous fine-grained sandstone beds alternating with hemipelagic marls, representing middle- to outer-fan turbidite deposits sedimented from predominantly low-density turbidity currents. In the upper part of the quarry, the sedimentary succession is intruded by the andesitic sills, laccoliths and dykes of the Neogene Bârgău Southern Volcanic Group. The emplacement of these subvolcanic bodies locally produced contact thermal metamorphism within the surrounding sedimentary rocks (Mészáros and Hosu, 1989).

Sedimentological investigations, including facies analysis, paleocurrent reconstruction, and ichnofacies analysis, have constrained the depositional environments, clastic provenance, and paleogeographic evolution of the Transcarpathian Basin. The exposed succession is dominated by middle- to outer-fan turbidites deposited predominantly from low-density turbidity currents. Four superposed thinning- and fining-upward depositional cycles can be recognized, representing distal lobe deposits. Individual beds are characterized by incomplete Bouma sequences (Tb–e and Tc–e), displaying parallel, ripple cross- and convolute lamination, together with abundant sole marks and trace fossils indicative of deep-marine sedimentation (Chira *et al*., 2017). Particularly noteworthy is the occurrence of the trace fossil *Palaeodictyon* at the base of the second depositional cycle, providing additional evidence for deposition in a deep-marine environment. Paleocurrent indicators, represented mainly by flute and groove casts, consistently record sediment transport from WSW to ESE (west to east), in agreement with previous reconstructions of sediment dispersal within the Transcarpathian Basin (Jipa, 1962; Contescu *et al*., 1966).

To constrain the age of the succession, calcareous nannofossils were investigated from 80 samples collected throughout the quarry. The assemblages (Fig. 8) include *Sphenolithus dissimilis*, *Zygrhablithus bijugatus*, *Lanternithus minutus*, *Isthmolithus recurvus*, *Reticulofenestra umbilicus*, *Reticulofenestra dictyoda*, *Coccolithus eopelagicus,* and *Discoaster cf. lodoensis*, indicating an Oligocene age for the exposed part of the Borșa Formation (Mészáros and Hosu, 1989; Chira *et al*., 2013; Chira *et al*., 2017).

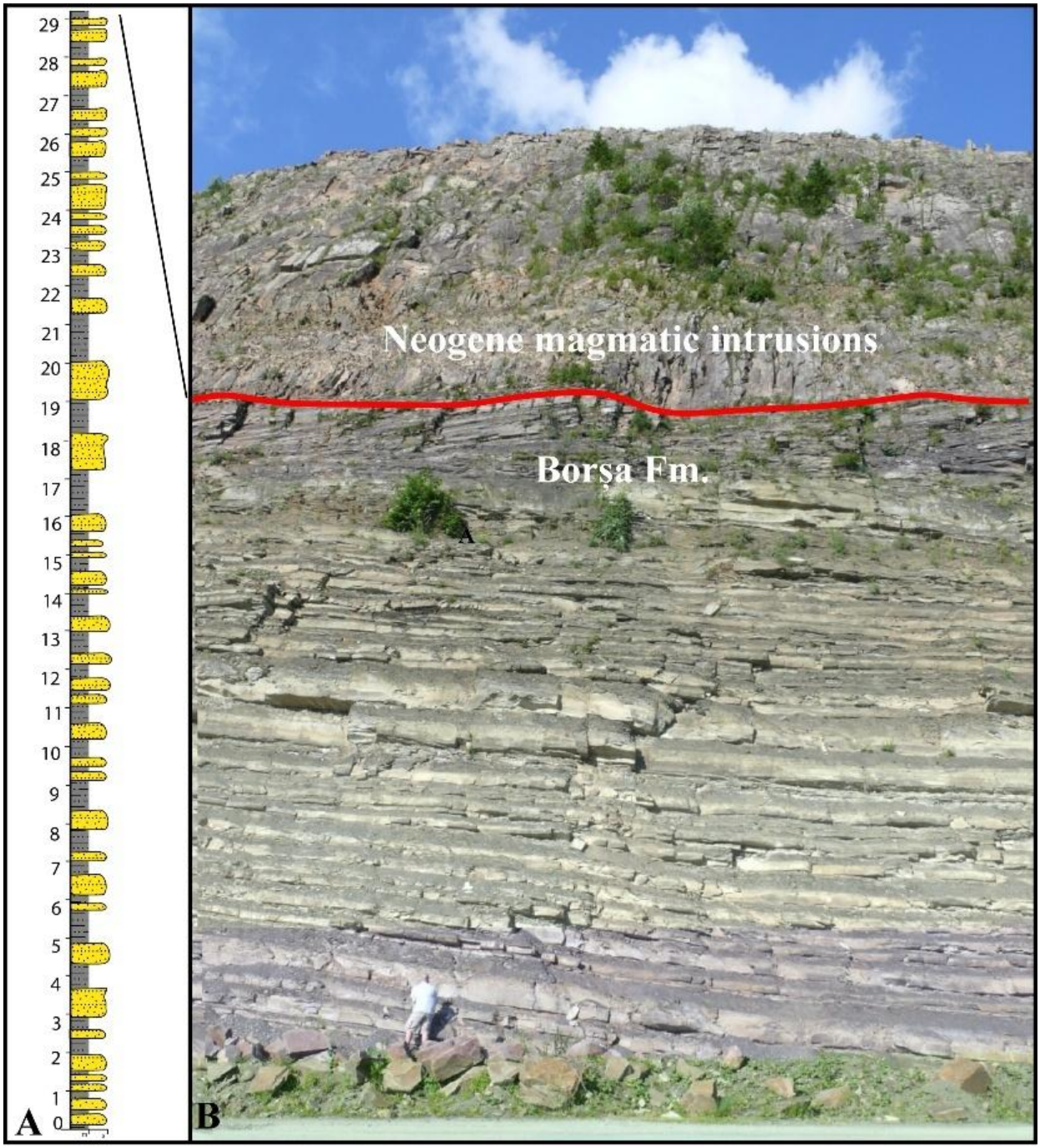


Fig. 7. Colibița Quarry. (A) Lithological column of the Borșa Formation. (B) View of the Borșa Formation showing the turbidite succession intruded by Neogene andesitic sills of the Bârgău Southern Volcanic Group.

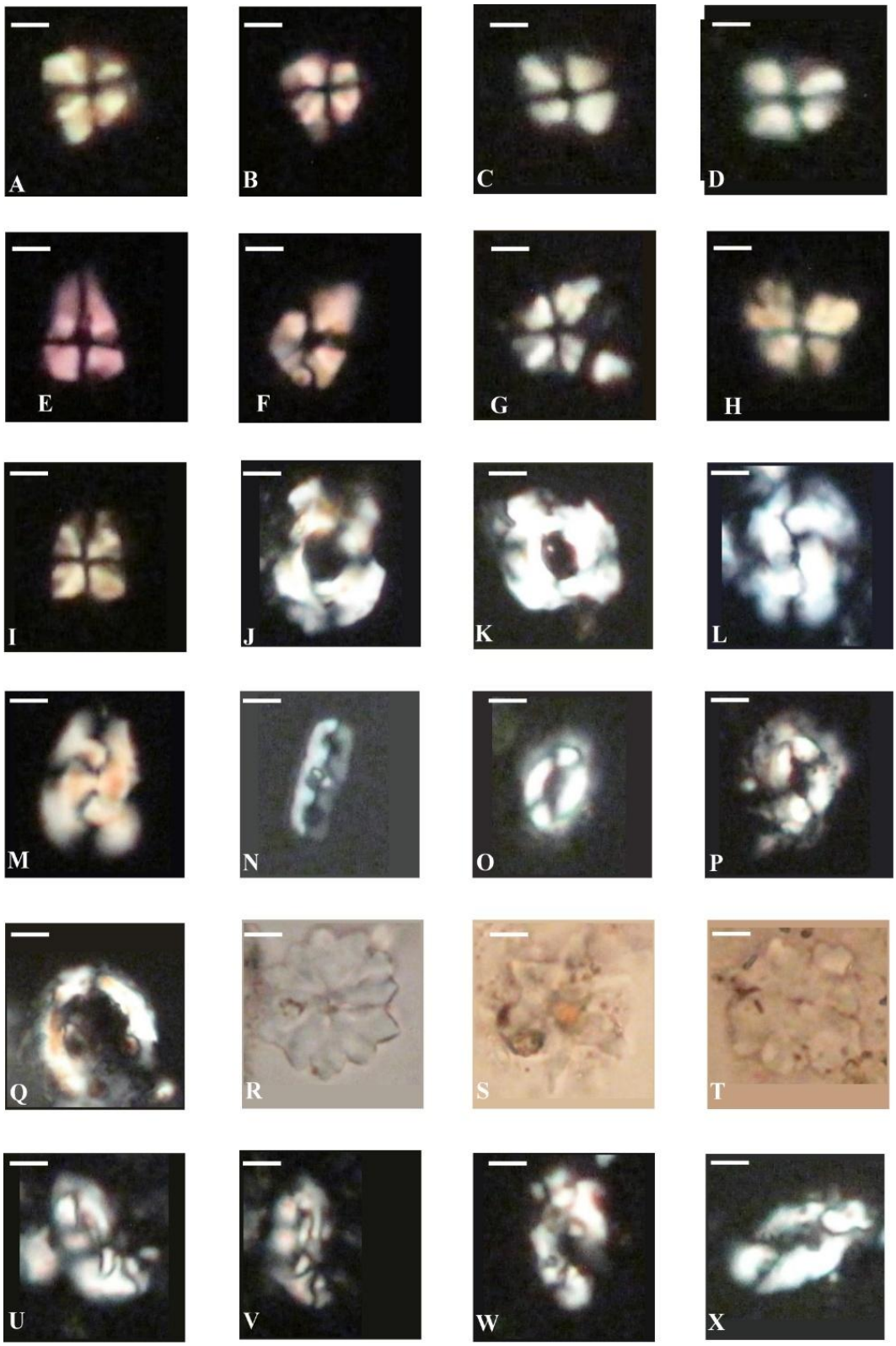


Fig. 8. Representative calcareous nannofossil assemblages from the Borșa Formation at the Colibița Quarry; A, B, C, D- *Sphenolithus spiniger* Bukry 1971; E, F- *Sphenolithus dissimilis* Bukry and Percival 1971; G, H, I- *Sphenolithus cf. stellatus* Gartner 1967; J, K- *Reticulofenestra cf. umbilicus* (Levin 1965) Martini and Ritzkowski 1968; L, M- *Reticulofenestra bisecta* (Hay Mohler and Wade, in Hay *et al*. 1966) Roth 1970; N- *Isthmolithus recurvus Deflandre, in Deflandre and Fert 1954*; O- *Coccolithus pelagicus* (Wallich 1877) Schiller 1930; P- *Coccolithus eopelagicus* (Bramlette and Riedel 1954) Hay, Mohler and Wade, in Hay *et al*. 1966; R- *Discoaster barbadiensis* Martini 1961; S- *Discoaster saipanensis* Bramlette and Riedel 1954; T- *Discoaster* sp.; U, V- *Helicosphaera* sp.; W, X- *Helicosphaera perch-nielseniae* (Haq 1971) Jafar and Martini 1975. Scale 2 μm.

The Colibița Lake, situated at an elevation of approximately 900 m in the Bistrița Valley, between the Bârgău and Călimani Mountains, is visible from the outcrop and provides an excellent overview of the regional geomorphological landscape (Fig. 9).



Fig. 9. View of the Colibița Lake in the Bistrița Valley, between the Bârgău and Călimani Mountains.

Stop 3. Mureşenii Bârgăului – the upper Borșa Formation (Oligocene-Lower Miocene)

Approximately 10 km west of Colibița, along the Blaju Valley near the Mureșenii Bârgăului village, the upper part of the Borșa Formation is exposed. This approximately 30 m thick succession belongs to the post-tectonic cover of the Median Dacides within the Transcarpathian foredeep basin and occupies a higher stratigraphic position than the Borșa Formation exposed in the Colibița Quarry (Mészáros and Hosu, 1989). The succession consists of alternating fine- to medium-grained sandstones and mudstones (S/M > 1), with thick (up to 1 m), commonly amalgamated sandstone beds separated by thin pelitic intervals (Fig. 10).

The lower part of the section is organized into three thinning- and fining-upward depositional cycles, whereas the upper part displays an overall coarsening-upward trend, recording progradation of the depositional system. Massive sandstone beds with sharp erosional and amalgamation surfaces, together with normally graded and parallel-laminated intervals, indicate deposition from sandy debris flows and high-density turbidity currents. These facies are interpreted as deposits of the upper middle-fan channel–lobe transition zone.

Paleocurrent indicators, including flute and groove casts preserved on bed soles, record sediment transport predominantly from west to east, although flow directions are rotated approximately 10–15° southward relative to those measured at Colibița. This subtle deflection probably reflects changes in basin morphology and sediment-routing pathways during progressive basin evolution.



Fig. 10. Mureșenii Bârgăului (Blaju Valley). (A) Lithological column of the upper part of the Borșa Formation. (B) General view of the outcrop exposing Upper Oligocene–Lower Miocene turbidite deposits.

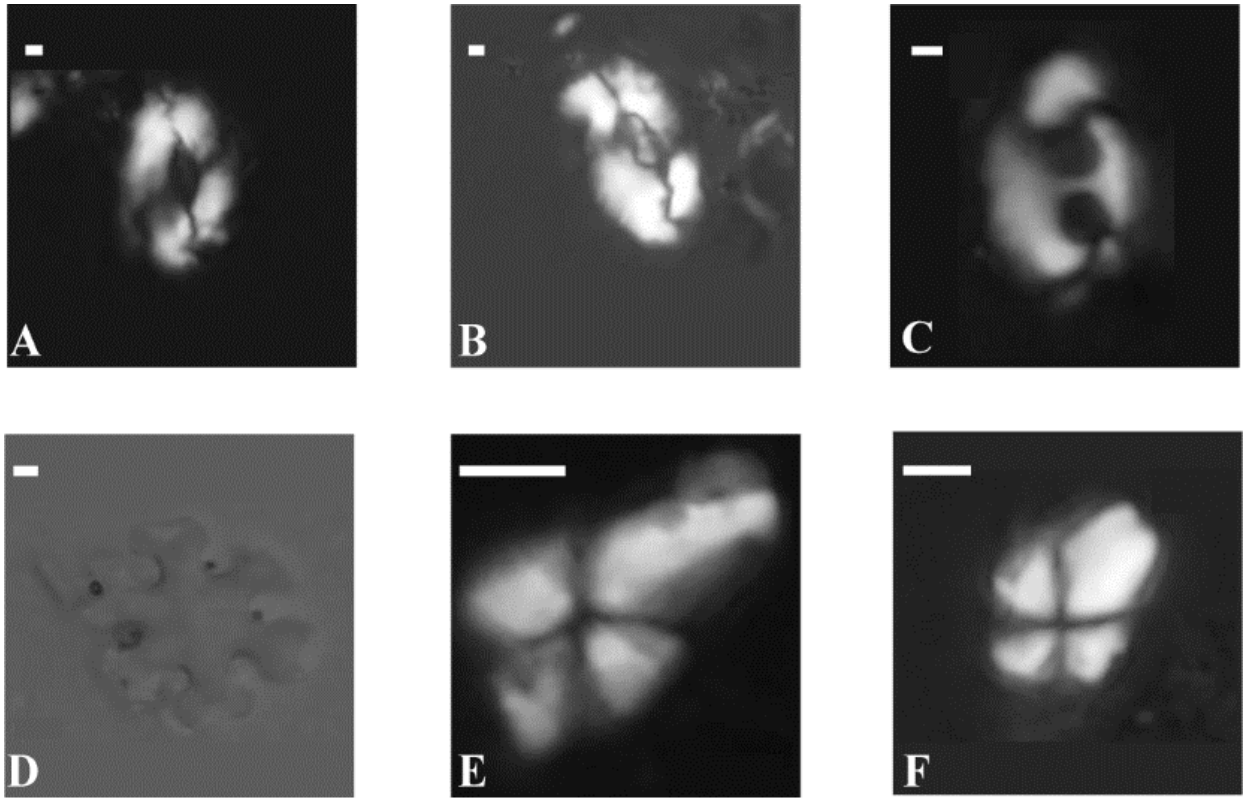


Fig. 11. Representative calcareous nannofossil assemblages from the Borșa Formation at Mureșenii Bârgăului*: A- Helicosphaera scissura* Müller 1981*; B- Helicosphaera euphratis* Haq 1966*; C- Helicosphaera mediterranea* Müller 1981; *D- Discoaster deflandrei* Bramlette and Riedel 1954*; E, F- Sphenolithus conicus* Bukry 1971. Scale 1 µm.

Calcareous nannofossil assemblages (Fig. 11) indicate the biozones NP25–NN3 (Martini, 1971), corresponding to a Late Oligocene–Early Miocene age. The most frequent and significant species that appear in the analyzed samples are: *Sphenolithus conicus*, *Sph. predistentus*, *Helicosphaera scissura*, *H. mediterranea*, *H. euphratis*, *Discoaster deflandrei*, *Cyclicargolithus floridanus*, *Reticulofenestra bisecta*, *R. cf. haqii*. In the calcareous nannoplankton assemblages, there are also present: *Sphenolithus moriformis*, *Sph. obtusus*, *Reticulofenestra minuta*, *R. dictyoda*, *R. umbilica*, *Discoaster cf. adamanteus*, *Coccolithus pelagicus*, *C. eopelagicus*, *Dictyococcites bisectus*, *D. stavensis*, *Pontosphaera multipora*, *P. discopora*, ascidian spicules and calcispheres.

The comparison with the Colibița succession demonstrates a clear basinward facies organization within the Borșa Formation. The outer-fan (distal lobe) turbidites exposed at Colibița pass upward and basinward into the more proximal upper middle-fan channel–lobe transition deposits exposed at the Mureșenii Bârgăului. Combined sedimentological and biostratigraphic evidence indicates progressive progradation of the Borșa turbidite system during the Late Oligocene–Early Miocene, probably driven by episodic uplift of the Median Dacides, increased sediment supply and migration of the basin depocentre toward the foreland (Mészáros and Hosu, 1989; Chira *et al.*, 2017).

Stop 4. Ieud – the Măgura Formation of the Wildflysch Nappe (uppermost Eocene-Oligocene)

The Ieud outcrop (Fig. 12) exposes the uppermost Eocene–Oligocene deposits of the Măgura Formation (Table 1), a lithostratigraphic unit of the Wildflysch Nappe (Pienidian Units), represented by a deep-marine turbidite succession composed of sandstone megabeds and subordinate mudstone intervals. The exposed succession consists of three amalgamated sandstone bodies, each 3–4 m thick, separated by thin (30–40 cm) pelitic intervals, containing centimetre-scale turbidite beds (Chira *et al.*, 2024).

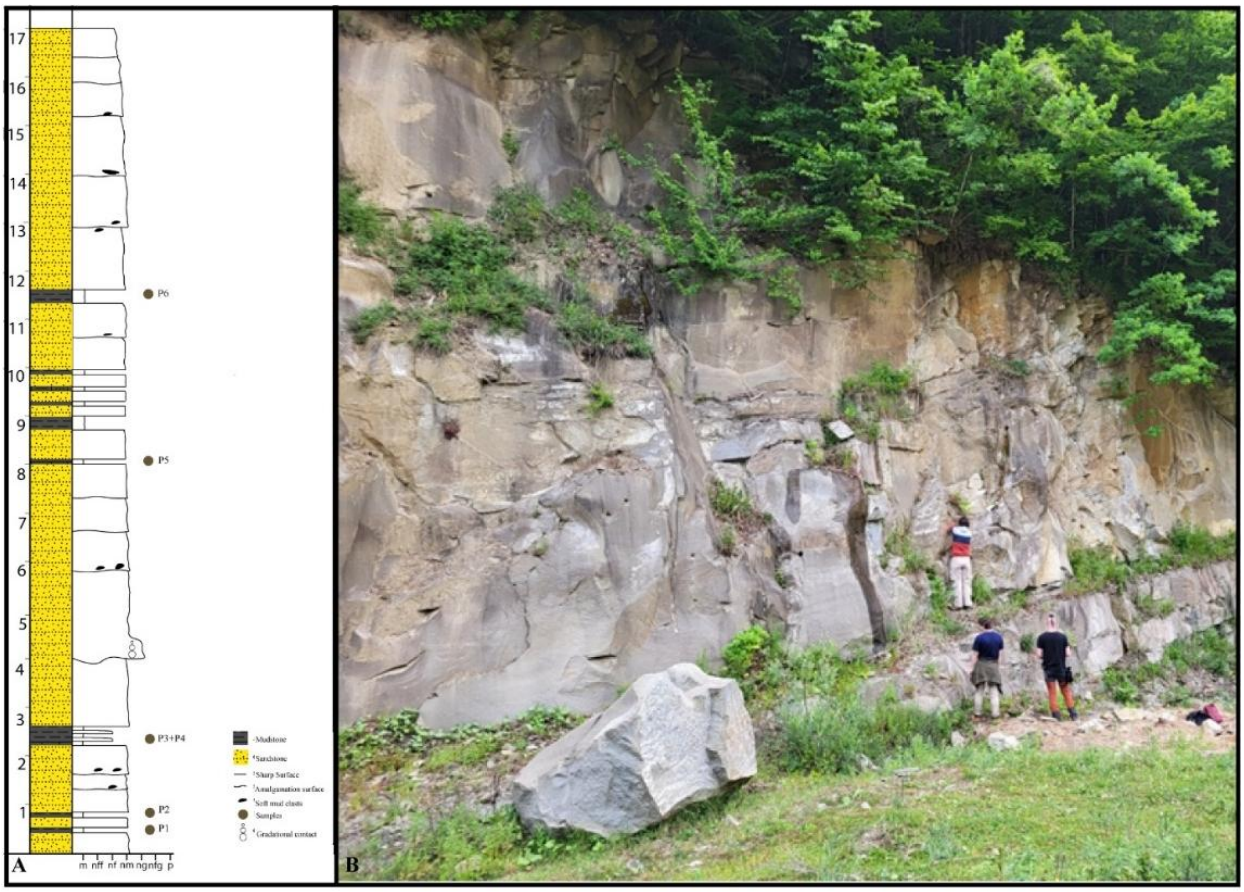


Fig. 12. Ieud. (A) Lithological column of the Măgura Formation. (B) General view of the outcrop exposing Upper Eocene–Oligocene turbidite deposits of the Măgura Formation.

The sandstone bodies comprise two types of amalgamated beds: (1) structureless, metre-thick sandstones containing abundant mudstone (rip-up) intraclasts, and (2) structured sandstone beds with erosional and amalgamation surfaces, displaying normal grading at their base followed by parallel lamination (Ta–Tb Bouma divisions). These sedimentary characteristics indicate deposition by sandy debris flows and high-density turbidity currents. The amalgamated sandstone bodies are interpreted as lobe-axis deposits within a mid-fan turbidite system, reflecting repeated high-energy gravity-flow events.

The intervening pelitic intervals represent interlobe deposits composed of hemipelagic mudstones interbedded with thin turbidites emplaced by low-density turbidity currents. Thin sandstone beds commonly preserve scour and tool marks on their lower surfaces, including flute, groove, and prod casts, whereas some bed soles display convex hypichnia and trace fossils such as *Planolites*. These intervals record periods of reduced sediment supply and hemipelagic settling between successive gravity-flow events (Chira *et al.*, 2024).

The vertical arrangement of three amalgamated sandstone bodies separated by pelitic intervals records the stacking of three successive turbidite lobes separated by two interlobe intervals, illustrating the lateral migration and compensational stacking typical of submarine fan systems.

Calcareous nannofossils (Fig. 13) recovered from the pelitic interbeds are generally sparse and dominated by small reticulofenestrids, including *Reticulofenestra bisecta*, *R. lockeri* and *R. dictyoda*, together with *Sphenolithus spiniger*, *Sphenolithus* sp., *Cyclicargolithus floridanus*, *Coccolithus eopelagicus*, *Coccolithus pelagicus*, *Chiasmolithus grandis*, *C. luminis*. These assemblages provide biostratigraphic evidence for an Oligocene age of the Măgura Formation.

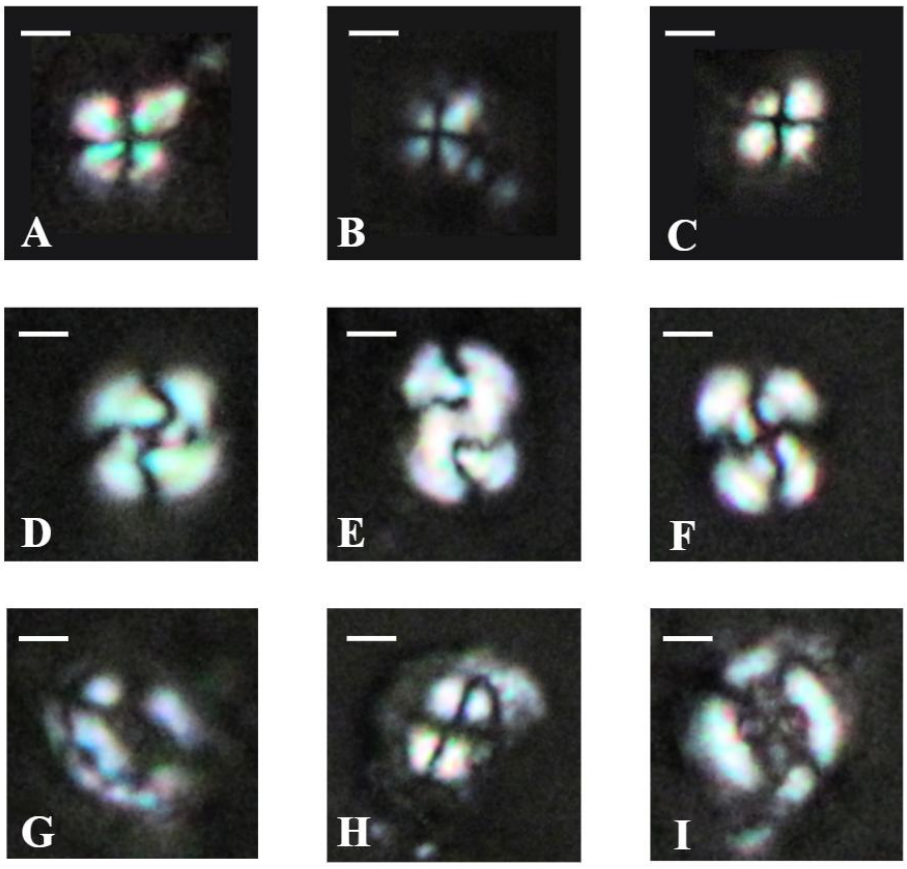


Fig. 13. Representative calcareous nannofossil assemblage from the Magura Formation at Ieud*:* A. *Sphenolithus spiniger* Bukry 1971; B. *Sphenolithus spiniger* Bukry 1971; C. *Sphenolithus* sp. Deflandre 1952; D. *Cyclicargolithus floridanus* (Hay *et al*. 1967) Bukry 1971; E. *Reticulofenestra bisecta* (Hay Mohler and Wade, in Hay *et al*. 1966) Roth 1970; F. *Reticulofenestra bisecta* (Hay Mohler and Wade, in Hay *et al*. 1966) Roth 1970; G. *Coccolithus eopelagicus* (Bramlette and Riedel 1954) Hay, Mohler and Wade, in Hay *et al*. 1966; H. *Coccolithus pelagicus* (Wallich 1877) Schiller 1930; I. *Chiasmolithus grandis* (Bramlette and Riedel 1954) Radomski 1968. Scale 2 µm.

Stop 5. Bârsana – the Strâmtura Sandstone and Dej Formation

This outcrop exposes the contact between the Strâmtura Sandstone (Table 1) (Săndulescu, 1984; Aroldi, 2001; Aroldi *et al.*, 2025; Chira *et al*., 2025, Chira *et al.*, 2026), representing the youngest deposits of the Petrova Nappe (northern sector of the Pienidian Units in Maramureș), and the unconformably overlying Badenian zeolitic tuff, a facies equivalent of the Dej Tuff (Fig. 14).

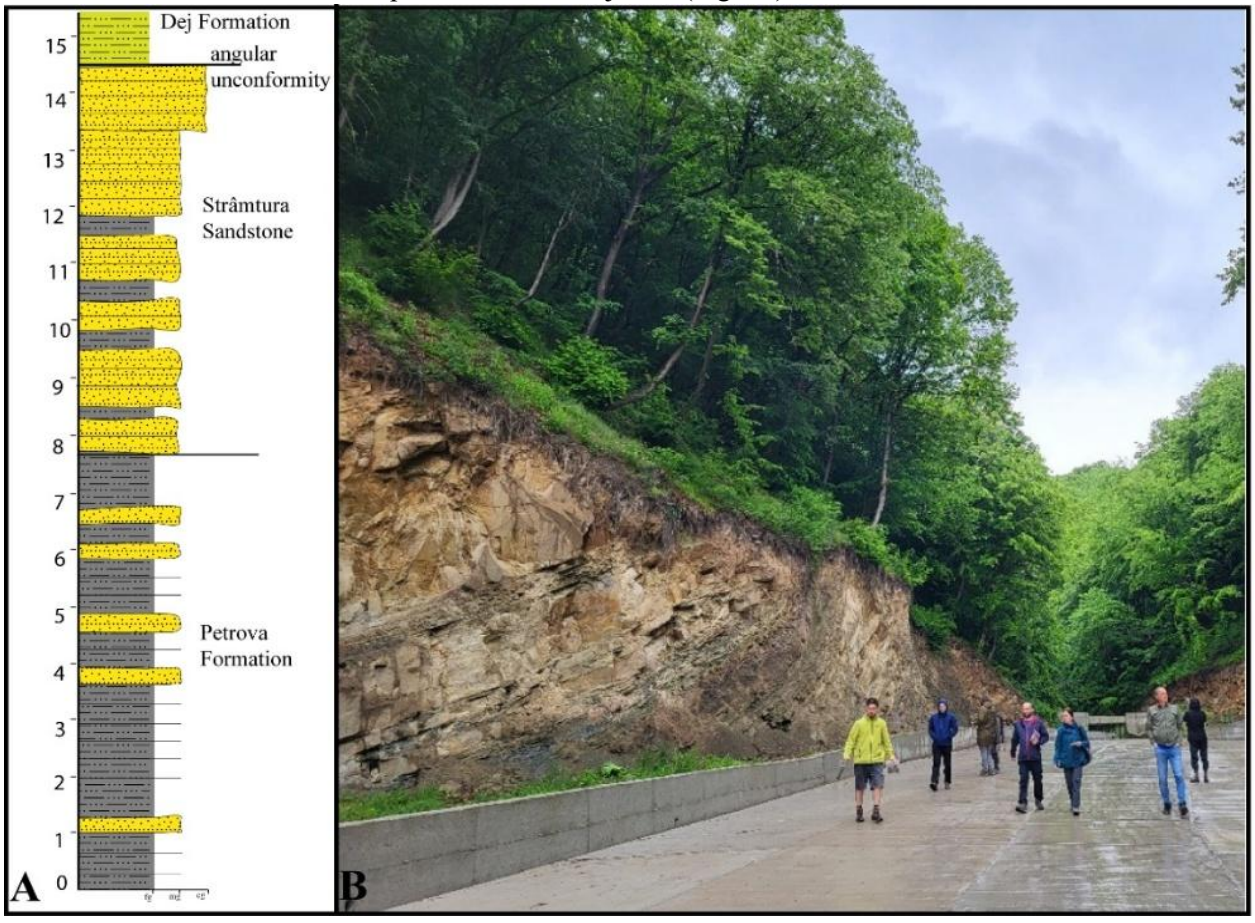


Fig. 14. Outcrop exposed near Bârsana Monastery, Petrova Nappe. (A) Lithological column of the Bârsana outcrop (redrawn after Aroldi, 2001). (B) General view of the Bârsana outcrop.

The Strâmtura Sandstone, well exposed behind the Bârsana Monastery (upper parking area), comprises the youngest deposits of the east-vergent Petrova Nappe, probably extending into the Early Oligocene. The Strâmtura Sandstone consists of thick (up to 3 m), commonly amalgamated, medium- to coarse-grained sandstone beds separated by thin (2–4 cm) mudstone interbeds. Both thinning- and thickening-upward depositional sequences can be recognized, reflecting variations in clastic sediment supply to the basin.

The sandstone beds have sharp, commonly erosional basal contacts and are either massive or normally graded (Ta Bouma division), locally passing upward into incomplete Tc–e Bouma intervals. Sole marks, including groove and flute casts, indicate a predominant west-to-east paleocurrent direction. From a structural point of view, in this outcrop we may notice different types of deformations, such as high-angle normal faults (with large slickensides) and narrow-angle chevron folds (Fig. 15).

Calcareous nannofossil assemblages (Fig. 16) recovered from the Paleogene mudstone interbeds are generally rare and include *Reticulofenestra minuta*, *R. reticulata*, *R. dictyoda*, *Coccolithus eopelagicus* and *C. pelagicus*. Although the lower part of the succession is locally barren or yielded only sparse calcareous nannofossils, these assemblages support a Late Priabonian–?Oligocene age for the Strâmtura Sandstone. The unconformably overlying zeolitic tuff contains calcareous nannofossil assemblages assigned to the NN5 **(***Sphenolithus heteromorphus*) and NN6 (*Discoaster exilis*) biozones, indicating a Badenian (Middle Miocene) age (Chira *et al.*, 2024, Fig. 17).

Petrographic analyses indicate that the Strâmtura Sandstone is dominated by lithic sandstones, containing abundant metamorphic rock fragments and subordinate sedimentary lithoclasts, mainly carbonates. Considering the sandstone composition, together with the predominant W-E detected paleocurrent direction, the Inner Dacides represent the most probable source area for the sediment routing into the basin.



Fig. 15. Chevron folds and fault slickensides in Paleogene turbidites from Bârsana (Maramureş).

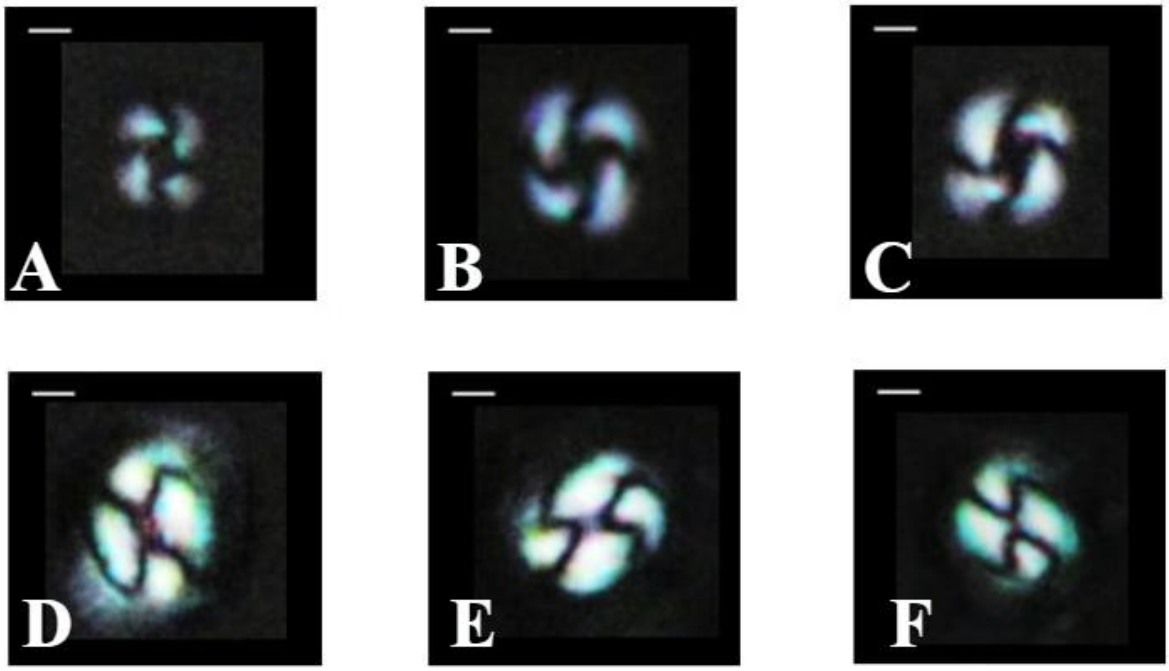


Fig. 16. Representative calcareous nannofossil assemblages from the Strâmtura Formation at Bârsana: A - *Reticulofenestra minuta* Roth, 1970; B - *R. reticulata* (Gartner and Smith, 1967) Roth and Thierstein, 1972; C - *R. dyctioda* (Deflandre in Deflandre and Fert, 1954) Stradner in Stradner and Edwards, 1968; D - *Coccolithus eopelagicus* (Bramlette and Riedel, 1954) Hay, Mohler and Wade 1966; E, F - *C. pelagicus* (Wallich 1877) Schiller, 1930. Scale 2 μm.

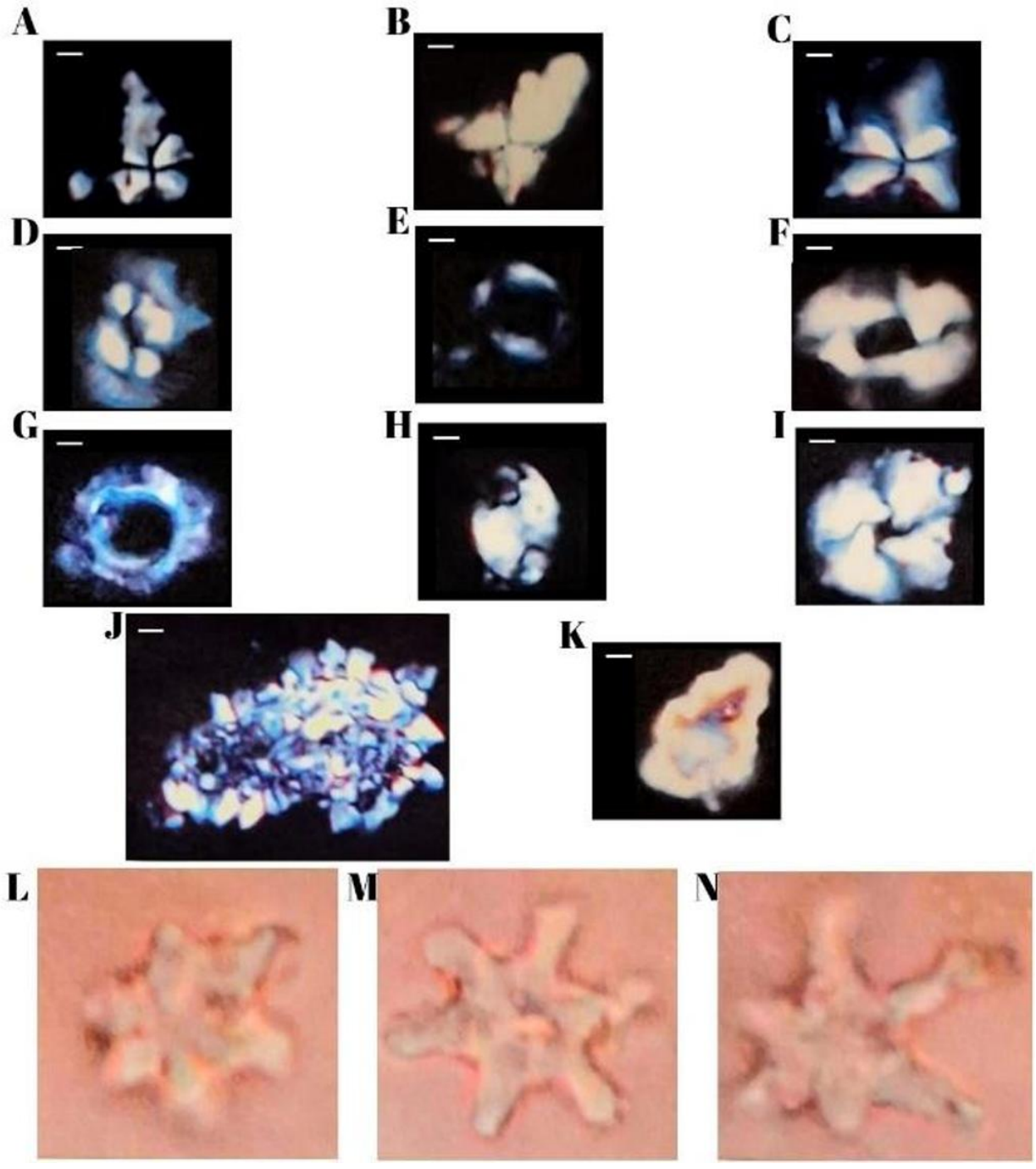


Fig. 17. Middle Miocene (Badenian) calcareous nannofossils from Bârsana (Chira *et al*., 2025). A, B. *Sphenolithus heteromorphus* Deflandre 1953; C. *Sph. abies* Deflandre in Deflandre and Fert, 1954; D. *Coccolithus miopelagicus* Bukry, 1971; E. *Syracosphaera histrica* Kamptner, 1941; F. *Reticulofenestra pseudoumbilicus* (Gartner, 1967) Gartner, 1969; G. *Umbilicosphaera rotula* (Kamptner, 1956) Varol, 1982; H. *Pontosphaera multipora* (Kamptner, 1948 ex Deflandre in Deflandre and Fert, 1954) Roth, 1970*; I. Cyclicargolithus floridanus* (Roth and Hay, in Hay *et al*., 1967) Bukry, 1971*;* J. *Toracosphaera sp.;* K. *Ascidian spicules;* L. *Discoaster musicus Stradner, 1959;* M, N. *Discoaster. variabilis* Martini & Bramlette, 1963. Scale 2 µm.

After completing the geological observations at the outcrop, participants will visit the nearby Bârsana Monastery (Fig. 18), one of the most important monuments of traditional Maramureș wooden architecture and a UNESCO World Heritage Site.



Fig. 18. Bârsana Monastery represents a traditional wooden monastery in Maramureș and a UNESCO World Heritage Site.

Stop 6. Botiza (near the accommodation)

The outcrop from Botiza (Fig. 19), situated near the Ancuța Guesthouse, had been examined previously, but only qualitatively, based on its calcareous nannoplankton assemblages (Chira *et al*. 2025). The results of our recent study indicate that the succession is of Early Miocene age and therefore belongs to the sedimentary succession of the Baia Mare Basin. New data concerning the calcareous nannoplankton and foraminifera were obtained, improving the understanding of the biostratigraphy and paleoenvironmental evolution of the studied succession.



Fig. 19. General view of the Botiza outcrop

The calcareous nannoplankton assemblage (Fig. 20) indicate a Late Oligocene–Early Miocene age (NP19–NN2), based on the occurrence of *Helicosphaera ethologa*, *Isthmolithus recurvus*, *Reticulofenestra bisecta*, and *Cyclicargolithus floridanus,* while the foraminiferal assemblage indicate a Miocene age. The Paleogene calcareous nannoplankton taxa could be reworked. Under this interpretation, the depositional age of the succession can be constrained to the Early Miocene (Aquitanian–Burdigalian).

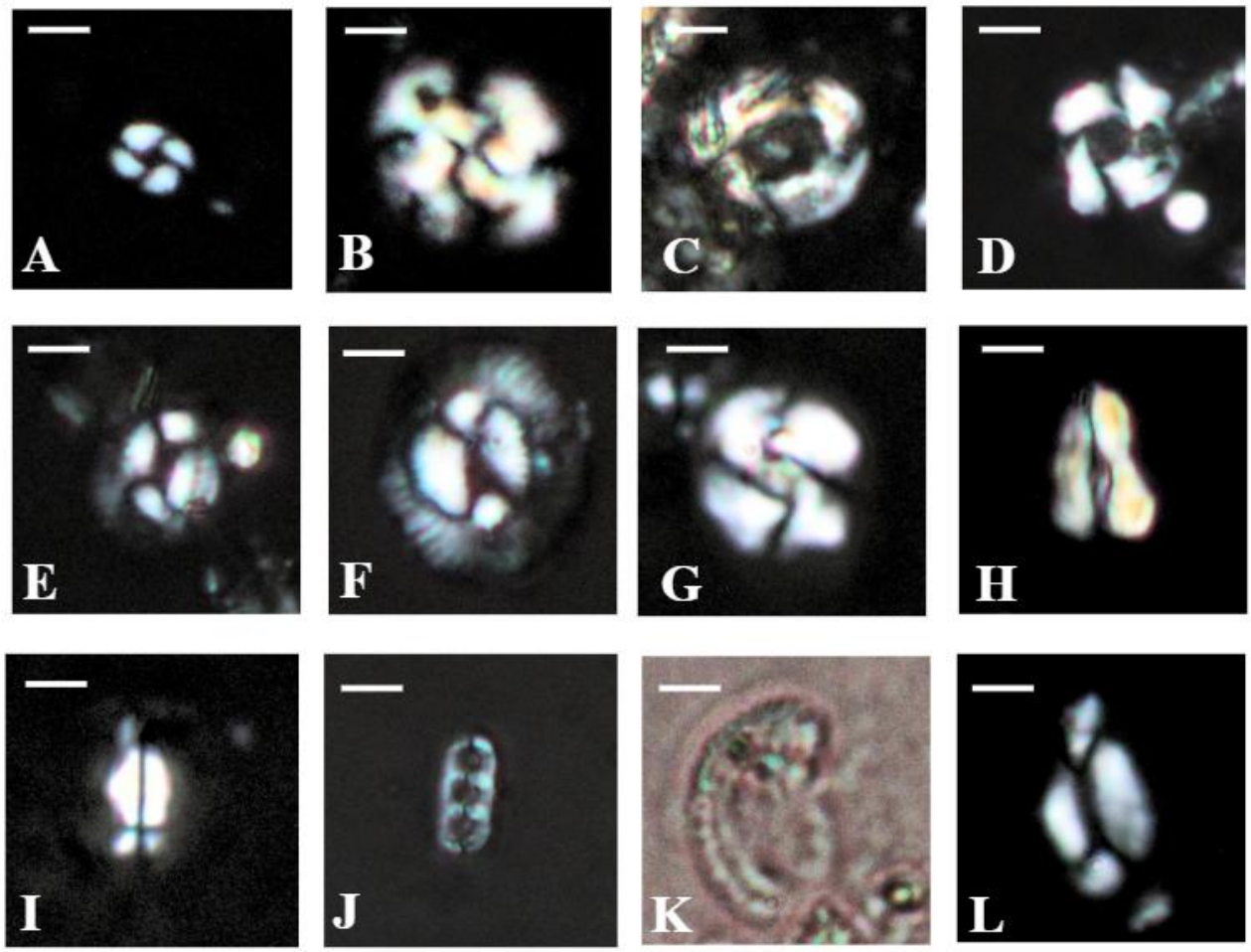


Fig. 20. Representative calcareous nannofossil assemblage from Botiza; A. *Reticulofenestra minuta* Roth 1970; B. *Reticulofenestra bisecta* (Hay Mohler and Wade, in Hay *et al*. 1966) Roth 1970; C. *Reticulofenestra umbilicus* (Levin 1965) Martini and Ritzkowski 1968; D. *Reticulofenestra dictyoda* (Deflandre, in Deflandre and Fert 1954) Stradner and Edwards 1968; E. *Coccolithus pelagicus* (Wallich 1877) Schiller 1930; F. *Coccolithus eopelagicus* (Bramlette & Riedel 1954) Hay, Mohler and Wade, in Hay *et al*. 1966; G. *Cyclicargolithus floridanus* (Hay *et al*. 1967) Bukry 1971; H. *Zygrhablithus bijugatus* (Deflandre, in Deflandre and Fert 1954) Deflandre 1959; I. *Sphenolithus pseudoradians* Bramlette and Wilcoxon 1967; J. *Isthmolithus recurvus* Deflandre, in Deflandre and Fert 1954; K., L. *Helicosphaera ethologa* Bown 2005.

The integrated paleoecological data from both fossil groups indicate a transition from a relatively cool marine environment to a warmer, eutrophic marine setting, based on the analysis of the relations between *Coccolithus pelagicus* and *Reticulofenestra minuta* (calcareous nannoplankton) and Rotaliida and Buliminida groups (foraminifera).

Accommodation and Dinner in Botiza, a traditional ethnographic village in the Maramureș region (Ancuța Guesthouse, 222 Botiza, 437065, Maramureș County, Fig. 21).



Fig. 21. Ancuța Guesthouse, Botiza, accommodation for the first night of the field trip.

DAY 2 (7th September): Botiza – Pojorâta – Gura Humorului – Voroneț – Piatra Neamț (305 km)

Leaving behind the Pienides, we will cross the structural units of the Median Dacides, Outer Dacides, and Moldavides, representing the former internal continental block Dacia, the Ceahlău-Severin Ocean, and its successor, the Moldavide Basin, respectively (Fig. 1). The Ceahlău-Severin Ocean most likely opened during the Middle Jurassic-Lower Cretaceous between the Dacia Block and the European Foreland. It might be an extension of the Silesian Basin or of the Magura Ocean from the Western Carpathians.

This transect represents one of the Northernmost profiles across the Eastern Carpathians, crossing the entire Flysch Zone, a thin-skinned nappe system subdivided into two structural sub-zones on the basis of their tectonic deformation age. The internal sub-zone consists of Upper Jurassic – Lower Cretaceous deposits, belonging to the former Ceahlău-Severin Ocean, while the external sub-zone, including Lower Cretaceous – Lower Miocene marine sedimentary successions, was deposited on a supposed thinned continental crust of the European margin in the Moldavide Basin. These subzones were tectonically deformed during the Cretaceous and Miocene tectogeneses, respectively.

This day will finish with a visit to the Natural Sciences Museum in Piatra Neamț, hosting an important collection of Oligocene fish fossils. There will also be an opportunity to have a geological overview of the Eastern Carpathians thanks to a 3D physical model of Central compartment of the Eastern Carpathians owned by the Museum.

Stop 7. Pojorâta – the Pojorâta Formation of the Bucovinian Nappe

The Pojorâta outcrop (Fig. 22) exposes the Pojorâta Formations (sensu Băncilă,1958, Table 1) also known as Aptychus Beds (sensu Grasu and Turculeț, 1973), an Upper Jurassic–Lower Cretaceous sedimentary unit belonging to the sedimentary cover of the Bucovinian Nappe, the innermost tectonic unit of the Middle Dacides (Băncilă, 1958; Săndulescu, 1984). The succession consists predominantly of thin- to medium-bedded calcareous sandstones, siltstones, and marls deposited in a deep-marine basin. These deposits record the sedimentation on the internal passive margin during the opening of the Ceahlău–Severin Ocean and represent one of the best-preserved Jurassic–Lower Cretaceous successions in the Bucovinian sedimentary cover.

Recent U–Pb dating of detrital zircons from the Pojorâta Formation showed that the sediment source area was dominated by Ordovician (460–480 Ma) magmatic rocks, consistent with the characteristic

Caledonian signature of the Bucovinian basement. In addition, subordinate Neoproterozoic (~630 Ma) and Triassic (~240 Ma) zircon populations reveal a more complex provenance than previously recognized. The Triassic zircons are interpreted to reflect Ditrău-type extensional magmatism that preceded the opening of the Ceahlău–Severin Basin, whereas the absence of characteristic foreland zircon populations indicates that sediment supply was derived almost exclusively from the Bucovinian domain (Smeu and Roban, 2024).



Fig. 22. General view of the Pojorâta outcrop exposing Upper Jurassic–Lower Cretaceous deposits of the Pojorâta Formation

Stop 8. West Gura Humorului – uppermost Eocene-Oligocene interval of the Doamna-Kliwa Lithofacies

This section allows us to see an interval of the Upper Eocene-Oligocene sedimentary record of the external tectono-sedimentary subdomain of the Tarcău Nappe depositional area in the former Moldavide Basin (Săndulescu, 1988). The Moldavide Basin had all the features of a foreland basin system (in DeCelles and Giles, 1996's terminology) with distinct depozones, being reinterpreted accordingly by Grasu *et al*. (1999) (Fig. 23).

The Cretaceous-Lower Miocene sedimentary record of the Moldavide Basin in the Tarcău Nappe sedimentation domain consists mainly of fines, but its internal subdomain was almost continuously supplied with coarse materials by the "Carpathian" source; consequently, the sandstones have a significant weight in the sedimentary succession. The sands supplied by this source area is rich in micas and lithics (e.g., Grasu *et al*., 1988; Roban *et al*., 2023).

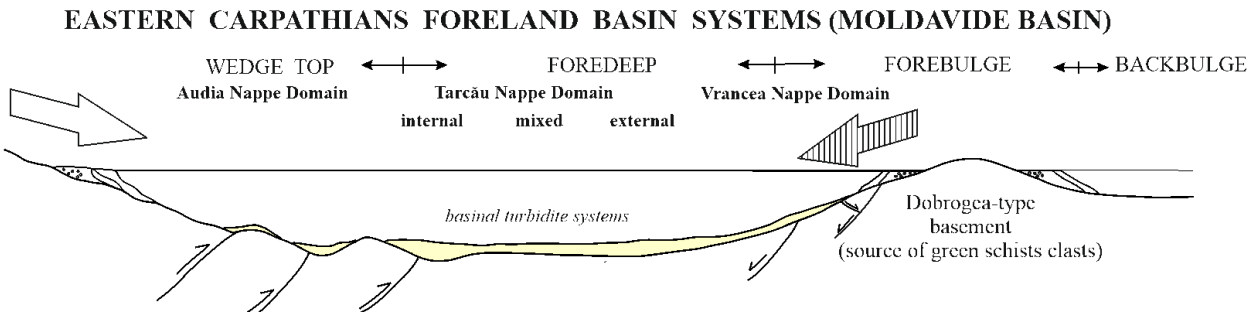


Fig. 23. Hypothetical transect across the Moldavide Basin (Eastern Carpathian foreland basin system) during Paleocene-Early Miocene (adapted by Miclăuș *et al*., 2009 after Mutti *et al*., 2003). The Tarcău Nappe Domain is seen as part of the foredeep depozone. The white arrow indicates the "Carpathian" supply and the striped arrow, "cratonic" supply of coarse sediments.

The external subdomain of the Tarcău Nappe area was sporadically supplied with coarse materials before the Kliwa Sandstone Formation sedimentation. The source area which supplied quartz sands and green schists clasts is almost unanimously placed on the external margin of the former Moldavide Basin where an elevated forebulge existed (e.g., Miclăuș *et al*., 2009; Roban *et al*., 2023 and references therein). In the same time, several sedimentary environments succeeded on the external sedimentation area of the Tarcău Nappe (Fig. 24, Table 1).

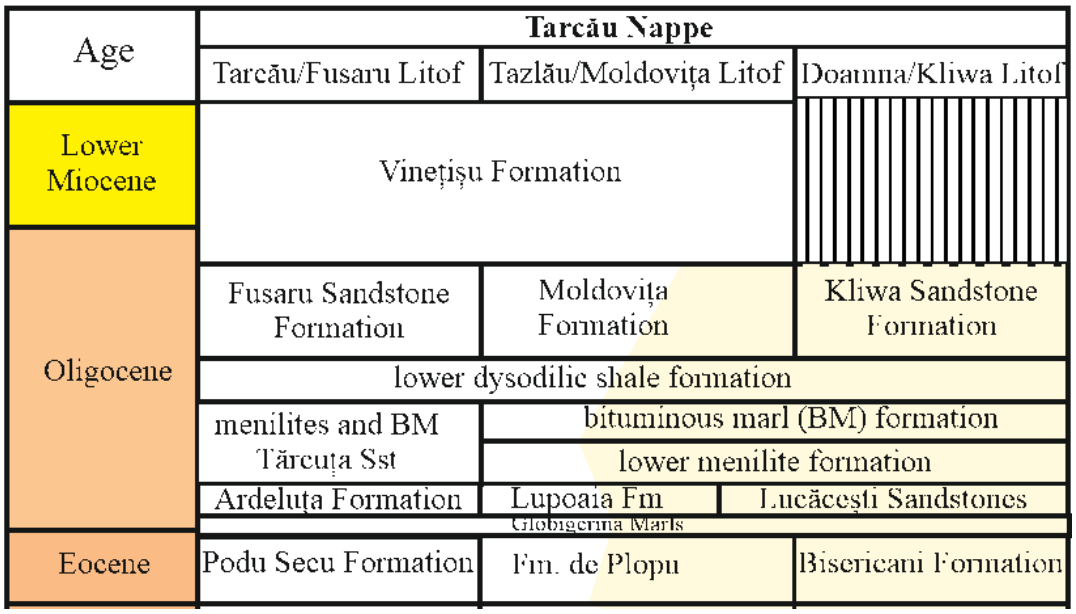


Fig. 24. Formal and informal lithostratigraphic units defined for the Tarcău Nappe for the upper Eocene-Lower Miocene time span (after Ionesi, 1971 and Grasu *et al*., 1988). The yellow field indicates the area supplied by the "cratonic" source, the white field by the "Carpathian" source.

In the section along the left bank of the Moldova River, upstream of the confluence with the Humor tributary, are exposed deposits of the Globigerina marls, Lucăcesti Sandstone, lower menilite and bituminous marls formations, lower dysodilic shale formation, and Kliwa Sandstone Formation (Table 1). The deposits younger than Kliwa Sandstone are not preserved.

The Globigerina marls is considered, due to its extended occurrence in the Carpathians, a highly correlatable lithostratigraphic unit of the so-called outer Carpathian Flysch. While in some sections it may occur as a distinct unit, in others it is interbedded with sandstones, either of "Carpathian" source or of "cratonic" source. When distinct, it is considered a member of the Bisericani or Plopu formations (Ionesi, 1971). Lithologically, consists of creamy marls, highly bioturbated. The biostratigraphic age is still

controversial, the majority of the scientist holding that it ranges across the Eocene-Oligocene boundary, not on the basis of planktonic foraminifers, but on nannoplankton (e.g., Micu, 1986).

The Lucăcești Sandstones, as the Globigerina marl, may occur as distinct unit or interlayered with the creamy marls with globigerinas. It is a Kliwa type sandstone with green schists clasts and glauconite, which in the Kliwa Litofacies (Table 1) of the Bucovina area may have 3-25 m (Ionesi, 1971). In this section, it has around 3 m and transitionally follows the Globigerina marl unit, the sandstone beds thickening upward.

The lower menilite formation consists of two subunits, ranked as members (e.g., Grasu *et al*., 1988), the Lingurești brown Marls with Ferăstrău Sandstones and compact menilites, respectively. While the brown marls of the Lingurești Member can be seen in the visited outcrop, the sandstones do not occur as a distinct subunit within. The compact menilites consist of well-bedded dark-brown cherts interlayered with siliceous shales. A discussion regarding the cherts origin as deeply diagenized diatomaceous deposits can be found in Puglisi *et al*. (2006).

The bituminous marl formation (meters - as in this section- to decameters thick) represents the second major correlatable unit in the entire Outer Carpathians. Lithologically, consists of medium-bedded chocolate brown marls.

It is worth mentioning that both compact menilite and bituminous marls are crisscrossed by sandstone injectites (Fig. 25), both dykes and sills (Miclăuș and Seserman, 2018), some of the sills being previously interpreted as normal sandstone interlayers (e.g., Grasu *et al*., 1988).



Fig. 25. Sandstone dykes in compact menilite member.

The lower dysodilic shale formation (60-100 m thick) consists of a variety of deposits, from black shale to sandy brown mudstones, with interlayers of Kliwa-type sandstones and rare debrites with green schists clasts, the latter solving the problem of coarse material supply on the external margin of the Tarcău Nappe

sedimentation area in the Moldavide Basin (Fig. 24). The sandstone beds, cm to 1 m thick, have a rough thickening upward trend.

The Kliwa Sandstone Formation (50-60 m thick in the Bucovina area) consists of medium to thick bedded white quartzarenites with green schist clasts, with some thin interlayers of dysodilic shales. The sandstones may be massive or show features of turbidites. In the visited section, it rather consists of massive amalgamated sandstone beds.

The Kliwa Sandstone ends the sedimentary succession in the external Kliwa Lithofacies of the Tarcău Nappe.

Stop 9. Voroneț Monastery

The next stop includes a visit to the Voroneț Monastery (Fig. 26), one of the Painted Churches of Bucovina and a UNESCO World Heritage Site. Founded in 1488 by Stephen the Great, the monastery is renowned for its exceptionally well-preserved exterior frescoes, particularly the monumental *Last Judgment* scene, painted in the distinctive "Voroneț Blue", a unique pigment that has retained its remarkable brilliance for more than five centuries. The monastery represents one of the finest examples of medieval Moldavian art and architecture and is among Romania's most important cultural landmarks.



Fig. 26. Voroneț Monastery, a UNESCO World Heritage Site, renowned for its exceptionally preserved exterior frescoes and the distinctive "Voroneț Blue", one of the masterpieces of medieval Moldavian art.

Stop 10. Piatra Pinului Paleontological Reservation – Gura Humorului

The Piatra Pinului outcrop exposes the upper part of the Kliwa Sandstone Formation (Table 1), consisting of thick sandstone beds interlayered with dysodilic shales, deposited in the Moldavide Basin (Fig. 23). The dysodilic shales represent organic-rich, low-energy deposits that preserve an exceptionally diverse Oligocene marine fauna (Grădianu *et al*., 2025). This locality is internationally known for yielding one of Romania's most remarkable fossil fishes, ***Palaeorhynchus humorensis*** Brustur and Grigorescu, 1973 (Fig. 27), discovered within dysodilic shale interbeds of the Kliwa Sandstone Formation (Brustur & Grigorescu, 1973; Grădianu *et al*., 2025). The specimen, reaching nearly 2 m in total length, represents one of the largest fossil billfishes known from the Oligocene of the Paratethys. A recent systematic revision confirmed ***Palaeorhynchus humorensis*** as a valid species and clarified its taxonomic position within the family Palaeorhynchidae (Grădianu *et al*., 2025).

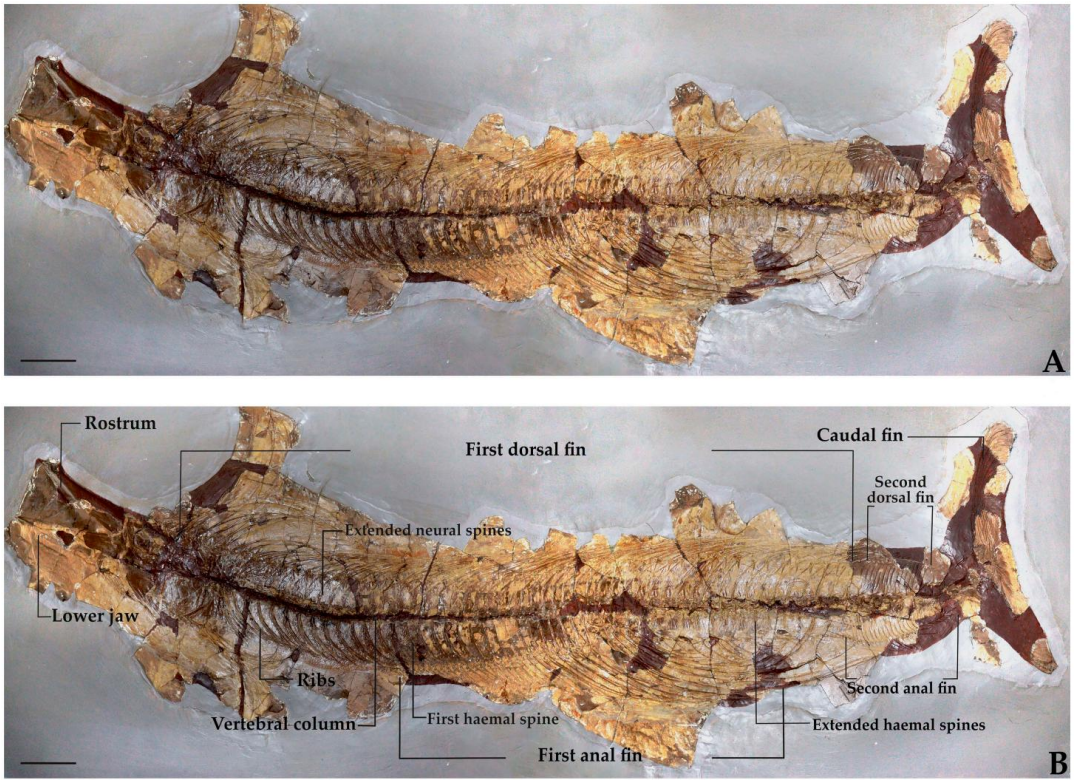


Fig. 27. *Palaeorhynchus humorensis* Brustur and Grigorescu, 1973 (CLPUB–LPB/II640), recovered from a dysodilic shale intercalation within the upper part of the Kliwa Sandstone Formation at Piatra Pinului, Gura Humorului. Scale bar = 10 cm (after Grădianu *et al*., 2025).

Together with the classic paleoichthyology localities from Piatra Neamț, Piatra Pinului represents one of the most important Oligocene vertebrate localities in Romania, providing valuable information on the diversity of Paratethyan marine ecosystems and the exceptional preservation potential of the Oligocene dysodilic shales (Grădianu *et al*., 2025).

Stop 11. Humor Monastery – the Eocene Sucevița and Bisericani formations (Vrancea Nappe)

This stop combines the visit to the UNESCO World Heritage Site of Humor Monastery (Fig. 28) with the examination of two nearby outcrops exposing the Middle Eocene Sucevița Formation and Upper Eocene Bisericani Formation, both belonging to the Vrancea Nappe (Table 1). The Sucevița Formation (Fig. 29, Table 1) consists predominantly of thin- to medium-bedded siliciclastic turbidites, represented by alternating fine-grained sandstones, siltstones and mudstones. Sandstone beds commonly display normal

grading, parallel lamination and ripple cross-lamination (Bouma Tb–Td divisions), together with locally preserved sole marks, indicating deposition from low- to moderate-density turbidity currents. The succession records sedimentation in a deep-marine basin-floor environment, where turbidity-current events alternated with hemipelagic settling.



Fig. 28. Humor Monastery, another UNESCO World Heritage Site and masterpiece of medieval Moldavian art.

The first outcrop exposes the Sucevița Formation, consisting predominantly of thin- to medium-bedded siliciclastic turbidites alternating with hemipelagic mudstones. The succession records deposition from low- to high-density turbidity currents in a deep-marine basin, with hemipelagic sedimentation occurring between successive gravity-flow events. Calcareous nannofossil assemblages (Fig. 30) indicate a Bartonian (Middle Eocene) age for this succession (Bindiu-Haitonic *et al*., 2019).



Fig. 29. Representative outcrops of the Sucevița Formation (left) and the Bisericani Formation (right) exposed in the vicinity of the Humor Monastery.

Calcareous nannofossil assemblages (Fig. 30) from the Sucevița Formation are characterized by *Helicosphaera bramlettei*, *Neococcolithes dubius*, *Lanternithus minutus*, *Pontosphaera distincta*, *Coccolithus formosus*, *Reticulofenestra bisecta*, *Reticulofenestra umbilicus*, *Reticulofenestra stavensis*, *Coccolithus eopelagicus*, *Discoaster deflandrei*, *Discoaster saipanensis*, *Discoaster barbadiensis*, *Zygrhablithus bijugatus*, *P. pulchra*, *Nannotetrina cristata* and *Discoaster* with overgrowths. This assemblage indicates a Bartonian (Middle Eocene) age for the succession (Bindiu-Haitonic *et al*., 2019).

The second outcrop exposes the Bisericani Formation (Fig. 29, Table 1), characterized by rhythmic alternations of fine-grained sandstone, siltstone and mudstone. The succession records repeated gravity-

flow events separated by intervals of hemipelagic sedimentation. Calcareous nannofossil assemblages likewise constrain these deposits to the Priabonian, confirming their Upper Eocene age (Bindiu-Haitonic *et al*., 2019).

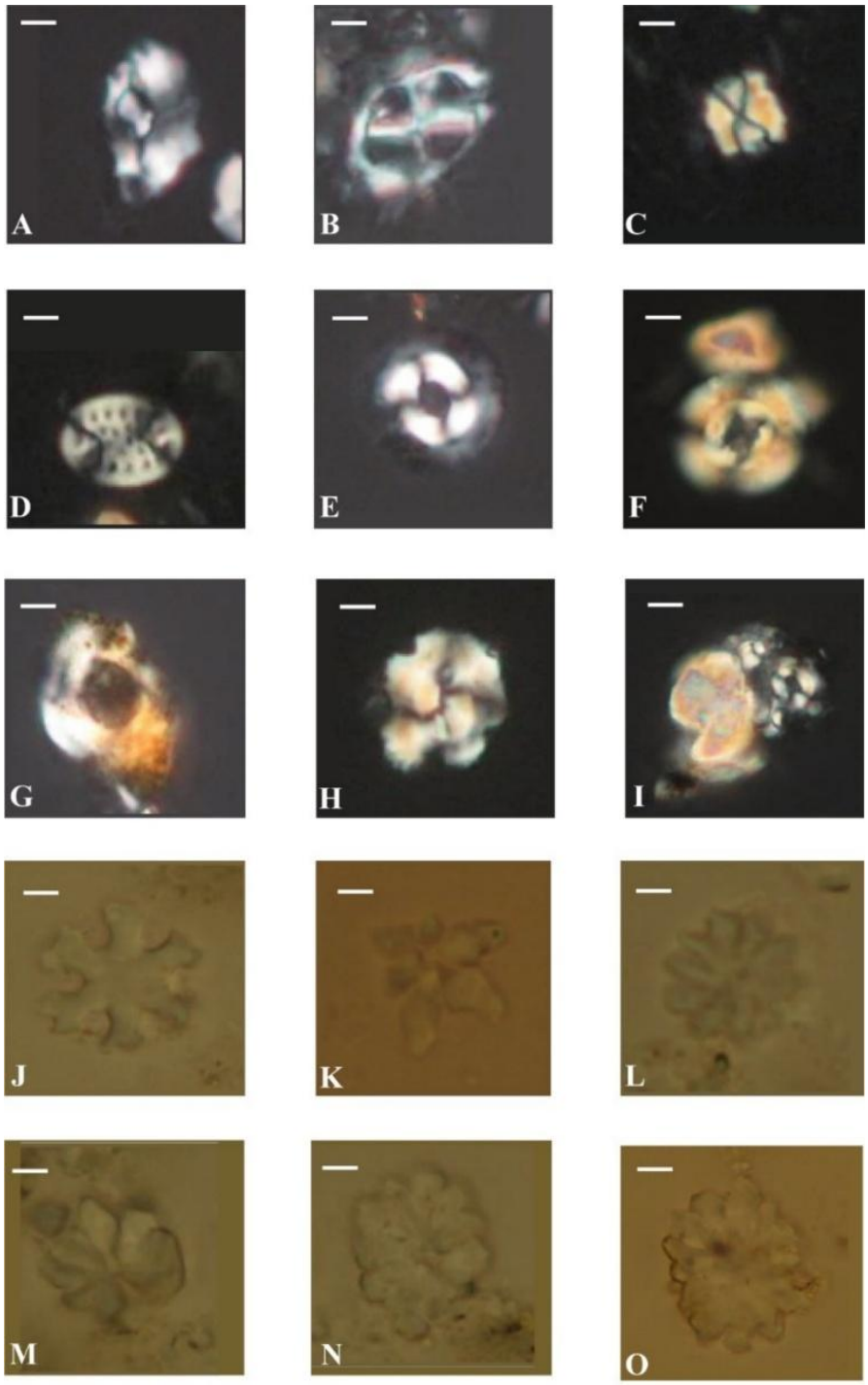


Fig. 30 - Representative calcareous nannofossil assemblages from the Sucevita Formation near Humorului Monastery, A- *Helicosphaera bramlettei* (Müller 1970) Jafar and Martini 1975; B- *Neococcolithes dubius* (Deflandre, in Deflandre and Fert 1954) Black 1967, C- *Lanternithus minutus* Stradner 1962; D- *Pontosphaera distincta* (Bramlette and Sullivan 1961) Roth and Thierstein 1972; E- *Coccolithus formosus* (Kamptner 1963) Wise 1973; F- *Reticulofenestra bisecta* (Hay Mohler and Wade, in Hay *et al*. 1966) Roth 1970; G- *Reticulofenestra umbilicus* (Levin 1965) Martini & Ritzkowski 1968; H- *Reticulofenestra stavensis* (Levin and Joerger 1967) Varol 1989, I- *Coccolithus eopelagicus* (Bramlette and Riedel 1954) Hay, Mohler and Wade, in Hay *et al*. 1966, J- *Discoaster deflandrei* Bramlette and Riedel 1954, K- *Discoaster saipanensis* Bramlette and Riedel 1954; L- *Discoaster barbadiensis* Martini 1961, M, N- Discoaster with overgrowths, Scale 2 µm.

The Bisericani Formation yields a more diverse calcareous nannofossil assemblage (Fig. 31) dominated by *Reticulofenestra umbilicus*, *R. reticulata*, *R. dictyoda*, *R. bisecta*, *Discoaster saipanensis*, *Coccolithus formosus*, *Orthozygus cf. brytkae* and *Isthmolithus recurvus*. These taxa provide a Priabonian (Upper Eocene) age for the succession and support its correlation with the Priabonian deposits of the Eastern Carpathians (Bindiu-Haitonic *et al*., 2019).

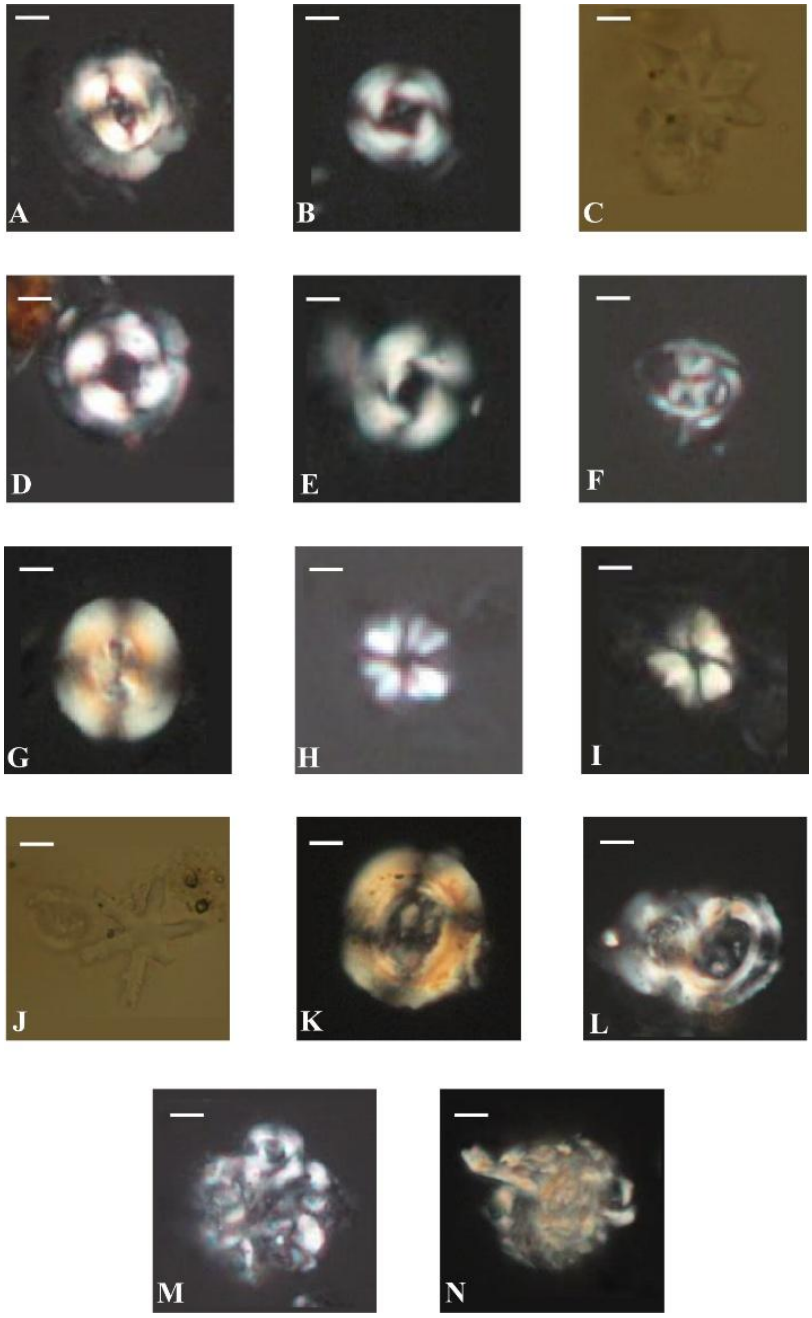


Fig. 31. Representative calcareous nannofossil assemblages from the Bisericani Formation near Humorului Monastery: A- *Coccolithus eopelagicus* (Bramlette and Riedel 1954) Hay, Mohler and Wade, in Hay *et al*. 1966; B- *Reticulofenestra reticulata* (Gartner and Smith 1967) Roth and Thierstein 1972; C- *Discoaster saipanensis* Bramlette and Riedel 1954; D- *Coccolithus formosus* (Kamptner 1963) Wise 1973; E- *Reticulofenestra dictyoda* (Deflandre, in Deflandre and Fert 1954) Stradner, in Stradner and Edwards 1968; F- *Orthozygus brytika* (Roth 1970) Aubry 1988; G- *Reticulofenestra bisecta* (Hay Mohler and Wade, in Hay *et al*. 1966) Roth 1970; H, I - *Sphenolithus moriformis* (Brönnimann and Stradner 1960) Bramlette and Wilcoxon 1967; J- *Discoaster binodosus* Martini 1958; K, L- *Reticulofenestra umbilicus* (Levin 1965) Martini and Ritzkowski 1968; M- Coccosphere of *Reticulofenestra dictyoda* (Deflandre, in Deflandre and Fert 1954) Stradner, in Stradner and Edwards 1968; N- Coccosphere of *Reticulofenestra cf. reticulata* Gartner and Smith 1967, Scale 2 μm.

Stop 12. Visit to the Natural Sciences Museum in Piatra Neamț

This day concludes with a visit to the Natural Sciences Museum in Piatra Neamț (Fig. 32). Opened for the public in 1969, the museum hosts one of the most important paleontological collections in Romania, including the country's largest collection of Oligocene fossil fishes, comprising more than 600 specimens and over 30 holotypes. The collection includes numerous type specimens from the Oligocene of the Eastern Carpathians, such as *Zenopsis tyleri*, *Agarcia agarciaensis*, *Scophthalmus stamatini*, and *Thynnus albui*, recovered from the lower dysodilic shales and bituminous marl formations exposed around Piatra Neamț.

In addition to its outstanding fossil fish collection, the museum displays representative minerals and rocks from Neamț County, together with ecological dioramas illustrating the ecosystems of Ceahlău National Park and Hășmaș-Cheile Bicazului National Park. The visit will also provide an overview of the geological architecture of the Eastern Carpathians through a detailed three-dimensional physical model of the central sector of the mountain chain, displayed in the museum (Fig. 32).





Fig. 32. Natural Sciences Museum in Piatra Neamț (https://zilesinopti.ro/locuri/muzeul-de-stiinte-naturale/).

Accommodation and dinner near Piatra Neamț (Troian Guesthouse, 276 Petru Movilă Street, 617505 Bistrița, Neamț County (Fig. 33)**.**



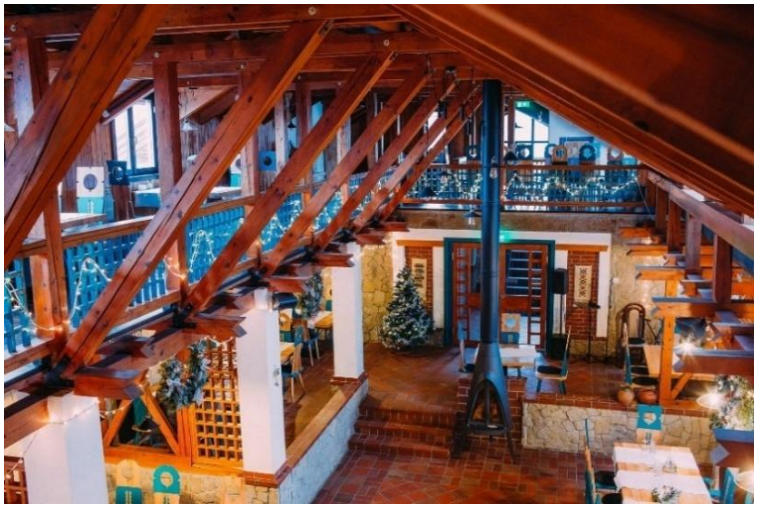


Fig. 33. Troian Guesthouse, accommodation for the second night (https://www.facebook.com/pensiunea.troian).

DAY 3 (8th September). Piatra Neamț – Bicaz – Bicaz Gorge – Lacul Roșu – Cluj-Napoca (304 km)

Our route from Piatra Neamț to Cluj-Napoca (Fig. 1) will pass through the "Flysch Zone" in reverse order, from the Moldavides to the Outer Dacides, then to the Middle Dacides, among which the Bucovinian Nappe, with its Triassic-Cretaceous sedimentary cover, is overthrust by one of the East Transylvanian obduction nappes (the Hășmaș Nappe).

The allochthonous Hășmaș Nappe originated from a branch of the Neotethys Ocean between the Dacia and Tisza continental blocks. This oceanic branch opened during the Triassic – Jurassic and gradually closed in the Late Jurassic – Lower Cretaceous through the continental collision of the two blocks, accompanied by subduction of the Transylvanian Ocean and obduction of oceanic crust fragments with their sedimentary covers over the Bucovinian area of the Dacia block. The Bicaz Gorge is incised into the overthrust Hășmaș Nappe.

The Triassic – Cretaceous sedimentary cover of the Bucovinian Nappe can be observed along the road. Finally, we will reach Lacul Roșu (the Red Lake), the largest and longest-lived natural dam lake in Romania, and will discuss about its geological genesis/formation.

Stop 13. Straja – the Tarcău Sandstone Formation (Palocene-Eocene) of the Tarcău Nappe

The Tarcău Sandstone Formation (Table 1) is a major lithostratigraphic unit (>1500 m) of the Tarcău Group (Belayouni *et al*., 2009) or the Tarcău Lithofacies (Ionesi, 1971), as it is called in the traditional literature, which was sedimented in the Moldavide Basin (Săndulescu, 1988) interpreted as a foreland basin system (Fig. 23) by Grasu *et al*. (1999). It is part of the Tarcău Nappe, belonging to Outer Moldavides, together with Vrancea and Pericarpathian nappes, units which were folded and thrust during Miocene tectogeneses (e.g., Săndulescu, 1988).

It consists mainly of thick bedded sandstones (>80%) characterized by meter to decameter thick beds (Grasu *et al*., 1988). It also contains intervals of red and green mudstones, the thickest being known as Giurgiu – Ghelința Member (Săndulescu and Săndulescu, 1964). The sandstones are very coarse to fine, being petrographically classified in the categories, "greywacke" and lithofeldspathic sandstones, "greywacke" and feldspatholytic sandstones, sandstones and lithic "greywackes" (Grasu *et al*., 1988). A conglomerate subunit (Bako-Sînzieni Conglomerate) may occur in its uppermost interval in some sections (Băncilă, 1958). The visited section is geostructurally located on the internal limb of the Straja Anticline (Băncilă, 1958) (Fig. 34). The Straja outcrop has been the subject of a preliminary sedimentological study (Cojocaru *et al*., 2023).

By classic sedimentary facies analysis, six sedimentary facies were identified and interpreted in terms of their sedimentary processes in the Tarcău Sandstone Formation, namely: massive sandstones of concentrated flows, base-cut-out turbidites, top-cut-out turbidites, black micaceous sandstones rich in organic matter, fine turbidites (laminated red and green mudstones), mudstones with endichnia (hemipelagites). The sedimentary facies interpretation suggest that gravity flows were the dominant sedimentary processes.

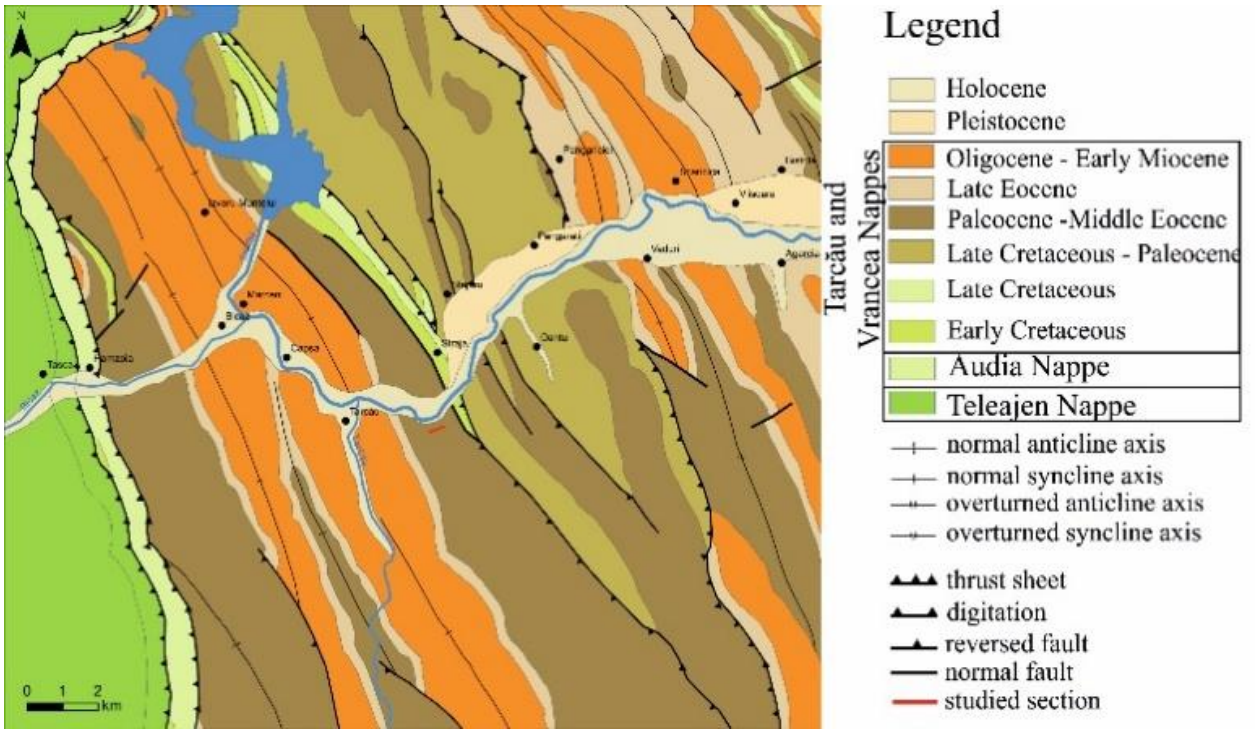


Fig. 34. Simplified geological map of the area (based on Mirăuță, 1968).

Considering the sandstones percentage weight in different intervals there can be defined four facies associations representing depositional sub-environments (cf. Prelat *et al*., 2009; Prelat and Hodgson, 2013 terminology): lobe axis (la), >90% mostly amalgamated m-thick sandstone composite beds; lobe off-axis (loa), 50-90% dm-m thick sandstone simple and composite beds with thin mudstone interlayers; lobe fringe (lf), <50% mostly dm-thick sandstone beds; lobe distal fringe (ldf) with <25% cm-dm thick sandstone beds. The model of hierarchical analysis of the sedimentary succession proposed by Prelat *et al*. (2009), Prelat and Hodgson (2013), and Prelat *et al*. (2010) allowed us to define the architectural elements, as follows (Fig. 35): bed (result of a unique depositional event); lobe element (several stacked beds); lobe (several stacked lobe elements); lobe complex (several stacked lobes). The lobes are bound by thin (dm to m) intervals of interlobes consisting mostly of fine deposits (red and green mudstones with very thin turbidites), while the lobe complexes are bounded by thick intervals of similar types. The thickness of the lobes ranges from 1.3 to 15 m, while of the interlobes ranges from 0.7 to 5.8 m. Several lobe complexes of 12 to 52 m thicknesses were recognized, bounded by interlobe complexes of 11 to 16 m thicknesses. The so-called Giurgiu-Ghelința Member (Săndulescu and Săndulescu, 1964) may be one among several interlobe complexes in the Tarcău Sandstone Formation.

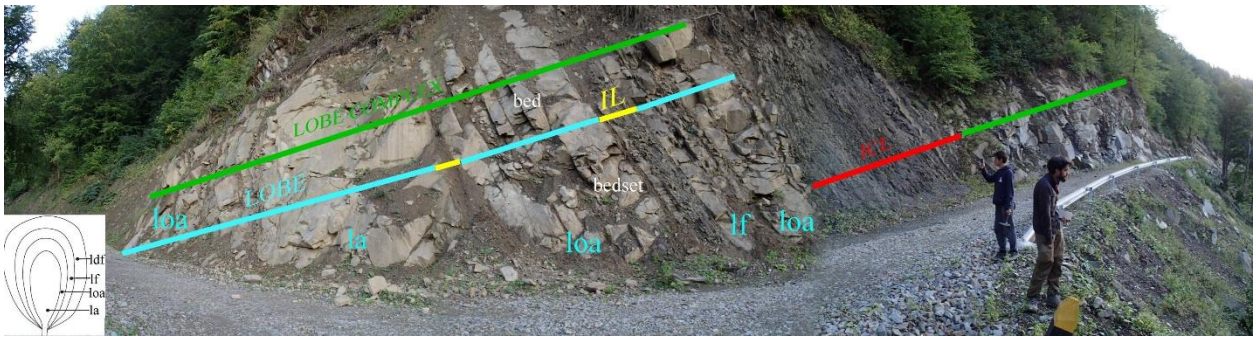


Fig. 35. The architectural elements and depositional subenvironments (shown in the left down corner) of a lobe defined in the Tarcău Sandstone Formation: IL – interlobe; ICL – interlobe complex; la – lobe axis; loa – lobe off-axis; lf – lobe fringe.

The sedimentary facies and facies associations that have been defined indicate that the sedimentary succession is the result of accumulation in a turbiditic system characterized by the presence of lobes. Considering the complex of lobes being equivalent to an active submarine fan, the rather thick interlobe complexes indicate reorganization of the turbiditic system by allogenic processes, although the autogenic ones (e.g. supply channel avulsions, abandonments) cannot be excluded.

More studies of this kind must be done in order to reconstitute the turbiditic system which contributed to the Tarcău Sandstone Formation.

Stop 14. Bicazu Ardelean – the Sinaia Formation (Tithonian-Barremian) of the Ceahlău Nappe

The Sinaia Formation (Table 1, Tithonian-Barremian) is the oldest sedimentary deposit of the former Ceahlău-Severin Ocean, part of the Alpine Tethys, opened between the European continent and Dacia Megaunit in Middle Jurassic-Early Cretaceous (e.g., Săndulescu, 1988; Matenco, 2017). Its shaly deposits have a peculiar dark grey to black color and a silky luster (Fig. 36). The ocean branch was closed during Cretaceous tectogeneses, its basement and deposits being emplaced as a system of nappes (e.g., Black Flysch, Ceahlău) onto the internal margin of the Moldavide Basin (Săndulescu, 1988; Mațenco, 2017 and references therein).

The sedimentary succession exposed at this point (the Ţepeşeni Quarry; Fig. 36) belongs to the most internal subunit of the Ceahlău Nappe, namely to the Ciuc Digitation (Săndulescu, 1987). It was divided in three subunits ranked as members (Săndulescu, 1987; Grasu *et al*., 1996).

The lower member (≈200 m) consists of shale (silty-calcareous claystone, silky sandy-silty claystone), clayey limestone, sandy limestone, and calcareous sandstones. The sandstones are of lithic-feldspathic and feldspathic-lithic, sub-lithic and arkose types. Based on the carbonate:silica ratio, they are calcareous sandstones and quartz siltic limestone. The coarser interlayers have features of turbidites. In the stratotype area (Sinaia, Predeal County), the lower member contains ophiolite-type rocks (diabases) and very low-grade metamorphics defined as Azuga Beds. The ophiolite-type rocks would belong to N-MORB-like basalts formed along a fast-spreading oceanic ridge, according to the most recent data (Roban *et al*., 2024).



Fig. 36. Tepeșeni Quarry (Bicazu Ardelean). Right: General view of the lower and middle members of the Sinaia Formation. Left: A sample of the peculiar dark grey, silky-lustrous shale.

The middle member is the thickest (600-1000 m) of this formation and is characterized by turbidite beds up to 1.5 m thick on a black shale background. The turbidite beds were petrographically analyzed by Grasu *et al*. (1996). From a petrographic point of view, they consist of calcareous litharenite and sublitharenite, followed by sandy sparites, sparitic quartzsiltites, clayey micrites and silty clays; this type of turbidite has sole marks. Some beds may be cut-off base turbidites, without the coarser subdivisions.

The upper member (150-200 m) is characterized by a higher frequency of turbidites and also the occurrence of some debrites. The turbidite beds also consist of many different petrographic types such as: sub-litharenite, litharenite, lithic-feldspatic arenite, quartz-lithic siltstone, sandy and silty sparites, biopelsparites and pelsparites, marls, and silty-sandy shale. By percentage weight, the black shales represent 50%, the sandstones, 25%, clayey limestones, 15%, debrites, 5%, and siltites, 5% (data in Grasu *et al*., 1996).

The mineralogical analysis (Grasu *et al*., 1996) of the clay fraction (< 2 μm) in all members of the Sinaia Formation showed that all the shales consist of illites and chlorites. The illite crystallinity index (IC), intensity ratio (Ir), and expandability (%S) differ among the three members due to the different diagenesis degree. As such, the shale in the lower member is characterized by IC of ca 0.4 (very low-grade metamorphism), while those in the middle and upper members are characterized by higher values.

Stop 15. Bicaz Gorge Area

The Bicaz Gorge is located along the middle reach of the Bicaz River and can be seen on the Bicaz-Gheorgheni national road DN12C. The first access road to the gorge, from Gheorgheni, was built in 1910, while the section to Bicaz in 1937 (Grasu *et al*., 2011).

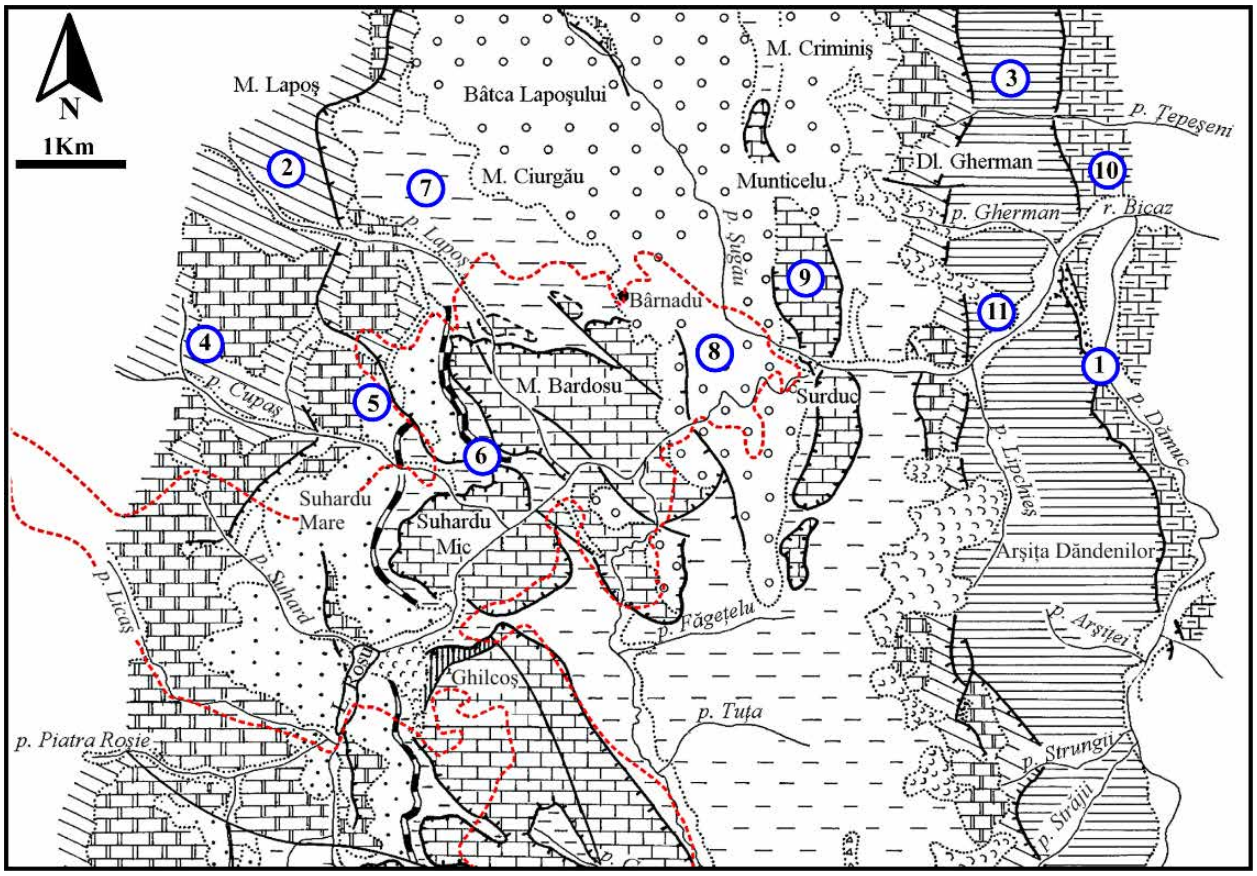


Fig. 37. Geological sketch of the Bicaz Gorge area (redrawn by Grasu *et al*., 2010 from Grasu, 1971; Săndulescu *et al*., 1975): Subbucovinian Nappe: 1 – Triassic-Neocomian deposits; Bucovinian Nappe: 2 – metamorphics of Bretila-Rarău Group; 3 – metamorphics of Tulgheș Group; 4 – conglomerates, sandstones, dolomites, and limestones (Triassic); 5 – red limestones, sandstones, and sandy limestones (Liassic-Dogger); 6 – jaspers and radiolarites (Callovian-Oxfordian); 7 – wildflysch with olistoliths (Barremian-Albian); 8 – Bârnadu Conglomerates (Vraconian-Cenomanian); Hășmaș Nappe: 9 – limestones (Tithonian-Aptian); Ceahlău Nappe: 10 – Sinaia Formation; 11 – Quaternary landslides. The red dashed line represents the boundary of Cheile Bicazului-Hășmaș National Park.

Their formation is related to the evolution of the hydrographic network in the area and especially of the Bicaz River. Bojoi (1971) recognized several stages:

1) the epigenetic stage during which the early hydrographic network entrenched into the post-tectonic conglomerates (Vraconian-Cenomanian Bârnadu Conglomerates), covering both the sedimentary cover of Bucovinian Unit and the overthrust Hășmas Nappe.

2) the karstic stage following the removal of the conglomerates, when the Bicaz River and its tributaries (Cupaș, Lapoș, Bicăjel, and Șugău) incised into the massive limestone of the Hășmaș Nappe (Fig. 37), concurrently developing a network of underground flows, then into the wildflysch deposits of the Bucovinian sedimentary cover. Collapses of cavern roofs gave rise to karst towers (such is the Altar Stone) and important slope breaks, such as the one in the road big turnings.

Two main sectors are distinguished along the Bicaz Gorge: the Small Gorge (ca 4 km) incised through the Bârnadu Conglomerates and the Big Gorge (ca 4 km) incised into the limestones of the Hășmaș Nappe.

The Bârnadu Conglomerates (Fig. 38, Table 1) (Vraconian-Cenomanian) were defined by Săndulescu (1975) as post-tectonic cover unconformable overlying both the youngest deposits of Bucovinian sedimentary succession (the wildflysch formation) and the Hășmaș Nappe (Fig. 37). Lithologically, they are polymictic gravels with clasts reflecting the entire sedimentary succession of the Bucovinian Nappe and also of the Hășmaș Nappe (metamorphics of different grades; Triassic dolomites; Jurassic red, grey, and white limestone; white Urgonian-type limestones etc). Grasu *et al*. (2010) distinguished two populations of clasts: a polymictic population of small, well-rounded clasts (< 4 cm) mostly of Bucovinian source and an oligomictic population consisting of angular boulders (dm-m diameter) of Urgonian-type limestone, respectively. The polymictic population is a component of the Bârnadu Conglomerates matrix together with sandstones and sandy mudstones.

Several sedimentary facies can be distinguished in the Bârnadu Conglomerates: lenticular beds (decametres wide and m thick) of very coarse ortobreccia with exotic limestone boulders; parabreccia with sandy fine rudite matrix with exotic limestone boulders; tabular beds of rough horizontal stratification with normal grading of coarsest clasts (Fig. 38); beds of coarse sandstones with erosive lower bounding surfaces and cross stratification, etc. The sedimentary facies features suggest mainly debris flow processes, subordinately tractive sedimentary processes (Grasu *et al*., 2010).



Fig. 38. Bicaz Gorge. Left: The Small Gorge incised in the Bârnadu Conglomerates. Right: The Deep (/Big) Gorge incised into the Jurassic limestones of the Hășmaș Nappe.

Along the Deep (/Big) Gorge, the elevation differences are spectacular, reaching 350 m in the so-called "Neck of the Hell" at the confluence of Bicăjel Creek with Bicaz River (Fig. 38).

At the confluence of Bicăjel Creek with Bicaz River, the Tithonian-Neocomian succession of the Hășmaș Nappe is exposed (Săndulescu, 1975):

a) massive light-colored neritic limestone (Tithonian) with gastropods (*Nerinea*), foraminifers (*Trocholina alpina*, *T. elongata*, *Kurnubia*, *Kilianina*, etc.), calcareous algae (*Salpingoporella anulata*, *Elipsactinia*, *Cladocoropsis mirabilis*, *Clypeina* div. sp., *Actinoporella podolica*, etc.).

b) thin bedded pelagic limestone (Neocomian) with *Calpionella elliptica*, *Tintinopsella carpathica*, *Calpionellopsis oblonga*, *Neocomites neocomiensis*, *Berriassiella privasensis*; Bicăjel Creek is incised into such limestone;

c) Urgonian-type white, yellowish and light reddish limestones (Barremian) with Pachyodonts (*Requienia* div. sp., *Toucasia carinata*), large foraminiferas (*Orbitolina conica*) as well as calcareous algae and briozoarians.

The gorges on the tributaries of Bicaz River are quite short (Fig. 37), but also spectacular in their wilderness, having between 350 m at the mouth of the Șugău Creek and almost 2 km on Bicăjel Creek. The Șugăului Gorge is the shortest, but also the narrowest, the distance between the walls not exceeding 3-4 m. Here is the clear proof of their epigenetic evolution, given by the presence of both the current and lateral riverbed pots, suspended up to a height of 30 m from the talwegs (Grasu *et al*., 2010).

Upstream of the Deep (/Big) Gorge, near the former Bicaz Gorge Cottage, an exceptional outcrop (Fig. 39) provides one of the few localities in the Eastern Carpathians where well-preserved pillow lava structures can be directly observed in the field. They can be seen in the Bicaz-Chei tectonic window that exposes a ~250 m long section of basaltic rocks, diabases, including the amygdaloid variety, and spilites belonging to the ophiolitic complex of the Hășmaș Nappe, part of the Transylvanian nappes (Fig. 40) (Săndulescu, 1975, 1984; Grasu *et al*., 2010; Grasu *et al*., 2011).



Fig. 39. General view of pillow lavas of the Hășmaș Nappe in Bicaz-Chei tectonic window.

A peculiar feature of the basalts in this site is their content of large xenoliths of limestones. Petrographic investigations of these xenoliths revealed microfacies such as biopelsparites, biopelmicrites, pelsparites and pelmicrosparites, containing a fossil assemblage, including fragments of *Lamelaptychus* sp., *Globochaete* sp., *Cladocoropsis mirabilis*, *Trocholina alpina*, echinoid and crinoid fragments, as well as foraminifera such as *Glomospira* sp. and *Ophthalmidium* sp (Turculeț in Grinea, 1998). The fossil content indicates Upper Jurassic. This ophiolitic complex is overlain by the Acanthicum Formation of Kimmeridgian age; consequently, its age is not younger than Kimmeridgian.

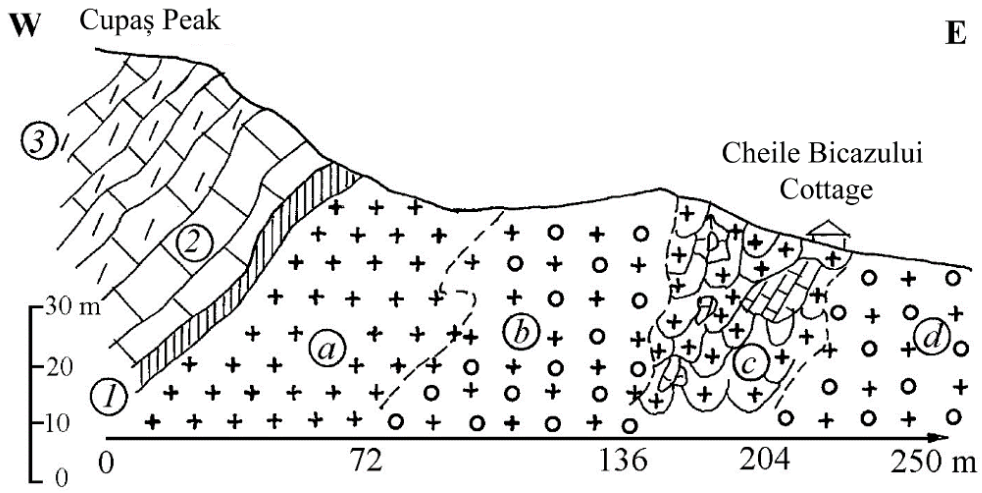


Fig. 40. Detailed geological section of the ophiolite exposure in the Bicaz Gorges tectonic semi-window (modified after Grinea, 1998). Hăşmaş Transylvanian Nappe: (1) Acanthicum Formation (Kimmeridgian); (2) Stramberg Limestone Formation (Tithonian–Neocomian); (3) Urgonian limestones; (a) diabases and spilites; (b) amygdaloidal diabases and spilites; (c) amygdaloidal diabases displaying pillow-lava facies with limestone xenoliths; (d) basalts.

Stop 16. The Red Lake area – an interval of the Bucovinian sedimentary cover and the Red Lake

The geological relationships between the Bucovinian sedimentary cover and the overthrust Hăşmaş (Transylvanian) Nappe are illustrated in the cross-section shown in the Figure 41. During the field stop, participants will examine representative Middle–Upper Jurassic successions of the Bucovinian sedimentary cover, including Middle-Upper Jurassic siliciclastic deposits together with Callovian–Oxfordian jaspers and radiolarites exposed near the Red Lake (Fig. 42).

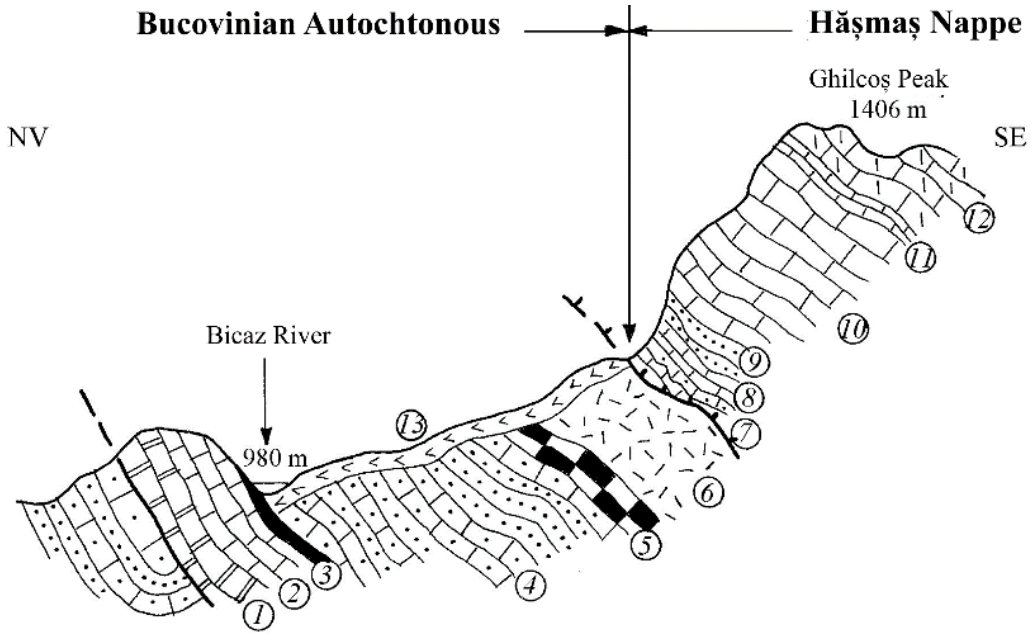


Fig. 41. Geological cross-section through Ghilcoş Mountain in natural dam sector of the Red Lake (after Grasu *et al*., 2010): Bucovinian Autochtonous: 1 – Campilian-Anisian (dolomite); 2 – Middle-Late Triassic (dolomite and limestone); 3 – Liasic in Hierlatz facies; 4 – Dogger; 5 – Callovian-Oxfordian (jaspers and radiolarites); 6 – Barremian-Albian (wildflysch); Hăşmaş (Transylvanian) Nappe; 7 – Kimmeridgian (red nodular limestone); 8 – Kimmeridgian (grey-greenish limestone); 9 – Kimmeridgian (silty-sandy marlstone); 10 – Tithonian (Štramberk-type limestones); 11 – Neocomian; 12 – Barremian-Aptian (Urgonian-type limestone); 13 – slumped deposit.



Fig. 42. Jurassic deposits near Red Lake. Left: Middle-Upper Jurassic siliciclastic deposits, Right: Callovian–Oxfordian jaspers and radiolarites.

The Red Lake (Fig. 43) is situated in the Central Group of the Eastern Carpathians, within the Hăşmaş Mountain, part of the so-called Moldavian-Transylvanian Carpathians group. From a geo-structural point of view, it lies in the Tulgheş-Hăşmaş-Ciuc Syncline belonging to the External Marginal Syncline where the Permian-Cenomanian sedimentary cover of the Bucovinian Unit is preserved under the overthrust Hăşmas Nappe (Grasu *et al*., 2012 and references therein).

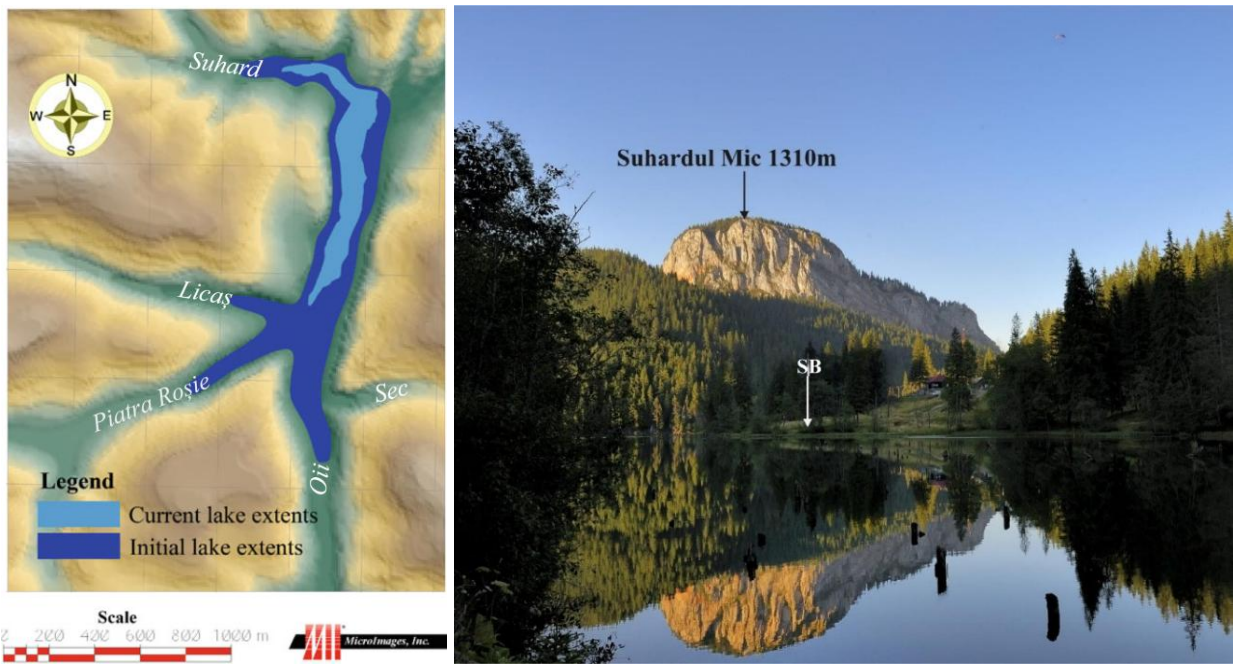


Fig. 43. Red Lake. Left: changes in the surface area of Red Lake during its evolution (after Romanescu *et al*., 2013). Right: view of Red Lake (Photo: Sorin Baciu); SB - slided mass boundary.

The Red Lake (Figs. 37 and 43) is located on the Bicaz River pathway, being fringed by the Suhărzel (1310 m), Suhardul Mare (1506 m), and Piciorul Licaşului (1343 m) massifs toward the north and north-east and by Ghilcoş Mountain (1406 m) toward the east. The lake surface level is located at 980 m absolute altitude.

It is the largest (12.01 ha, 1.36 km max length, 10.5 m max depth) and longest-lived (188-189 years) natural dam lake in Romania. It was formed in 1837 as a result of rainfall-induced debris slides initiated from the Mount Ghilcoş located toward the east-southeast (Fig. 41). Another plausible hypothesis is that it was formed in 1838, after an earthquake-induced landslide (Grasu *et al*., 2010, 2011 and references within).

It is known that in 23rd January 1838, there was a Vrancea earthquake with an estimated magnitude of 7.5 on the Richter-equivalent scale and a maximum macroseismic intensity reaching VIII to IX on the Mercalli scale (Atanasiu, 1961). The lake was discovered two decades later by three tourists from Gheorgheni, and in 1910 the road from Gheorgheni to the Red Lake was cut (Grasu *et al*., 2010).

The main lithostratigraphic unit that supplied the slided debrites is considered to be the wildflysch formation, but all the sedimentary succession of the northern slope of the Ghilcoș Mt., belonging both to sedimentary cover of Bucovinian Unit and to the overthrust Hășmaș Nappe must have contributed (Grasu *et al*., 2010 and references within).The lake is supplied by several tributaries of the Bicaz River (Oii, Piatra Roșie, Licaș, and Suhard creeks), its drainage basin area being 36.6 km^2 (Fig. 43). The lake surface area shrank in time from 12.6 ha to 12.01 ha. At the beginning, the lake length measured on the Oii tributary was 2 km, decreasing to only 1 km in 1957 (data in Grasu *et al*., 2011). Data from 1968 (Bojoi, 1968) showed a 40% lake infilling despite the dams built on the tributary to prevent the sediment supply.

By hydro-biologic point of view, the lake evolved from an oligotrophic regime through oligotrophic-mesotrophic (after the macrophyte invasion) and mesotrophic to a mesotrophic-eutrophic one in present.

The Red Lake is an important site of the Cheile Bicazului-Hășmaș National Park, a protected natural area established in 1990 for the conservation of biodiversity and landscape, for the promotion of ecotourism, and for the awareness and education of the public in the spirit of nature protection (https://www.cheilebicazului-hasmas.ro/).

From the Red Lake, we will head directly to Cluj-Napoca to arrive by 5:00 PM

References

Aroldi, C. 2001. The Pienides in Maramureș: Sedimentation, Tectonics and Paleogeography. *Cluj University Press*, Cluj-Napoca, 156 pp.

Aroldi, C. 2003. Identification of the source areas for the Paleogene turbiditic deposits of the Pienidian units in Maramureș. *Studia Universitatis Babeș-Bolyai, Geologia* 48 (2), 51–58.

Aroldi, C., Chira, C.M., Bindiu-Haitonic, R., Miclăuș, C., Smeu, A., Erbinucci, F.C., Coman, H. 2025. Depositional trends and biostratigraphic framework of the Petrova Nappe (Paleogene, Northern Maramureș, Romania). In: *Abstracts and Field Trip Guide. The 15th Romanian Symposium on Palaeontology*, Cluj-Napoca, 10–14 September 2025. Editura Presa Universitară Clujeană, 60–61.

Atanasiu, I. 1961. Cutremurele de pământ din România. *Editura Academiei Române*, București, 194 pp.

Bădescu, D. 2005. Tectono-stratigraphic evolution of the East Carpathians during Mesozoic and Cenozoic. *Editura Economică*, București, 312 pp. (in Romanian).

Băncilă, I. 1958. Geology of the East Carpathians. *Editura Științifică*, București, 368 pp. (in Romanian).

Belayouni, H., Di Staso, A., Guerrera, F., Martín-Martín, M., Miclăuș, C., Serrano, F., Tramontana, M. 2009. Stratigraphic and geochemical study of the organic-rich black shales in the Tarcău Nappe of the Moldavidian Domain (Carpathian Chain, Romania). *International Journal of Earth Sciences* 98 (1), 157–176.

Berggren, W.A., Kent, D.V., Swisher III, C.C., Aubry, M.-P. 1995. Revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V., Hardenbol, J. (Eds), *Geochronology, Time Scales and Global Stratigraphic Correlation: A Unified Temporal Framework for an Historical Geology*. Society of Economic Paleontologists and Mineralogists, Special Publication 54, 129–212.

Beldean, C., Bercea, R., Filipescu, S. 2013. Sedimentology and biostratigraphy of the Early–Middle Miocene transition in NW Transylvanian Basin (Păglișa and Dej sections). *Studia Universitatis Babeș-Bolyai, Geologia* 58 (1), 57–70.

Bindiu-Haitonic, R., Filipescu, S., Aroldi, C., Oltean, G., Chira, C.M. 2019. Eocene Deep-Water Agglutinated Foraminifera from the Eastern Carpathians (Romania): Paleoenvironments and Biostratigraphical Remarks. *Micropaleontology* 65 (1), 47–61.

Bojoï, I. 1970. Aspecte ale evoluţiei geomorfologice a văilor din bazinul superior al Bicazului. Muzeul de Ştiinţe Naturale Piatra Neamţ, *Studii şi cercetări de geologie-geografie-biologie-muzeologie* 1, 177–192.

Brustur, T., Grigorescu, D. 1973. Une nouvelle espèce du genre *Palaeorhynchus*: *Palaeorhynchus humorensis* dans les dépôts oligocènes de la zone de Gura Humorului. *Revue Roumaine de Géologie, Géophysique et Géographie*, Série de Géologie 17, 99–114.

Chira, C.M., Aroldi, C., Ștefănuț, V.I. 2013. Oligocene–Miocene calcareous nannoplankton from the turbiditic deposits of the Colibița–Mureșenii Bârgăului area (Bistrița-Năsăud County, Romania). In: *Abstract Book of the 9th Romanian Symposium on Paleontology*, Iași, 25–26 October 2013, 20–21.

Chira, C.M., Aroldi, C. 2017. Oligocene–Lower Miocene calcareous nannofossils and sedimentology of the Transcarpathian Basin in Romania. In: *Book of Abstracts of the 16th International Nannoplankton Association Conference (INA16)*, Athens.

Chira, C.M., Aroldi, C., Miclăuș, C., Smeu, A., Erbinucci, F., Turinovici, M. 2024. Biostratigraphic study of the Babei Gorges and the lower Iza Valley area (Maramureș, Romania) based on calcareous nannofossils. In: *Book of Abstracts Sesiunea Științifică "Ion Popescu Voitești",* Cluj Napoca (in Romanian).

Chira, C.M., Aroldi, C., Bindiu-Haitonic, R., Miclăuș, C., Coman, H., Smeu, A., Zabulic, G., Erbinucci, F., 2024. Integrated biostratigraphy of the Upper Cretaceous – Eocene deposits from Poiana Botizei – Botiza (Maramures, Romania). *Journal of Nannoplankton Research INA19 Abstracts*, Conwy, UK, September 2024, p. 40 – 41.

Chira, C.M., Bindiu-Haitonic, R., Aroldi, C., Smeu, A., Miclăuș, C., Popa, M.V., Todoran, V., Săsăran, L., Trif, N., Erbinucci, F., Andreica, I., Coman, H. 2025. Upper Cretaceous, Paleogene and Miocene deposits from Sălaj and Maramureș areas. In: *Book of Abstracts and Field Trip Guide of the 15th Romanian Symposium on Palaeontology*. Presa Universitară Clujeană, Cluj-Napoca, 152–172.

Chira, C.M., Aroldi, C., Smeu, A., Haitonic, R., Erbinucci, F. 2026. Integrated biostratigraphy and sedimentology of the Paleogene–Neogene deposits from Bârsana (Maramureș, Northern Romania). In: *XXIII International Congress of the Carpathian-Balkan Geological Association, Cluj-Napoca, Romania, 9–11 September 2026, Abstracts*.

Cojocaru, F.E., Smeu, A., Miclăuș, C., Seserman, A. 2023. Turbiditic lobes and interlobes in the Tarcău Sandstone. In: Smeu, A. (Ed.), *Abstract Volume of the 21st National Symposium of Geology and Geophysics Students*. Bucharest, ISBN 978-606-9658-24-6 (in Romanian).

Contescu, L., Jipa, D., Mihăilescu, N., Panin, N. 1966. The internal Paleogene flysch of the Eastern Carpathians: paleocurrents, source areas and facies significance. *Sedimentology* 7 (4), 307–321.

Csontos, L., Vörös, A. 2004. Mesozoic plate tectonic reconstruction of the Carpathian region. *Palaeogeography, Palaeoclimatology, Palaeoecology* 210, 1–56.

DeCelles, P.G., Giles, K.A. 1996. Foreland basin systems. *Basin Research* 8 (2), 105–123.

Dumitrică, P., Gheța, N., Popescu, G. 1975. New data on the biostratigraphy and correlation of the Middle Miocene in the Carpathian area. *Dări de Seamă ale Institutului de Geologie și Geofizică* 61 (4), 65–84.

Grădianu, I., Monsch, K.A., Baciu, D.S. 2025. Systematic Revision of the Oligocene Billfishes (Istiophoriformes: Palaeorhynchidae) from Romania. *Diversity* 17 (6), 393

Grasu, C., Turculeț, I. 1973. Câteva precizări în legătură cu stratigrafia și poziția structurală a Stratelor cu Aptychus din Sinclinalul Hăghimaș. Muzeul de Științe Naturale Piatra Neamț*, Studii și Cercetări de Geologie–Geografie–Biologie. Seria Geologie–Geografie* 2, 65–74. (in Romanian).

Grasu, C., Cătană, C., Grinea, D. 1988. Carpathian Flysch. Petrography and Economical Considerations. *Editura Tehnică*, București, 227 pp. (in Romanian).

Grasu, C., Cătană, C., Boboș, I. 1996. Petrography of the Inner Flysch Formations of the Carpathians. *Editura Tehnică*, București, 178 pp. (in Romanian).

Grasu, C., Catană, C., Miclăuș, C., Boboș, I. 1999. East Carpathian Molasse. Petrography and sedimentogenesis. *Editura Tehnică*, Bucureşti, 227 pp. (in Romanian with abstract in English).

Grasu, C., Miclăuş, C., Brânzilă, M., Baciu, D.S. 2010. The Hăşmaş Mountains. Geological and Physical-Geographical Monograph. *Editura Universităţii "Alexandru Ioan Cuza",* Iaşi, 343 pp (in Roamnian).

Grasu, C., Brânzilă, M., Miclăuș, C., Baciu, D.S. 2011. Bicaz Gorge–Hăşmaş National Park. Guide to the Geological and Physical-Geographical Sites. *Editura Universităţii "Alexandru Ioan Cuza",* Iaşi, 97 pp. (in Romanian).

Grasu, C., Miclăuş, C., Brânzilă, M., Baciu, D.S. 2012. he Tulgheș–Hăşmaş–Ciuc Mesozoic Syncline. Geological Monograph. *Editura Universităţii "Alexandru Ioan Cuza",* Iaşi, 250 pp. (in Romanian)

Grinea, D. 1998. Studiul mineralogic și geochimic al rocilor eruptive bazice mezozoice din Munții Hăghimașului și Munții Tulgheșului. PhD thesis, Universitatea "Alexandru Ioan Cuza" din Iași.

Golonka, J., Krobicki, M., Oszczypko, N., Ślączka, A., Słomka, T. 2003. Geodynamic evolution and palaeogeography of the Polish Carpathians and adjacent areas during Neo-Cimmerian and preceding events (latest Triassic–earliest Cretaceous). *Geological Society, London, Special Publications* 208, 138–158.

Golonka, J., Picha, F.J. (Eds). 2006. The Carpathians and Their Foreland: Geology and Hydrocarbon Resources. *AAPG Memoir 84*, American Association of Petroleum Geologists, Tulsa, 833 pp.

Ionesi, L. 1971. Paleogene flysch from the Moldova River Drainage Basin. *Editura Academiei Române*, București, 250 pp. (in Romanian).

Jipa, D., 1962. Directions d'apport dans le gres de Borsa (Maramureș). *Commun. Acad. Rep. Populare Romine*, 12, 1363-1368.

Krézsek, C., Bally, A.W. 2006. The Transylvanian Basin (Romania) and its relation to the Carpathian fold and thrust belt: Insights in gravitational salt tectonics. *Marine and Petroleum Geology* 23 (4), 405–442.

Martini, E. 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: *Proceedings of the II Planktonic Conference, Roma, 1970*. Ed. Tecnoscienza, 739–785.

Matenco, L.C. 2017. Tectonics and exhumation of the Romanian Carpathians: Inferences from kinematic and thermochronological studies. In: Rădoane, M., Vespremeanu-Stroe, A. (Eds), *Landform Dynamics and Evolution in Romania*. Springer, Switzerland, 15–56.

Mészáros, N., Hosu, A. 1989. Stratigraphic significance of the nannoplankton in the Colibița area (Bârgău Mountains). *Studia Universitatis Babeș-Bolyai, Geologia* 34, 39–42.

Mészáros, N., Filipescu, S. 1991. Le nannoplankton du Complexe du Tuf de Dej (Râpa Dracului). In: Bedelean, I., Ghergari, L., Mârza, I., Mészáros, M., Nicorici, E., Petrescu, I. (Eds), *The Volcanic Tuffs from the Transylvanian Basin*. Cluj-Napoca, 79–82.

Miclăuș, C., Loiacono, F., Puglisi, D., Baciu, D.S. 2009. Eocene-Oligocene sedimentation in the external areas of the Moldavide Basin (Marginal Folds Nappe, Eastern Carpathians, Romania): sedimentological, paleontological and petrographic approaches. *Geologica Carpathica* 60 (5), 397–417.

Miclăuș, C., Seserman, A. 2018. Injectites and possible injectites in the Oligocene deposits of the Tarcău and Vrancea Nappes. Unpublished paper presented at the Scientific Symposium "Grigore Cobălcescu", "Alexandru Ioan Cuza" University of Iași, Iași. (in Romanian)

Micu, M., Gheţa, N. 1986. Eocene-Oligocene boundary in Romania on calcareous nannoplankton. *Dări de Seamă ale Institutului de Geologie și Geofizică* 70–71 (4), 289–307.

Mirăuţă, O. 1968. Geological map of Romania, scale 1:200,000, sheet 13 – Piatra Neamţ. Geological Institute of Romania, Bucharest.

Mutti, E., Tinterri, R., Benevelli, G., Di Biase, D., Cavanna, G. 2003. Deltaic, mixed and turbidite sedimentation of ancient foreland basins. *Marine and Petroleum Geology* 20 (6–8), 733–755.

Popescu, G. 1975. Études des foraminifères du Miocène inférieur et moyen du nord-ouest de la Transylvanie. *Mémoires – Institut de Géologie et de Géophysique* 23, 1–121.

Puglisi, D., Badescu, D., Carbone, S., Corso, S., Franchi, R., Gigliuto, L.G., Loiacono, F., Miclăuș, C., Moretti, E. 2006. Stratigraphy, petrography and palaeogeographic significance of the Early Oligocene "menilite facies" of the Tarcău Nappe (Eastern Carpathians, Romania). *Acta Geologica Polonica* 56 (1), 105–120.

Prélat, A., Covault, J.A., Hodgson, D.M., Fildani, A., Flint, S.S. 2010. Intrinsic controls on the range of volumes, morphologies, and dimensions of submarine lobes. *Sedimentary Geology* 232, 66–76.

Prélat, A., Hodgson, D.M. 2013. The full range of turbidite bed thickness patterns in submarine lobes: controls and implications. *Journal of the Geological Society* 170, 209–214.

Prélat, A., Hodgson, D.M., Flint, S.S. 2009. Evolution, architecture and hierarchy of distributary deep-water deposits: a high-resolution outcrop investigation from the Permian Karoo Basin, South Africa. *Sedimentology* 56, 2132–2154.

Roban, R.D., Ducea, M.N., Mihalcea, V.I., Munteanu, I., Barbu, V., Melinte-Dobrinescu, M.C., Olariu, C., Vlăsceanu, M. 2023. Provenance of Oligocene lithic and quartz arenites of the East Carpathians: Understanding sediment routing systems on compressional basin margins. *Basin Research* 35 (1), 244–270.

Roban, R.D., Luffi, P., Ducea, M.N., Lazăr, I., Costin, G., Munteanu, I., Barbu, V., Ene, V., Melinte-Dobrinescu, M.C. 2024. Deciphering the early-stage evolution of relict marine basins: the case of the Ceahlău-Severin Ocean of the Romanian Carpathians. In: *International Association of Sedimentologists Conference Abstract Volume,* IAS 2024, Aberdeen, Scotland, UK, 24–28 June 2024.

Romanescu, Gh., Stoleriu, C.C., Enea, A. 2013. Limnology of the Red Lake, Romania. An interdisciplinary study. *Springer*, Dordrecht, 234 pp.

Săndulescu, M., Săndulescu, J. 1964. Aspecte stratigrafice şi structurale ale flişului paleogen din regiunea Ghelinţa (Tg. Secuiesc). *Dări de Seamă ale Comitetului Geologic* XLIX (1), 93–104.

Săndulescu, M. 1975. Studiul geologic al părţii centrale şi nordice a Sinclinalului Hăghimaş (Carpaţii Orientali). *Anuarul Institutului de Geologie şi Geofizică* 45, 200 pp.

Săndulescu, M., Krautner, H., Borcoș, M., Năstăseanu, S., Patrulius, D., Ștefănescu, M., Ghenea, C., Lupu, M., Savu, H., Bercia, I., Marinescu, F. 1978. Harta geologică a României, scara 1:1.000.000. Institutul Geologic al României, București.

Săndulescu, M. 1980. Analyse géotectonique des chaines alpines situées autour de la mer Noire Occidentale. *Anuarul Institutului de Geologie și Geofizică al României* 56, 5–55.

Săndulescu, M., Neagu, T., Antonescu, E. 1982. Contributions à la connaissance des klippes de type pienin de Poiana Botizei (Maramureș). *Dări de Seamă ale Institutului de Geologie și Geofizică* 67 (4), 79–96.

Săndulescu, M. 1984. The geotectonics of Romania. *Editura Tehnică*, București, 336 pp. (in Romanian).

Săndulescu, M. (1987). Le flysch Cretace de la zone du Mont Ceahlău et du bassin du Bicaz (Carpathes Orientales). *Dări de seamă ale Institutului de Geologie și Geofizică* 74(4), 31-44.

Săndulescu, M. 1988. Cenozoic tectonic history of the Carpathians. In: Royden, L.H., Horváth, F. (Eds), *The Pannonian Basin: A Study of Basin Evolution*. AAPG Memoir 45, 17–25.

Schmid, S.M., Bernoulli, D., Fügenschuh, B., Matenco, L., Schefer, S., Schuster, R., Tischler, M., Ustaszewski, K. 2008. The Alpine-Carpathian-Dinaridic orogenic system: Correlation and evolution of tectonic units. *Swiss Journal of Geosciences* 101 (1), 139–183.

Seghedi, I., Szakács, A. 1991. The Dej Tuff from the Dej–Ciceu area: Some petrographical, petrochemical and volcanological aspects. In: Bedelean, I., Ghergari, L., Mârza, I., Mészáros, M., Nicorici, E., Petrescu, I. (Eds), *The Volcanic Tuffs from the Transylvanian Basin*. Cluj-Napoca, 135–146.

Smeu, A., Roban, R.D. 2024. The provenance of Upper Jurassic–Early Cretaceous sediments from the Bucovinian Nappe sedimentary cover – implications for U–Pb geochronology of the Dacia Block. In: *Book of Abstracts. Geo Iași, Scientific Symposium*. *Analele Științifice ale Universității "Alexandru Ioan Cuza" din Iași (Serie Nouă), Geologie*. Iași, Romania.

Szakács, A., Pécskay, Z., Silye, L., Balogh, K., Vlad, D., Fülöp, A. 2012. On the age of the Dej Tuff, Transylvanian Basin (Romania). *Geologica Carpathica* 63 (2), 139–148.

Tischler, M., Matenco, L., Filipescu, S., Gröger, H.R., Wetzel, A., Fügenschuh, B. 2008. Tectonics and sedimentation during convergence of the ALCAPA and Tisza–Dacia continental blocks: The Pienide nappe emplacement and its foredeep (N. Romania). *International Journal of Earth Sciences* 97 (2), 309–332.

FIELD TRIP 11

FT11. Geological section through the East Carpathians: Neogene Magmatic Arc, Median Dacides, Ditrău Alkaline Massif (T-K1), Outer Dacides

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INTRODUCTION TO GEOTECTONIC SETTING OF MEDIAN DACIDIC UNIT FROM THE EAST CARPATHIANS

The Carpathian orogen is part of the Alpine-Carpathian-Dinaric Belt, which consists of a complex assemblage of Mesozoic and Cenozoic accretionary terranes. The Romanian East Carpathians are the southward prolongation of the Ukrainian Carpathians. The East Carpathian (EC) segment of the Carpathian orogen comprises, from east to west, N-S-trending tectonic units:

- A fold-and-thrust belt (External Dacides, (Săndulescu, 1984, 1988, 1988a, 1994)) represents cover nappes composed of sedimentary formations detached from their primary basement and overthrust eastward above the Foreland. The innermost nappes (Black Flysch, Baraolt nappe and, in the Carpathian bend zone: Ceahlău-Severin and Bobu nappes) (Fig. 1) contain only Tithonian-Cretaceous formations, with Paleogene units forming their post-tectogenic cover. The other units, the Moldavides, comprise two main units (the inner part with the Convolute Flysch/Teleajen, Macla and Audia nappes, and the outer part with the Tarcău, Marginal Folds and Subcarpathian nappes). The inner molasse nappes and the Tarcău and Marginal Folds units comprise Cretaceous, Paleogene and Miocene (Lower and Middle) sedimentary formations. The Subcarpathian Nappe is the outermost overthrust unit of the East Carpathians. It consists mostly of Miocene formations, to which, in the cores of some anticlines, Oligocene and, exceptionally, Upper Eocene formations are associated. The tectogenetic events that generated the current structural features of the Flysch Zone and the Subcarpathians are: Mid-Cretaceous/Austrian tectonic phase (overthrusting of the Black Flysch and Baraolt nappes and folding of the Ceahlău Nappe), Late-Cretaceous/Laramian tectonic phase (overthrusting of the Ceahlău Nappe; slight folding of the Convolute Flysch Nappe), Intra-Burdigalian (overthrusting of the Convolute Flysch, Macla and Audia nappes), Intra-Badenian (overthrusting of the Tarcău and Marginal Folds nappes), and Intra-Sarmatian (overthrusting of the Subcarpathian Nappe, the last important underthrusting of the Foreland). The Miocene tectonic events are related to lateral escape tectonics during collision and Carpathian orocline formation (Ratschbacher et al., 1991, 1991a) in the area.
- Sheared and imbricated continental basement slices (Crystalline-Mesozoic Zone or Median Dacides (Săndulescu, 1984; Săndulescu and Dimitrescu, 2004) or Eastern Getides (Balintoni, 1997), overthrust by Transylvanides (as obducted Meliata oceanic slices) and their post-tectogenetic cover (above which the Pienides are overthrust). -tectogenetic cover (above which the Pienides are overthrust).
- There are three main Transylvanian nappes of Laramian tectogenesis (Perșani, Olt and Hăghimaș/Hăşmaş), each with distinct lithostratigraphic successions and ages of the ophiolitic complexes in the basal parts of the nappes (except the Perșani nappe, which derives from the rifting zone preceding the opening of the Tethyan Ocean). Transitional successions between these three basic units may also be recorded.
- The Pienides, relics of the Alpine Tethys, are situated north of the Transylvanian Depression and north of the Bogdan Dragoş Vodă Fault. The Pienides consist of cover nappes overthrust above the

Upper Cretaceous-Paleogene-Lowermost Miocene post-tectogenetic cover of the Crystalline-Mesozoic Zone during the Burdigalian.

- A Neogen magmatic arc.

The metamorphic basement of EC derives from the Dacia microplate (Săndulescu and Dimitrescu, 2004; Săndulescu, 1984) or Getic microplate (Balintoni, 2005), which, during the Jurassic, was separated from the South European continental margin by the Civcin-Severin rifting (Săndulescu, 2009) and spreading system. It represents the continuation of the East of the Alpine Tethys (Schmid et al., 2020) (Fig. 1). This rift ("External Dacian Rift" after Săndulescu, 1984) evolved into a narrow ocean, which was closed during the Upper Jurassic–Lower Cretaceous and filled with limestone-bearing flysch (Sinaia flysch, Săndulescu, 1984; Kräutner, 1996). During the Austrian compressional stage, the Dacia microplate was sheared and stacked into a thick nappe pile, described as the Median Dacides (Săndulescu, 1984; Săndulescu et al., 1981; Vodă and Balintoni, 1994). described as Median Dacides (Săndulescu, 1984; Săndulescu et al., 1981; Vodă and Balintoni, 1994).

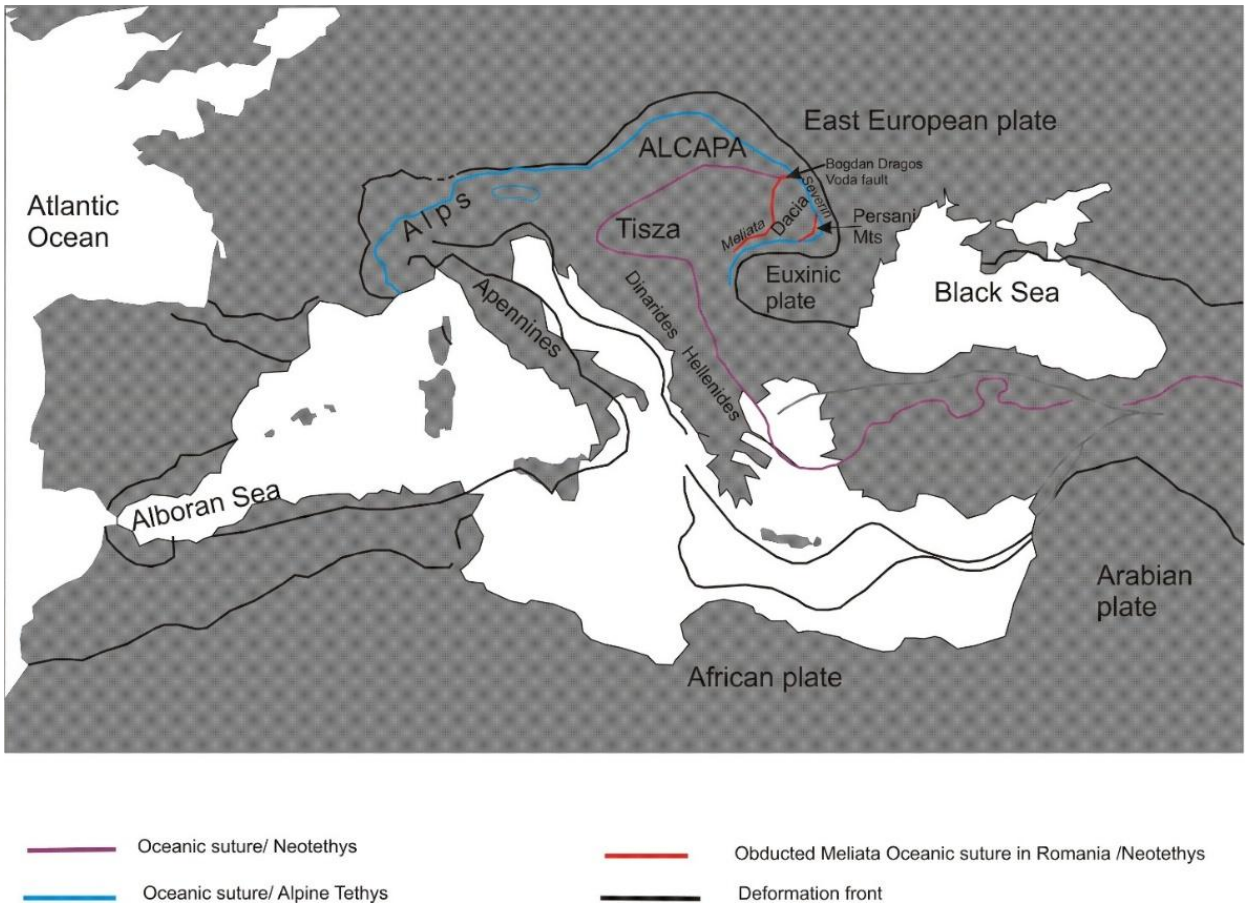


Fig. 1. Alps-Carpathian- Dinaric system with the suture zones of the Alpine Tethys (Civcin- Severin Ocean) and Neotethys (Meliata Ocean) and the major deformation front (after Ustaszewski et al., 2010, modified)

Due to Miocene lateral extrusion tectonics (Ratschbacher et al., 1991, 1991a; Csontos and Vörös, 2004), the Carpathian orogen was also bent (Csontos and Vörös, 2004), resulting in the Eastern and Southern Carpathians. The Pienides consist of cover nappes overthrust above the Upper Cretaceous-Paleogene-Lowermost Miocene post-tectogenetic cover of the Crystalline-Mesozoic Zone during the Burdigalian. They represent the easternmost tip of ALCAPA in Burdigalian times. They consist of non-metamorphic flysch nappes and were emplaced in Early Burdigalian times along the Bogdan-Dragos Vodă

fault system (Săndulescu et al., 1981; Săndulescu and Dimitrescu, 2004; Săndulescu, 2009; Gröger et al., 2008; Gröger et al., 2013; Tischler et al., 2008).

The Median Dacian (Crystalline-Mesozoic) Unit was sheared into a duplex structure during the Austrian tectonic phase, and three main Alpine Units: the Bucovinian, Subbucovinian, and Infrabucovinian nappe systems, resulted (Fig. 2). The Meliata oceanic crust (as a prolongation of Neothetys from the Alps) (Schmid et al., 2020) developed between the Tisza, Dacia, and Euxinic plates. The Austrian Transylvanides were obducted (Balintoni, 2005) and structured during the Mid Cretaceous under E-to-W-oriented compression. Later, during the Laramian phase, the Austrian Transylvanides were reworked under SE-to-NV-oriented compression, and oceanic rock piles were emplaced to the east over the Dacic microplate (Ionescu et al., 2009) and even over the Median Dacides. These oceanic relics were preserved as outliers in the Perșani Mountains, Bicaz Gorges, or the Repedea-Rica Valley in Maramureș (Hoeck et al., 2009).

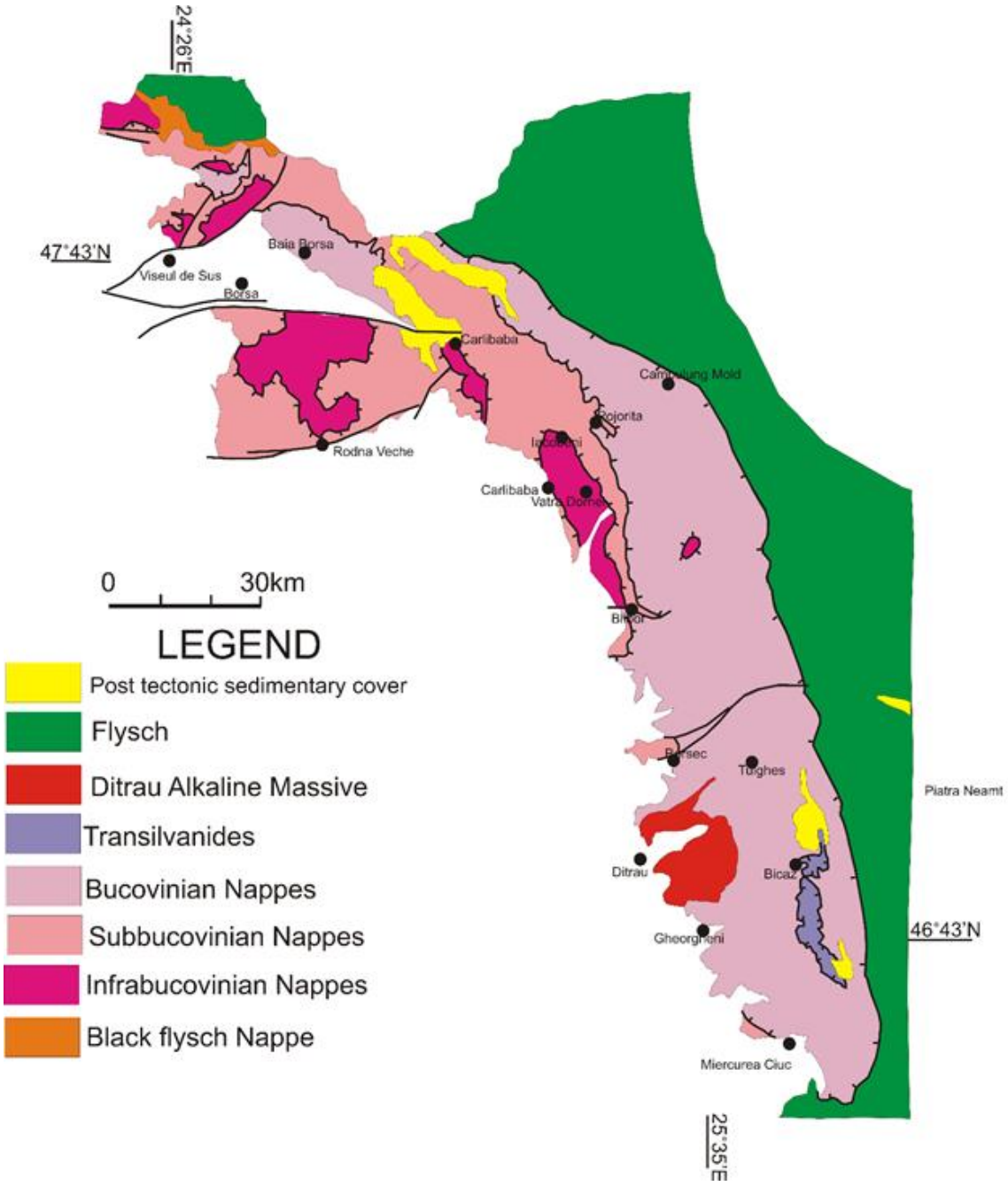


Fig. 2. In the Borsec area (Balintoni and Baier, 2001) are outcropping, in our opinion, the Bucovinian Rebra carbonatic metamorphics in a Variscan tectonic window.

A geological section through the East Carpathians Median Dacidic zone was drawn by Kräutner and Bindea (2002) (Fig. 3):

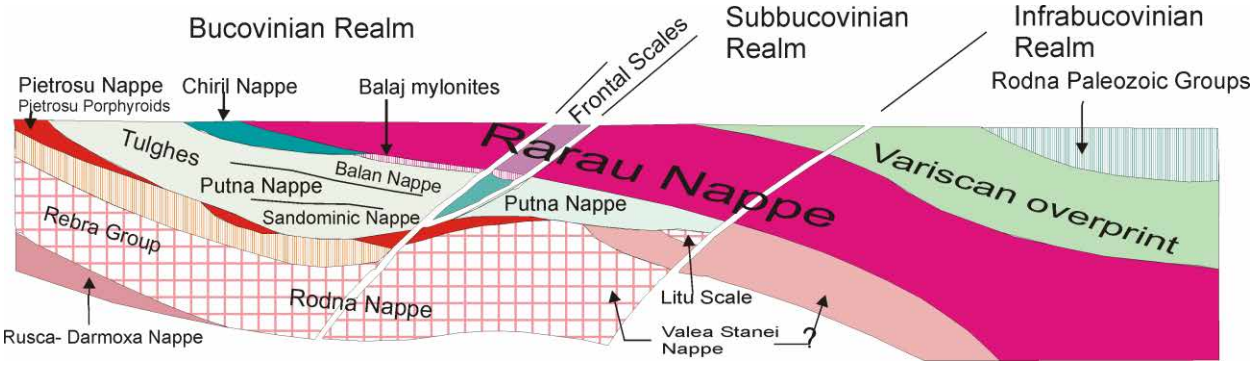


Fig. 3. Geological section through Median Dacidic Zone of Eastern Carpathians (after Kräutner and Bindea, 2002, modified).

The Bucovinian Nappe outcrops along the entire length of the EC. The Subbucovinian Unit is visible only in the northern part, whereas the Infra Bucovinian Unit is exposed only in some isolated Alpine tectonic windows (e.g., Vatra Dornei and Rodna half-window).

Each of these Bucovinic units consists of Pre-Alpine basement nappes composed of crystalline schists and a Mesozoic sedimentary cover (Săndulescu, 1967; Rădulescu and Săndulescu, 1973; Balintoni, 1981; Balintoni în Săndulescu et al., 1981; Balintoni et al., 1983).

In the Pre-Alpine basement of the Median Dacidic Unit, Variscan napping is evidenced: by Permian–Triassic sediments transgressively overlying metamorphics of different tectonic basement units, and by the biphasic (232 Ma and 160 Ma) Ditrău Alkaline intrusive massif, whose thermal contact haloes five superposed tectonic sheets. The Variscan nappes were emplaced from the Middle to the Upper Carboniferous (310 – 280 Ma), as indicated by deformed metamorphics (Kräutner and Bindea, 2002), with westward vergence opposite to Alpine napping, as suggested by Săndulescu and Dimitrescu (2004) and Săndulescu (1984).

These pre-Alpine tectonic units of the Bucovinian and Subbucovinian Nappes (from bottom to top) are: Rodna Nappe (consisting of Rebra terrane rocks), Pietrosu Bistriţei Nappe (Negrioşara terrane and Pietrosu Bistriţei porphyroids), Putna Nappe (Tulgheş terrane rocks), Rarău Nappe (Bretila-Rarău terrane rocks and Mândra granitoids), and Hăghimaş Nappe (only at the top of the Bucovinian Unit, composed of Hăghimaş granitoids of the Bretila terrane) (Săndulescu et al., 1981; Kräutner and Bindea, 2002; Kräutner et al., 1992; Kräutner and Bindea, 1995; Balintoni et al., 2001; Pană et al., 2002; Balintoni and Balica, 2013) (Table 1).

Chiril nappe and Balaj mylonite zone. In the NE part of the Bucovinian unit, below the Rarău nappe, a well-defined rock sequence of unknown age (Chiril Formation) occurs. It was affected by Variscan greenschist-facies metamorphism (biotite-in zone) and is separated from the overlying and underlying metamorphics by mylonitic schist zones. In the south, at the tectonostratigraphic position of the Chiril nappe, only a 100–200 m thick sheet of blasto-mylonites and phyllonites ("Balaj mylonitic zone" with mylonitic linear gneisses) occurs, as delimited by Bindea, 1998, at the boundary between the Putna and Rarău nappes. These zones represent the mylonitised Tulgheș rock sequences.

Table 1. Variscan tectonic units, after Kräutner and Bindea, 1995:

Lithologic units	Variscan Tectonic units	
Bretila- Rarău terrane with Hăghimaş granitoids and Mândra granitoids	1.Rarău Nappe (with scales of Hăghimaş Granitoids)	Rarău N.
Balaj mylonitic schists ("linear gneisses")	2.Balaj unit	
Tulgheş terrane (formationsTg1-Tg4) Baratu sequence (Tg3-Tg4) Bălan sequence (Tg3-Tg4) Sândominic sequence (Tg3-Tg4)	3a. Bălan Nappe 3b. Baratu Mare Nappe 3c. Sândominic Nappe 3a-c previously separated as Putna Nappe	Putna nappe Bălan N. Baratu Mare N. Sândominic N.
Pietrosu Pophyroids	4. Pietrosu Nappe (previously included in the Pietrosu Bistriței Nappe)	Pietrosu N.
Negrișoara terrane	5. Negrişoara Nappe (previously included in the Pietrosu Bistriței Nappe)	Negrişoara N.
Izvorul Mureș mylonitic rocks	6. Izvorul Mureș unit	
Rebra terrane	7. Rodna Nappe	Rodna N.

The pre-Alpine tectonic units within the Infrabucovinian Nappe comprise Bretila Group/terrane rocks and ± Paleozoic Group rocks, which may bear different names. The nappe names depend on the tectonic window in which they are exposed (such as the Valea Vinului Nappe, Stiol Nappe, Anieș Nappe, and Negoiasa Nappe, all from the Rodna half-window, or the unit from the Vaser window in Maramureș (1:50.000 geological map sheets Rodna Veche, Anieș, Pietrosu, and Vodă (2013)). In the front zone of the Bucovinian and Subbucovinian Units, Alpine compression produced structures at various scales (Săndulescu, 2009).

The most important part of EC metamorphism is amphibolite-facies, and the first metamorphism is Ordovician (430 to 470 Ma for schistose granitoid rocks of the Bretila terrane, ca. 490 Ma for the Pietrosu Bistritei porphyroids, ca. 410 to 380 Ma for the Nichitas orthogneiss of the Rebra terrane, and concordia upper intercepts of ca. 485 Ma for the Brezuta metarhyolite in the Tg 3 Formation of the Tulgheș terrane (Pană et al., 2002; Munteanu and Tatu, 2003; Balintoni and Balica, 2013).

The Bucovinian nappe comprises a pre-Alpine metamorphic basement and a T-K1 sedimentary cover (Săndulescu, 1984).

The sedimentary cover consists of the following beds.

- Werfenian conglomerates and quartzitic sandstones
- Campilian grey bedded limestones,
- Upper Campilian-Anisian massive dolomites,
- Ladinian beds with jaspers and white limestones, limestones with *Diplopora annulata*
- Sinemurian-Carixian hematitic oolithic limestones,
- Dogger marly sandy limestones, brown siltstones,
- Callovian-Oxfordian radiolarites and radiolarian siltstones,
- Tithonian-Valanginian with Lunca beds, Aptichus beds, Stejaru flysch in the Vârghiș digitation, Clifele beds in the Tarnița digitation.
- Hauterivian-Lower Barremian with Muncelu conglomerates in the Sadova digitation,

- Upper Barremian-Lower Aptian or Albian, represented by wildflysch formation. Inside this formation, Săndulescu (1967) delimited 2 subunits: the newest is the wildflysch formation of the Bucovinian unit, overthrusted by the Transylvanian Hăghimas nappe, and the other is the Bârnadu conglomerates, which transgressively covers both the Bucovinian Nappe and the Hăghimas Nappe.

In this Bucovinian sedimentary pile, there are three main angular unconformities (Săndulescu, 1975, 1984). The first angular unconformity lies at the base of the Toarcian or Aalenian (upper part of the Lower Jurassic), corresponding to the Outer Dacic/Severin-Civcin rifting. The second angular unconformity occurs at the base of the Lunca beds. The third angular unconformity lies at the base of the Wildflysch formation, or around the upper pre-Barremian. According to Săndulescu (1984), the frontal digitation of the Bucovinian nappe, which contains Bucovinian flysch, could be synchronous with movements related to the mentioned unconformity. The post-Vraconian sedimentary cover of the Bucovinian unit was deposited during the Vraconian-Cenomanian.

The Bucovinian metamorphic rocks comprise distinct lithologic sequences, with Precambrian protoliths preserved in tectonic relationships. They form a pile of Variscan nappes, recognised through detailed lithostratigraphic napping and numerous drill holes. The contacts between these units (see Table 1) are marked by shear zones containing mylonitic schists and phyllonites, the latter being thick mylonitic rocks with proper names.

The Rebra metamorphics consist of three formations (Kräutner, 1980, 1988; Săndulescu, 1981): formation Rb1 - pelitic gneisses; formation Rb2 - carbonate rocks with Mississippi Valley-type base-metal ores, mica schists, amphibolites and quartzites; and formation Rb3 - paragneisses and mica schists with amphiboles. The rocks underwent Barrovian metamorphism under amphibolite-facies PT conditions, reaching the sillimanite isograd in metapelitic rocks (Savul, 1938; Balintoni and Gheuca, 1977). Locally, a superimposed LP/HT metamorphism is evidenced by andalusite and cordierite.

The Negrisoara terrane**,** based on Balintoni and Neacsu (1980), comprises two lithological formations: (a) the Pietrosu Bistritei porphyroids (Savul, 1938), a volcano-sedimentary formation composed of intrusive and extrusive rocks, mainly dacitic (Pietrosu porphyroid), with metapelitic (micaschist) intercalations, which underlies (b) the Pinu Formation (Balintoni, 1997), composed of pelitic gneisses, micaschists, amphibolites, quartzites and carbonate rocks.

The Tulgheș metamorphics are a sequence of four formations (Kräutner and Bindea, 2002) with polymetamorphic evolution: formation Tgl, psammitic (sericite quartzites, sericite-chlorite schists); formation Tg2, graphitic (sericite-chlorite-graphite schists, graphitic metacherts + Mn deposits, carbonate rocks); formation Tg3, volcanic (felsic metavolcanics, + Kuroko-type base-metal ores and sericite-chlorite schists) and formation Tg4 (metagrauwacke, metarilites, metabasites).

The Bretila-Rarău metamorphics represent a leptinite-amphibolite formation and consist of augen-gneisses (migmatites), gneisses, micaschists, granitoids (Rarău granitoids), and amphibolites, reflecting a polymetamorphic evolution (Kräutner, 1988). Kräutner (1988) included the Mândra metagranitoids in the upper part of the Tulgheș sequence, but U-Pb dating by Balintoni et al. (2009) yielded an older age (468 Ma), so the Mândra granitoids were subsequently included in the Bretila-Rarău metamorphic sequence.

Carbonate rocks are absent from this rock sequence. This absence is an important criterion for geotectonic setting parallelisation in the Carpathian orogen.

Ditrău Alkaline Massif (DAM)

The DAM represents a truncated, tilted, ring-shaped Mesozoic alkaline intrusion (e.g. Morogan et al., 2000) with miaskitic character (Jakab, 1998). It has a ~19 km diameter and intruded the pre-Alpine metamorphic rocks of the Bucovinian nappe (Fig. 4).

Honor et al. (2018), based on field observations, considered that the massif initially was a horizontal magma chamber that was subsequently tilted eastward during the Carpathian Cenozoic thrusting, which also folded the Bucovinian nappe (Matenco et al., 2010) and tilted and deformed the Ditrău Massif. The mafic-ultramafic cumulates (the Jolotca hornblendite and Sărmaș gabbro) show deformation banding/foliation dipping broadly eastward, and this part could be interpreted as the original lower zone of the magma chamber.

The DAM lies within the Neogene-Quaternary volcanic arc of the Harghita-Călimani Mts. Andesitic pyroclastics and lava flows from these volcanoes unconformably overlie parts of the DAM. The Ditrău Massif is also covered by lacustrine sedimentary deposits, which separated the volcanic arc from the East Carpathian land mass during the Upper Pliocene and Pleistocene.

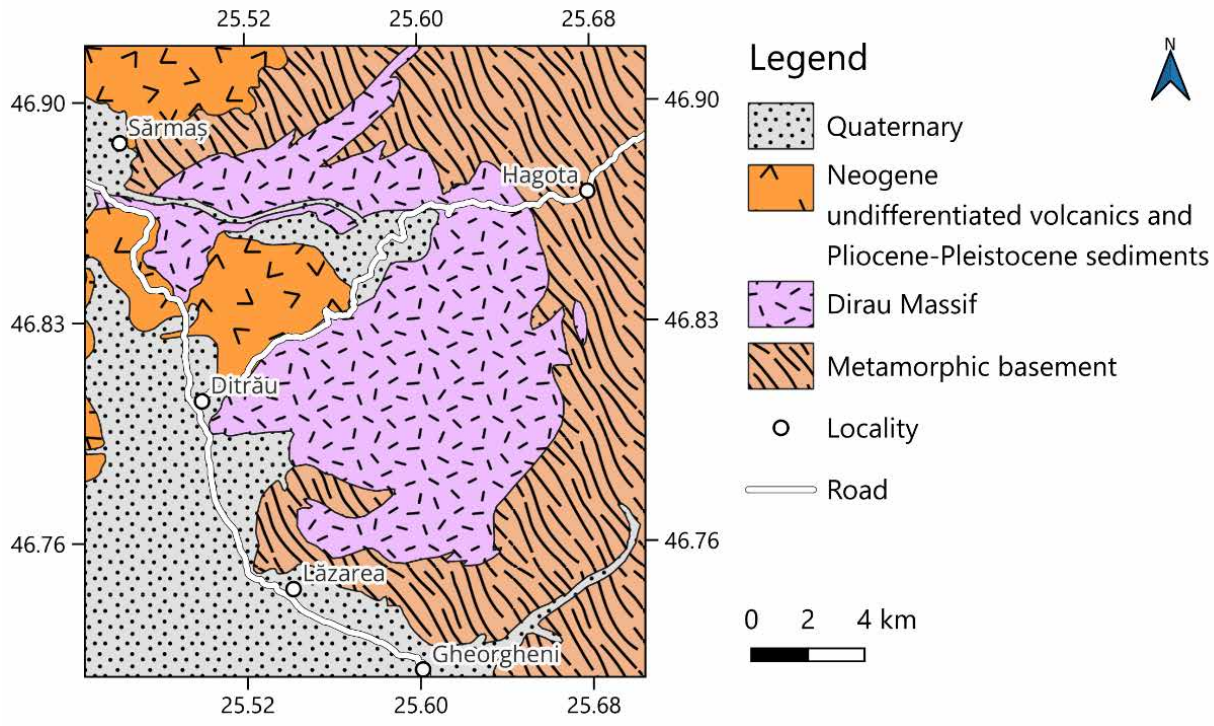


Fig. 4. The simplified geology map of the DAM area (after Alexandrescu, 1968, modified)

Pre-Alpine metamorphic rocks of the Bucovinian Nappe outcrop around the DAM. The DAM thermal contact aureole overprinted the Variscan shear zones within the Bucovinian unit. The first radiometric data suggested a Jurassic emplacement of the Ditrău massif (Streckeisen and Hunziker, 1974), and for this reason Balintoni (1981) and Mureșan (1983) considered the DAM intrusion as proof of Variscan stacking of the nappe structure within the metamorphic basement of Alpine nappes.

The DAM is characterised by a specific lithologic association and a complex internal ring structure: **Jolotca Complex** (pyroxenite, hornblendite, hornblendite-diorite, monzodiorite); **Güdücz Complex** (Ditro-essexite); **Tarna/Tarnița Complex** (alkali granite, syenite-alkalifeldsparic, quartz-bearing, liebneritic nepheline syenite, aplitic syenite); and the youngest **Piricske Complex** (pegmatoid nepheline syenite, nepheline syenite, layered alkali syenite). The petrographic complexity results from a series of ultrabasic to silica-oversaturated and silica-undersaturated alkaline rocks with both massive and oriented textures. There are many concepts and petrologic models for DAM genesis, ranging from alkali metasomatic to magmatic origin, and from emplacement by a single magmatic intrusion to multiple successive intrusions (Streckeisen, 1952; Codarcea et al., 1958; Pal-Molnar, 1994; Kräutner and Bindea, 1995).

A three-stage evolution model of Kräutner and Bindea (1998) is based on radiometric data (K/Ar and Ar/Ar methods), relationships between the main rock and mineral associations observed in the natural field and at the microscopic level. The stages are between 230 and 215 Ma for ultramafic, gabbro and diorites rocks and 160 Ma for the nepheline syenite intrusion (Table 2).

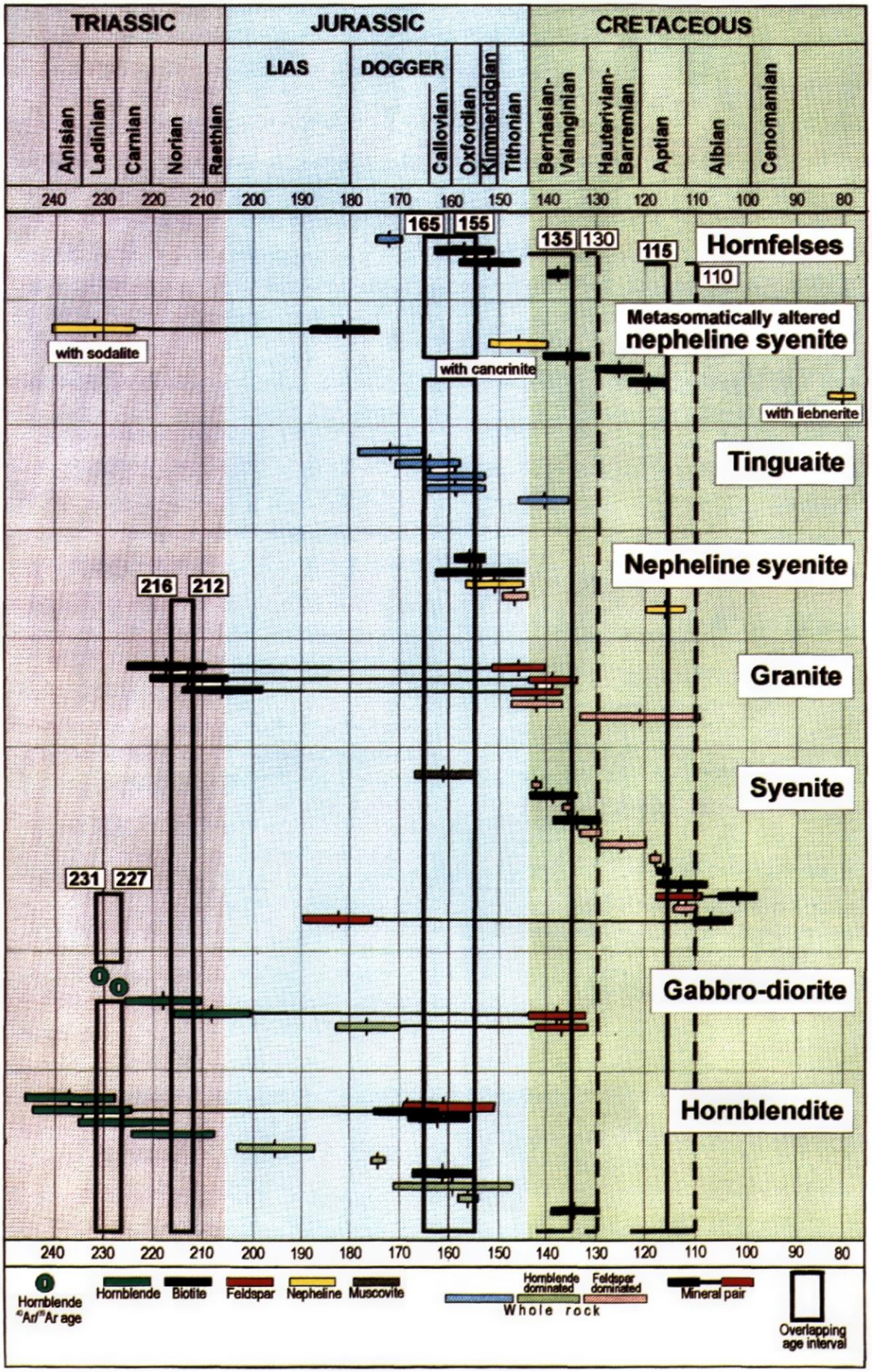
1. The earliest DAM phase (230 Ma) is represented by gabbros and diorites of mantle origin, with xenoliths of olivine pyroxenites, partly or completely altered into hornblendites.

2. During the rise of gabbro-dioritic magmas into the crust (probably at the subsolidus stage, 215 Ma), they were partly mixed and mingled with a crustal syenitic magma. In this dynamic environment, part of the syenitic magma evolved toward both flow-oriented monzonitic components by mixing with the ascending basic rocks and toward granitic melts by assimilating quartz-rich crustal rocks.

3. At a later stage (160 Ma), a nepheline syenitic magma, derived from partial melting of the mantle, intruded the previously mentioned Ditrău rock associations. This resulted in rock veining, hybridisation, and metasomatic alteration of DAM and mafic foid-rocks (ditro-essexite). This occurred in relation to the genesis of the Civcin-Severin rifting and spreading system. A long cooling period followed, lasting up to 135 Ma. During this stage, pegmatitic facies developed locally, and sodalite- and/or cancrinite-bearing nepheline syenites formed. Associated with white nepheline syenites, tinguaites form thin dykes enriched in LREE.

Tinguaite veins cut through the whole structure. Tinguaite dykes (Batki and Pál-Molnár, 2011) occur in the northern part of the DAM and are light grey to greenish grey. Their texture is fine-grained, porphyritic, and hypidiomorphic to xenomorphic. The main rock-forming minerals are andradite-grossular or aluminian sodian ferroan diopside and aegirine-augite phenocrysts, with a groundmass of eckermannite, albite (Ab 98-99), orthoclase and nepheline. Accessory minerals are titanite, zircon and magnetite. Secondary minerals are phlogopite (Mg=0.57–0.76), chlorite, epidote, calcite and sericite. The Ti vs Al ratio of diopsides indicates formation under high pressure, whereas aegirine-augites formed under low pressure (Pál-Molnár et al., 2010). The diopsides are anorogenic and derive from an alkaline magma, as indicated by their Ti+Cr vs Ca and Ti vs Ca+Na ratios, respectively.

Table 2. Radiometric data of DAM rocks and minerals (Kräutner and Bindea, 1998).



The DAM tinguaites are characterised by high concentrations of alkalies, LREE and other incompatible trace elements such as Zr, Nb, Ba, Rb and Sr

Finally, at a cooling stage below 300˚C (115 Ma), a local hydrothermal stage associated with stockwork and vein mineralisation (enriched in rare earth elements (REE), niobium, and molybdenum), alongside hydrothermal liebneritisation and secondary foids (sodalite and cancrinite, pseudomorphosing primary nepheline) from alkali syenite, contributed to the development of the Ditrău Massif. In the SE part of the massif, hydrothermal effects also affected the neighbouring Tulgheș metamorphics (Belcina mining zone).

Honor et al. (2018) studied REE mineralisation at the Jolotca Complex. Their theory was that during fractional crystallisation in the magma chamber, highly evolved nepheline syenites formed. At an early stage within the crystallising melt, the REE behaved compatibly and were preferentially concentrated in titanite and apatite within ultramafic cumulates. During crystallisation in the magma chamber, a Na-rich hydrothermal system developed, which affected the nepheline syenites, pseudomorphosing nepheline by cancrinite and sodalite. Subsequently, mafic dykes provided conduits for the upward migration of late-stage K-rich fluids, which leached REE and HFSE from the Güdücz nepheline syenite. These fluids accumulated in the roof zone of the complex, where they were trapped, causing the alteration (liebneritisation) of nepheline and the crystallisation of hydrothermal minerals, such as pyrochlore. The roof zone rocks (Jolotca Complex) do not present important REE mineralisation. The REE mineralisation is hosted in carbonate-rich veins that crosscut the Jolotca Complex and the massif"s SE border zone in Bucovinian Tulgheș schists (Belcina mining district).

During the Mid Cretaceous compressional stage, the DAM was involved in the Alpine nappe system (the Bucovinian nappe detachment plane cut the DAM at a depth of about 1800 m – Bindea, 2010). Its shear zone was overprinted by ductile deformation and uplifted by tectonic transport.

Neogene volcanic arc zone

In the Carpathian-Pannonian region, Neogene magmatism, driven by subduction, rollback, collision and extension, has calc-alkaline and alkaline characteristics. Based on the spatial distribution of magmatic activity, four segments can be defined (Seghedi et al., 2004): Western Segment (magmatism occurring on the Alcapa block), Central Segment (magmatism occurring on both the Alcapa and Tisia blocks), South-Eastern Segment and Interior Segment (both on the Tisia block) (Fig. 5).

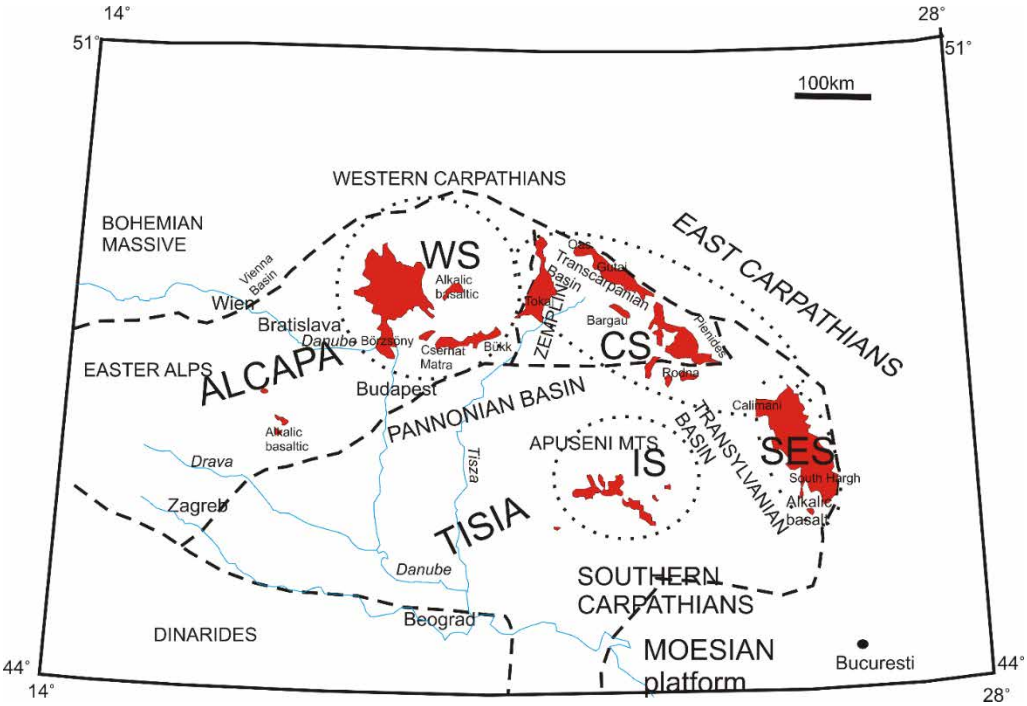


Fig. 5. Neogene magmatic rocks distribution (Seghedi et al., 2004, modified)

1. Western Segment - in the area of the West Carpathians and the Pannonian Basin (North Hungary and Central Slovakia). Here, calc-alkaline volcanism occurred between around 20 and 11 Ma, with large volumes of acidic and intermediate rocks distributed randomly within the orogenic belt. Alkaline basaltic volcanism followed between 11 and 0.5 Ma, after the calc-alkaline magmatism;

2. Central Segment (area between Tokaj-Slanske´ –Vihorlat and the Călimani Mountains), where calc-alkaline acidic and intermediate volcanic activity occurred around 15–8 Ma ago. Alkalic magmatism was absent from this area;

3. South-Eastern Segment (area of Călimani–Gurghiu–Harghita Mountains) with mainly intermediate calc-alkaline rocks. This magmatism ranges from 10 to < 1 Ma, migrating southeastward and progressively waning. Alkalic basaltic and shoshonitic volcanism occurred at 1.5–0.5 Ma and was partly synchronous with the end of calc-alkaline volcanic activity;

4. Interior Segment in the Apuseni Mountains. Volcanic activity was mainly intermediate and occurred between 15 and 8 Ma. In this area, alkalic basaltic and shoshonitic volcanism post-dated the calc-alkaline magmatism (2.5–1.5 Ma).

Calc-alkaline magmatism in the region resulted mainly from melting of a heterogeneous asthenospheric mantle source, modified by the addition of fluids and sediment. Assimilation and fractionation at shallow crustal levels were observed in most segments, strongly masking deeper source processes. In the Interior Segment, evolution from typical calc-alkaline magmas to adakite-like ones (resulting from fluid-dominated lithospheric melting) was linked to extension driven by rapid rotations and transtensional tectonics during collision. Alkalic basaltic volcanism with an OIB-like asthenospheric source followed the calc-alkaline stage, as in the Western Segment, or was synchronous with it (in the South-Eastern and Interior Segments), mainly in response to local extensional tectonics.

The field trip presents a cross-section through the Eastern Carpathian Mountains, revealing the Neogene Magmatic Arc, Median Dacides, Transylvanides, Ditrău Alkaline Massif and the Outer Dacides (Figs. 6 and 7).

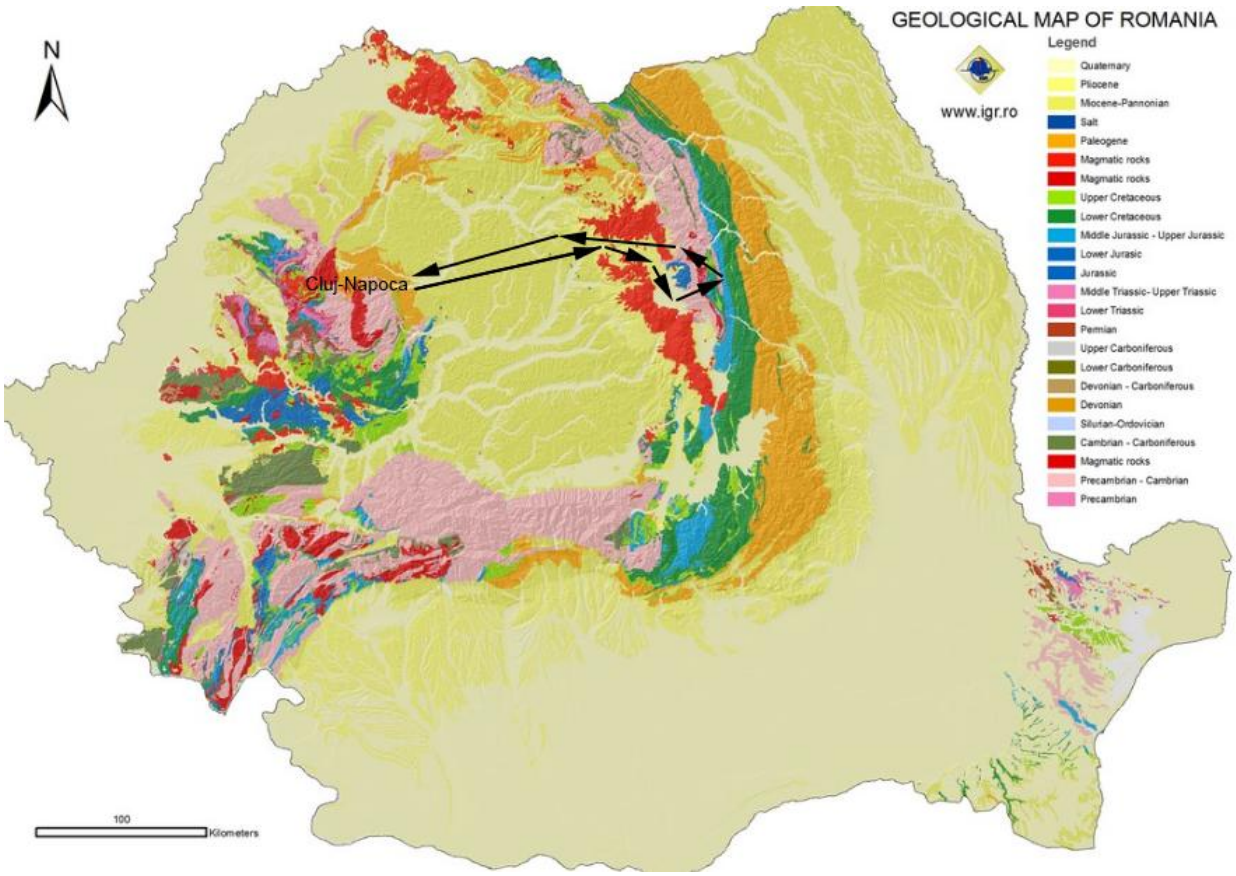


Fig. 6. Simplified route of the FT11 field trip, with departure and arrival in Cluj-Napoca and the area of interest in the Eastern Carpathians.

Day 1 (Sept. 6, 2026)

Cluj Napoca - Reghin- Deda-Răstolița- Sălard-Toplița-Sărmaş- Jolotca mining waste damp- Ditrău (on Ditrău – Hagota road-) -Gheorgheni (accomodation)

Departure at 8:00 o'clock from Cluj Napoca (University Babeş-Bolyai - central building' parking, with minibus) up to Gheorgheni (210km) the field trip route passes through the Neogene sedimentary sequences of the Transylvanian basin and from Răstolița up to Ditrău (57km), the route passes through the Neogene volcanic chain of the Eastern Carpathians, an interfingering between the Călimani and Gurghiu Mts. with medial-facies volcanoclastics, along the Mureș Valley.

The field trip route continues into Ditrău town and then heads upstream the Jolotca Valley towards the Jolotca Complex, with rocks belonging to the Ditrău Alkaline Massif (DAM) of Triassic-Cretaceous age. The route then continues for about 30 km along the Ditrău-Hagota road, passing other outcrops of the DAM (Fig. 8), which intruded the metamorphic rocks of the Bucovinian unit of the Median Dacides (Fig. 9). The Median Dacides tectonic structure formed during the Austrian compressional phase as a duplex, composed of the Bucovinian, Sub-Bucovinian and Infra-Bucovinian units. The DAM intrusions created thermal contact and metasomatic (alkali feldspar) haloes in Rebra and Tulgheș terrane rocks from the Bucovinian unit. The Bucovinian and Sub-Bucovinian units include Variscan tectonic nappes containing metamorphics such as Rebra-, Negrişoara-, Tulgheș-, Bretila-Rarău terrane rocks. The Infra-Bucovinian units contain only Bretila terrane and/or "Paleozoic groups" – such as Rusaia, Repedea, Cimpoiasa - rocks.

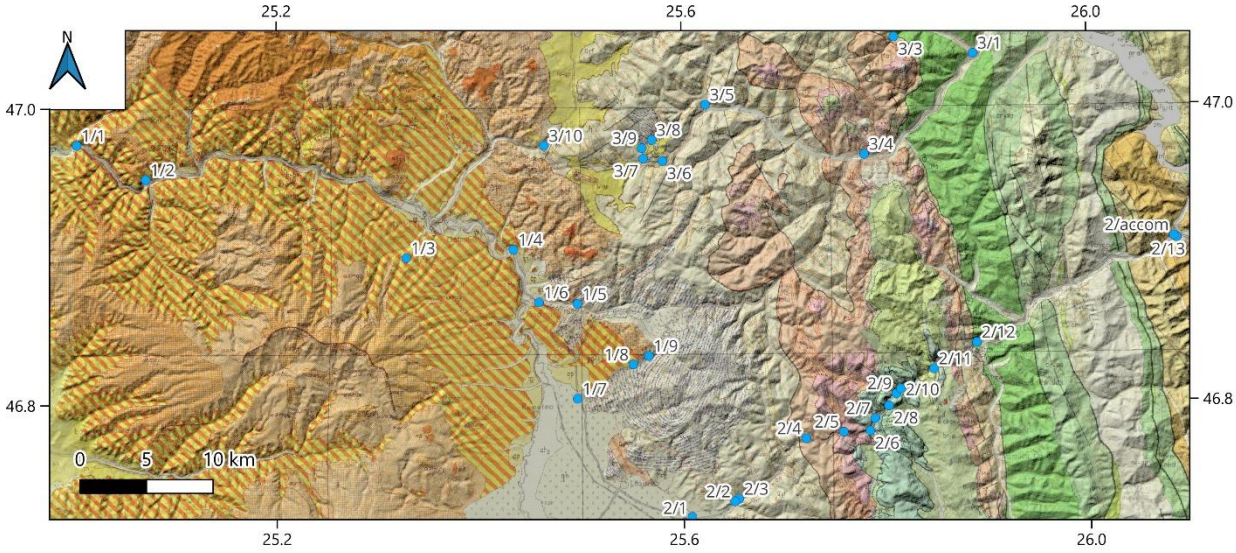


Fig. 7. Detailed track of the FT11 field trip superposed on the Romanian geologic map showing the stops of the Day 1 (1/1 to 1/9), of the Day2 (2/1 to 2/12), and the Day 3 (3/1 to 3/10). 1/accom- accommodation in Gheorgheni, 2/accom= accommodation on Bicaz area hostels.

Along the Ditrău-Hagota road, the DAM includes hornblendites, red syenite, nepheline-syenite with aegirine, and secondary foids such as sodalite and cancrinite, as well as granites and monzonites. Complex relationships among these rock types indicate magma mingling, mixing, and assimilation of crustal xenoliths. The western part of the DAM is unconformably overlain by Neogene andesitic pyroclastics, with some interbedded basalt-andesite lava flows from the Gurghiu-Călimani volcanoes.

In the centre of Gheorgheni, the participants will visit the Tarisznyás Márton Museum, which contains petrographical and palaeontological collections donated by the geologist Dr. Jakab Gyula.

Accommodation and dinner will be in downtown Gheorgheni, an important tourist, historical and ethnographic centre of Harghita county.

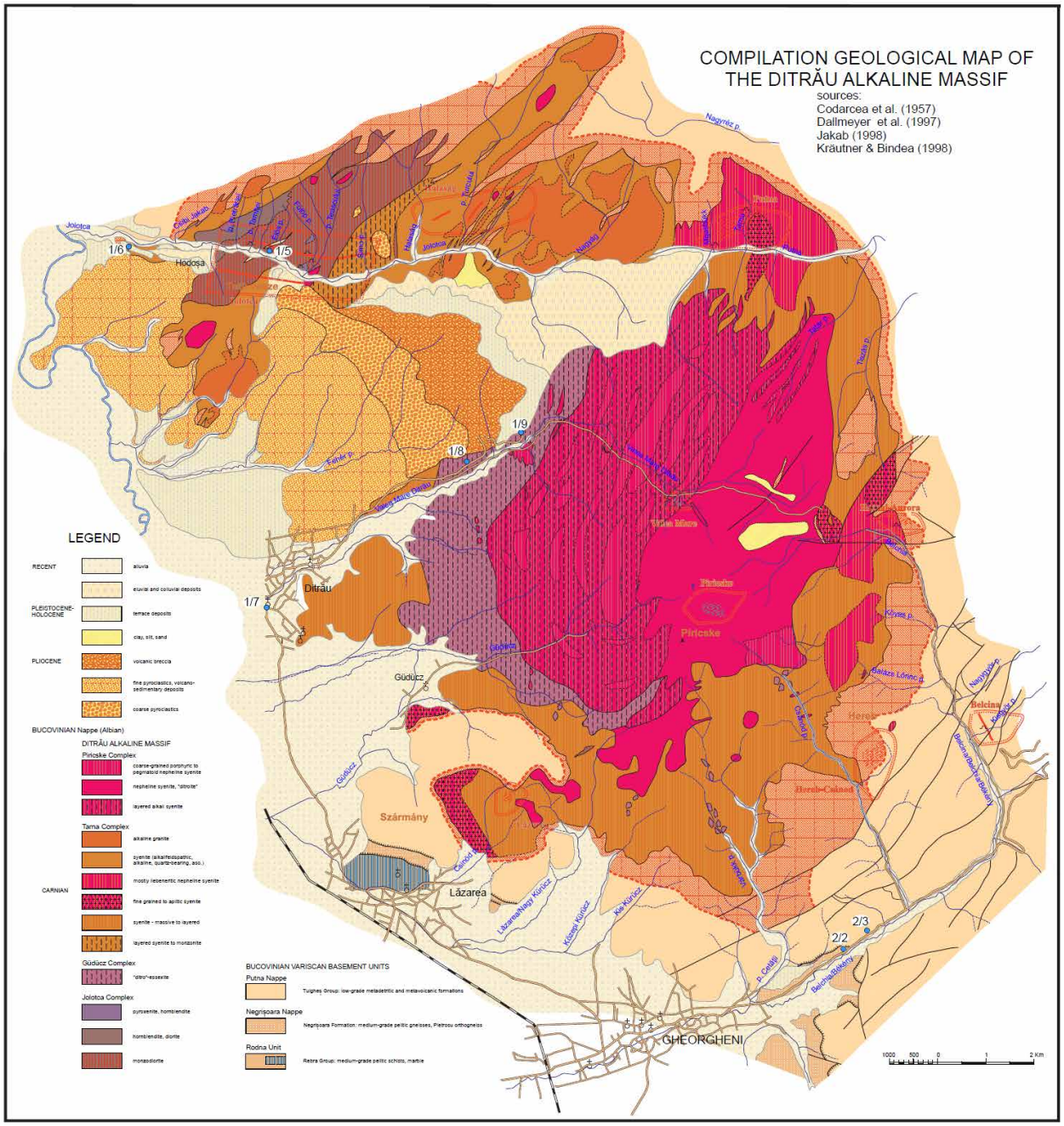


Fig. 8. Geological map of the Ditrau Alkaline Massif (Sabău and Negulescu, 2015).

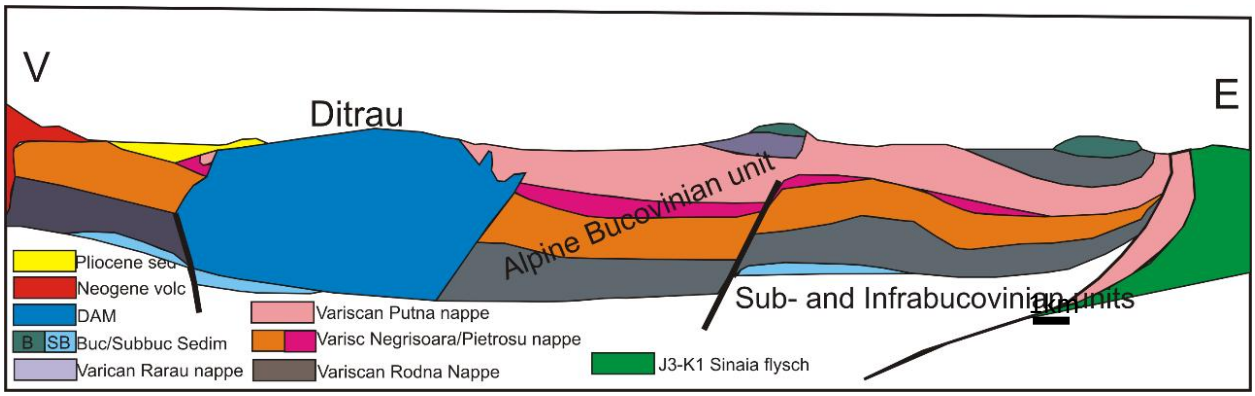


Fig. 9. Schematic geological profile through the Central Eastern Carpathians. Ditrău Masssif is intruded in the Alpine Bucovinian Nappe and cuts therein the Variscan nappe structure (after Kräutner and Bindea, 1998, modified)

Description of stops on the 1st. day

Between Deda and Toplița, along the Mureș Valley, we can see: Interfingering Călimani and Gurghiu Mts. medial-facies volcaniclastics (Fig 10).

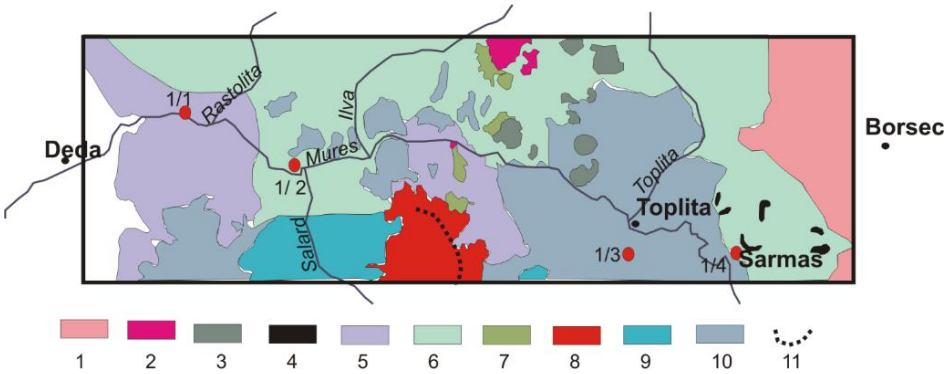


Fig. 10. Geological map of the Călimani and northern part of Gurghiu Mountains (after Seghedi et al., 2005): 1-Prevolcanic basement (Tulgheș schists), 2-Prevolcanic intrusions, 3-Drăgoiasa formation (dacite, rhyolite), 4-Sărmaş basalt lavas, 5- Rusca-Tihu debris avalanche, 6- Rusca-Tihu volcanoclastic formation (andesite, basalt-andesite), 7-Peripheral domes (andesite, dacite), 8- Jirca volcano (andesite, diorite), 9- Fâncel-Lăpuşna pre-caldera rocks (volcanoclastics, lavas), 10- Fâncel-Lăpuşna volcanoclastic formation (andesite, dacite), 11- crater rim.

Stop 1/1. Răstolița: parking (Lat./Long.: N46.97544, E25.00279)

Here is a debris avalanche of the Rusca-Tihu volcano. A thick sequence of post-debris-avalanche Rusca-Tihu formation volcaniclastics. This is a 300 m-wide outcrop with thick, heterogeneous volcanic breccia, debris avalanche of chaotic arrangement (variable clast-to-matrix ratio, matrix colour from greyish white, rust-coloured to pinkish, and stratification position varies in both vertical and horizontal planes). In the upper part of the outcrop, the debris avalanche grades into debris flow (Photo 1/1).



Photo 1/1. In the upper part of the outcrop, the debris avalanche grades into debris flow.

Stop 1/2. Sălard - parking (Lat./Long.: N46.95231, E25.07093)

This is an outcrop of block-and-ash flow deposits similar to those of the Merapi (Indonesia) volcano**.** Thick sequence of Rusca-Tihu basaltic andesite block-and-ash-flow (pyroclastic flow originates from lava dome collapse) deposits of the Rusca-Tihu Formation (Photos 1/2A, B, C, and D).



Photo 1/2A. Block-and-ash flow deposits of Rusca-Tihu formation (pyroxene basaltic andesite composition)



Photo 1/2B. Graded granulometry of pyroclastics. Polygonal blocks



Photo 1/2C. "Sintering" at high temperature between smaller and bigger pyroclastic clasts.



Photo 1/2D. Radial cooling fissures in polygonal clasts.

Over 50 m high rock cliffs in the extremely steep northern valley-side expose a thick sequence of metres-thick depositional units of medium- to coarse-grained monomictic matrix-supported breccias, frequently with undulated erosional basal contacts and finer tops. Almost all lithic blocks are dark-coloured basaltic andesites, many of them pyroxene-phyric, a characteristic feature of the Rusca-Tihu volcano products. In the interior of many of the depositional units, the lithic clasts and the matrix are sintered together, lending the deposit a hard-rock appearance. The units frequently show rough normal grading of the lithic clasts.

Several depositional units host mostly sub-horizontal, metres-long, decimetre-diameter tree-log holes (named "tree-caves" by speleologists). The sequence is interpreted as a succession of block-and-ash-flow deposits of the Rusca-Tihu Formation, generated by post-edifice (i.e. post-debris-avalanche) activity of the Rusca-Tihu volcano in the Călimani Mts.

The pyroclastic flow clasts are monolithological, meaning pyroxene basaltic andesite clasts with the same matrix composition. Around 20 flow units may be identified, with graded granulometry, discordant boundaries and sintering processes.

Stop 1/3. Toplița, parking place at Toplița ski resort area (Lat./Long.: N46.89924, E25.32781)

We can see the Călimani caldera with peripheral domes, such as the dacitic Pietricelu dome. In the foreground, pyroclastic flow deposits of the Fâncel-Lăpuşna volcano. A large number of volcanic features from both the Călimani and Gurghiu Mts. are visible from this point. These include the remnants of the collapsed Rusca-Tihu volcano and the Călimani caldera rim, with the Pietricelul dome in the background; peripheral domes and the Sărmaş basalt occurrence area in the middle ground; and Fâncel-Lăpuşna caldera-forming eruption products and their landforms in the foreground. A brief introduction to the volcanic history of the Călimani Mts. and the northern Gurghiu Mts. volcanoes will be presented – based on information published in Seghedi et al. (2005). Features related to medial facies interfingering of Călimani and Gurghiu volcanic products will be illustrated and explained – based on information published in Szakács and Seghedi (1996). Panoramic view on the Călimani Mts. from the Toplița ski resort area (Lat./Long.: N46.90147, E25.32849) (optional).

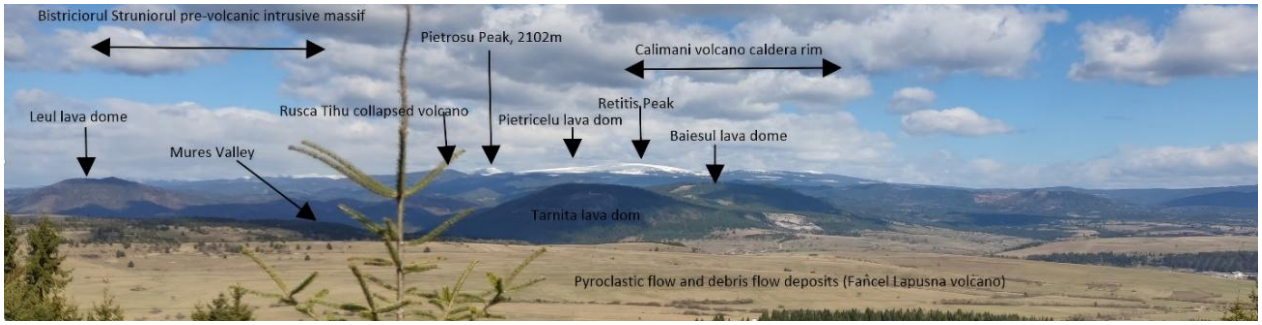


Photo 1/3. Panoramic view on the Călimani Mts. from the Toplița ski resort area

Stop 1/4. Sărmaş, Nearest parking place (Lat./Long.: N46.90448, E25.43338).

Unique Ca-alkaline basalts alongside the Rusca-Tihu Formation and the Fâncel-Lăpuşna Formation within the Neogene volcanic chain (Photo 1/4).



Photo 1/4. Contact between the Sărmaş basalt and the overlying debris-flow deposits, which mainly contain basaltic andesite lithoclasts derived from the Rusca-Tihu volcano.

An abandoned roadside quarry east of the Gălauţaş locality exposes lavas of the subalkaline Sărmaş basalts. The Sărmaş basalts are the most mafic rocks, apart from some Rusca-Tihu volcano products, and belong to a small, shield-like effusive volcano in the earliest stages (8.3-8.5 Ma K-Ar age, Seghedi et al., 2005) of the evolution of the Călimani Mts. volcanism, the only monogenetic basaltic edifice in the whole Călimani-Gurghiu-Harghita range. Its products are largely covered by later volcaniclastic deposits, specifically post-debris-avalanche Calimani volcaniclastic deposits. Sărmaş basalt appears as aphyric, dark-grey rocks, massive to slightly porous in the lower part, and auto-brecciated and clinker towards the top.

A roughly 300-meter-long roadside outcrop west of the quarry exposes the contact between the Sărmaş basalt and overlying debris-flow deposits mainly composed of basaltic andesite lithoclasts from the Rusca-Tihu volcano. Downstream, this succession continues with polymictic debris flow deposits that overlay monomictic basaltic andesite debris flows. The sequence's polymictic nature is evidenced by a gradual transition from a bottom rich in basaltic andesite lithoclasts to a top abundant in amphibole andesite lithoclasts sourced from the Fâncel-Lăpuşna volcano, all embedded within a fine volcaniclastic matrix. These mixed-clast deposits gradually give way to a thick sequence of amphibole andesite volcaniclastics, mostly of epiclastic origin, including coarser, non-bedded debris flows and finer laminated fluvial deposits with pumice clasts, locally forming lenticular bodies. Polymictic conglomeratic epiclastics are prevalent in the upper sections. We interpret this sequence as part of the Fâncel-Lăpuşna Formation (Szakács and Seghedi, 1996), formed during and shortly after the caldera eruption of the Fâncel-Lăpuşna volcano. It overlies the Rusca-Tihu volcaniclastic deposits (Szakács and Seghedi, 1996), which in turn overlie the Sărmaş basalts.

Stop 1/5. Jolotca Valley (Lat./Long.: N46.86770, E25.49615)

On the way to Gheorgheni, we leave the main road and take an approximately 4 km-long unpaved road to an abandoned, partially rehabilitated mining waste dump and to outcrops of the Jolotca Complex (monzodiorite and hornblendite) (Fig. 8 and photos 1/5A and B). This is the "Jolotca Complex" of the Ditrău Alkaline Massif, which was previously exploited in the Jolotca mining area. The old Jolotca mining region lies in the northern part of the Ditrău massif, along Jolotca Creek. According to Morogan et al. (2000), the area exhibits an asymmetrical structure: alkali gabbro and alkali diorite occur mainly in the west, whereas quartz syenites, syenites, and alkali granites dominate the east. West of Jolotca shows heterogeneity, with complex mingling of alkali gabbro and diorite with quartz syenite. Mafic rock bodies of various sizes, with irregular margins, are embedded in and veined by felsic rocks, forming net-like intrusions. These mafic lenses appear to have been injected as melts into syenitic magma, which then underwent compaction, deforming the original lens-like bodies during a sub-solidus stage of magmatic consolidation. As the salic-to-mafic component ratio increased, these mixed rocks transitioned into quartz syenite and granite. Within this zone, small ultramafic bodies, such as kaersutite peridotite, olivine pyroxenite, and hornblendite, occur. Olivine-free ultramafic rocks, up to hundreds of metres in diameter, form lenticular masses within the alkali gabbros and diorites of the Jolotca Complex. Anastasiu and Constantinescu (1979) described dioritic rocks forming stratiform and schlieric bodies and nests, with a variety of textures ranging from "pegmatoid" to micrograined, flow-oriented, and non-oriented. Based on the colour index (M), they classified rocks as leucodiorites (M<25%) and diorites (M=25–50%). Pál-Molnár (2000) categorised these rocks as: a) Meladiorites, including textured varieties; b) Diorites, with oriented or non-oriented textures, feldspar schlieren, or feldspar aggregates; c) Leucodiorites, with oriented or non-oriented textures. Diorites with oriented textures, termed "gneissic diorites" by Ianovici et al. (1968), are predominant. According to Streckeisen and Hunziker (1974), the main minerals are plagioclase and amphibole, with accessories such as biotite, various pyroxenes, K-feldspar, and sometimes nepheline. Occasionally, white nepheline syenite grades into red hydrothermally altered rocks, called red syenites,

where nepheline has been replaced by micaceous aggregates ("liebenerite"), mafic phases by chlorite, and feldspars have been hematitised.

Hydrothermal mineralisation in the older Tarnica quarry comprises sulfides (including gold-bearing pyrite, sphalerite, galena, molybdenite), oxides (ilmenite, magnetite), xenotime, parisite, and bastnäsite, hosted in gangue minerals such as carbonates, feldspars, and apatite. Jakab and Garbașevschi (1977) identified key elements such as Cu, Pb, Zn, Ni, and Co as potentially economically important. Hydrothermal carbonate veins, up to 1 m wide and dipping at 60°N, together with polymetallic ores, occur in the Jolotca Complex, which also hosts REE mineralisation. The mineralogy includes LREE-phosphates, LREE-silicates (notably zoned black garnets), and LREE-carbonates, often associated with pyrite, molybdenite, and Ta- and Nb-bearing phases (Hirtopanu et al., 2013; Săbău, 2009). In the southeast, another vein-hosted deposit, Belcina, occurs in Tulgheș schists, with mineralisation similar to Jolotca, including Y-phosphates, Th-silicates, zircon, minor sulfides, and Ta- and Nb-bearing phases within a carbonate gangue (Hîrtopanu et al., 2013). These veins were explored in the 20th century through five deep cores (about 1400 m) and numerous historic adits with waste dumps, though most are now inaccessible. Much of the drill core has been lost or remains under government control, with limited samples available at the Gheorgheni geological museum.

The earliest data on mineralisation come from Ianovici (1933, 1938), who describes sphalerite, galenite, pyrite, chalcopyrite and goethite in the Jolotca area. Other minerals identified in the area include Y-allanite, pyrochlore, baddeleyite, rhönite, xenotime and molybdenite. According to Constantinescu and Anastasiu (2004), the main rock-forming minerals are: a) salic minerals: orthoclase, microcline, albite, oligoclase, andesine, nepheline, cancrinite, sodalite, very rare quartz; b) femic minerals: ferrohornblende, biotite, Ti-augite, diopsidic augite, rare olivine; c) accessory minerals: apatite, titanite, ilmenite, allanite-(Y), epidote, etc.



Photo 1/5A. This is an old mining area, resulting from the exploitation of the Jolotca Complex mineralised veins (ilmenite, REE, Nb-Ta minerals, molybdenite).

The mineralisation consists of oxides, sulphides, carbonates, phosphates and subordinate silicates and native elements, i.e. bismuthinite, isocubanite, joséite, mackinawite, valleriite, tetradymite, native silver, anatase, brookite, Mn-rich ilmenite, pseudobrookite.



Photo 1/5B. Outcrop images: a and b- gabbro xenoliths and mafic clots can be observed in the Ne-syenite melt, c - magma mingling, d-hydrothermal epidote veins cut the gabbro and ultrabasic xenolith, e-outcrop with quartz-syenite

The previously mentioned mineralisation genesis, which took place during the main (pneumatolitic and hydrothermal) stages, indicates a sequential formation. This is evidenced by several mineral generations and by important discontinuities marked by brecciation intervals. The REE mineralisation (Nb-Th minerals) can be considered genetically linked to the alkaline rocks (Honor et al., 2018), with mineralogical and geochemical data showing a common geochemical trend for OIB settings of the REE, Ca and Nb with Th. Mineralogical heterogeneity and petrochemical incompatibilities – the presence of silica-oversaturated rocks (granitoids) beside the undersaturated ones (foid syenites) – indicate two deep magmatic sources.

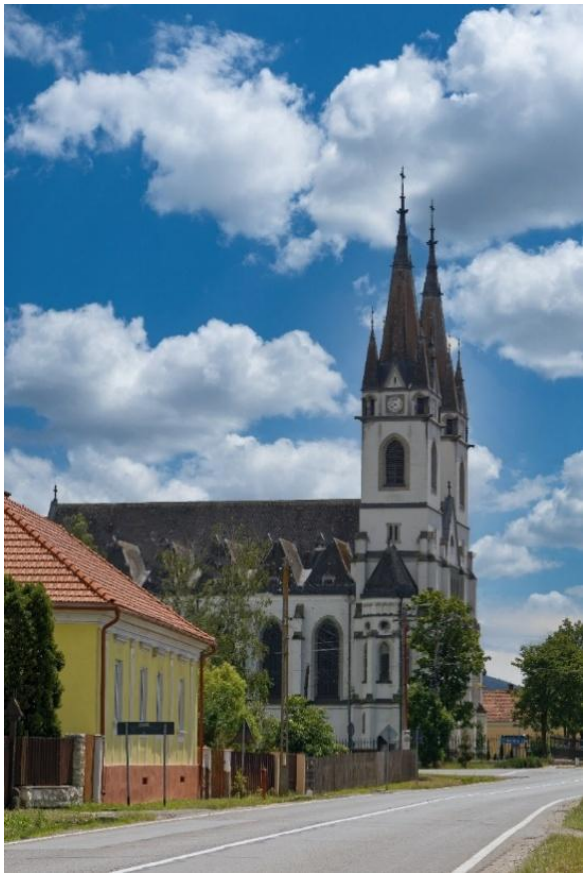
Stop 1/6. Pietrosu Bistritei porphyroid (Lat./Long.: N46.86886E25.45837)

Along the Toplita-Gheorgheni road, at this location, a faulted Pietrosu Bistritei porphyroid is exposed. The porphyroid exhibits a mylonitic extension crenulation foliation. The rock's main mineral composition comprises porphyroclasts/porphyroblasts of greyish-blue quartz (with a few wt% Ti), feldspars, and chloritised dark micas within a fine-grained, oriented matrix. (Photo 1/6, outcrop and sample)



Photo 1/6. Pietrosul Porphyroid outcrop and closer detail of the rock.

Between the Tulgheş and Rebra metamorphics, the Pietrosul Porphyroids (metadacites and metaporphyric granodiorites with metamorphic biotite in their matrix) occur as tectonic lenses, with lengths ranging from a few metres to more than 50 km. They are strongly overprinted by Variscan and Alpine greenschist-facies mylonitisation. Unaffected rocks were preserved only in the central parts of the thickest lenses.



Stop 1/7. Ditrău Romano-Catholic Church (Lat./Long.: N46.803705, E25.495909)

Ditrău (in Hungarian, Ditró) is a locality dating back to the 15th century. It is the region's largest Neo-Gothic Roman Catholic church (73 m high) with two towers. It was consecrated in 1913 by Count Mailáth Gusztáv Károly, the Bishop of Transylvania. (Lunch time)

Photo 1/7. Ditrău Romano-Catholic Church.

Stop 1/8. DAM rocks along Ditrău-Hagota- Tulgheș road (Lat./Long.: N46.82666, E25.55088)

Outcrop of the Güdücz Complex (Photo 1/8) with Ditro essexite (a hybrid zone showing evidence of magma mingling). Dark-coloured diorites and white syenite interpenetrated and overprinted by a banded foliation during a tectonic event.



Photo 1/8. Fine foliated Güdücz Complex rocks

Stop 1/9. Güdücz Complex, hybrid rocks (Lat./Long.: N46.83223, E25.56629)

The outcrop contains nepheline syenite veins and dykes (of two or more generations) within dark alkaline gabbro (Photos 1/9A and B). Honor et al. (2018) considered that the extensive evidence of hybridisation in the central part of the magma chamber (gabbro hybrids) indicates that more highly evolved magmas mixed and mingled with the mafic crystal mush. The Güdücz nepheline syenite represents the most highly evolved magmas in the upper part of the chamber. Along the Ditrău –Tulgheș road, where Güdücz Complex rocks outcrop, the gabbros and gabbro hybrids are strongly plastically deformed, exhibiting near-mylonitic textures.



Photo 1/9A. Outcrop of Güdücz Complex. Alkaline gabbros and nepheline syenite veins, resulting hybrid rocks, named Ditro essexite. Mafic parts were intensively altered to biotite.

Relatively undeformed syenitic veins cut across this deformation fabric. The high-temperature deformation within this outcrop most likely indicates a zone of active shearing within the magma mush, which has since been reactivated by faulting. Brittle faults and fractures are common throughout the complex.

The outcropping rocks are part of the Güdücz complex (Kräutner and Bindea, 1998), which consists of hybrid alkaline gabbro, diorite and monzonite, metasomatised by the intrusion of nepheline syenites. Streckeisen (1952, 1954, 1960) used the general term "Ditro-essexites" for these rocks.

Based on Streckeisen and Hunziker (1974), these rocks are commonly foliated/schistose and intermingled with bands/veins of massive, sometimes pegmatoid syenite and nepheline syenite. We interpret the rocks' schistosity as also generated by plastic deformation in the deep shear zone, during or after emplacement in the crust. Streckeisen (1960) proposed the term "Ditroessexites" for the heterogeneous rock masses, including gabbros, diorites, monzodiorites and monzosyenites. Morogan et al. (2000) subdivided these "Ditro-essexites" into alkali gabbro, alkali diorite, monzodiorite and monzosyenite. The same authors classified the alkali gabbros into two subgroups. The first comprises coarse-grained alkali gabbros (crystals up to 5 mm), typically with an equigranular or subophitic structure. The main minerals are: amphibole (kaersutite and/or Ti-rich ferroan pargasite), plagioclase (An60–23%), titanite and apatite. Titanite is frequently (> 20 % of rock mass), forming crystals up to 1 cm, together with accessory minerals such as ilmenite, magnetite and zircon. The second subgroup is alkali gabbro II, occurring mainly in the Jolotca area, where it forms lenses/veins in quartz syenites. It is finer-grained (1 ± 0.3 mm or even < 1 mm grain-size) than alkali gabbro I. It frequently exhibits a fluidal texture and sometimes contains dendritic amphibole (magnesiohastingsite) intergrown with apatite, titanite, biotite and plagioclase. The Ditrău rocks could assimilate xenoliths of white and black quartzite and crenulated schists from the Tulgheș terrain.



Photo 1/9B. Güdücz Complex, hybrid rocks: a - ultramafic xenolith in the alkaline gabbro, b - Tulgheș schist xenolith in the alkaline gabbro, both cut by nepheline syenite veins.

Day 2 (Sept. 7, 2026)
Gheorgheni Museum - Red Lake - Bicaz Gorge - Bicaz village (accommodation)

On this day, after visiting the museum, we will follow a transect from Gheorgheni to Bicaz, passing through the internal units of the Eastern Carpathians (Median Dacides) and the Eastern Transylvanides, and through the contact zone of the Jurassic-Cretaceous Civcin-Severin Ocean (Alpine Tethys), with relics preserved within the geological units of the External Dacides (Săndulescu, 1988, 1988a) (Figs. 7, 11).

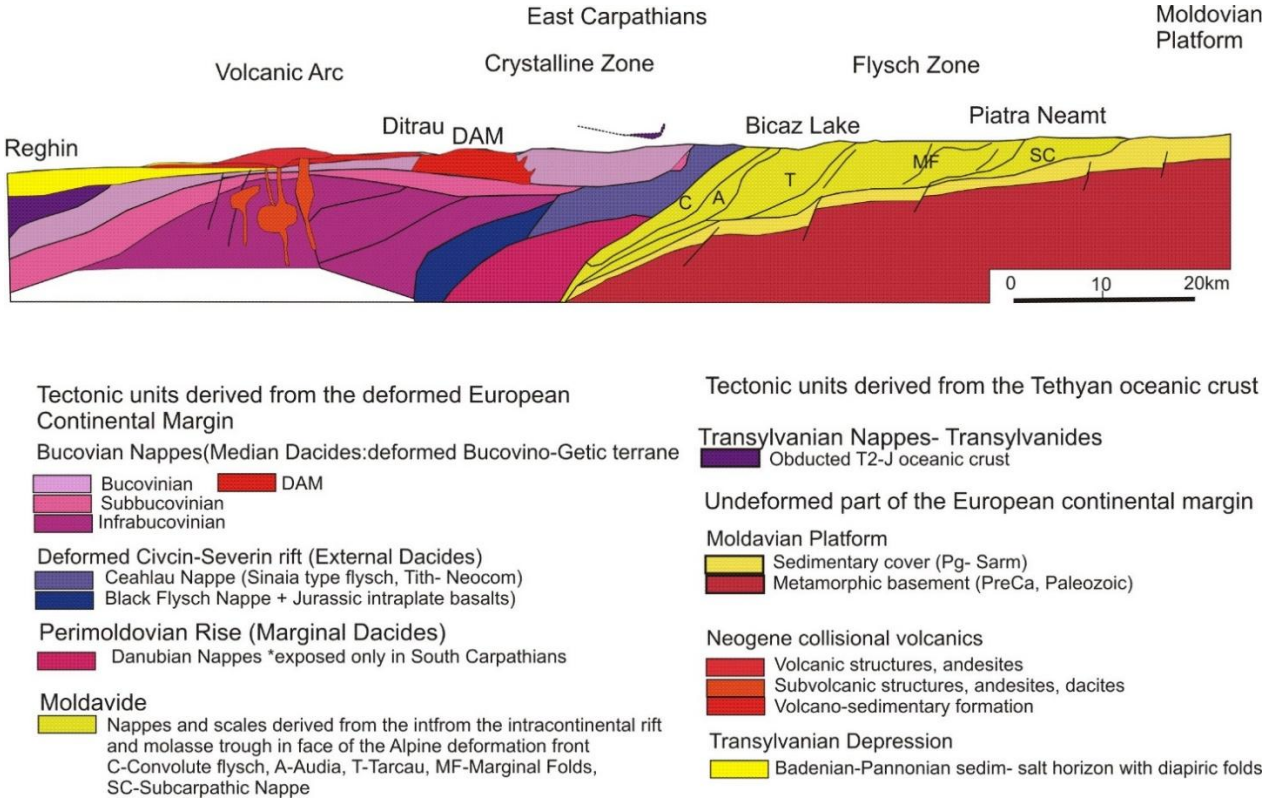


Fig. 11. V-E geologic profile through East Carpathians between Reghin – Piatra Neamț (after Săndulescu, 2004, modified)

The road from Gheorgheni to Bicaz begins in the Belcina Valley, passes through the Bucovinian Alpine Nappe of the Middle Dacides, comprising metamorphic basement rocks (Pietrosu porphyroid and Negrişoara terrane schists, overthrust during the Variscan tectonic phase by Tulgheș terrane schists and Bretila-Rarău terrane gneisses) and a Triassic-Cretaceous sedimentary cover of Bucovinian facies, the latter overthrust by one of the Laramian East Transylvanian obduction nappes (Hăghimaş/Hăşmaş nappe) of Meliata ocean origin, and continues eastward into the External Dacides contact at Bicaz Chei (Bicaz Gorge).

Around the Lacul Roșu (Red Lake), a natural dam lake, there are numerous outcrops of the sedimentary cover units of the Bucovinian and Transylvanian Hășmaș Nappes.

Downstream of Lacul Roșu, the Bicaz Gorge lies within the Hășmaș Nappe and the Bârnadu Conglomerates, the latter unconformably overlying both the Hășmaș Nappe and the youngest sedimentary deposits of the Bucovinian Nappe cover unit. On the eastern edge of the Bicaz Gorge, the road passes through a Sub-Bucovinian tectonic scale (sheared and dragged along a tectonic plane at Gura Dămucului), which is exposed in front of the Bucovinian Nappe. A relatively thin sedimentary succession of Middle Triassic to Lower Cretaceous deposits is exposed.

Further from Bicaz village, the road cuts through the entire Flysch Zone, a cover nappe system (Ceahlău Nappe with Tithonic-Neocomian Sinaia-type flysch) belonging to the Civcin-Severin Ocean (External Dacides).

Stop 2/1. Tarisznyás Márton Museum (Lat./Long.: N46.723458, E25.607822)

The Tarisznyás Márton Museum building (Rákóczi Ferenc Street, 1) was constructed between 1770 and 1778 in the Baroque style. It is one of the oldest civil houses (Photo 2/1). The museum is named after its founder, Tarisznyás Márton (1927-1980), a historian, museographer and ethnographer who mapped the traditional folk world of the Gheorgheni area. The museum hosts three permanent exhibitions. The first is divided into two categories: the Szekler-Hungarian and Armenian folk costumes from the Gheorgheni area, along with the folk costumes of the Csangos, the Romanians from Voşlobeni, and the Gypsies from Gheorgheni, together with the tools and materials used to weave them.

The second exhibition displays minerals, rocks, mine flowers and fossils found in the Gheorgheni area and beyond, while the third exhibition features the paintings of János Karácsony. Notably, the mineral exhibition, in terms of its diversity, is one of the largest collections of this kind in the country. In addition, temporary exhibitions and many thematic activities are held at different times of the year. (source: https://www.tmmuzeum.ro/).

The museum contains mineralogical and petrographical collections from this region, donated by Dr Gyula Jakab, a geologist. It opened to the public in 2008. The museum comprises several rooms, each with a specific collection:

Room 1. The exposed material comprises the Geology of the Ditrău Alkaline Massif, including a 3D geological map (scale 1:10,000) of the area, representative drill cores from various depths within the geological structure, characteristic rock and ore samples, and numerous polarising microscopic images of specific minerals from the Ditrău Massif.
Room 2. Characteristic fossils from the Palaeozoic, Mesozoic and Cenozoic eras.
Room 3. Mineralogical and geological equipment and mining tools.
Room 4. Features igneous, metamorphic, and sedimentary rocks from various regions of Romania. Additionally, over 60 plates displaying ornamental rocks from around the world are showcased.
Room 5. "Mine flowers", i.e. large crystals of various oxides, carbonates, sulphates, and sulphides. Minerals were arranged according to Strunz's mineral classification.



Photo 2/1. The Tarisznyás Márton Museum building (source from https://www.tmmuzeum.ro/).

Stop 2/2. Along the Belcina Valley road (Lat./Long.: N46.73374, E25.65005)

Mylonitised Bucovinian Pietrosu Porphyroid and Negrișoara terrane folded gneisses. The mylonitisation from the thick (kilometre-scale) brittle-ductile shear zone has intensively overprinted the porphyroid texture and, by isoclinal folding, has transposed the previous S2 foliation after S3 of Alpine tectogenesis (Photo 2/2).

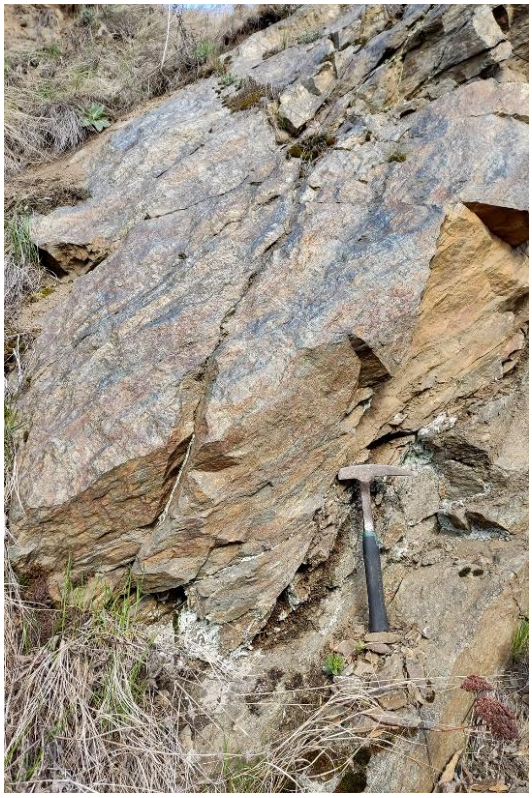


Photo 2/2. Outcrop of the Mylonitised Bucovinian Pietrosu Porphyroid and Negrișoara terrane folded gneisses



Stop 2/3. Tulgheș terrane schists (Lat./Long.: N46.73550, E25.654061)

Outcrop of folded, mylonitised schists of the Tulgheș terrane (quartzitic, sericitic, chloritic schists) within the Bucovinian Unit. The mylonitisation, from the same shear zone as at stop 2/2, also obscures the previous rock texture.

Photo 2/3. Outcrop of the mylonitised schists of the Tulgheș terrane.

Stop 2/4. Pângărați Cap (with restaurant) (Lat./Long.: N46.775810, E25.720511)

Bretila terrane micaschists and gneisses could be observed due to the building works around the restaurant.

Stop 2/5. Bucovinian Rarău gneisses. Parking (Lat./Long.: N46.780069, E25.757436)

The outcrop of Bucovinian Rarău mylonitised gneisses with red alkali feldspar (Photo 2/5). The Bretila terrane rocks are part of the Variscan Rarău nappe and occur within the basement of the Alpine Bucovinian,

Subbucovinian and Infrabucovinian Nappes. The Bretila rock sequence outcrops in several tectonic windows, including Iacobeni, Vatra Dornei, Bretila, Vaser and the Rodna half-window. This represents the oldest terrane (Prt2-3) in the EC. For the protolith age of Bretila rocks, Sm-Nd methods (TDM model for total rock sample) yielded 1.65 Ga for gneisses and 1.56 and 1.57 Ga for the Hăghimaş and Mândra granitoid intrusions (Pană et al., 2002). U/Pb methods on zircon crystals from Hăghimaş granitoids indicated an intrusion age of 500-600 Ma, with additional age populations for restitic zircons of 1.1-1.2 Ga (Pană et al., 2002).



Photo 2/5. Outcrop of Bucovinian Rarău gneisses and a detailed view.

The Bretila terrane was metamorphosed under amphibolite-facies peak conditions, with local migmatic processes (Anies-type augen gneisses, quartz-feldspar veins, stromatitic gneisses), overprinted by a Variscan regional extensional retrogression (Balintoni, 1969; Bercia et al., 1976; Kräutner, 1980, 1988; Kräutner and Savu, 1978). In the shear zones of the Variscan and Alpine nappes, the mylonitic Bretila schists may contain HP/LT minerals such as chloritoid and phengitic white micas (Bindea, 1998; Mosonyi, 1999). In the northern part of the East Carpathians (Rodna Mountains), Mosonyi (1999, 2003) described retrogressed eclogite-type rock lenses with characteristic relic microstructures within the Bretila terrane rock sequences, near migmatitic sequences.

Ar^{40}/Ar^{39} dating of muscovite concentrates indicates peak metamorphic conditions around 300 Ma (Kräutner et al., 1976; Kräutner, 1988; Pană et al., 2002; Strutinski et al., 2006). Published U-Pb zircon ages are 433-435 Ma for the Hăghimaş granitoids and 468 Ma for the Mândra granitoids. Magmatic processes followed the peak metamorphic events, and their ages could fall between 300 Ma and the granitoids' crystallisation ages. The suite comprises: metapelites (chloritic micaschists containing garnet, staurolite, kyanite), metagranitoids, amphibolites and gneisses (leptyte – amphibolite formation), and granites. The latter, as part of an old accretionary wedge, could be interpreted as island-arc-related granitoid intrusions (Mândra granitoid and Hăghimaş granitoid) along its boundary (Balintoni, 1997).

Formerly, Hăghimaş-Granitoids were considered part of the Rarău nappe, but their flat position and tectonic contacts with the underlying Bretila lithology, including greenschist-facies mylonites overlain by Triassic sediments, rather suggest a discrete Variscan granitoid nappe.

Stop 2/6. Oii (Haghimas) Creek. Parking (Lat./Long.: N46.780725, E25.783581)

At Oii (Haghimas) Creek, sandy marls of the Middle-Jurassic (Toarcian-Dogger) sequence of Bucovinian facies are composed of sandy limestones, oolithic limestones, and fine stratified limestones, white to red in colour, with examples such as *Spiriferina haueri*. Grasu et al., 2011, paralleled these sequences with the Hierlatz facies (Fig. 12).

Stop 2/7. Red Lake (Lacu Roșu). Parking place (Lat./Long.: N46.788961, E25.78856)

The Red Lake (Photo 2/7) is bounded to the north by Suhărzel Massif (1310 m), to the north-west by Suhardul Mare (1506 m) and Piciorul Licaşului (1343 m), to the south by Bâtca lui Cioflec (1179), and to the south-east by Ghilcoş/Gyilkos Mountain (1406 m) (Figs 30, 32). It is the largest natural dam lake in Romania. According to one view, it formed after a prolonged rainy period in 1837, when the Bicaz River valley was dammed by a large landslide originating from the Ghilcoş Mountain slope (Herbich, 1878; Vadasz, 1915; Mihăilescu, 1940; Zaruba and Mencl, 1954) (Figs. 31, 33). Another view attributes its formation to an earthquake in January 1838, which triggered the landslide. Four tributaries of the Bicaz River in this sector also contribute to the lake's development, namely: Oii, Piatra Roşie, Licaşul, and Suhardul. The lake was not discovered until 1857, and access to it was not possible until 1910, when the road from Gheorgheni to "The Neck of the Hell" was constructed. The lake's initial dimensions were: 2 km in length along the Oii creek, 1.6 km along the Suhard creek, and a maximum depth of 12.5 m (Dragoş, 1957).



Photo 2/7. Red Lake (Lacu Roșu) is a natural dam lake formed when a major landslide from Mount Ghilcoș obstructed the Bicaz River basin.

After 120 years of evolution, its dimensions changed. The length along Oii Creek decreased to 1 km, and along the Suhard to 442 m; the maximum depth decreased to 10.5 m (Pişotă and Năstase, 1957). The initial water volume was estimated at 680000 m^3.

After 130 years, sediment input was about 480000 m3, but the water volume decreased by 40%. Dams were built on the Oii and Piatra Roşie tributaries to reduce the sediment supply to the lake, but the results were insufficient, as one is already overfilled and the other is almost full.

The thermal regime of the Red Lake is mixed: normal thermal stratification during the warm season and reverse thermal stratification during the cold season, with short isothermal intervals between them. During the winter, the lake is covered by an ice cover 0.45-0.6 m thick from December to the second half of April.

Ecologically, from the lake's origin to the present, the Red Lake has evolved through three stages: a) the oligotrophic stage; b) the mesotrophic stage, during which aquatic macrophytes invaded the lake; and c) the mesotrophic-eutrophic stage. The geological sketch of the Red Lake area is shown in Fig. 12.

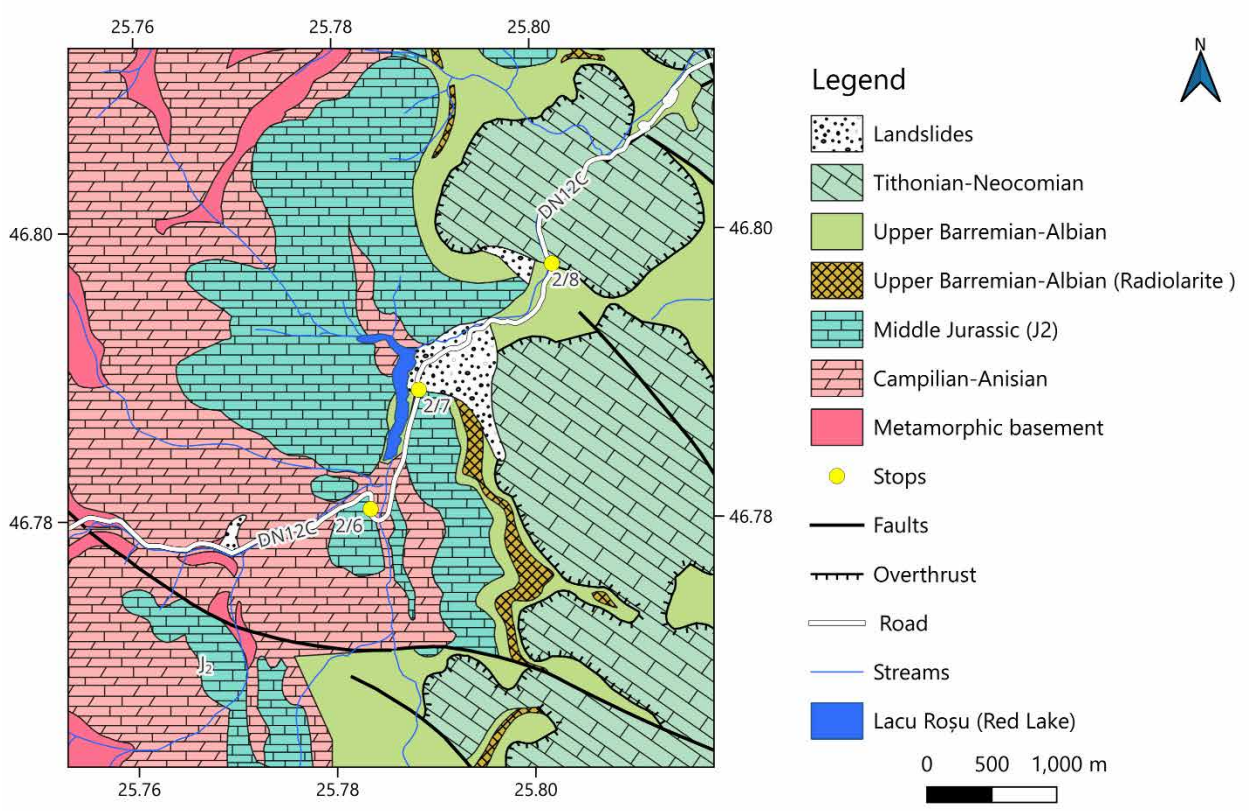


Fig. 12. Geological sketch of Lacu Roșu (Red Lake) area (data from Săndulescu et al., 1975)

Stop 2/8. Hăşmaş Nappe (Lat./Long.: N46.797625, E25.802114)

Hăşmaş Nappe (Laramian East Transylvanides: Kimmeridgian-Aptian). Carbonate micaceous sandstones, followed by fossil-rich sandstones and marls (*Aspidoceras acanthicum*, *Lamellaptychus lamellosus*, belemnites, brachiopods, crinoids) (Figs 12, 13, and 14).

The Transylvanian Hăşmaş/Hăghimaş nappe composition along the Bicaz River between Red Lake and Cupaş Creek, after Săndulescu (1967), comprises: Upper Kimmeridgian sandy limestones and marlstone (blue dot in Fig. 13); Tithonian-Neocomian massive limestones, limestones with platy stratification, oolithic limestones, and limestone breccia.

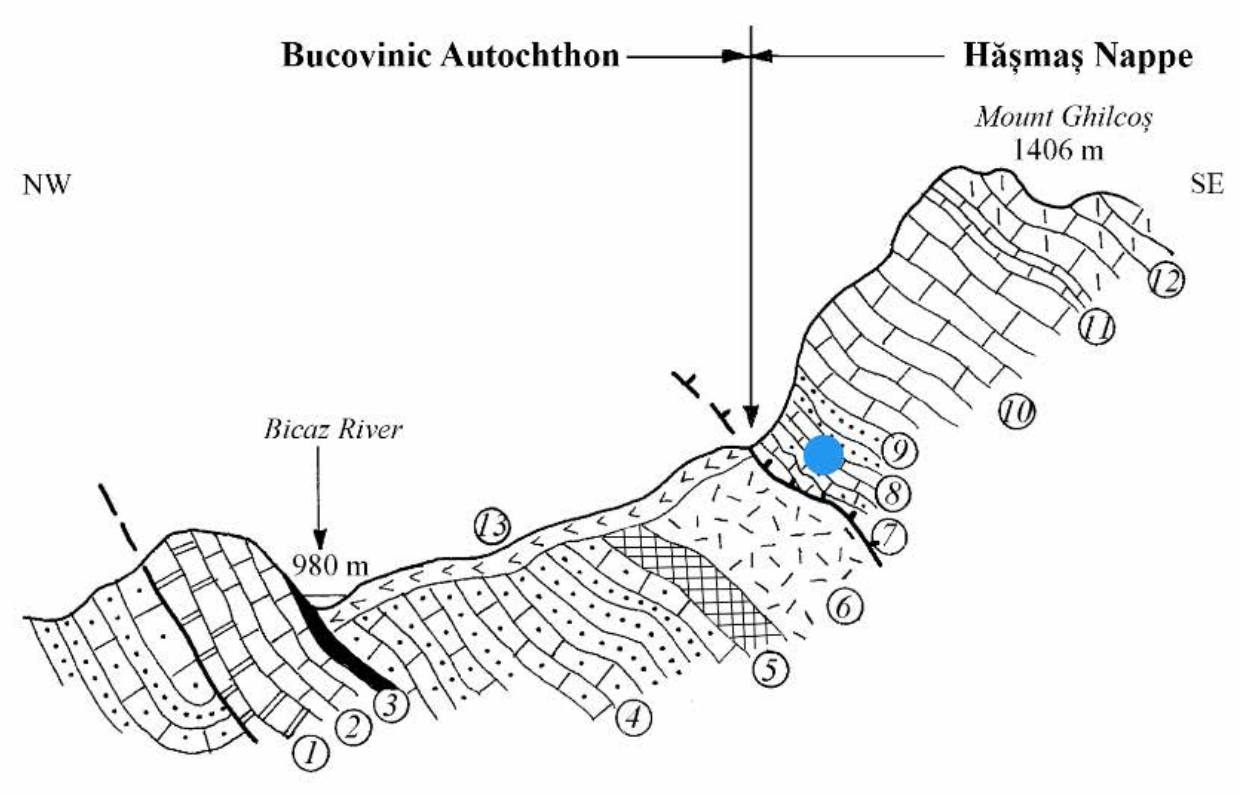


Fig 13. Geological cross-section through northern side of Gyilkos Mountain in natural dam sector (after Grasu et al, 2010, modified). **Bucovinian Autochthonous**: 1 Campilian-Anisian (dolomite); 2 Middle-Late Triassic (dolomite and limestone); 3 Liasic in Hierlatz facies; 4 Dogger; 5 Callovian-Oxfordian (jaspers and radiolarites); 6 Barremian-Albian (wildflysch); **Hășmaș (Transylvanian) Nappe**; 7 Kimmeridgian (red nodular limestone); 8 – Kimmeridgian (grey-greenish limestone); 9 Kimmeridgian (silty-sandy marlstone); 10 Tithonic (Stramberg Limestone); 11 Neocomian; 12 Urgonian; 13 slumped deposits. Blue dot is the stratigraphic position of stop 2.8.

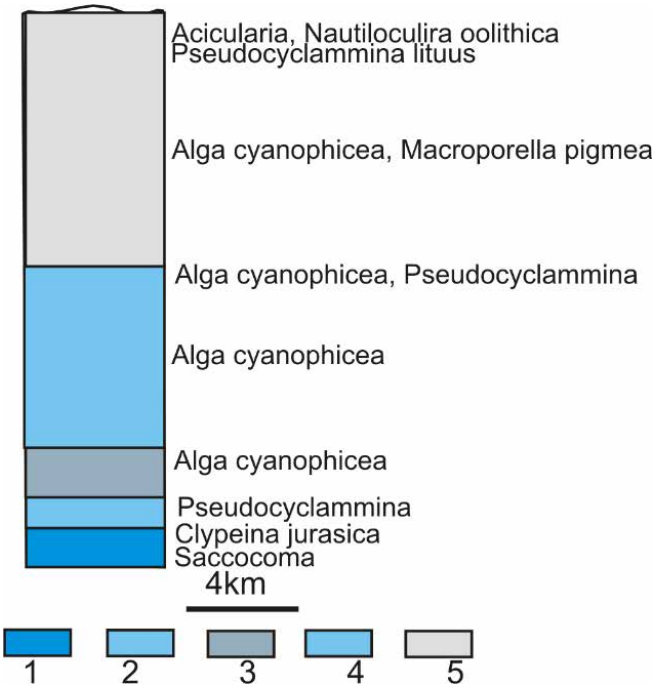


Fig. 14. Stratigraphic column of Hăsmaș nappe (Upper Kimmeridgian and Tithonic- Neocomian) between Red Lake and Cupas Creek. Legend: 1-Upper Kimmeridgian sandy limestones, Tithonic –Neocomian: 2- massive limestones, 3- limestones with platy stratification, 4- oolithic limestones, 5- calcarenitic breccia (after Săndulescu, 1967, 1967a, 1967b)

Stop 2/9. Hășmaș Nappe limestones. Parking place (Lat./Long.: N46.805633, E25.809607)

Hășmaș Nappe limestones (from the East Transylvanides, resulting from Laramian tectonic events and forming the central part of the general syncline structure) in Bicaz Gorge are represented in this outcrop by Kimmeridgian-Aptian (J3) nodular limestones, stratified limestones with sandstone intercalations, followed by sandstones and marls rich in fossils). The Bicaz Gorges (Fig. 15 and Photo 2/9) are linked to the evolution of the Bicaz River. Two stages were recognised in this evolution:

a) an epigenetic stage during which the river cut through the post-tectonic conglomerates, covering the limestone;

b) A karstification stage occurred when the Bicaz River and its tributaries (Cupaşul, Lapoşul, Bicăjelul, and Şugăul) dissolved the bedrock, then disappeared into the limestone and carved caves whose hanging roofs collapsed. Under these conditions, slope breaks and karst towers formed, such as the Altar/Bardos Stone.

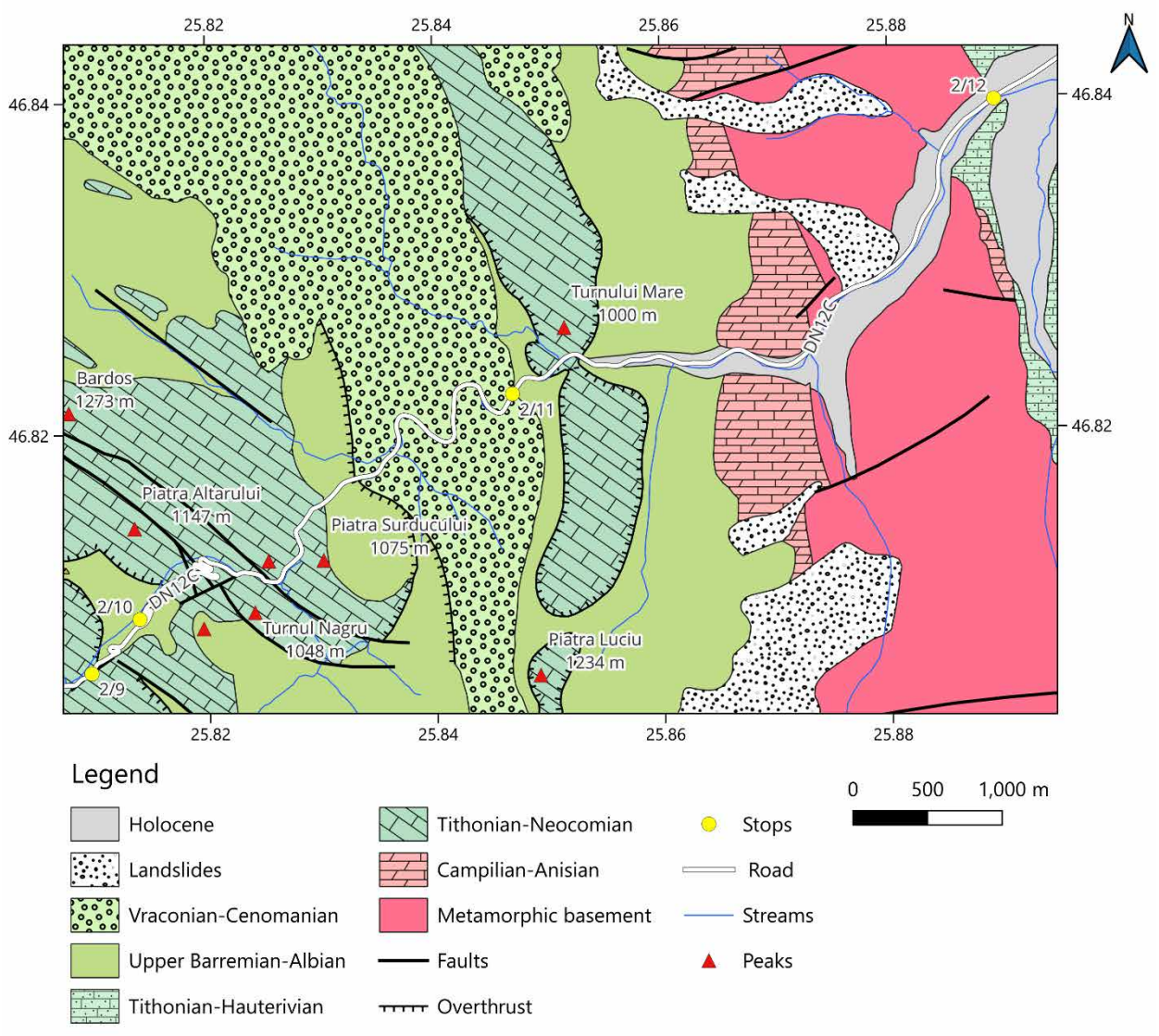


Fig. 15. Simplified geology of the central part of the Hășmaș syncline (after, Săndulescu et al., 1975, 2018)

The Bicaz Gorges are 8 km long and are cut into post-Vraconian Bârnadu Conglomerates (4 km, Small Gorges) and limestone (upstream 4 km, Big Gorges). In the easternmost sector, the Bicaz River crosses the Surduc-Munticelu limestone ridge. The highest relative altitude of the gorges is > 350 m in the sector known

as “The Neck of the Hell” at the confluence of Bicăjel Creek with the Bicaz River. At the confluence of Bicăjel with the Bicaz River, the Tithonian-Neocomian sequences of the Hăşmaş Nappe are exposed (Săndulescu, 1975):

a) **The Tithonian** is represented by massive, light-coloured neritic limestone in the Stramberg facies, which contains gastropods (Nerinea), foraminifers (*Trocholina alpina*, *T. elongata*, Kurnubia, Kilianina, etc.), and calcareous algae (*Salpingoporella anulata*, as well as Elipsactinia, *Cladocoropsis mirabilis*, *Clypeina div. sp.*, *Actinoporella podolica*, etc.).

b) **The Neocomian** is represented by well-layered pelagic limestone containing *Calpionella elliptica*, *Tintinopsella carpathica*, *Calpionellopsis oblonga*, *Neocomites neocomiensis*, and *Berriassiella privasensis*; the Bicăjel River is located on such deposits.

c) **The Early Barremian** (possibly the whole Barremian) of Urgonian facies, with white, yellowish and light reddish limestones and calcarenitic breccias containing Pachyodonts (*Requienia div. sp.*, *Toucasia carinata*), large foraminifers (*Orbitolina conica*), as well as calcareous algae and bryozoans.

The Şugău Gorges are the narrowest, with widths of no more than 3-4 m in some sectors. Upstream of the confluence of Şugău Creek with the Bicaz River, there is an area where calcareous tuffs are deposited.

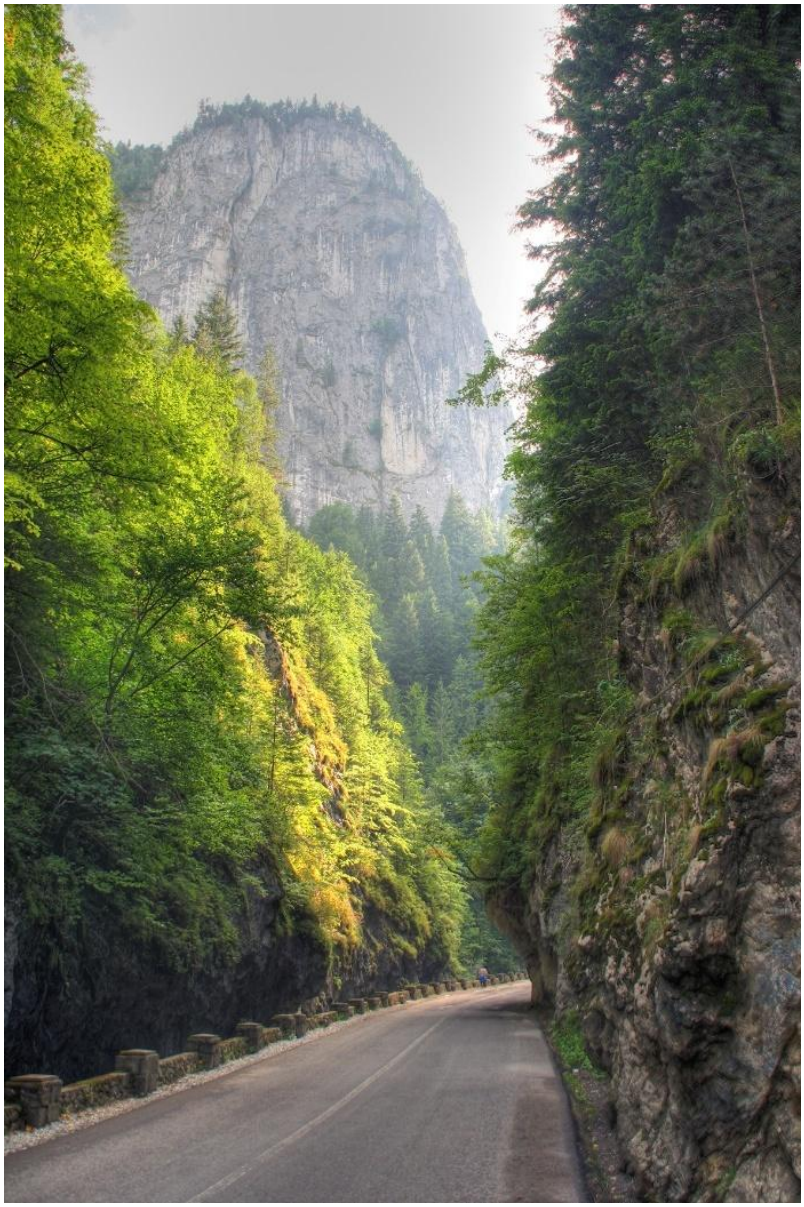


Photo 2/9. Piatra Surduc at the end of Bicaz Gorges.

Stop 2/10. Limestones (Kimmeridgian-Aptian) (Photo 2/10) (Lat./Long.: N46.808881, E25.813878)



Photo 2/10. Piatra Altarului/Bardosului (on left) and Santinela de la Gâtul Iadului (on right)

Stop 2/11. Bârnadu conglomerates (Lat./Long.: N46.822269, E25.846824)

Bârnadu conglomerates (Vraconian–Cenomanian, Săndulescu, 1967, 167a, 167b) are post-tectonic deposits that transgressively overlie the tectonic contact between the Hășmaș Nappe and the Bucovinian Barremian–Albian Wildflysch Formation (Fig. 15). They are visible at local landmarks such as the Suhardu massif and along the Șugău Creek. These deposits comprise two lithological facies (Săndulescu, 1967, 167a, 167b): one consists of conglomerates rich in quartz and crystalline schist clasts, with minor limestone and dolostone clasts. The conglomerate matrix is sandy. The other is enriched in limestone clasts and large blocks, sometimes resembling megabreccia. This rock type results from erosion of the Hășmaș Nappe and partial erosion of the Wildflysch Formation.

Stop 2/12. Sub-Bucovinian Rabotage (Lat./Long.: N46.839790, E25.889410)

Sub-Bucovinian Rabotage Outlier at Gura Dămucului. This is a Sub-Bucovinian frontal scale, sheared and displaced in front of the Bucovinian Nappe, lying between the crystalline schists and the Sinaia flysch of the Ceahlau Nappe. The Sub-Bucovinian sedimentary cover comprises a succession of Triassic, Liassic (Photo 2/12A), Dogger and Tithonic-Neocomian strata (Fig 16). The Sub-Bucovinian succession at Gura Dămucului comprises Triassic-Neocomian deposits, characterised by numerous stratigraphic unconformities, thin beds and notable occurrences of rudites. These successions comprise: Triassic (bedded and massive dolomites), Liassic ("limonitic" breccias), Dogger (quartz-silty pelasparites and biosparites) and Tithonian-Neocomian (rudites, litharenites and tintinnid-bearing clayey micrites).

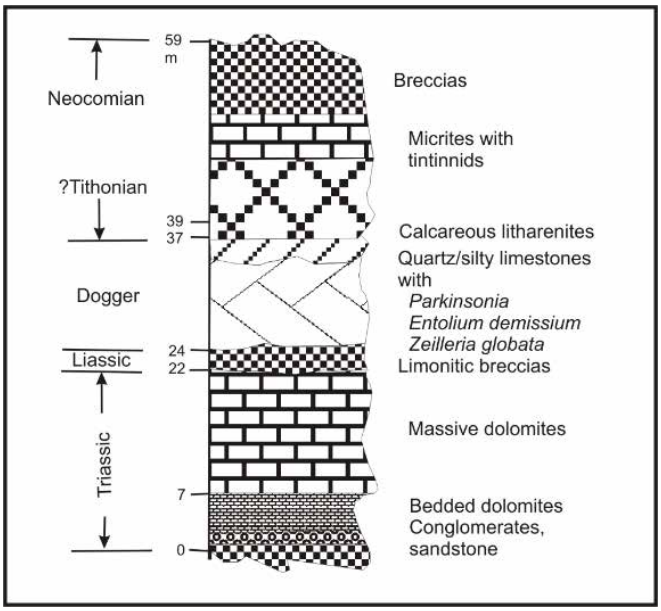


Fig. 16. Lithostratigraphic column of the rabotage outlier at Gura Dămucului 0 (after Grasu et al., 1995)

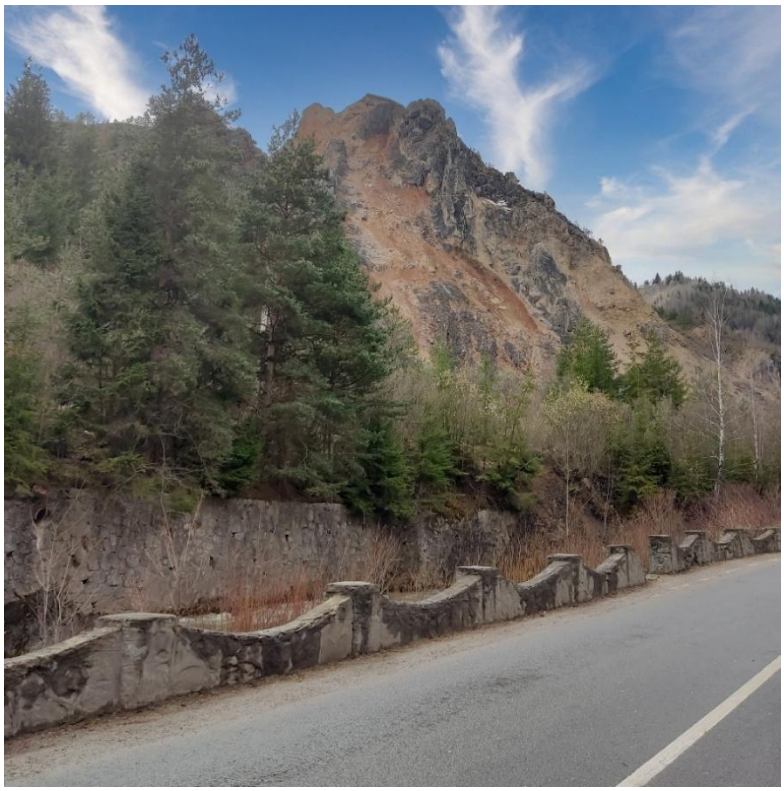


Photo 2/12A. On the right side of the Bicaz Valley, the Subbucovinian rabotage outlier with Liassic cliffs (Campilian-Anisian), represented by quartzitic limonitic breccias and dolomites, is visible from the road. It occurs between the dolomites and the Dogger limestones (Săndulescu, 1975). Here, a steep yellowish-red Triassic sandy limestone cliff is uplifted along a fault plane.

At Bicaz Chei village, parking coordinates at Gura Dămucului (Lat./Long.: N46.839799, E25.889412). In the neighbourhood of the confluence of the Bicaz Valley with Dămuc Brook, around 100 m upstream along the abandoned railway, there is an outcrop with a carbonaceous silt-pelite succession exhibiting rhythmic stratification of Sinaia strata from the Ceahlău nappe (Fig. 16, Photo 2/12B).



Photo 2/12B. Sinaia flysch at Gura Dămucului.

Stop 2/13. Bicaz village (Lat./Long.: N46.909300, E26.087400)

Day 3 (Sept. 8)
Bicaz Lake – Grințieș – Capu Corbu – Borsec – Creanga – Toplița - Cluj-Napoca

This day will begin at 8 o'clock, when we will take the back trail towards Cluj-Napoca via Bicaz-Grințieș (Primătaru Creek) – Borsec – Toplița. From Bicaz, the back-trail route follows the road along the tail of Bicaz Lake to Grințieș, Capu Corbului and Borsec (90 km), crossing mylonitised Bucovinian and Tulgheș terrane rocks, Bretila terrane gneisses and micaschists, Mândra granite and Pietrosu porphyroid. At Borsec, dolomitic marbles of the Rebra terrane from the Bucovinian unit are exposed in a pre-Alpine tectonic window, overridden by Pietrosu porphyroid, Negrișoara schists and Tulgheș terrane schists and metarhyolithes during a Variscan tectonic event. The town of Borsec is a spa, cultural and tourist centre. From Borsec, through Creanga Cap up to Toplița, the Tulgheș terrane schists are exposed.

Stop 3/1. Ceahlău nappe (Lat./Long.: N47.03482, E25.88812)

At Grințieș locality (at the tail of Bicaz Lake) and at Grințiesul Mare Creek, the exposed rock belongs to the flysch zone (Ceahlău nappe).

Stop 3/2. Sinaia strata (Lat./Long.: N47.05307, E25.82386)

On Primataru Creek, a tributary of Grintiesul Mare Brook, this is an outcrop around 100 m wide, with folded and faulted sandy carbonaceous flysch of Sinaia strata (Neocomian-Tithonian) (Photo 3/2) from Ciuc digitation, based on data from Săndulescu et al. (1975).



Photo 3/2. Sinaia strata along Primătaru Creek.

Stop 3/3. Tectonic contact (Lat./Long.: N47.04643, E25.81018)

Tectonic contact between the flysch zone and the Bucovinian quartz-feldsparic mylonitic schists (metaryolithes) of the Tulgheș terrane. Quartz-feldsparic mylonitic schist outcrop (Photo 3/3). The metaryolithes within this shear zone contain base-metal sulphide disseminations, mainly pyrite, which have

been altered by surface weathering into iron oxyhydroxides. These sulphides also appear to be of tectogenetic origin.



Photo 3/3. Both intensely deformed (mylonitised, folded, faulted) quartz-feldspathic schist of the Tg3 formation, containing pyrite disseminations, epigenetically altered.

Since 1963, when the first gamma anomalies and ore deposits were discovered, the Primătaru Creek-Tulgheș area has been investigated and exploited for radioactive (U, Ra, Th) ores. The radioactive mineralisation is hosted within the Bretila terrane (Sandu et al., 2020), similar to the Crucea-Botușana mine district (Suceava county), and possibly within the Tulgheș terrane (e.g., Sandu et al., 2018), though Th may also be incorporated into the mineral structure of the red alkaline feldspar of the Rarău granitoids. From 1994 to 1997 (Topan et al., 2016), mining activity was conducted in an experimental phase, followed by full-scale mining, but only in a single mining block and a single gallery (between 1997 and 2001). In 1998, due to a lack of funding, the operation was abandoned. The following year, a feasibility study was carried out to open the northern part of the deposit. In 2001, the mining operation in the only active gallery was halted due to a lack of permits for the feasibility study, which in turn halted the investment.

In 2005, the National Uranium Company initiated a project to reopen mining operations at the existing uranium deposits in the Tulgheș and Grințieș area. The area currently contains several mining galleries at different stages of conservation. Geological surveys were carried out by S.C. Radioactiv Mineral Măgurele S.A, a company formed through the reorganisation of the National Uranium Company, whose main objectives are to survey and exploit radioactive mineral deposits, as well as to preserve and close mines and to clean and restore the environment. Its main work station is the Tulgheș-Bicazu Ardelean district, where many of the neighbouring perimeters have been studied (preliminary, general, detailed and experimental exploitation), such as: Grințieșului Valley - Bicazu Ardelean – Dămuc - Chicera - Pârâul Danci - Păltiniș (Neamț County); Bilbor - Corbu (Barasău) - Tulgheș (Putna Valley – Hagota-Șumuleu Valley - Prisecani - Pintic - Pârâul cu Pești - Putna Întunecoasă Valley (Harghita County), etc. The “For@drill” Baia Mare Company was involved as a partner in the prospecting project and in geological and physico-chemical research in the Preluca Ursului perimeter. The conclusions of Topan et al.'s (2016) research were that, in the Tulgheș-Grințieș exploitation perimeter, there are no dangers to the environment or to the area's inhabitants, because the concentration of radioactive material is extremely low. From an economic point of view, unfortunately, this makes the area less profitable.

Stop 3/4. Bretila terrane mica-gneisses (Lat./Long.: N47.04643, E25.81018)

An outcrop of quartz-feldsparic mylonitic schists on Bretila terrane (Photo 3/4) mica-gneisses, with blocks of mylonitised Mândra granitic porphyroid.



Photo 3/4. Mylonitised Bretila gneisses.

Stop. 3/5. Bucovinian Unit (Lat./Long.: N47.00158, E25.62350)

Capu Corbu village, along the Bistricioara Valley with Pietrosu Porphyroid (Photo 3/5) (metadacitic) rocks from the Bucovinian Unit.



Photo 3/5. Pietrosu Porphyroid metadacite outcrop and detail.

Stop 3/6. Negrisoara terrane (Lat./Long.: N46.96370, E25.58091)

Parking place on the road into Borsec, intensely folded, mylonitised Negrisoara terrane schists (Photo 3/6).



Photo 3/6. Mylonitised, faulted Negrişoara schists.

The Negrişoara and Pietrosu porphyroid rock sequences have Precambrian protolith ages and polymetamorphic histories. Balintoni and Gheuca (1977) considered that the Negrişoara rocks represent the upper part of the Rebra sequence, which was detached during Variscan nappe overriding. The Negrişoara terrane rocks consist of biotite-quartzitic gneisses with few amphibolite and carbonate lenses. This sequence was metamorphosed to amphibolite-facies peak conditions, reaching the garnet and staurolite zones (without sillimanite, in contrast with the Rebra schists), and retrogressed during Variscan events. They contain centimetre- and decimetre-scale complex folding. In this rock sequence, the Pietrosu porphyroid occurs. The Pietrosu porphyroid gneiss is developed as a tabular, homogeneous body of dacitic composition along the Crystalline-Mesozoic zone, with some tectonic discontinuities (Balintoni and Neacsu, 1980). A mesoscale feature of this gneiss is the presence of bluish-grey quartz porphyroclasts. On the microscale, the porphyroclasts are composed of quartz, microcline, plagioclase, white mica and biotite. The Pietrosu porphyroid body was involved in a ductile shear zone during nappe stacking and underwent dynamic retrogression. During retrogression, mainly the thin, tabular bodies were affected by microcrenulation and crenulation foliation S3; biotite underwent chloritisation, and feldspars (microcline and oligoclase) underwent albitisation.

Protolith ages for these sequences were obtained as 1.69-1.71 Ga (by Sm/Nd method, TDM model age for Pietrosu Porphyroid) and 2.04 Ga (for Negrişoara terrane biotitic gneisses). Metamorphic ages by U/Pb methods on zircon crystals suggested the same age as the Rebra rocks (Pană et al., 2002; Balintoni et al., 2009).

The U-Pb and Pb-Pb ages indicate two age populations (Boiko et al., 1982): 1) determinations on probable magmatic idiomorphic zircons from the porphyroid are around 835 Ma, and 2) determinations on some sedimentary zircons from the same rock are 1.6 Ga (Balintoni, 1997).

Stop. 3/7 Borsec town Kecskés mineral spring (Lat./Long.: N46.96535, E25.56186)

The Kecskés spring (Goat Spring) is in the village of Borsec and has served as a drinking water source for locals since at least 1806. Borsec (the village and the spa resort) has many sparkling mineral water springs, where meteoric surface water infiltrates deeply through fractures in the surrounding Mesozoic limestone/dolomites and crystalline schists. During its deep subterranean transit, carbon dioxide (from the nearby Călimani-Gurghiu volcanic chain) dissolves into the groundwater under high pressure. The resulting water is a hypotonic, carbonated mineral water with Mg and Na. The Goat Spring water (Photo 3/7) has a pH of 6.27, 1672 mg/L CO_2, 2135 mg/L HCO_3, 40.8 mg/L Cl, and 5 mg/L SO_4. Main cation concentrations are: 436.7 mg/L Ca, 139.7 mg/L Mg, 130.2 mg/L Na, 25.1 mg/L K, 4 mg/L Fe^{2+}, and 0.27 mg/L Mn. The higher iron content derives from water circulating through metamorphic schists.



Photo 3/7. Kecskés spring (Goat Spring)

Stop 3/8. Rebra terrane dolomitic marble (Lat./Long.: N46.97800, E25.57049)

In a Variscan tectonic window, the Rebra terrane dolomitic marble, intensively deformed and hydrothermally altered (talc, pyrite), is exposed and overthrust by the Pietrosu Porphiroid and Tulgheș schists, all included in the Alpine Bucovinian unit during the Austrian tectonic phase.



Photo 3/8. Deformed dolomitic marble of the Rb2 formation containing quartz boudins (due to extensional deformation in the shear zone).

The rock was impregnated with hydrothermal talc and pyrite. The rocks of the Rebra terrane have Precambrian protoliths, and Ordovician is the earliest overprinted metamorphic event, as in the Bretila terrane. They form the Variscan Rodna Nappe. During Variscan collision, the Rebra terrane evolved with the Negrişoara and Tulgheș terranes, forming the Rebra-Negrișoara-Tulgheș terrane. During Alpine compressional tectonics, the Rebra sequence was involved in the Cretaceous Subbucovinian and Bucovinian Nappe system.

The U/Pb zircon age of the Nichitaș ortogneisses from the Rebra rock sequences is 460 Ma (Pană et al., 2002) (melt emplacement age), but TDM and Sm/Nd (total rock samples) ages were also reported for some micaschists: 1.7-2.07 Ga for the protolith ages (Pană et al., 2002). The Pb/Pb age of the Mississippi Valley-type Zn-Pb ore is 800 Ma, which could indicate the depositional age (Kräutner and Bindea, 1995) or may reflect the presence of detrital Pb ages of 715 Ma ± 22 Ma (Zincenko, 1995).

The Rebra terrane rocks exhibit polymetamorphic characteristics. The peak metamorphic conditions (M1) were in the amphibolite facies, up to the sillimanite isograd (Mosonyi, 1999). Locally, during the second metamorphic event, LP/HT conditions were reached (cordierite and andalusite isograds, Balintoni, 1997). In the shear zones, mylonitic schists are associated with the emplacement of the Pre-Alpine and/or

Alpine nappes, and HP/LT minerals have been identified in Rebra rocks, for example chloritoid and phengitic white micas (Mosonyi, 1999). The Rebra terrane evolved in a lower-plate tectonic setting during the M1 and M2 metamorphic events, separately from the Bretila terrane, which at the same time was in an upper-plate tectonic setting. After the M2 event, both terranes evolved together, as indicated by penetrative structure diagrams (Balintoni et al., 1997; Mosonyi, 2003).

Lithostratigraphically, 3 formations have been delineated within the Rebra terrane. The sequence is bounded at the base and top by metapelitic rocks, with a carbonate middle. The sequence comprises rocks such as: silicate marbles (tremolite-bearing dolomitic marbles, steatite-bearing marbles, cipoline, i.e. mica-bearing marbles, fuchsite- and phlogopite-bearing marbles, and diopside/amphibole-bearing marbles), metapelites (garnet ±staurolite, ±kyanite, ±sillimanite-bearing micaschists, amphibole-bearing garnet micaschists), quartzites (white quartzite, graphitic quartzite, piemontite-bearing quartzite), amphibolites (garnet-, epidote-, diopside-, epidote-bearing amphibolite), and metagranitoids (e.g. Nichitaş-type).

In the Rebra terrane, the Rb2 formation hosts syngenetic, metamorphosed volcanogenic-sedimentary Zn-Pb-Cu ore deposits (Mississippi Valley-type ores from the Valea Blaznei and Guşet Mines, localised in the marbles of the Rb2 formation). Other ore deposits are hydrothermal complex sulphides and magnetite skarns (Valea Vinului and Cobăşel Mines, all in the Rodna Mountains) within the same Rb2 formation, genetically correlated with Neogene andesitic/dioritic intrusions.

Stop 3/9. Borsec spa resort (Lat./Long.: N46.972513, E25.560761)

Borsec is well known for its mineral water springs and travertine quarries (Fig. 17) related to Neogene volcanism (lunch time).

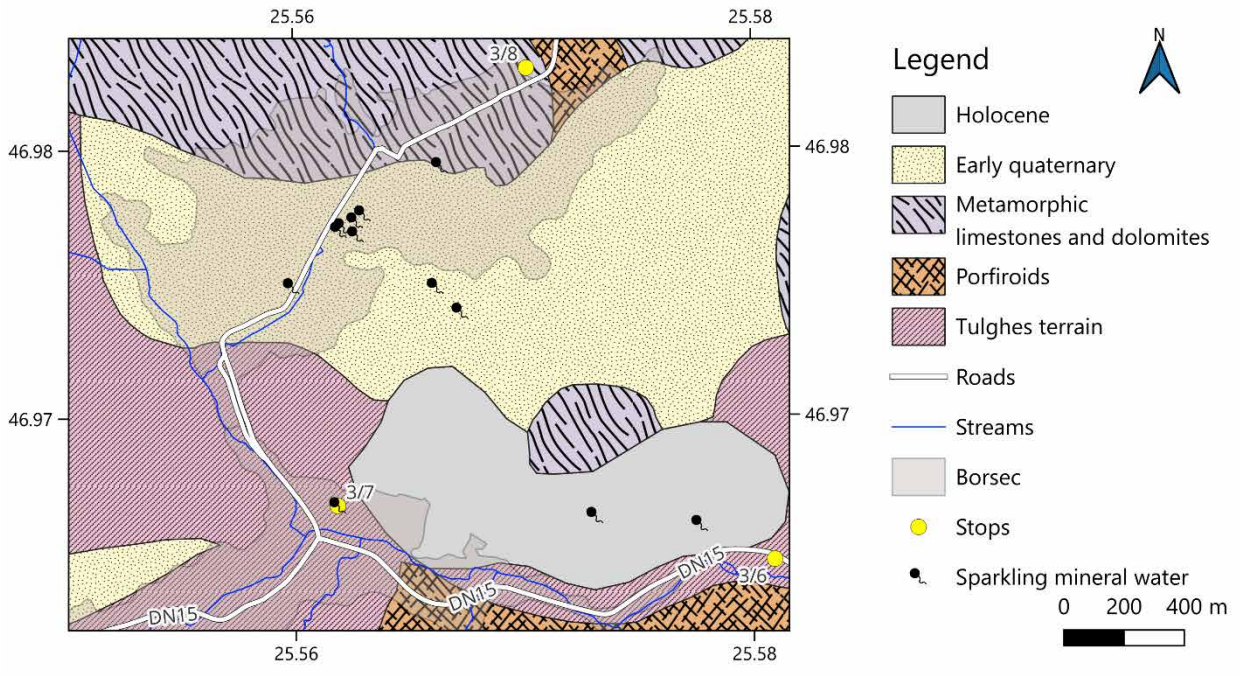


Fig. 17. Geologic background of Borsec town, with the positions of stops 3/6, 3/7 and 3/8 (after Alexandrescu et al., 1968, modified)

Stop 3/10. Tulgheș terrane (Lat./Long.: N46.97453, E25.46416)

Along the road between Borsec and Toplita, an outcrop of the Tulgheș terrane, with sericitic, chloritic, quartzitic schists (intensively folded, with minor decimetric folds) from the Bucovinian Unit (Photo 3/10) (BG and EM).



Photo 3/10. Intensely folded quartzitic, chloritic, and sericitic schists of the Tulgheș terrane within the Bucovinian unit.

The rocks of the Tulgheş terrane are part of the Variscan Putna, Sândominic, and Bălan nappes and the Liţu scale. These tectonic units include the LT/MP Variscan metamorphics of the Tulgheş sequence, derived from Ordovician sediments and volcanics (Vaida 1998), formerly assigned to the Cambrian (Vodă, 1993). This sequence records an early siliciclastic platform stage (Formation Tg1), followed by an initial basinal phase (Formation Tg2) and a period of extensional intracontinental rifting and collapse, associated with bimodal magmatism (Formation Tg3). Syngenetic manganese (Iacobeni, Oiţa, Dadu, Dealul Rusului)

and barite (Holdiţa-Broşteni) ores formed during the Tg2 basinal stage, whereas the prevailing rhyolitic Tg3 volcanism is related to VHMS (Volcanogenic Massive Sulphides deposits) (Baia Borşa, Fundul Moldovei, Leşul Ursului, Bălan), which contain syngenetic metamorphic copper ore deposits in greenschists and/or metaryolithes, or "porphyrogens" in Romanian geological literature. The final stage was a rifting basin, partly filled with flysch-like deposits and local interlayers of basic volcanics (Formation Tg4). Detailed lithostratigraphic mapping, together with intensive and extensive drilling and mining, shows that the Tulgheş Group was involved in a complicated Variscan nappe system interposed between units of older and higher-grade metamorphics (Figs. 1, 2, 3, 4). Thus, in the Bucovinian basement, the Bălan, Putna-Baratu Mare, and Sândominic nappes were distinguished, each with specific lithologic characteristics. In the Subbucovinian nappe, the main unit is considered coeval with the Putna nappe, whereas the lower unit (Valea Stânei) could have an Infrabucovinian equivalent in the albite porphyroblast schists drilled in the core of the Barnar tectonic window. Some relict mineral phases of coarse-grained Tg4 sediments, such as blue magmatic quartz with rutile needles, prevailing plagioclase feldspar, and high quartz content, could suggest that, in part, the Tg4 formation deposits were fed from Rebra and Pietrosul lithologies, which form the lower Variscan nappes.

References

Alexandrescu, G., Mureşan, G., Peltz, S., & Săndulescu, M. 1968: Geological map of Romania, 1:200.000, L-35-VIII, Map sheet 12 Toplița.

Anastasiu, N. & Constantinescu, E. 1979: Structure and petrogenesis of the alkaline massif of Ditrău. Unpublished geological report, IPEG "Harghita", Miercurea-Ciuc Archives (in Romanian)

Balintoni, I., Mosonyi, E., Puşte, A. 1997: Informaţii şi interpretări litostratigrafice, metamorfice şi structurale, privitoare la Masivul Rodna, Carpaţii Orientali. Studia Univ. "Babeş-Bolyai", Geologia, XLII, 2, 52-66, Cluj-Napoca.

Balintoni, I. 1981: The importance of the Ditrău Alkaline Massif and its emplacement moment for dating of basement overthrusts in the Eastern Carpathians. Rev Roum Geol Geogr Bucuresti, 25: 89-94

Balintoni, I. 2001: The structure of the Romanian Territory. In I.I. Bucur, S. Filipescu, E. Săsăran (eds.), Field Trip Guide, 4th Regional Meeting of IFAA, 1-8, Cluj University Press

Balintoni, I. 1997: Geotectonica terenurilor metamorfice din Romania, Cluj-Napoca, Ed. Carpathica

Balintoni, I, & Balica, C. 2013: Carpathian peri-Gondwanan terranes in the East Carpathians (Romania): A testimony of an Ordovician, North-African orogeny. Gondwana Research, 23(3), 1053–1070. https://doi.org/10.1016/j.gr.2012.07.013

Balintoni, I. 1997: The Crystalline -Mezozoic zone of the East Carpathians. A review. Rom. Journ. Mineralogy 78, 3-13

Balintoni, I. 2005: Raport de cercetare Grant 6/166. Revista de politica ştiinţei şi scientometrie. ISSN 1582-1218

Balintoni, I. 1997: The Crystalline- Mesosoic Zone of the East Carpathians. A review, 4th National Symposium on Mineralogy, Iasi, Field Trip, Roumanian Journal of Mineralogy, 78/2

Balintoni, I., Balica, C., Ducea, M., Chen, F., Hann, H.P., Sabliovschi, V. 2009: Late Cambrian-Early Ordovician Gondwanan terranes in the Romanian Carpathians: a zircon U/Pb provenance study Gondwana Research, 16 (2009), pp. 119-133

Balintoni, I. & Baier, U. 2001: Cercetări structurale în Carpaţii Orientali. Studia Univ. "Babeş-Bolyai", Geologia, XLVI, 1, 3-14, Cluj-Napoca

Balintoni, I. & Gheuca, I. 1977: Metamorfism progresiv, metamorfism regresiv şi tectonica in regiunea Zugreni-Barnar (Carpaţii Orientali). (Pogressive metamorphism, regressive metamorphism and tectonics within the Zugreni-Barnar region (East Carpathians) Dări Seamă Inst. Geol. Geofiz. Rom., LXIII/5, 11–38. (in Romanian)

Balintoni, I., Neacşu, V. 1980: Studiul petrochimic al unor gnaise porfiroide de Pietrosu Bistriţei. D.S. Inst. Geol., Geof., Bucureşti, 65, 1, 79-100.

Batki, A. and Pál-Molnár, E. 2011: Petrology of Tinguaites from the Ditrău Alkaline Massif, Romania, 9th CETEG 2011 meeting – Skalský Dvůr – Czech Republic, pg 2..

Bindea, G. 1998: Blastomylonites study in the East Carpathians An, Inst Geol Rom, 70: 152-153

Boiko, A., Bartnitzkii, E. and Tepliakova, N. 1982: New ages if the detrital zircons from the oldest rocks of the Maramures Massif (in Russian). J. Geol. Kiev v. 42/3, pp. 123-127.

Bojoi, I. 1971: Munţii Hăşmaş şi zona Cheile Bicazului. Studiu geomorphologic cu privire specială asupra carstului. Teză de doctorat, Univ. "Al. I. Cuza" Iaşi.

Constantinescu, E. & Anastasiu, N. 2004: The Massif of Ditrău: A mineralogical and petrological approach at Dan Giuşcă centenary. Romanian Journal of Petrology, 79 (1): 11–12.

Csontos, L., & Vörös, A. 2004: Mesozoic plate tectonic reconstruction of the Carpathian region. Palaeogeography, Palaeoclimatology, Palaeoecology, 210(1), 1–56. https://doi.org/10.1016/j.palaeo.2004.02.033

Dragoş, V. 1957: Deplasări de teren. Ed Ştiinţifică, Bucureşti,

Grasu, C, Miclăuş, C., Brânzilă, M & Baciu, D. 2010: Hăşmaş Mountains. Geologic and physico-geographic monograph (in Romanian).

Grasu, C., Turculeţ, I. 1965: Asupra vârstei "Recifului" de la Gura Dămucului. Com. De Geol, SSNG, III, Bucureşti.

Grasu, C., Turculeţ, I., Catana, C., Niţă, M. 1995: Petrografia mezozoicului din "Sinclinalul Marginal Extern". Edit. Academiei, Bucureşti.

Grasu, C, Turculet, I. 1967: Câteva date noi cu privire la Liasicul din împrejurimilile Lacului Roşu, Com Geol SSNG IV.

Gröger, H. R., Fügenschuh, B., Tischler, M., Schmid, S. M., & Foeken, J. P. T. 2008: Tertiary cooling and exhumation history in the Maramures area (internal eastern Carpathians, northern Romania): Thermochronology and structural data. Geological Society Special Publication, 298(February 2014), 169–195, https://doi.org/10.1144/SP298.9

Gröger, H.R., Tischler, M., Fügenschuh, B., & Schmid, S. M. 2013: Thermal history of the Maramureş area (Northern Romania) constrained by zircon fission track analysis: Cretaceous metamorphism and Late Cretaceous to Paleocene exhumation. Geologica Carpathica, 64(5), 383–398. https://doi.org/10.2478/geoca-2013-0026.

Herbich, P. 1859: Die geologishen Verhältnisse des nordestlichen Siebenbürgens. Jahrbuch Ungarn Geologische Anstalt: 293-350.

Hirtopanu, P., Jakab, G., Andersen, C., Fairhurst, J. 2013: Thorite, thorogummite and xenotime-(Y) occurrence in Ditrau alkaline intrusive massif, East Carpathians, Romania. Proceed. Roman. Acad. Ser. B 15, 111–132.

Hoeck, V., Ionescu, C., Balintoni, I., & Koller, F. 2009: The Eastern Carpathians "ophiolites" (Romania): Remnants of a Triassic ocean. Lithos, 108(1–4), 151–171. https://doi.org/10.1016/j.lithos.2008.08.001

Honour V.C. Goodenough, K.M., Shaw, R.A., Gabudianue, I., Hirtopanu, P. 2018: REE mineralisation within the Ditrău Alkaline Complex, Romania: Interplay of magmatic and hydrothermal processes, Lithos 314–315 (2018) 360–381.

Ianovici, V. 1938: Considerations sur la consolidation du massif syenitique de Ditrau, en relation avec la tectonique de la region. CR Acad Sci Roum 2, 689-694.

Ianovici, V. 1933: Étude sur le massif syénitique de Ditráu, région Jolotca, district Ciuc (Transylvanie). Ann. Scient. Univ. Jassy, 20, 86-97.

Ianovici, V., Rădulescu, D., Rădulescu, I. & Săndulescu, M. 1968: Crystalline, Mesozoic complexes and volcanism in the East Carpathians (Central Sector). Guide to Excursion 47 AC, Romania, International Geological Congress XXIIIrd Session,Prague, 1968. Bucharest: Geological Institute of Romania, 56 p.

Jakab, Gy. & Garbaşevschi, N. 1977: Consideration on the pyrite from the Jolotca vein mineralisation (Eastern Carpathians). Dări de Seamă ale Şedinţelor, Institutul de Geologie şi Geofizică, Bucharest, 63: 13–25 (in Romanian).

Jakab, Gy., 1998. Geologia Masivului alcalin de la Ditrău. Pallas-Akademia, Miercurea-Ciuc.

Kräutner, HG and Bindea, G. 1995: Structural units in the prealpine basement of the Eastern Capathians, Geologica Carpathica, 46, 203–204.

Kräutner, H.G. 1991: Prealpine geological evolution of the East Carpathians metamorphics. Some common trends with the West Carpathians, Geologica Carpathica, 42/4, 209-217.

Kräutner, H. G. 1980: Lithostratigraphic correlation in Precambrian of the Romanian Carpathians). An. Inst. Geol. Geofiz., 57, 229–296. (in Romanian)

Kräutner, H. G. 1988: East Carpathians. In Zoubek, V. (ed.): Precambrian in Younger Fold Belts. London: Wiley, 625–638.

Kräutner, H. G. 1996: Alpine rifting, subduction and collision in the Romanian Carpathians. In: Amann, G., Handler, R, Kurz, W., Steyer, H. P. (eds.): VI. Symposium für Tektonik Struktur- und Kristallingeologie, Salzburg. 230–234.

Kräutner, H. G., Bindea, G. 2002: Structural units in the pre-Alpine basement of the Eastern Carpathians. Geologica Carpatica, Spec. Issue, 53, 143–146.

Kräutner, H. G., Kräutner, F., Tănăsescu, A., Neacsu, V. 1976: Interpretation des ages radiometriques K/Ar pour les roches metamorphiques regenerees. Un exemple - les Carpates Orientales. (Interpretation of the K-Ar ages in the polymetamorphic rocks. An example: East Carpathians) An. Inst. Geol. Geof., 50, 167–229.

Kräutner, H.G. & Bindea, G. 1995: The Ditrău alkaline intrusive complex and its geological environment. In Guidebook to excursion E, 3rd Symposium on Mineralogy, Bucharest. Romanian Journal of Mineralogy, 77, Suppl. 3, 18.

Kräutner, H.G. & Bindea, G. 1998: Timing of the Ditrău alkaline intrusive complex (Eastern Carpathians, Romania). Slovak Geological Magazine, 4, 213–221.

Matenco, L., Krezsek, C., Merten, S., Schmid, S., Cloetingh, S., Andriessen, P. 2010: Characteristics of collisional orogens with low topographic build-up: an example from the Carpathians. Terra Nova 22, 155–165.

Mihăilescu, V. 1940: Cum s-a format Lacul Roşu de la intrarea Cheilor Bicazului, Bul. Soc Rom Geogr, LVIII/LIX), 322–326.

Morogan, V., Upton, B., Fitton, J. 2000: The petrology of the Ditrău alkaline complex, Eastern Carpathians. Mineral. Petrol. 69, 227–265.

Mosonyi, E. 1999: Geological and structural studies on metamorphics from the southern part of Rodna Mts. Unpublished PhD thesis. Univ. "Babeş–Bolyai", Cluj-Napoca

Mosonyi, E. 2003: Retrogressed eclogitic rocks in the Rodna Mts (East Carpathians, Romania). EMU workshop "Ultra High Pressure" 18-28 July, 2003 Budapest. Acta Miner. Petrogr. (Szeged), Abstracts, 23.

Munteanu, M., Tatu, M. 2002: The East-Carpathian Crystalline-Mesozoic Zone (Romania): Paleozoic Amalgamation of Gondwana- and East European Craton-derived Terranes. Gondwana Research, Intern. Assoc. Gondwana Research, Japan. 6/2, 185–196.

Mureșan, M. 1983: Relations entre le massif alcalin de Ditrău et le nappés de charriage des Carpathes Orientales. An Inst Geol Geof, Congr XII Asoc Carp- Balk LX: 159-168.

Pál-Molnár E., Batki A. and Ódri Á. 2010: Mineralogy of nepheline syenite dykes from the Ditrău Alkaline Massif, Romania. In: Zaharia L, Kis A, Topa B, Papp G, Weiszburg TG (ed.) IMA2010, 20th General Meeting of the International Mineralogical Association 21–27 August, 2010 Budapest, Hungary. Acta Min. Petr. Abstr. Ser. 6, p. 529.

Pál-Molnár, E. 2010: Rock-forming minerals of the Ditrău Alkaline Massif, Eastern Carpathian, in: Mineralogy of Székelyland, Eastern Transylvania, Romania, Ed. Szakáll S. and Kristály F, Csik County Nature and Conservation Society, Sfântu Gheorghe- Miercurea Ciuc- Târgu Mureș, 63-89.

Pál-Molnár, E. 2000: Homblendites and diorites of the Ditrău Syenite Massif. Ed: Dept, of Mineralogy, Geochemistry and Petrology, University of Szeged, 172p.

Pană, D., Balintoni, I., Heaman, L., & Creaser, R. 2002: The U-Pb and Sm-Nd dating of the main lithotectonic assemblages of the Eastern Carpathians, Romania. Geologica Carpathica, 53, 177–180.

Pişotă, I. & Năstase, A. 1957: Lacul Rosu, nod de confluență a trei bazine hidrografice. Probl. Geogr. IV, 181–203.

Ratschbacher, L., Merle O., Davy, P. & Cobbold P. 1991: Lateral extrusion in the Eastern Alps, Part 1: Boundary conditions and experiments scaled for gravity, Tectonics, 10(2), 245–256, doi:10.1029/90TC02622.

Ratschbacher, L., Frisch, W. Linzer H.-G. & Merle O. 1991a: Lateral extrusion in the Eastern Alps, Part 2: Structural analysis, Tectonics, 10(2), 257–271, doi:10.1029/90TC02623.

Sandu, M. C., Iancu, G. O., Chelariu, C., & Niculita, M. 2018: Preliminary study on the geochemistry of stream sediments from Grintietul Mare Brook, Eastern Carpathians, Romania. Rom. J. Mineral Deposits 91(1-2), 79–84.

Sandu, M. C., Iancu, G. O., Chelariu, C., Ion, A., Balaban, S. I., & Scarlat, A. A. 2020: Radiological risk assessment and spatial distribution of naturally occurring radionuclides within riverbed sediments near uranium deposits: Tulgheș-Grințieș, Eastern Carpathians (Romania). Journal of Radiation Research and Applied Sciences 13(1), 730–746. doi:10.1080/16878507.2020.1838038

Săndulescu, M., Mureşan, M., & Mureşan, G. 1975: Geological map of Romania, 1:50.000, L-35-40-D, Map sheet 47d Dămuc.

Săndulescu, M., Mureşan, M., Mureșan, G., Săndulescu, D., & Alexandrescu, G. 2018: Geological map of Romania, 1:50.000, L-35-40-B, Map sheet 47b Tulgheș.

Alexandrescu, G., Mureşan, G., Peltz, S., & Săndulescu, M. 1968: Geological map of Romania, 1:200.000, L-35-VIII, Map sheet 12 Toplița.

Săndulescu, J. 1967: Contributii microppaleontologice la cunoasterea Cretacicului din sinclinalul Haghimas. DDS, Ser. Stratigraphy, LIV/3, pg. 307.

Săndulescu, M. 1975: Studiul geologic al părții centrale şi nordice al sinclinalului Hăghimaş (Carpații Orientali), An. Inst. De Geol. si Geof. Vol. XlV, Bucuresti.

Săndulescu, M. 1967a: La nappe de Hăghimaş une nouvelle nappe de decollement dans les Carpathes Orientales. Carp.-Balk. Geol. Assoc., VIII Congr., (Géotectonique), I: 179-185, Belgrad.

Săndulescu, M, 1967b: Structura geologica a părții centrale a sinclinalului Hăghimaş, DDS, Stratigraphy, LVI/3, 227-253.

Săndulescu, M. & Dimitrescu, R. 2004: Geological Structure of the Romanian Carpathians. Field trip guide book – B12. 32nd International Geological Congress. Rome: APAT, 48 p.

Săndulescu, M. 1975: Essai de synthèse structurale des Carpathes. Bulletin de la Société Géologique de France, Série 7, 17 (3) 299–358. Paris

Săndulescu, M. 1988: Cenozoic Tectonic History of the Carpathians. In: Royden, L.H. and Horváth, F., Eds., The Pannonian Basin: A Study in Basin Evolution, Am. Assoc. Pet. Geol. Memoir, 45, 17-25.

Săndulescu, M. 1988a: Probleme tectonice de la curbura internă a Carpaţilor Româneşti (Les problemes tectoniques de la courbure interne de Carpathes Roumaines.) Dări Seamă Inst. Geol. Geofiz. Rom., 72-73/5, 283–289. (in Romanian)

Săndulescu, M. 2009: The black flysch nappe of the Maramureş, East Carpathians - A “valaisanne-type” tectonic unit? Proc. Rom. Acad., Series B, 1, 45–51

Săndulescu, M. 1984: Geotectonica României. (Geotectonics of Romania). Bucureşti: Ed. Technică. 336p. (in Romanian)

Săndulescu, M. 2004: Geological Structure of the Romanian Carpathians, 32nd International Geological Congress, Italy, Vol.1 from PR01to B15, Trip Guide Book B12.

Săndulescu, M., Kräutner, H. G., Balintoni, I., Russo-Săndulescu, D., Micu, M. 1981: The structure of the East Carpathians (Moldavia- Maramureş Area). Guide to Excursion B1 of the XIIth Carp.-Balkan Geol. Congr., Bucharest. Inst. Geol. Geoph. Rom., Bucureşti. 92p.

Săndulescu, M. 1975: Studiul geologic al părţii centrale şi nordice a sinclinalului Hăghimaş (Carpaţii Orientali). An Inst. Geol. Rom., XLV, Bucureşti.

Savul, M. 1938: Le cristalin de Bistrița. La région Dorna - Broşteni. Ann. Sci. Univ. Iassy, 24, 2, 206-285.

Schmid, S. M. Fügenschuh, B., Kounov, A., Maţenco, L., Nievergelt, P., Oberhänsli, R., van Hinsbergen, D. J. J. 2020: Tectonic units of the Alpine collision zone between Eastern Alps and western Turkey. Gondwana Research, 78(February), 308–374. https://doi.org/10.1016/j.gr.2019.07.005Ionescu et al, 2009

Seghedi, I., Downes, H., Szakács, A., Mason, P.R.D., Thirlwall, M.F., Roşu, E., Pécskay, Z., Marton, E. & Panaiotu, C. 2004: Neogene- Quaternary magmatism and geodynamics in the Carpathian-Pannonian region: a synthesis. Lithos, 72: 117–146.

Seghedi, I., Szakács, A., Pécskay, Z. & Mason, P.R.D. 2005: Eruptive history and age of magmatic processes in the Călimani volcanic structure (Romania). Geologica Carpathica, 56: 67–75.

Streckeisen, A. 1960: On the structure and the origin of the nepheline syenite complex of Ditró (Transylvania, Rumania). 21th International Geological Congress, Report, 13: 228–238

Streckeisen, A. 1952: Das Nephelinsyenit- Massiv von Ditro (Siebenbürgen), I. Teil.Schweiz. Mineral. Petrogr. Mitt., 32, 251-309.

Streckeisen, A. 1954: Das Nephelinsyenit- Massiv von Ditro (Siebenbürgen), II. Teil.Schweiz. Mineral. Petrogr. Mitt., 34, 336- 409.

Streckeisen, A., Hunziker, J. 1974: On the origin and age of the Nepheline Syenite Massif of Ditro (Transsylvania, Rumania). Schweiz. Mineral. Petrogr. Mitt. 54, 59–77.

Strutinski, C., Puste, A., Stan, R. 2006: The metamorphic basement of Romanian Carpathians: a discussion of K-Ar and 40Ar/39Ar ages Studia Universitatis Babeş-Bolyai, Geologia, 2006, 51 (1-2), 15 – 21

Szakács A. & Seghedi I. 1996: Volcaniclastic sequences around andesitic stratovolcanoes, East Carpathians, Romania, Workshop guide, of the IAVCEI, CEV and CVS commissions. Rom. Jour. of Petrology, 77, supplement 1, 55p.1.5

Tischler, M., Matenco, L., Filipescu, S., Gröger, H. R., Wetzel, A., & Fügenschuh, B. 2008: Tectonics and sedimentation during convergence of the ALCAPA and Tisza-Dacia continental blocks: The Pienide nappe emplacement and its foredeep (N. Romania). Geological Society Special Publication, 298, 317–334.https://doi.org/10.1144/SP298.158

Tofan, G. B., Niţă, A., Nimară, C, Păcurar, B. N. 2016: The Exploitation of the Tulgheş-Grinţieş uranium deposit. Between benefits and controversy Studia UBB Geographia, LXI, 1, 2016, pp. 105 – 114

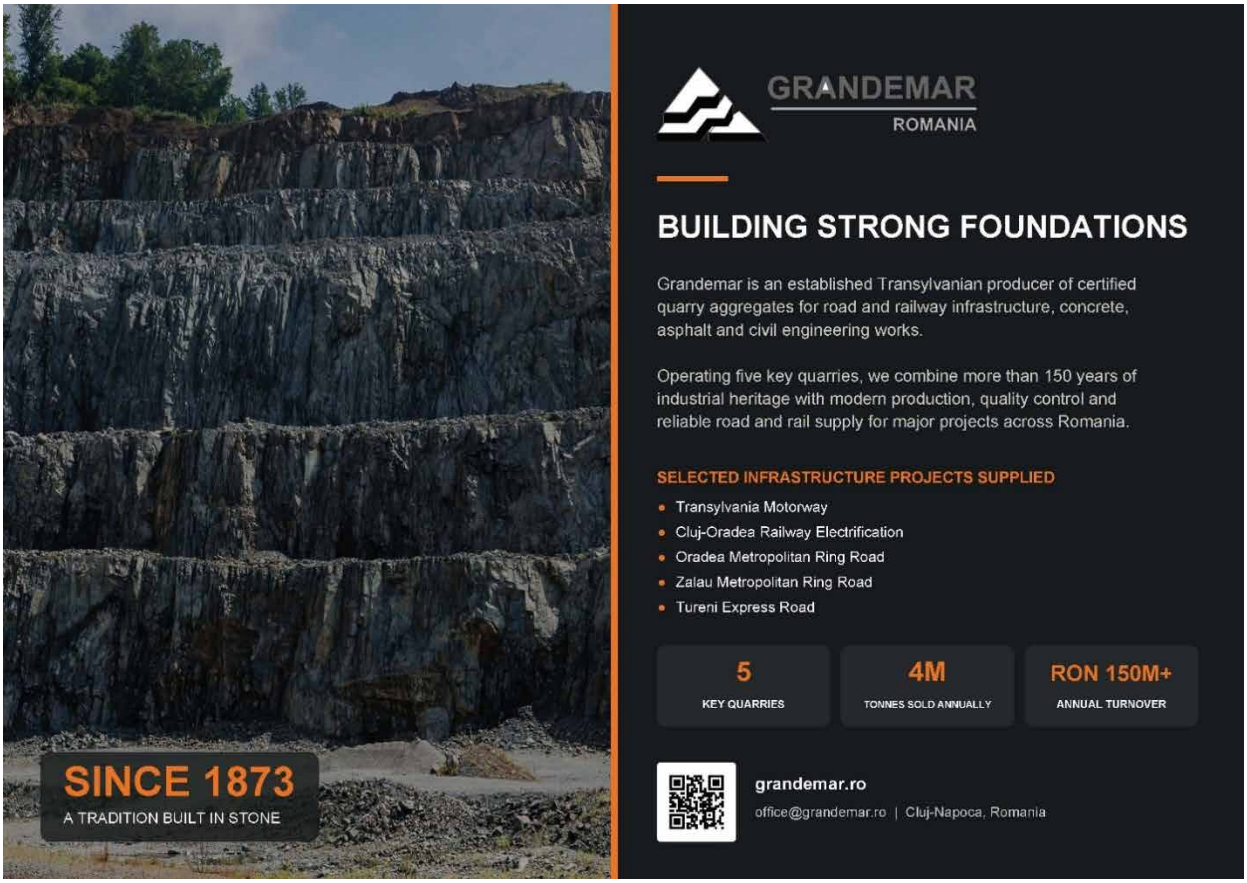
Ustaszewski, K., Kounov, A., Schmid, S. M., Schaltegger, U., Krenn, E., Frank, W., & Fügenschuh, B. 2010: Evolution of the Adria-Europe plate boundary in the northern Dinarides: From continent-continent collision to back-arc extension. Tectonics, 29(6), TC6017. https://doi.org/10.1029/2010TC002668

Vadasz, E. 1915: Geologische Beobachtungen im Persanyer und Nagyhagymas Gebirge.- Mitteilungen aus dem Jahresbericht der koeniglichen ungarischen geologischen Reichsanstalt, Budapest, p. 264-298.

Vaida, M. 1998: Palynological dating and correlation of metamorphic formations and associated syngenetic mineralizations of the southern Eastern Carpathians and Eastern-South Carpathians]. PhD thesis. Univ. “Al. 1. Cuza”, Iaşi. (in Romanian)

Vodă, A. 2013: Cârlibaba-Broşteni strike-slip fault - a possible old segment of Bogdan Vodă -Dragoş Vodă fault system: implications for the structural and metallogenetic correlations in the Crystalline-Mesozoic Zone of the Eastern Carpathians (Romania), Romanian Journal of Earth Sciences, vol. 87(2013), issues 1-2, p. 57-64.

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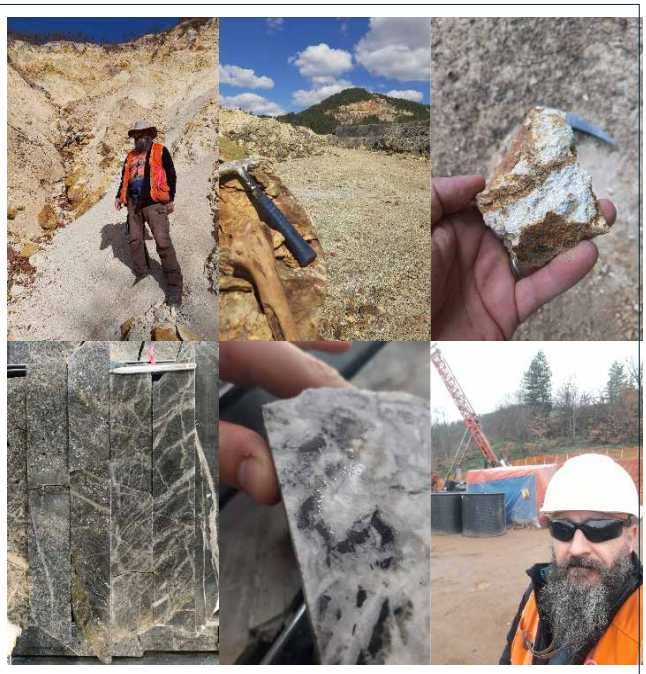


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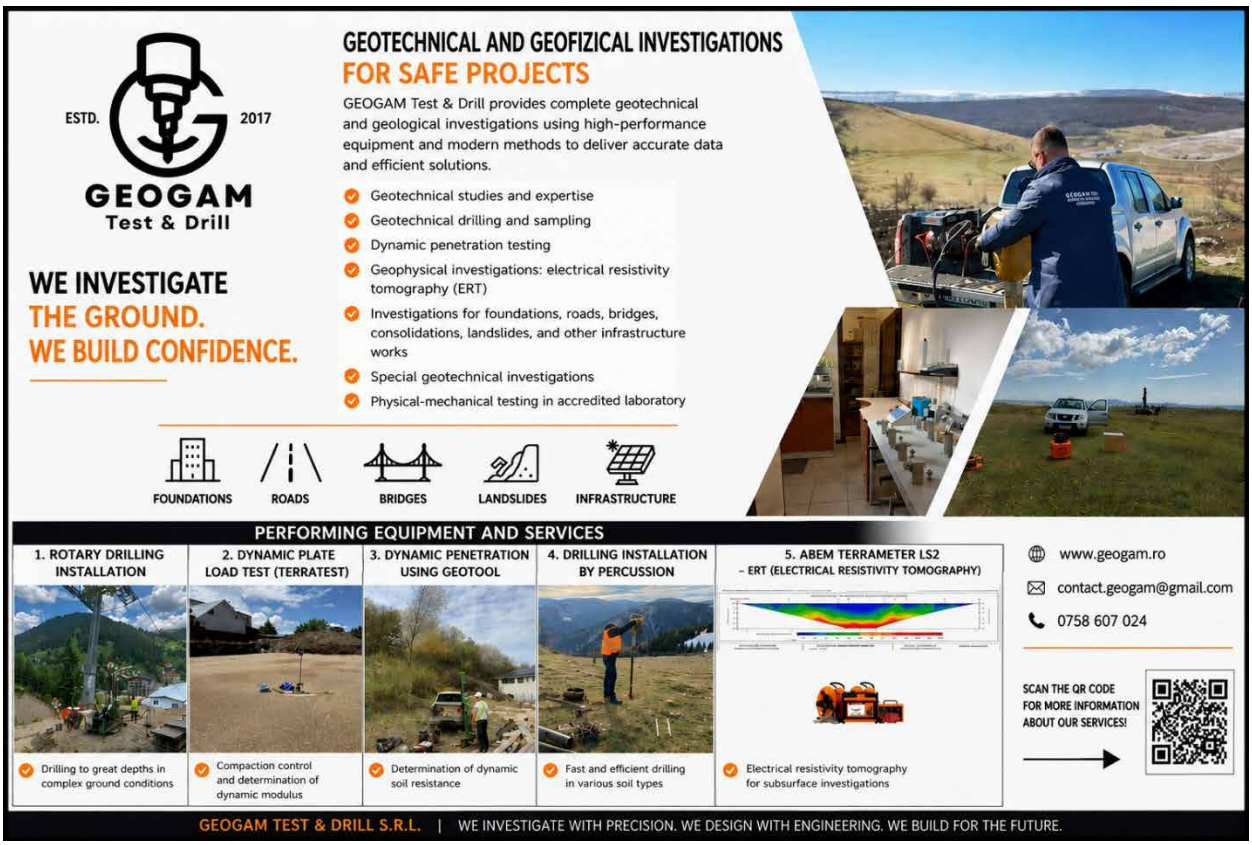


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