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New insights into the depositional environment and stratigraphic position of the Gugu Breccia (Pădurea Craiului Mountains, Romania)

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Abstract: The study of the carbonate clasts and matrix of a problematic sedimentary formation (the Gugu Breccia) from the Pădurea Craiului Mountains reveals new information concerning its depositional environment and stratigraphic position. The identified microfacies and micropaleontological assemblages demonstrate that all the sampled limestone clasts from the Gugu Breccia represent remnants of a fragmented Urgonian-type carbonate platform. The Barremian age of the clasts suggests that the stratigraphic position of the Gugu Breccia at its type locality could be uppermost Barremian-lowermost 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. The sedimentological observations together with the matrix mineralogy bring new arguments for the recognition of terrigenous input during the formation of the Gugu Breccia.

Key-words:

- breccia;
- microfacies;
- carbonate platforms;
- matrix mineralogy;
- benthic foraminifera;
- calcareous algae;
- Lower Cretaceous;
- Romania

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Résumé : ***Nouvel aperçu sur l'environnement de dépôt et la position stratigraphique de la Brèche de Gugu (Monts Pădurea Craiului, Roumanie).-*** L'analyse des clastes carbonatés et de la matrice d'une formation sédimentaire problématique, à savoir la Brèche de Gugu, dans les Monts Pădurea Craiului, apporte des précisions quant à son environnement de dépôt et sa position stratigraphique. Les microfaciès et assemblages micropaléontologiques identifiés démontrent que tous les clastes carbonatés échantillonnés dans la Brèche de Gugu représentent les vestiges d'une plate-forme carbonatée démantelée de type Urgonien. L'âge barrémien des clastes suggère que la position stratigraphic de la Brèche de Gugu dans sa localité-type pourrait être Barrémien terminal-Aptien basal, une donnée également soutenue par l'absence d'éléments provenant des plates-formes carbonatées du Crétacé inférieur situées plus haut dans la colonne stratigraphique (*e.g.*, Aptien ou Albien) de l'Unité de Bihor. Les observations sédimentologiques et la minéralogie de la matrice ont fourni de nouveaux arguments en faveur de la reconnaissance d'apports terrigènes pendant la mise en place de la "Gugu Breccia".

Mots-clefs :

- brêches ;
- microfaciès ;
- plates-formes carbonatées ;
- minéralogie de matrice ;
- foraminifères benthiques ;
- algues calcaires ;
- Crétacé inférieur ;
- Roumanie

1. Introduction

The Lower Cretaceous sedimentary deposits from the Pădurea Craiului Mountains (Bihor Unit, Northern Apuseni Mountains of Romania) have been the subject of many geological studies during the last decades (Cociuba, 2000; Avram *et al.*, 2001; Dragastan & Ciobanu, 2002; Dragastan *et al.*, 2009; Bucur *et al.*, 2010, 2013; Lazăr *et al.*, 2012; Papp *et al.*, 2013; Bruchental *et al.*, 2014; Pleş *et al.*, 2016a), originating from the numerous unsolved issues regarding the stratigraphic position and outcropping areas of the known lithostratigraphic units. Even though several authors (Bucur & Cociuba, 1998; Cociuba, 2000; Bucur *et al.*, 2008, 2013) managed to clarify some of these problems, more is still needed to be done in order to fully comprehend the real extension and age of these deposits.

An example of such an unresolved issue is given by the stratigraphic position and depositional setting of the Gugu Breccia. This breccia-type deposit crops out in limited areas from the central (Letii Hill-Gugu area) and south-western parts (Răcaş area) of the Pădurea Craiului Mountains (Cociuba, 1999). It consists mostly of centimeter to meter-sized Jurassic and Lower Cretaceous carbonate elements embedded either in sparitic cements, or in a reddish terrigenous matrix (Patrulius *et al.*, 1982; Cociuba, 2000). It was first placed by Patrulius *et al.* (1982) at the boundary between the Coposeni Member (*cf.* Cociuba, 2000) and the Ecleja Formation (lowermost Aptian/Bedoulian, Fig. 1.A). According to the latest studies on the Lower Cretaceous succession of the Bihor Unit (Papp *et al.*, 2013; Bucur *et al.*, 2013; Pleş *et al.*, 2016a), its position is placed at the boundary between the Valea Măgurii Formation and the Vârciorog Formation (boundary between lower and upper Aptian, Fig. 1.B) based on the existing regional discontinuity on the uppermost part of the Valea Măgurii Formation. Even so, no detailed microfacies study has been undertaken on the carbonate elements of the Gugu Breccia until now, and this might bring new arguments regarding the actual micropaleontological content of these limestone clasts and their age respectively. Such an investigation can also constrain the depositional setting, since no mineralogical/geochemical studies were made on the matrix of this deposits. Therefore, the stratigraphic position and the sedimentary setting of this problematic unit are still debatable.

The sampling of a large number of carbonate clasts from the existing Gugu Breccia outcrops can reveal clues for the identification of the depositional environments of the fragmented platform carbonates, the source area of the limestone elements and new arguments regarding the stratigraphic position of this sedimentary sequence within the Lower Cretaceous succession from Pădurea Craiului Mountains. Also, new information regarding the sedimentary setting of this breccia can be highlighted through X-ray diffraction of matrix samples. These represent the main objectives of the present study.

2. Brief geological setting

The Lower Cretaceous sedimentary sequence from Pădurea Craiului Mountains belongs to the Bihor Unit (Săndulescu, 1984) as part of the so-called Tisza Mega-Unit (*sensu* Schmid *et al.*, 2008). It comprises mostly carbonate deposits (Patrulius *in* Ianovici *et al.*, 1976; Dragastan *et al.*, 1988, 1989; Cociuba, 2000; Bucur *et al.*, 2013; Pleş *et al.*, 2016a) (Fig. 1). According to Cociuba (2000), the Lower Cretaceous sequence consists of the following lithostratigraphic units: the Blid Formation (including the Dobreşti and Coposeni Members), Ecleja Formation (with Valea Bobdei Limestone Member), Valea Măgurii Formation and Vârciorog Formation (Fig. 1.A-B).

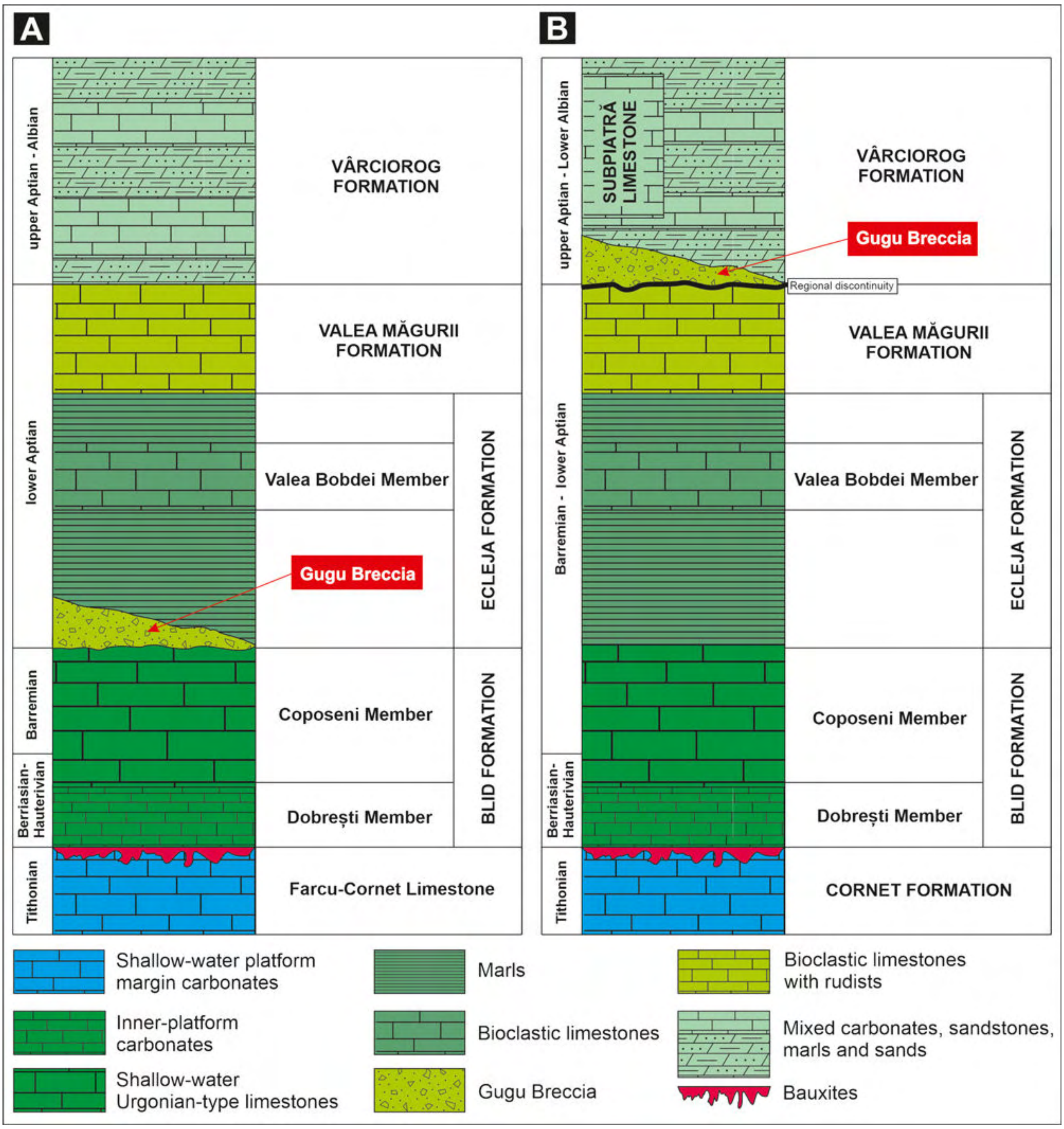
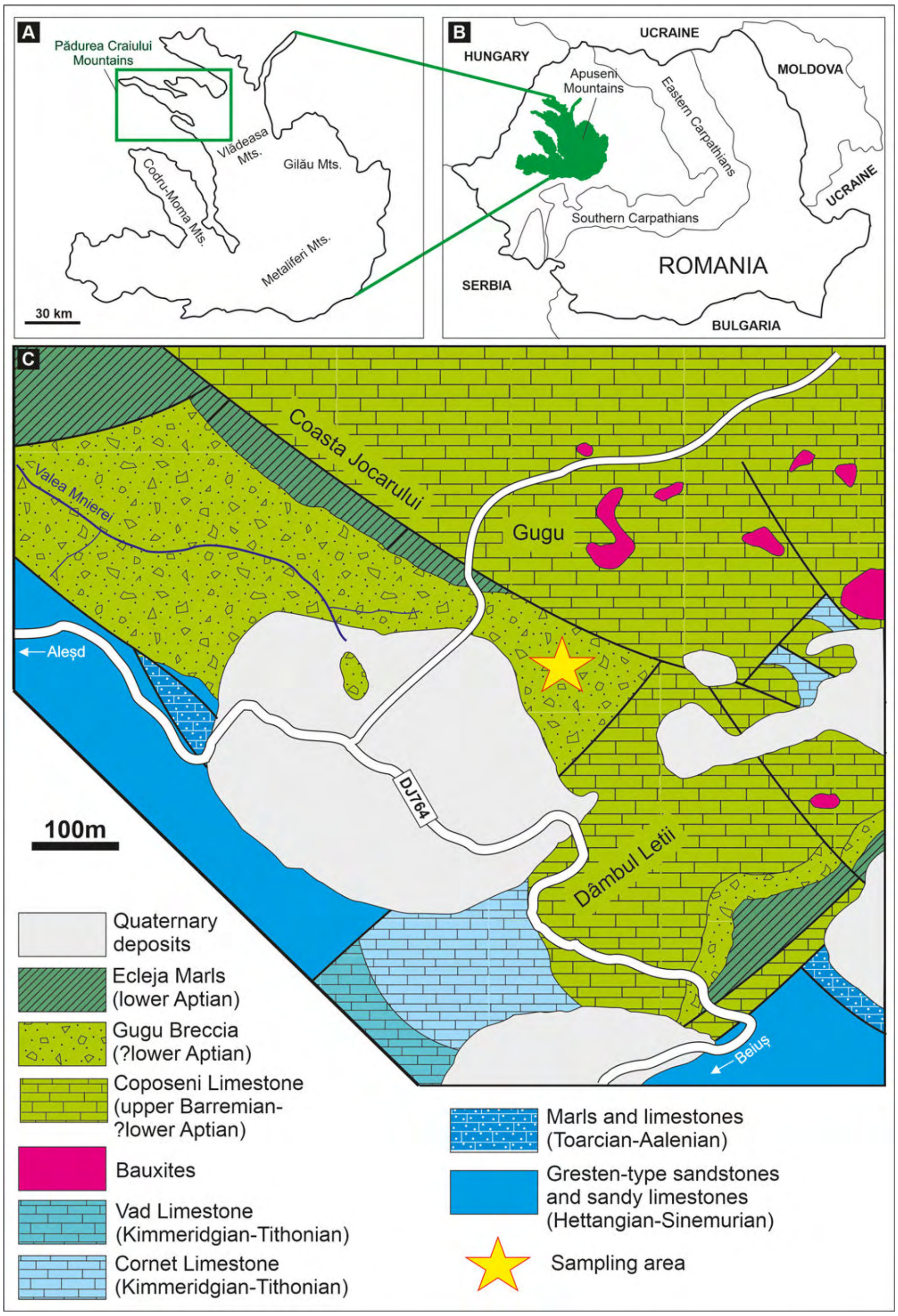


Figure 1: A-B) Lower Cretaceous succession of the Pădurea Craiului Mountains modified after COCIUBA (2000) and BUCUR *et al.* (2013). Notice in (A) the stratigraphic position of the Gugu Breccia according to PATRULIUS *et al.* (1982) and COCIUBA (2000) and in (B) - the position of the Gugu Breccia according to PAPP *et al.* (2013) and BUCUR *et al.* (2013).

The Blid Formation (Berriasian-Barremian) transgressively overlies the Upper Jurassic sequence and comprises stratified micritic bioclastic shallow-water carbonates (DRAGASTAN *et al.*, 1986; COCIUBA, 2000). The Dobreşti Member or "*the limestone with characeans*" (*sensu* PATRULIUS *in* IANOVICI *et al.*, 1976) is represented by dark brackish inner-platform limestone levels with green algae (characeans), ostracods and foraminifera and is sometimes interbedded with bauxitic lenses (COCIUBA, 2000). Its age (Berriasian-Hauterivian) was determined based on the following assemblage: *Salpingoporella annulata* CAROZZI, *Clypeina parasolkani* FARINACI & RADOIČIĆ, *Haplophragmoides joukowski* CHAROLLAIS *et al.*, and *Montsalevia salevensis* CHAROLLAIS *et al.* (COCIUBA, 1999; BUCUR, 2000). On top of these limestones, ?Hauterivian-upper Barremian Urgonian-type carbonates are developed (BUCUR & COCIUBA, 1998). These carbonates represent the "*lower pachyodont limestone*" (*sensu* PATRULIUS *in* IANOVICI *et al.*, 1976) or the Coposeni Member (*sensu* COCIUBA, 2000). The most biostratigraphically relevant microfossils within the Coposeni Member were



◀ **Figure 2: A)** Location of Pădurea Craiului Mountains within the Northern Apuseni Mountains; **B)** Location of the Apuseni Mountains; **C)** Geological map of the Gugu Breccia type locality (Dealu Letii-Gugu) and the location of the sampling area (modified from PATRULIUS *et al.*, 1982).

identified by BUCUR & COCIUBA (1998) and COCIUBA (1999): *Moulladella jourdanensis* (FOURY & MOULLADE), *Palorbitolina lenticularis* (BLUMENBACH), *Salpingoporella melitae* RADOIČIĆ, and *S. muelhbergii* (LORENZ).

The Ecleja Formation (PATRULIUS *et al.*, 1982, ?Barremian-lower Aptian) crops out on wide areas within the studied region and consists mostly of marls and some bioclastic carbonate levels (Valea Bobdei Member *sensu* COCIUBA, 2000) with shallow-water microfossils: *Orbitolinopsis kiliani* SILVESTRI, *O. buccifer* ARNAUD-VANNEAU & THIEULOY, *Palorbitolina lenticularis*, *Paracoskinolina maynci* (CHEVALIER), and *Nezzazatinella macovei* NEAGU (COCIUBA, 1999, 2000). This assemblage pleads for a Bedoulian age (early Aptian) for the Valea Bobdei Member.

The Valea Măgurii Formation (lower Aptian, Bedoulian) (COCIUBA, 2000), previously known as the "*middle pachyodont limestone*" (*sensu* PATRULIUS *in* IANOVICI *et al.*, 1976), is developed above the Ecleja marls and is represented by thick massive banks of gray bioclastic limestones with rudists, calcareous green algae and benthic foraminifers. According to COCIUBA (2000), the micropaleontological content of the Valea Măgurii Formation is partly similar with the one from the Valea Bobdei Member and pleads for an early Aptian (late Bedoulian) age. The upper part of this formation is characterized by a distinct erosional surface (regional discontinuity), best visible in the Valea Măgurii limestone quarry near Dobreşti Village.

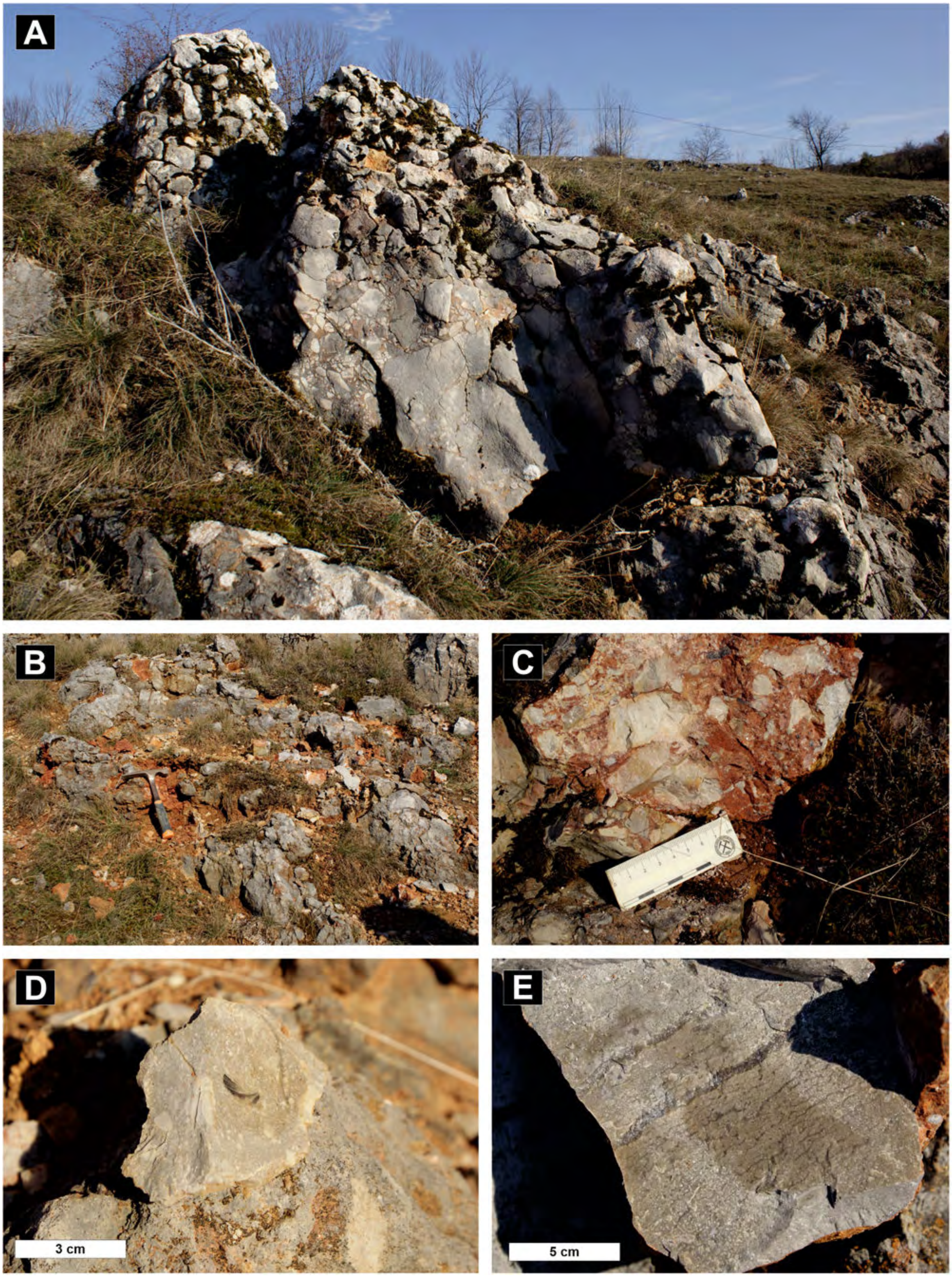


Figure 3: Field pictures from the Gugu Breccia outcrop in Dealu Letii-Gugu. **A)** The upper part of the outcrop. Notice the chaotic appearance of the main components and also the size differences between the carbonate clasts; **B)** Decimeter-sized clasts embedded in a reddish detrital matrix (middle part of the outcrop); **C)** Micritic limestone clasts within a reddish matrix; **D)** Granular bioclastic limestone clast with bivalve (rudist) shell fragments; **E)** Fenestral fabrics within a limestone clast from the median part of the outcrop.

The youngest unit of the Lower Cretaceous sequence from the Pădurea Craiului Mountains is represented by the Vârciorog Formation (upper Aptian/Gargasian-Albian) (Cociuba, 2000) or the "*glauconitic sandstone and upper limestone with pachyodont complex*" (Patrulius *in* Ianovici *et al.*, 1976). As its previous name indicates, this mixed lithostratigraphic unit is composed of sandstones with glauconite, conglomerates and marls alternating with limestones levels. Also, shallow-water bioconstructed carbonates (Subpiatră Limestone Member) were laterally developed within the Vârciorog Formation (Cociuba, 2000; Bucur *et al.*, 2008, 2010, 2013; Pleş *et al.*, 2016a). The Subpiatră Limestone contains rudists, calcareous green algae and the orbitolinid *Mesorbitolina texana* (Roemer) that indicate a late Aptian/Clansayesian-middle Albian age (Schroeder *et al.*, 2010; Bucur *et al.*, 2010, 2013).

3. Methodology

The present study is based on 204 thin-sections made from 200 limestone clasts and several matrix samples collected from the Gugu Breccia type-locality (Letii Hill-Gugu). The studied outcrop is located in the vicinity of Tomnatic Village, GPS coordinates: 46°54'41.0"N 22°26'43.0"E (Fig. 2). Here, the breccia deposits crop out over a wide area that permitted selective sampling. The outcrop was divided into five different sectors, each sector being sampled from the lowest part towards the top. It is important to mention that the fact that besides its type locality, no other outcrop with such breccia deposits was identified in the field campaigns performed during the duration of this study. The very few other zones from Pădurea Craiului Mountains where the Gugu Breccia was identified by Cociuba (1999) are not accessible anymore since the outcrops are totally covered (*e.g.*, the Răcaş plateau). To our knowledge, the Letii Hill-Gugu represent the only remaining outcrop where the Gugu Breccia deposits can be observed in the field. Microfacies analyses represent the main method used for revealing the main components, structural/textural traits, biotic assemblages and facies/microfacies associations. The description and classification of the microfacies follows Dunham (1962) and Embry & Klovan (1971). For the integration of the main microfacies assemblages within a general zonation model of a carbonate platform, the "*Standard Microfacies Types*" (SMF) and "*Wilson's Model*" from Flügel (2010) were used.

X-ray diffraction (XRD) was employed on selected matrix samples to determine their mineralogical composition using a Bruker D8 diffractometer with Cu ($\lambda_{K\alpha}$=1.5418Å) and Co ($\lambda_{K\alpha}$= 1.7889Å) tubes. Due to the high amount of calcite in the matrix, the samples were dissolved in acetic acid to remove the carbonate, the remaining material being reanalyzed. The clay fraction (<2 µm) was separated through sedimentation and then deposited on glass slide mounts. The oriented clay samples were successively treated with ethylene glycol (24h) and then heated at 400°C (1h) and 550°C (1h). Mineral identification was done using the Bruker DiffracEVA 2.1 software and the PDF2 database (International Centre for Diffraction Data).

4. Results

Field observations and sedimentological remarks

In the lowest parts of the outcrop the breccia deposits consist of densely packed (clast-supported) centimeter-sized carbonate clasts. The clasts have mainly sub-angular shapes, being represented by both micritic and sparitic facies. In some clasts, bivalve (rudist) fragments and other mollusc shells are well preserved (Fig. 3.D). Towards the middle parts of the outcrop, a relatively chaotic development of the clasts can be observed. It is characterized by the appearance of much larger angular carbonate clasts (decimeter-sized) embedded in a reddish detrital matrix (Fig. 3.B-C). In the uppermost parts of the outcrop, large boulders and numerous centimeter/decimeter sized limestone clasts are present (Fig. 3.A). These carbonate elements possess a wide variety of facies, from fenestral (Fig. 3.E), to granular-micritic and sparitic. Moreover, very small carbonate clasts are visible within the reddish matrix in some cases.

Main microfacies types (MFT) from the sampled carbonate clasts

All of the sampled limestone clasts generally correspond to four main microfacies types based on the observed differences/similarities regarding their morphostructural traits and the existing biotic content. These are represented by: bio-peloidal grainstone (MFT1), bioclastic wackestone (MFT2), bio-oncoidal wackestone (MFT3) and fenestral lime mudstone/wackestone (MFT4). All of the main characteristics of each main microfacies type are presented in Figure 4.

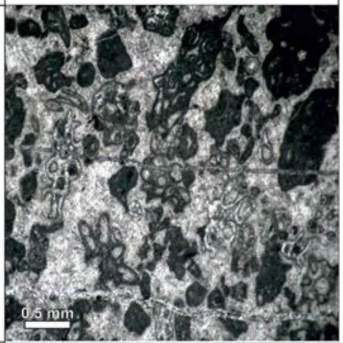
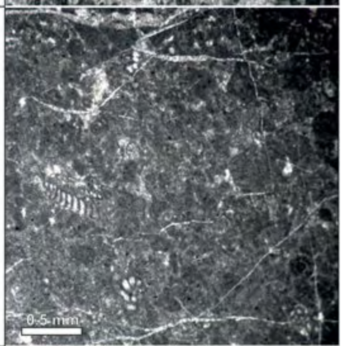
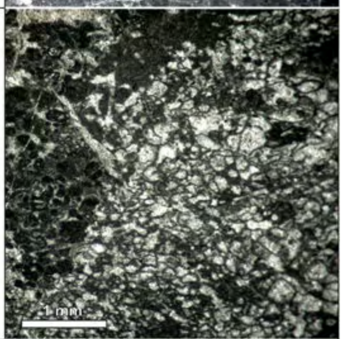
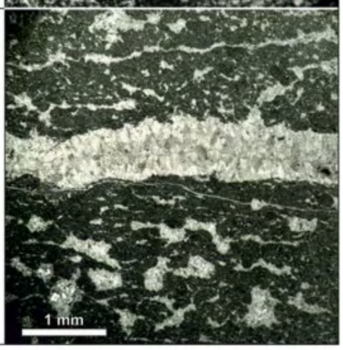
Main microfacies types (MFT)	Facies zones (Wilson Model)	*Standard microfacies types* (Flügel, 2010)	Main components	Microfacies features	Microfacies illustrations
MFT1 - Bio-peloidal grainstone	FZ6-7	SMF 18 - *Bioclastic grainstones and packstones with abundant benthic foraminifera or calcareous green algae*	• Numerous calcareous green algae fragments and benthic foraminifera, mollusc fragments, rare cyanobacteria fragments and echinoid spines; • Abundance of peloids; • Micritic grains; • Scarce aggregate grains; • Rare (mostly micritic) intraclasts	• High abundance of microfossils; • Sorting is moderate to good; • Fragmentation is common; • Plastic deformation is sometimes observed (elongated clasts); • Two generation of marine cements are present (fibrous-isopachous and granular/drusy-type)	
MFT2 - Bioclastic wackestone	FZ7	SMF 8 - *Wackestones and floatstones with whole fossils*	• Mainly benthic foraminifera, calcareous green algae, rudist fragments, rare *Bacinella*-type oncoids; • Peloids and micritic grains	• Poor sorting of the main components; • Cracks and fissures are common; • Different stages of micritization occur (incipient, partly and total); • Rare bioturbational features	
MFT3 - Bio-oncoidal wackestone	FZ8	SMF 22 - *Oncoid floatstones or wackestones*	• Highly abundant *Bacinella*-type oncoids, *Rivularia*-type cyanobacteria, scarce foraminifera and rare small rudist fragments; • Peloids and micritic grains	• Intense microbial activity; • Good development of bacinellid fabrics (oncoids, intra-granular meshworks within rudist shells, microbial micro- and mesostructures); • Rare fenestral pores can be noticed in some cases	
MFT4 - Fenestral lime mudstone/wackestone	FZ8	SMF 21 - *Fenestral bindstones, packstones or mudstones*	• High abundance of peloids and small micritic grains; • Extremely rare foraminifera, small gastropods and *Rivularia*-type cyanobacteria	• Poor microfossils; • Well development of fenestral networks (mainly small sized bird-eyes-type structures); • Thin microbial lamination might occur in some clasts; • Large fissures are common	

Figure 4: General features of the main microfacies types (MFTs) for the sampled clasts from the Gugu Breccia.

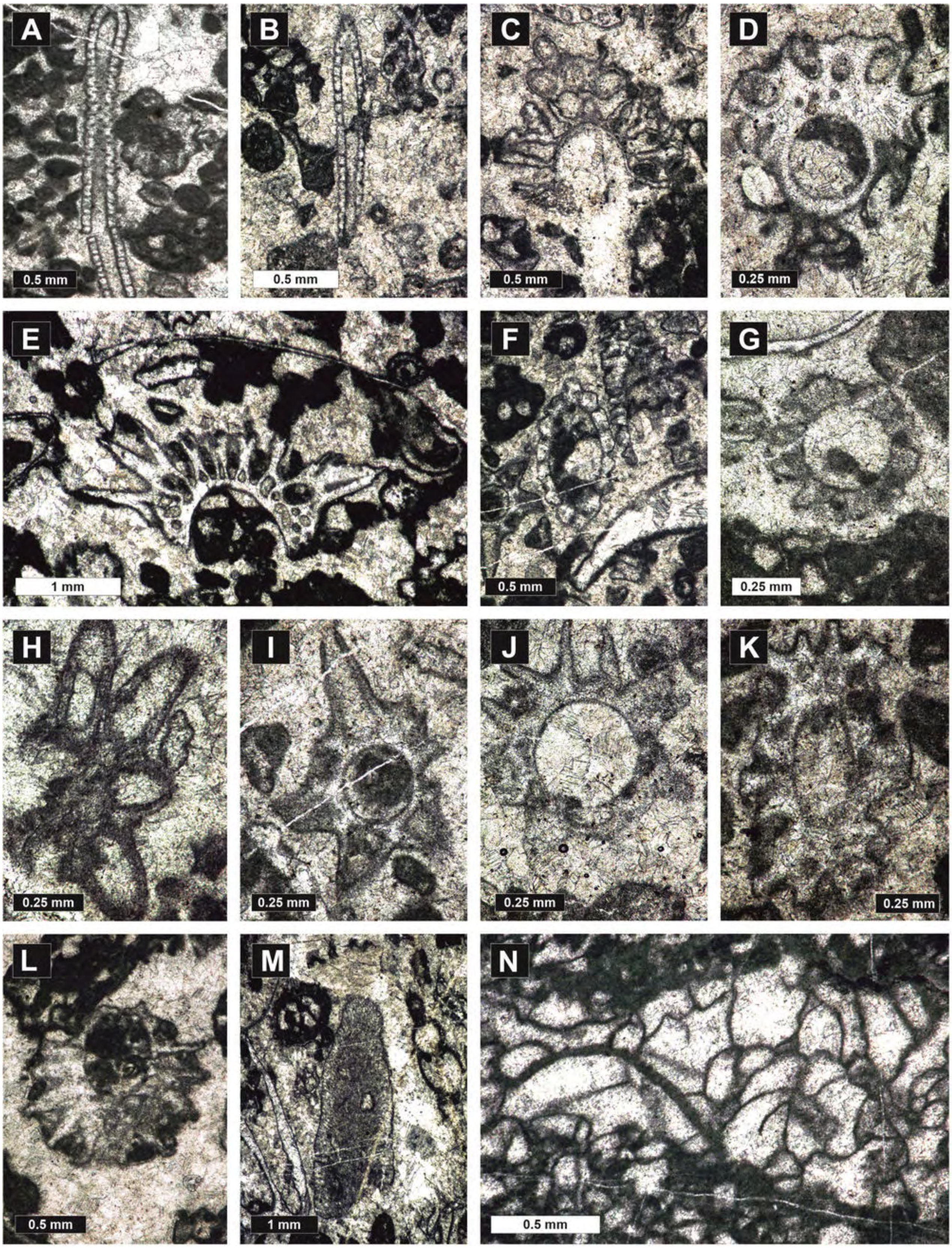


Figure 5: Calcareous algae and micro-problematic organisms from Gugu Breccia carbonate clasts. **A-B)** *Salpingoporella muelhbergii*. Samples 1715B (A) and 1673 (B); **C, J-L)** *Pseudoactinoporella*? *silvaeregis*. Samples 1853 (C), 1673 (J), 1710 (K), 1853 (L); **D)** ?*Falsolikanella danilovae.* Sample 1856; **E)** *Actinoporella podolica.* Sample 1856; **F)** *Salpingoporella heraldica.* Sample 1710. **G)** *Salpingoporella* sp.. Sample 1853; **H-I)** *Clypeina* cf. *maslovi*. Sample 1710 (H), 1710 (I); **M)** *Arabicodium* sp. Sample 1695. **N)** Bacinellid meshwork and *Thaumatoporella parvovesiculifera*. Sample 1792.

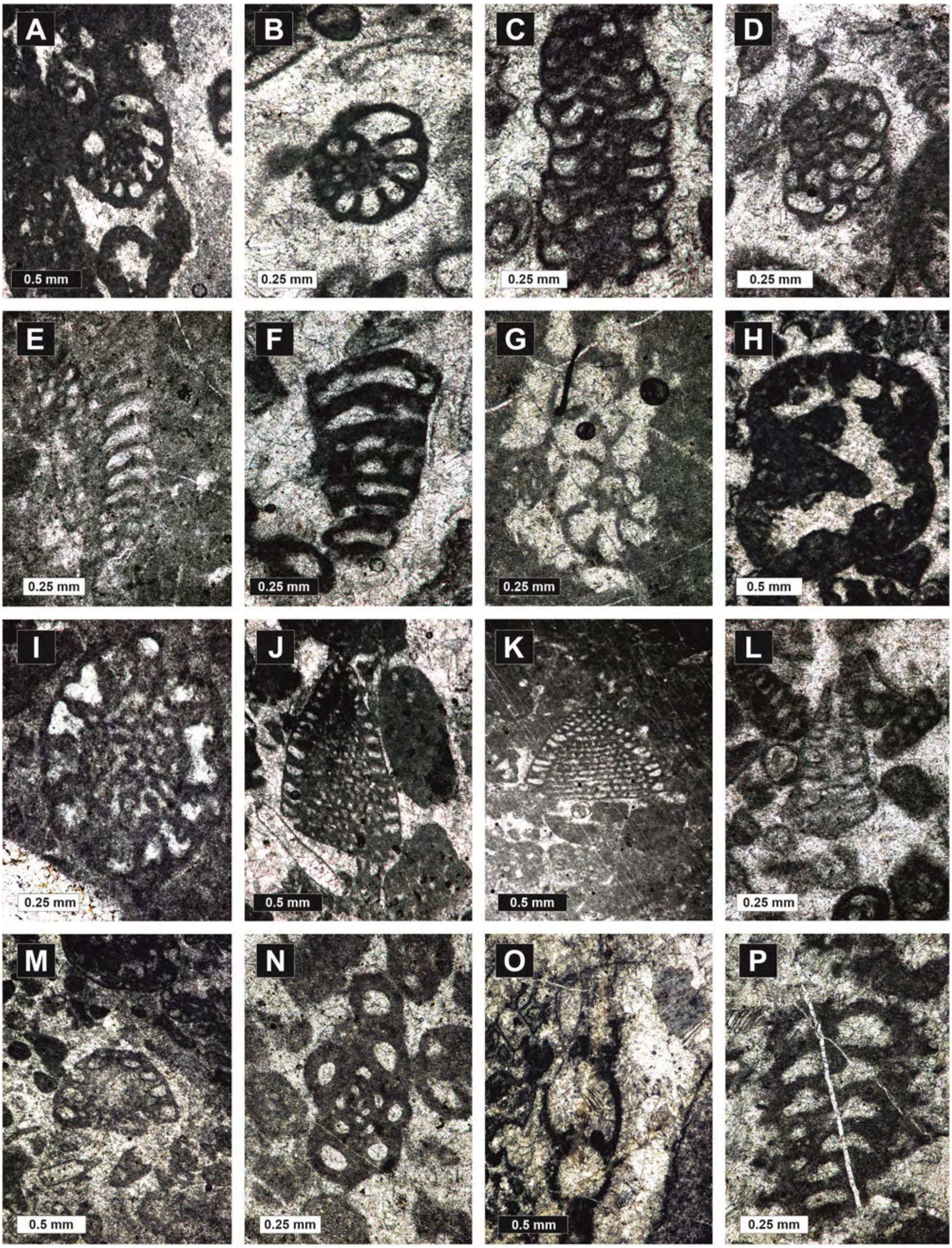


Figure 6: Benthic foraminifers from Gugu Breccia carbonate clasts. **A-B)** *Pfenderina globosa*. Samples 1717 (A) and 1679 (B); **C-D),** *Orbitolinopsis* sp.. Samples 1710 (C) and 1679 (D); **E- F)** *Pseudolituonella gavonensis*. Samples 1698 (E) and 1673 (F); **G)** *Bulbobaculites felixi.* Sample 1814; **H)** *Buccicrenata* cf. *hedbergi*. Sample 1692. **I-K)** *Moulladella jourdanensis*. Samples 1792 (I), 1800 (J) and 1767 (K); **L)** *Coscinoconus* cf. *delphinensis.* Sample 1857; **M)** ?*Coscinoconus* sp.. Sample 1679; **N)** Miliolid foraminifer. Sample 1676; **O)** ?*Bulbobaculites* fragment. Sample 1695; **P)** ?*Kaminskia* sp. Sample 1695.

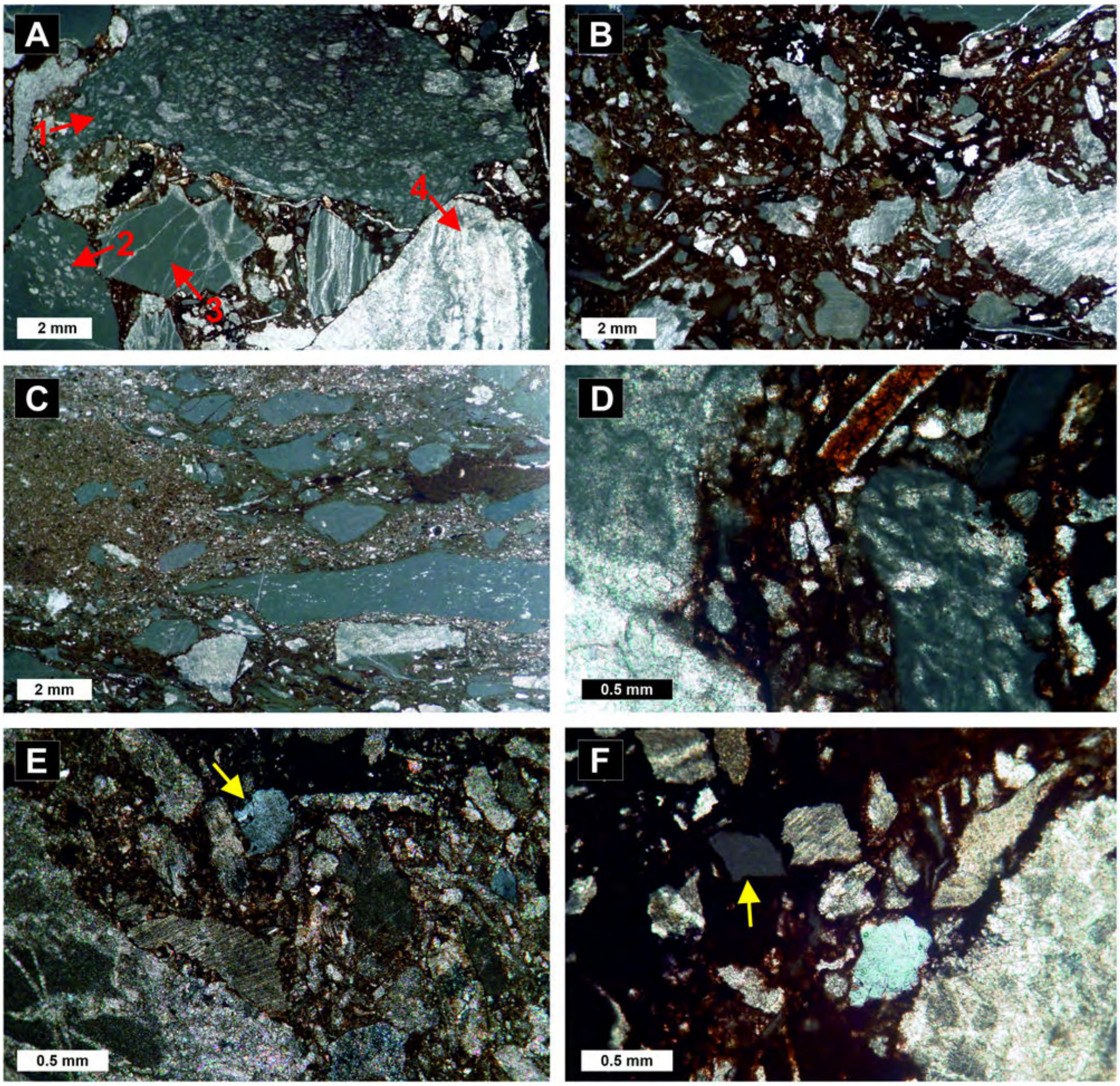


Figure 7: Thin-section pictures of the Gugu Breccia matrix. **A)** Silt-sand sized limestone clasts embedded in a reddish matrix. Note the different microfacies types of these carbonate elements: bioclastic packstone with algae (1, 2), mudstone (3) and a highly recrystallized limestone clast (4). Sample GBM1; **B-C)** Small sized micritized and recrystallized clasts. Sample GBM2; **D)** Ferrous microlaminae coating the main carbonate elements. Sample GBM1; **E-F)** Siliciclastic elements within the matrix (the yellow arrows indicate quartz particles). Sample GBM1.

Fossil assemblages

The micro-/macropaleontological biota identified within the sampled clasts from the Gugu Breccia is relatively abundant (especially within MFT1 and MFT2) and consist of the following biotic groups: calcareous green algae (dasycladaleans) – *Salpingoporella muelhbergii* (LORENZ) (Fig. 5.A-B), *Pseudoactinoporella*? *silvaeregis* BUCUR (Fig. 5.C, .J-L), *Falsolikanella danilovae* (RADOIČIĆ) (Fig. 5.D), *Actinoporella podolica* (ALTH) (Fig. 5.E), *Salpingoporella heraldica* SOKAČ (Fig. 5.F), *Salpingoporella* sp. (Fig. 5.G), *Clypeina* cf. *maslovi* PRATURLON (Fig. 5.H-I), and *Arabicodium* sp. (Fig. 5.M); benthic foraminifera - *Pfenderina globosa* FOURY (Fig. 6.A-B), *Orbitolinopsis* sp. (Fig. 6.C-D), *Pseudolituonella gavonensis* FOURY (Fig. 6.E-F), *Bulbobaculites felixi* PLEŞ *et al.* (Fig. 6.G), *Buccicrenata* cf. *hedbergi* (MAYNC) (Fig. 6.H), *Moulladella jourdanensis* (FOURY & MOULLADE) (Fig. 6.I-K), *Coscinoconus* cf. *delphinensis* ARNAUD-VANNEAU *et al.* (Fig. 6.L), ?*Coscinoconus* sp. (Fig. 6.M), ?*Kaminskia* sp. (Fig. 6.P), miliolids (Fig. 6.N), and textulariids; microproblematic organisms – *Bacinella*-type microstructures/oncoids (Fig. 5.N), rivulariaceans, and *Thaumatoporella*-type ladders (Fig. 5.N); mollusc fragments (mostly rudists and small gastropods); very rare coral fragments and coprolites. The whole identified assemblage is illustrated in Figures 5 - 6.

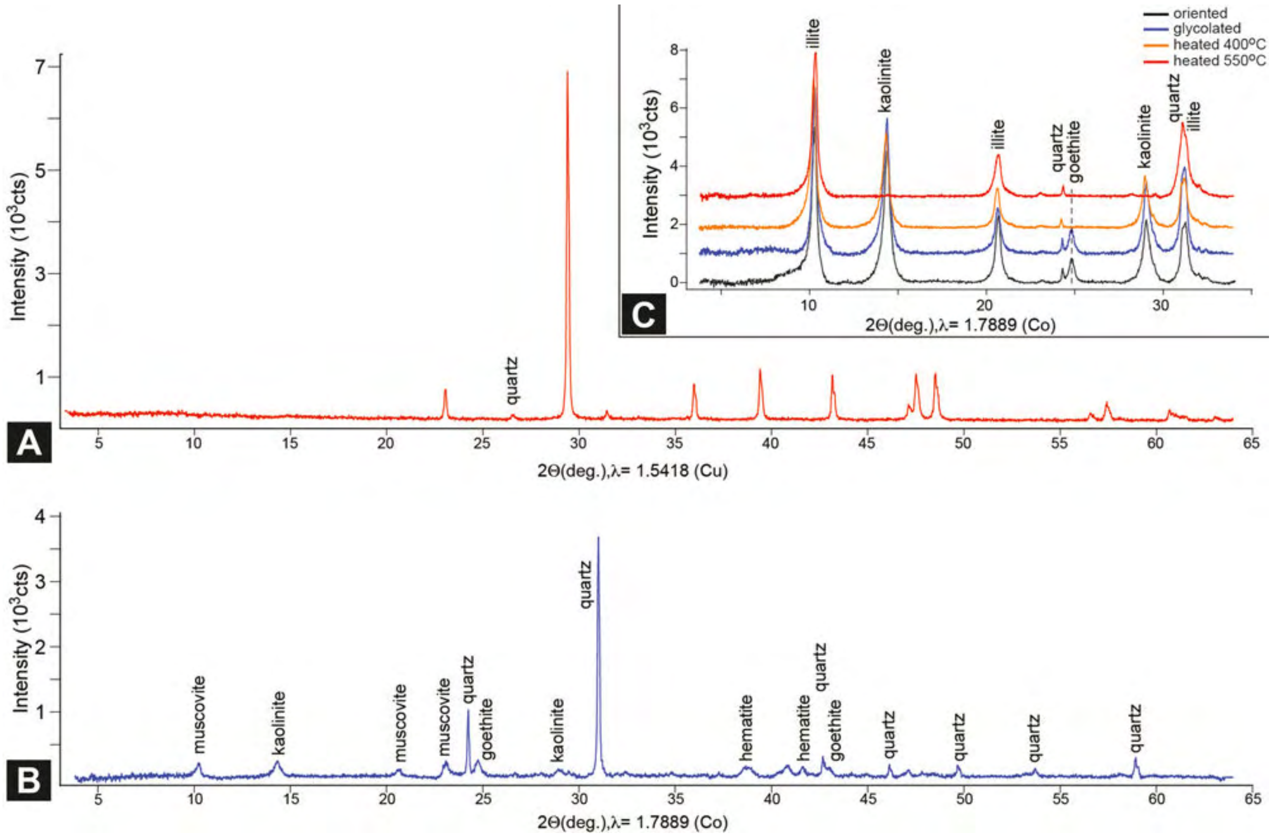


Figure 8: X-ray diffraction patterns of samples from the Gugu Breccia matrix. **A)** Raw matrix sample containing mostly calcite (whole pattern) and quartz (indicated); **B)** Pattern of a sample where calcite was dissolved, consisting of quartz, muscovite, kaolinite and iron oxy-hydroxides (goethite and hematite); **C)** (Inset) patterns of a clay fraction sample consisting of illite, kaolinite, goethite and quartz.

Matrix description

As previously mentioned, within the red matrix of the Gugu Breccia numerous small sized clasts of various microfacies can be noticed (Fig. 7.A). Thin-section analysis of matrix samples revealed the fact that such carbonate elements can be micritized or partly to fully recrystallized (Fig. 7.C). Also, corrosive micro-structures can be noticed on numerous clasts. Thin ferrous microlaminae are also identified coating the main carbonate elements or can appear dispersed within the matrix (Fig. 7.D). XRD analyses show the dominance of calcite in the raw matrix samples, associated with a very small amount of detrital quartz (Fig. 8.A). After calcite dissolution in acetic acid, the samples were reanalyzed and the detrital content was found to consist of quartz, muscovite and significant goethite and hematite, which account for the pronounced reddish color of the matrix (Fig. 8.B). The clay fraction of the matrix is mainly illitic - kaolinitic in character and also contains goethite, shown by a characteristic peak at ca. 25° (2theta) that disappears when heated at 400°C (Fig. 8.C), as the iron oxyhydroxide is transformed into hematite at ca. 300°C (GIALANELLA *et al.*, 2010).

5. Discussion

Interpretation of the main microfacies types (MFT)

The most striking feature of MFT1 (bio-peloidal grainstone - Fig. 9.A-C) is given by the high abundance of dasycladalean algae (mostly broken fragments of *Salpingoporella muelhbergii* and *Falsolikanella danilovae*), benthic foraminifera and peloids/micritic pellets (Fig. 9.A-C). Even if species diversity is relatively low, the identified microfossils represent shallow-water subtidal assemblages from an inner-platform environment (probably an open circulation shelf lagoon) characterized by a moderate hydrodynamic regime (HARRIS *et al.*, 1985; TUCKER & WRIGHT, 1990; SĂSĂRAN, 2006; FLÜGEL, 2010; SĂSĂRAN *et al.*, 2017). This fact is supported by the general sub-angular shape of the main elements (clasts) that imply abrasion features and a short distance transport. According to FLÜGEL (2010), such features may be characteristic for identifying sand shoals and bars within lagoonal environments. It is possible that some of the sampled limestone clasts could have been derived from some bioclastic bars within platform margin environments (back-reef), since they contain rare rounded anthozoan fragments. Furthermore, the elongated appearance of the main components within MFT1 in some samples can be regarded as a consequence of plastic deformation generated by compactional stress.

The morphostructural features and the muddy facies from MFT2 (bioclastic wackestones - Fig. 9.D) represent good indicators for low-energy shallow-water deposits from the platform interior (lagoon) (GINSBURG, 1975; WRIGHT, 1984; FLÜGEL, 2010; PLEŞ *et al.*, 2016b; SĂSĂRAN *et al.*, 2017). The abundance of micritic grains and cortices surrounding the main components may reflect a relatively high rate of microbial activity which is common within these environments (FLÜGEL, 2010). This statement is strengthened also by the fact that different stages of micritization are commonly observed on many skeletal fragments. Incipient stages are highlighted by the development of the micritic envelopes and by the micritization of the intra-granular pores within the main elements. These are succeeded by more advanced micritization stages represented by the presence of partly or fully micritic grains. The whole microfossil assemblage (calcareous algae, cyanobacteria, foraminifera and small rudists) also pleads for an inner-platform lagoonal environment (LONGMAN, 1980; HARRIS *et al*, 1985; FLÜGEL, 2010; PLEŞ *et al.*, 2019).

The carbonate clasts included in MFT3 (bio-oncoidal wackestone - Fig. 9.E-G) were formed in the more restrictive setting of a shallow-water lagoon. The large amount of *Bacinella*-type oncoids and mesostructures (Fig. 9.E-G), together with the rivulariacean abundance (Fig. 9.E) are consistent with this interpretation (HARRIS *et al.*, 1985; SĂSĂRAN, 2006; PLEŞ *et al.*, 2019). The development of the bacinellid fabrics as different sized oncoids and intra-microframeworks within large skeletal grains points to intense microbial activity. The large numbers of rivulariaceans and bacinellid meshworks point to a very shallow paleoenvironment, since such organisms commonly dwell in restricted/isolated inner-platform settings (FLÜGEL, 2010).

The fenestral fabrics, microfossil scarcity and the presence of microbial lamination in some cases within the mudstones/wackestones (MFT4) are suggesting an intertidal environment for the development of these carbonate pebbles (HARRIS *et al.*, 1985; TUCKER & WRIGHT, 1990; SĂSĂRAN *et al.*, 2017). Most of these fenestral structures are forming parallel birds-eyes networks interlayered with a large amount of bedded peloidal material (Fig. 9.H), probably of microbial origin. Such features were commonly identified within intertidal-supratidal ponds and swamps in both recent and ancient platform carbonates (GINSBURG *et al.*, 1977; WRIGHT, 1984; SĂSĂRAN, 2006; BUCUR *et al.*, 2010; PLEŞ *et al.*, 2016b). The numerous fissures and cracks within MFT1 can be regarded as a consequence of frequent exposure episodes (FLÜGEL, 2010).

Biostratigraphic remarks

Most of the microfossils identified within the carbonate clasts from Gugu Breccia represent species with biostratigraphic importance for the Lower Cretaceous Neotethysian carbonates. The calcareous algae and benthic foraminiferal assemblages are considered good markers for the recognition of Urgonian-type facies.

Concerning the calcareous algae assemblage, *Salpingoporella muelhbergii* represents one of the most common species of dasycladalean algae from Lower Cretaceous platform carbonates. Even if it has a stratigraphic range from upper Hauterivian to lower Aptian (CARRAS *et al.*, 2006), the most common reports of this species are from Barremian-Aptian deposits of the Neotethys (BUCUR *et al.*, 2000, 2014; BUCUR, 2001). Beside the Barremian-Aptian occurrences of *S. muelhbergii* from the Romanian Carpathians (BUCUR, 1999, 2008; COCIUBA, 2000), other reports of this alga from Urgonian-type carbonates are: Barremian-Aptian bioclastic carbonates from the Dinarides (SOKAČ & GRGASOVIĆ, 2008); Tirgan Formation (Barremian-Aptian) from Iran (TAHERPOUR KHALIL ABAD *et al.*, 2010; BUCUR *et al.*, 2019); Barremian-Aptian limestones of Eastern Serbia (BUCUR *et al.*, 2021).

Salpingoporella heraldica was commonly identified within Barremian-Aptian platform carbonates from Croatia (SOKAČ, 1996; CARRAS *et al.*, 2006), Iran (TAHERPOUR KHALIL ABAD *et al.*, 2017) and Romania (BRUCHENTAL *et al.*, 2014).

Pseudoactinoporella? *silvaeregis* was described by BUCUR (1981) from Barremian carbonates from the Pădurea Craiului Mountains (Blid Formation, *sensu* COCIUBA, 2000). *P. silvaeregis* occurrences seem to be concentrated within the Urgonian-type limestones of the Carpathian Mountains (BUCUR, 1992) since very few reports of this alga are known from other areas of the Neotethys (*e.g.*, the Barremian of Kopet-Dagh, Iran - BAHARI *et al.*, 2020).

Falsolikanella danilovae also represents a cosmopolitan species of calcareous green algae from Lower Cretaceous (Hauterivian-lower Aptian) carbonates (BUCUR, 1999; GRANIER *et al.*, 1999; COCIUBA, 2000; HUSINEC & SOKAČ, 2006; GRANIER & CLAVEL, 2019). The association of *F. danilovae* with other algal species such as *Salpingoporella muelhbergii* or *Actinoporella podolica* (as in the present case) can characterize in many cases the Barremian stage (DRAGASTAN, 1975, 1980; BUCUR, 2008). The presence of *Actinoporella podolica* specimens within the sampled carbonate clasts from the Gugu Breccia is important, since this species does not occur above the lower Barremian (GRANIER & DELOFFRE, 1993; BUCUR *et al.*, 2020).

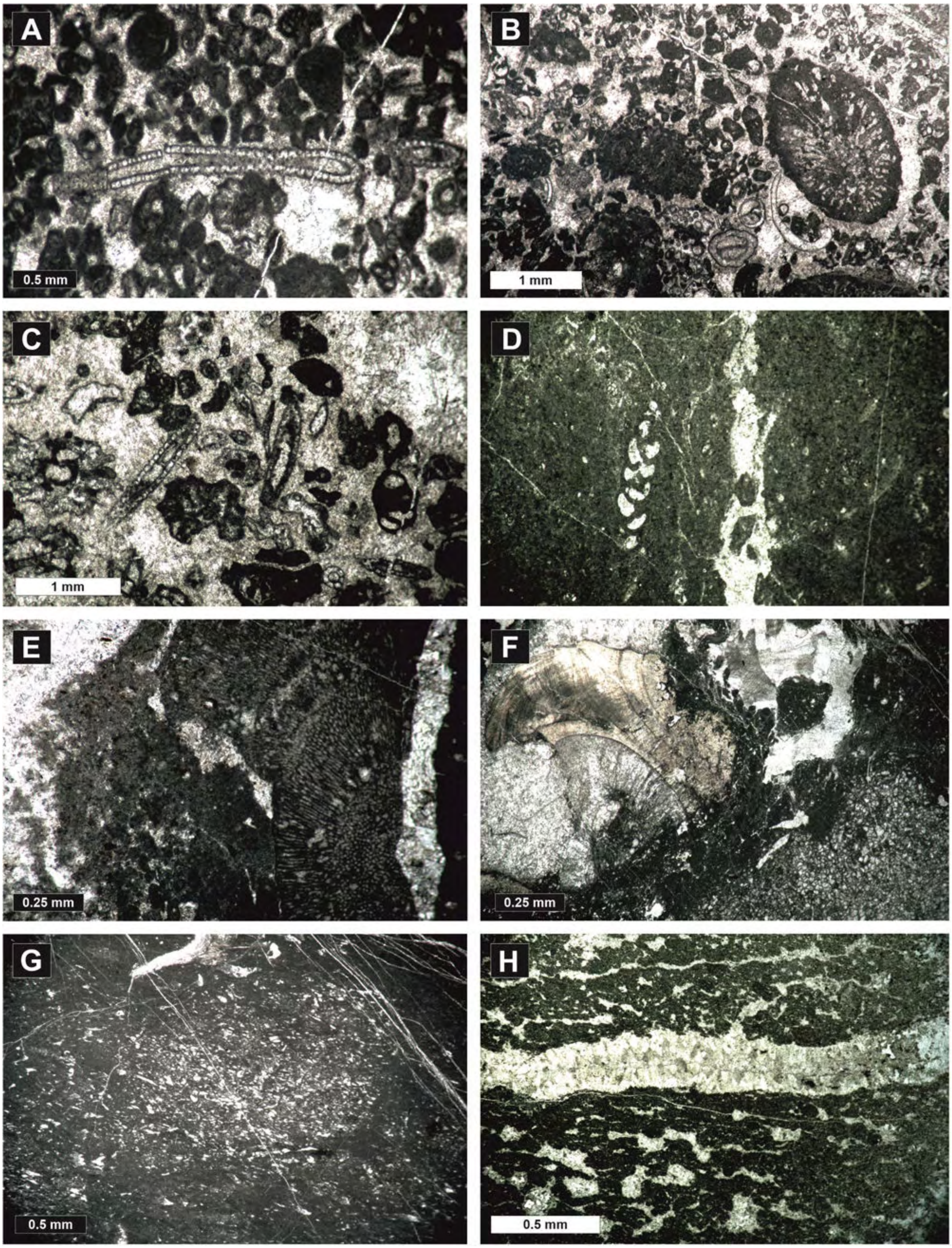


Figure 9: A) Bio-peloidal grainstone (MFT1) with *Salpingoporella muelhbergii.* Sample 1715; **B)** Bioclastic grainstone (MFT1) with coral fragments (right side of the picture). Sample 1675; **C)** Bioclastic grainstone (MFT1) with dasycladalean algae fragments. Sample 1673; **D)** Bioclastic wackestone (MFT2) with benthic foraminifera. Sample 1698; **E)** Oncoidal wackestone (MFT3) with large *Rivularia*-type cyanobacteria. Sample 1710; **F)** Bio-oncoidal wackestone/floatstone (MFT3) with rudist shell fragments and bacinellid oncoids (bottom-right side of the picture). Sample 1792; **G)** Fissured oncoidal wackestone (MFT3). Notice the development of the *Bacinella*-type meshwork in the middle of the picture. Sample 1790; **H)** Fenestral-peloidal lime mudstone/wackestone (MFT4). Note the fenestral network interlayered with bedded peloidal material. Sample 1689.

In addition, the benthic foraminiferal assemblage pleads also for a Barremian age of the sampled carbonate clasts. *Moulladella jourdanensis* represents a species with a stratigraphic range from Berriasian to lower-upper Barremian (Bucur *et al.*, 2020). However, except its relatively few occurrences from Berriasian-Valanginian carbonates (Săsăran *et al.*, 2017; Bucur & Schlagintweit, 2018) this pfenderinid foraminifer was regarded for decades as a common, mainly Barremian, Urgonian-type species (Arnaud-Vanneau, 1980; Bucur *et al.*, 1993; Clavel *et al.*, 2010; Michetiuc *et al.*, 2012; Granier *et al.*, 2013, 2017; Pleş *et al.*, 2016b).

Pfenderina globosa and *Pseudolituonella gavonensis* were described by Foury (1968) from Hauterivian-lower Barremian deposits of Southern France (Alpilles). These species were commonly reported from Barremian carbonates from France (Arnaud-Vanneau, 1980), the Romanian Carpathians (Daoud *et al.*, 2004; Bruchental *et al.*, 2014) or Carpatho-Balkanides (Polavder, 2014; Bucur *et al.*, 2018).

Buccicrenata cf. *hedbergi* is known to dwell within the Urgonian-type carbonate platforms of the Neotethys, commonly within the Barremian-Aptian interval (Canérot, 1984; Chiocchini *et al.*, 1984; Banner & Highton, 1990; Omana-Pulido & Pantoja-Alor, 1998; Marian & Bucur, 2012; Pleş *et al.*, 2016b).

Based on these biostratigraphic remarks, the age of the sampled limestone clasts from the Gugu Breccia is early-middle Barremian. The lack of orbitolinids such as *Palorbitolina lenticularis* or *Mesorbitolina texana* exclude the presence of the Aptian stage within the sampled limestones. The identified microfossils, together with the microfacies traits are suggesting that all of the sampled clasts belong to the Blid Formation (middle part of the Coposeni Member *sensu* Cociuba, 2000). Similar microfacies and microfossils were described and illustrated by Cociuba (1999, 2000) from several zones within the Pădurea Craiului Mountains where the carbonate deposits of the Coposeni Member crop out.

Depositional environment

The sedimentological/microfacies analyses performed on the limestone clasts and pebbles collected from the Gugu Breccia, together with the mineralogical investigation of the matrix, have raised several new arguments concerning its depositional environment. The microfacies/microfossil assemblages are suggesting that the majority of the carbonate elements of the Gugu Breccia represent fragments of different facies zones belonging to the Barremian carbonate platform (the Coposeni Member). Based on clast morphologies and facies variations it can be assumed that such elements were derived from levels affected by tectonic stress, most probably linked with the development of an active fault that indicates *in situ* brecciation. The numerous recrystallized small sized clasts for the matrix might imply that such processes were triggered by meteoric diagenesis. The fractures and fissures generated by the fault development caused numerous infiltration pathways for meteoric waters. Therefore, a large number of siliciclastic particles and carbonate sediments were eroded and transported form the upper levels of the upraised carbonate platform. This statement is based on the large amount of quartz grains (Fig. 7.E-F), clay minerals (illite-kaolinite) and ferrous oxy-hydroxides (Fig. 8) present within the matrix. The presence of quartz and muscovite/illite demonstrates the fact that terrigenous input existed during the sedimentation processes of the Gugu Breccia under periods of subaerial exposure. Also, the presence of kaolinite, goethite and hematite can be an indicator of *in situ* weathering of iron and aluminium silicates, common in lateritic sediments. Furthermore, the clay minerals can suggest a warm and humid paleoenvironment (Fagel, 2007; Chaudhri & Singh, 2012; Doval *et al.*, 2012; Lintnerová *et al.*, 2013). Based on these, it can be concluded that the genesis of the Gugu Breccia can be linked with tectonic activity that fragmented some parts of the carbonate platform into subaerially exposed blocks (demonstrated mainly by the matrix mineralogy and clast morphologies). The newly developed faults have favoured the accumulation of a large amount of carbonate clasts and terrigenous particles through various processes (abrasion, meteoric weathering and transport), and consequently, to the formation of the Gugu Breccia. The only question that remains open concerns the actual time when this fault became active. Based on the clast morphologies and their age, together with the matrix characteristics, one may assume that the fault systems became active in a post-depositional manner somewhere within the latest Barremian-earliest Aptian.

Remarks on the stratigraphic position of Gugu Breccia

Concerning the stratigraphic position of the Gugu Breccia within the Lower Cretaceous succession of Pădurea Craiului Mountains, we propose the following scenarios.

Firstly, according to Papp *et al.* (2013), the Gugu Breccia should have been formed at the boundary between the lower and upper Aptian, as a slide breccia developed on top of the subaerially exposed platform carbonates of the Valea Măgurii Formation (see Fig. 1.A-B). The existing paleorelief and the ferruginous/bauxitic material from the base of the Vârciorog Formation corresponds to a regional discontinuity (Fig. 1.A-B) and, respectively, to an uplift of the Valea Măgurii carbonate platform at the end of the lower Aptian. This discontinuity represented one of the main arguments of Papp *et al.* (2013) and other later studies (Bucur *et al.*, 2013; Bruchental *et al.*, 2014; Pleş *et al.,* 2016a) in considering the stratigraphic position of the Gugu Breccia between the lower and upper Aptian. However, the field investigations made in this region have shown that the existing brecciated level from the top of the discontinuity level in the Valea Măgurii Quarry is considerably different (in morphostructural terms, petro-facies features and stratigraphic thickness) from the deposits from the Gugu Breccia-type locality (Dealu Letii-Gugu).

Secondly, our data suggests that all of the sampled clasts can be integrated based on micropaleontological/microfacies characteristics into the Coposeni Member (Blid Formation). Therefore, the age of the Gugu Breccia in its type locality should be younger than early-middle Barremian. It is important to mention that carbonate clasts from the Valea Bobdei Member (lower Aptian) and the Valea Măgurii Formation (upper lower Aptian) or even marl fragments of the Ecleja Formation (lower Aptian) were not encountered so far within the sampled outcrop to support a stratigraphic position higher than the upper lower Aptian. This statement confirms the view of PATRULIUS *et al.* (1982) in placing the Gugu Breccia somewhere around the earliest Aptian (Bedoulian), between the "*lower pachyodont limestone*" (Coposeni Member *sensu* COCIUBA, 2000) and the Ecleja Marls Formation.

Thirdly, the data obtained in the frame of this study confirm the fact that an important tectonic event occurred within the latest Barremian-earliest Aptian and was responsible for the fragmentation of the Urgonian-type carbonate platforms (Coposeni and Valea Măgurii). The blocks resulted from extensive faulting and were affected by various grades of uplift that allowed the formation of the Gugu Breccia-type deposits on their slopes. These tectonic movements are considered by PATRULIUS *et al.* (1982) to correspond more or less with the so called "Austro-Alpine phase" that started in the latest Barremian-earliest Aptian. According with SCHMID *et al.* (2008), the Lower Cretaceous tectonic activity (Austrian phase) did not affect the Tisza Mega-Unit to which the sedimentary sequence of Pădurea Craiului belongs. Therefore, it can be assumed that the Lower Cretaceous tectonic movements that affected the Northern Apuseni Mountains (Pădurea Craiului) can be linked with rotations and translations of the Tisza Block that started to deviate from those of the European continent around 130 million years ago (late Barremian) (SCHMID *et al.*, 2008). Also, these features coincide with crustal shortening of the adjacent Dacia and ALCAPA Mega Units (*sensu* SCHMID *et al.*, 2008) that commenced within the Neotethysian realm during the Barremian-early Aptian.

6. Conclusions

1. The study and interpretation of microfacies-microfossil associations from the Gugu Breccia carbonate clasts from its type locality (Dealu Letii-Gugu) revealed the fact that all of these elements represent fragments of different facies zones (shallow-water bioclastic shoals/bars, subtidal-intertidal and restrictive "lagoonal" deposits) of a Urgonian-type carbonate platform.
2. Concerning its depositional environment, the field observations coupled with sedimentological features and the mineralogy of the matrix support a tectonically-controlled formation of Gugu Breccia in a continental regime, on the slopes of several upraised blocks from a fragmented carbonate platform. The clay minerals and iron oxyhydroxides revealed through X-ray powder diffraction analyses from the Gugu Breccia matrix suggest that terrigenous input occurred during the formation of the Gugu Breccia.
3. The microfossil association indicates a Barremian age for the collected samples, and respectively, the integration of the sampled carbonate elements within the Copseni Member of the Blid Formation. Considering these, one may conclude that the age of the Gugu Breccia in its type locality is younger than lower-middle Barremian. The lack of limestone clasts from the Valea Bobdei Member (lower Aptian) and the Valea Măgurii Formation (upper lower Aptian) suggest that the age of this breccia could be latest Barremian-earliest Aptian. It is however possible that the Gugu Breccia-type deposits could have been formed at the boundary between the Valea Măgurii and Vârciorog formations (between lower and upper Aptian) above a regional discontinuity level. Based on the present data, the differences between these two breccia deposits (stratigraphic thickness, clast provenance and age, the presence/lack of subaerially exposed surfaces) may support the idea of their development through similar mechanisms (upraised blocks) but probably linked with different rotation/ translation phases of Tisza Mega-Unit: the first one during the late Barremian-earliest Aptian (Gugu Breccia *sensu stricto*) and the second, during around the boundary between the lower and upper Aptian (the breccia deposits from the base of the Vârciorog Formation). Therefore, the Gugu Breccia should be regarded as an indicator for the onset of the "mid"-Cretaceous tectonic phase that affected the evolution of central Neotethys carbonate platforms.

4. Last but not least, the microfacies/microfossil analyses represent a step forward in order to decipher the Gugu Breccia stratigraphic position. Further geochemical analyses will probably contribute more to the elucidation of this issue.

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