

Jurassic-Cretaceous transition on the Getic carbonate platform (Southern Carpathians, Romania): Benthic foraminifera and algae

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Abstract: The carbonate succession of the Piatra Craiului Massif, *i.e.*, the eastern part of the Getic carbonate platform (Southern Carpathians, Romania), comprises reefal and peritidal limestones that contain a diverse microfossil assemblage composed mainly of calcareous green algae and benthic foraminifera. The biostratigraphically most significant benthic foraminifera found in the several sections studied are described; some (*Anchispirocyclus lusitanica*, *Neokilianina rahonensis*, *Bramkampella arabica*, *Everticyclammina praekelleri*) are reported for the first time in this area. Hence, assemblages of both foraminifera and calcareous algae characterize three biostratigraphic intervals in the studied succession, the Kimmeridgian - lower Tithonian, the upper Tithonian - lower Berriasian, and the upper Berriasian - ? lower Valanginian intervals. The main microfacies types (bioclastic rudstone, coral-microbial boundstone, bioclastic grainstone, interbedded mudstones and wackestones with cyanobacteria nodules) as well as both the foraminifera and the calcareous algae are paleoecological indicators that may contribute to the decipherment of the depositional environments and to building a depositional model for the eastern part of the Getic carbonate platform at the Late Jurassic-Early Cretaceous transition.

Key-words:

- Upper Jurassic;
- Lower Cretaceous;
- Getic carbonate platform;
- Southern Carpathians;
- biostratigraphy;
- foraminifera;
- paleoenvironment.

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Résumé : *Passage Jurassique-Crétacé sur la plate-forme carbonatée gétique (Carpathes méridionales, Roumanie) : Foraminifères et algues benthiques.*- La série carbonatée du Massif de Piatra Craiului, c'est-à-dire de la partie orientale de la plate-forme carbonatée gétique (Carpathes méridionales, Roumanie), est constituée de calcaires récifaux et péritidaux qui recèlent des associations variées de microfossiles constituées d'algues vertes calcaires et de foraminifères benthiques essentiellement. Parmi les foraminifères benthiques identifiés dans les nombreuses coupes étudiées, nous décrivons ceux auxquels on attribue une certaine valeur biostratigraphique. Quelques-uns (*Anchispirocyclus lusitanica*, *Neokilianina rahonensis*, *Bramkampella arabica*, *Everticyclammina praekelleri*) sont signalés pour la première fois dans ce secteur. De ce fait, dans la série étudiée, grâce aux associations combinées de foraminifères et d'algues calcaires, nous caractérisons trois intervalles biostratigraphiques : le Kimméridgien - Tithonien inférieur, le Tithonien supérieur - Berriasien inférieur et le Berriasien supérieur - ? Valanginien inférieur. Les principaux types de microfaciès (rudstone bioclastique, boundstone corallien-microbien, grainstone bioclastique, alternances de mudstones et de wackestones à nodules cyanobactériens) sont des indicateurs paléocéologiques qui, avec les foraminifères et les algues calcaires, peuvent contribuer au décodage des environnements de dépôt et à la construction d'un modèle dépositionnel pour la partie orientale de la plate-forme carbonatée gétique à la transition du Jurassique supérieur au Crétacé inférieur.

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Mots-clefs :

- Jurassique supérieur ;
- Crétacé inférieur ;
- plate-forme carbonatée gétique ;
- Carpathes méridionales ;
- biostratigraphie ;
- foraminifères ;
- paléoenvironnement.

1. Introduction

This paper is part of a larger integrated study that aims to describe the geological evolution of the Piatra Craiului Massif by using sedimentological and stratigraphic techniques. The geomorphological characteristics of the Piatra Craiului Massif with extensive outcrops represent an optimal feature for studying the entire carbonate succession.

Several sections comprising the Jurassic-Cretaceous transition were studied. Earlier authors (JEKELIUS, 1923; ONCESCU, 1943; POPESCU, 1966) assigned a Late Jurassic age to the studied limestones. However, other biostratigraphic studies (BUCUR, 1978; PATRULIUS *et al.*, 1980; BUCUR *et al.*, 2009; DRAGASTAN, 2010) revealed the presence of Lower Cretaceous deposits in the upper part of the carbonate succession. The present paper brings new biostratigraphical information regarding the Upper Jurassic-Lower Cretaceous transition in the studied area. Three biostratigraphic intervals (Kimmeridgian-lower Tithonian, upper Tithonian-lower Berriasian and upper Berriasian-lower Valanginian) are identified.

2. Geological framework

The Piatra Craiului Massif forms the western flank of a larger syncline unit, which was defined in the geological literature as the Piatra Craiului Syncline. This structural unit is considered an integral part of the Dâmbovicioara Couloir (PATRULIUS, 1969) (Fig. 1) and it represents the eastern part of the Getic Carbonate Platform (PATRULIUS, 1976).

The lower part of the sedimentary succession is Bajocian-early Callovian in age (Fig. 2). It is characterized by the upward transition from sandstones and marly limestones to limestones and radiolarites (POPESCU, 1966). These deposits contain ammonite fragments and pelecypods [*e.g.*, *Bositra buchi* (ROEMER, 1836)]. PATRULIUS (1969) and GRĂDINARU (2011) described similar Bajocian deposits from the Dâmbovicioara Couloir. The age ascription is mainly based on pelecypod fragments, gastropods and solitary zoantharians. In the Bajocian-lower Callovian succession hardground levels and condensed intervals rich in macro-oncoids and stromatolitic structures are present (LAZĂR & GRĂDINARU, 2013). Upper Callovian-Oxfordian radiolarites overlie the Bajocian-lower Callovian succession (Fig. 2). Detailed information about these deposits can be found in BUCUR (1980), MÉSZÁROS and BUCUR (1980), and BECCARO and LAZĂR (2007).

The mid-Jurassic deposits are in turn overlain by thick units of Kimmeridgian - Berriasian (- ? lower Valanginian) shallow-water carbonates, *i.e.*, Štramberk-like limestones. They reach a total thickness of 1200 m (BUCUR *et al.*, 2011; PLEȘ *et al.*, 2013) near the La Om summit (Fig. 2). This succession represents an overall shallowing-upward megasequence that is defined by the shift from coral-microbial bioconstructions to peritidal carbonates (MIRCESCU *et al.*, 2014). BUCUR (1978) first reported the presence of Berriasian deposits in the northern part of the Piatra Craiului Massif. Recent studies (BUCUR *et al.*, 2009; SĂSĂRAN *et al.*, 2013; PLEȘ *et al.*, 2013; MIRCESCU *et al.*, 2014) have confirmed the presence of lowermost Cretaceous deposits in that area (Fig. 2). Overlying these Štramberk limestones are either Barremian-Aptian breccias/conglomerates (UNGUREANU *et al.*, 2015) or the Dâmbovicioara Formation the lowermost transgressive strata which are Early Valanginian in age (GRĂDINARU *et al.*, 2016).

3. Materials and methods

Seven sections were analysed for microfacies and micropaleontological content (A-G) (Fig. 2): Curmătura-Turnu (A), Padina Închisă-Drumul lui Lehmann (B), Padina Popii (C), Ciorânga Mare-Vf. Ascuțit-Padinile Frumoase (D), Vlădușca de Vest-Vlădușca de Est (E), Zaplaz-Lanțuri (F), Padina Lăncii (G). The total thickness of the sampled sections ranges from 700 m in the north to approximately 1200 m in the central part of the massif. Each section is defined by a gradual transition from massive limestones in their lower part towards metre/decimeter-thick carbonate beds in their upper part. Sections A-E were sampled at a resolution of 4 to 5 m and sections F and G were sampled at a resolution of 7 to 8 m. Nine hundred samples were evaluated for their microfacies and microfossil content. However, 120 samples were specifically used to describe the microfossil assemblages (Fig. 3). These sections were correlated by analysing repetitive patterns of microfossil content and microfacies characteristics. As a result, a composite bio-lithostratigraphic table was generated (Fig. 3).

Remark: In Tethyan basinal sections stratigraphers refer to two-fold divisions of both the Kimmeridgian and the Valanginian and three-fold divisions of both the Tithonian and the Berriasian based on ammonites. Because there is no record of ammonite find in the studied shallow-water limestones, we lack direct calibration to the ammonite zones. Therefore, we do not refer to the formal subdivisions of the above stages into substages (that come with the qualifying labels: Lower/Early, Middle and Upper/Late) but to informal two-fold subdivisions, *i.e.*, subdivisions into "lower/early" and "upper/late" standing for "lower/earlier part of" and "upper/later part of", respectively.

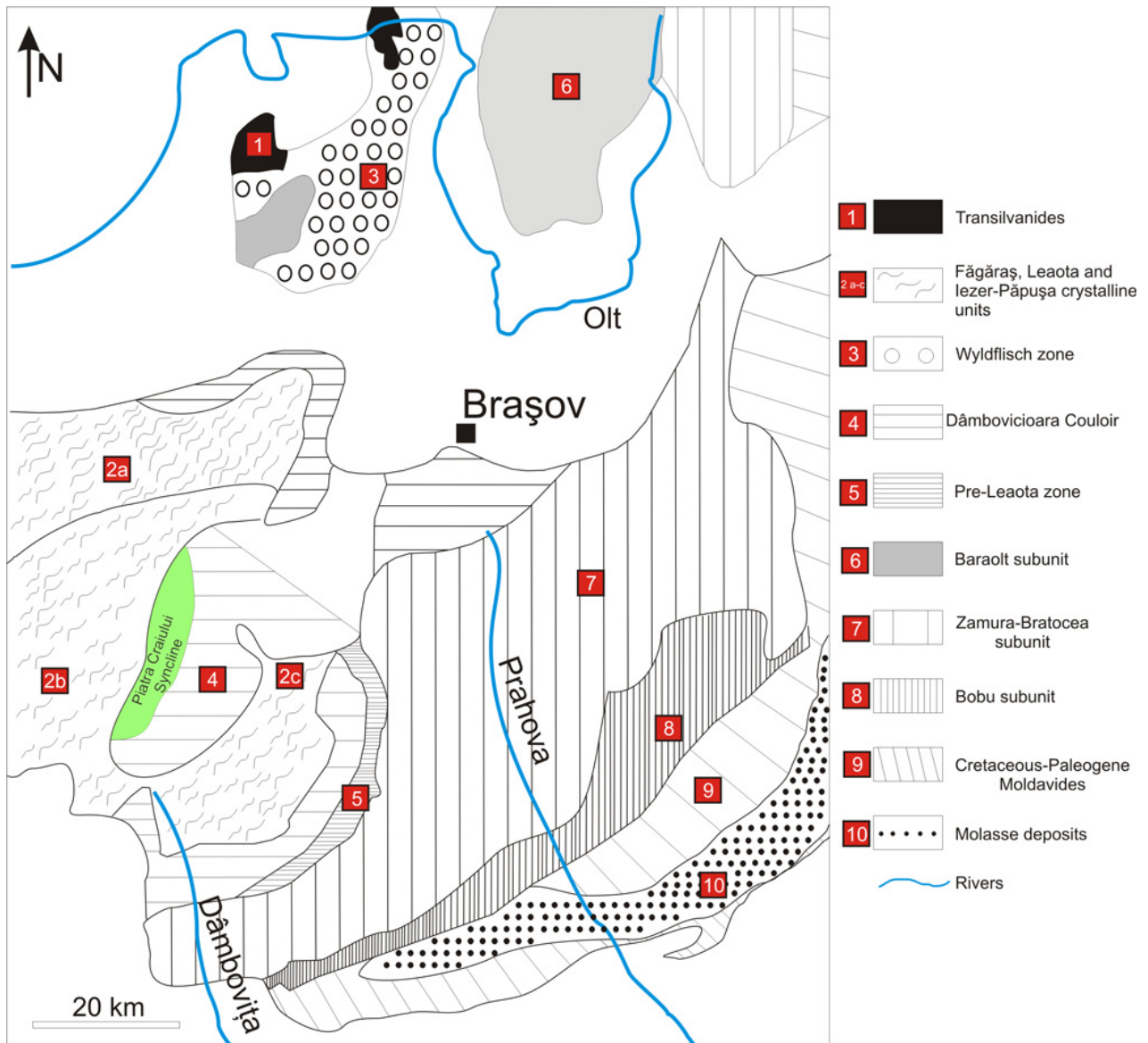


Figure 1: Paleogeographic map indicating the position of the Piatra Craiului Syncline unit within the Dâmbovicioara Couloir (modified from PATRULIUS, 1969).

4. Lithostratigraphy

Sedimentological and textural features were used to define three lithostratigraphic intervals labelled I to III from bottom to top of the studied succession (Fig. 3).

Lithostratigraphic interval I comprises the lowermost 290 m of the carbonate succession (Fig. 3). This unit consists of alternating coral-microbial boundstones and bioclastic intraclastic rudstones. The rudstone levels contain encrusting organisms [*Crescentiella morronensis* (CRESCENTI, 1969)], dasycladalean algae and echinoderm fragments (Fig. 3). Corals are heavily encrusted by *Lithocodium/Bacinella*-type structures. The sedimentology of this lithostratigraphic interval is fully documented by PLEȘ *et al.* (2013).

Lithostratigraphic interval II includes the entire package of carbonate deposits between 290 and 408 meters of stratigraphic thickness (Fig. 3). The main facies type is coarse bio-

intraclastic grainstones with gastropods, dasycladalean algae, sponges, echinoderm fragments, and foraminifera (Fig. 3). Intraclasts are represented at some levels by various-sized black pebbles (mm to cm). Some have a brecciated structure consisting of blackened bioclasts encased in a muddy matrix which is pigmented with organic matter. In some cases, they consist of darkened bioclasts (cyanobacteria nodules, dasycladalean algae).

Lithostratigraphic interval III comprises the middle and upper parts of the carbonate deposits from the Piatra Craiului Massif (between 408 and 880 m) (Fig. 3). Peloidal wackestone-packstone facies (Fig. 3) alternate with homogeneous mudstones with cyanobacteria and floatstones of cyanobacteria nodules. However, some levels of bioclastic packstone/grainstone with dasycladalean algae and foraminifera were also identified in the uppermost part of this interval (Fig. 3).

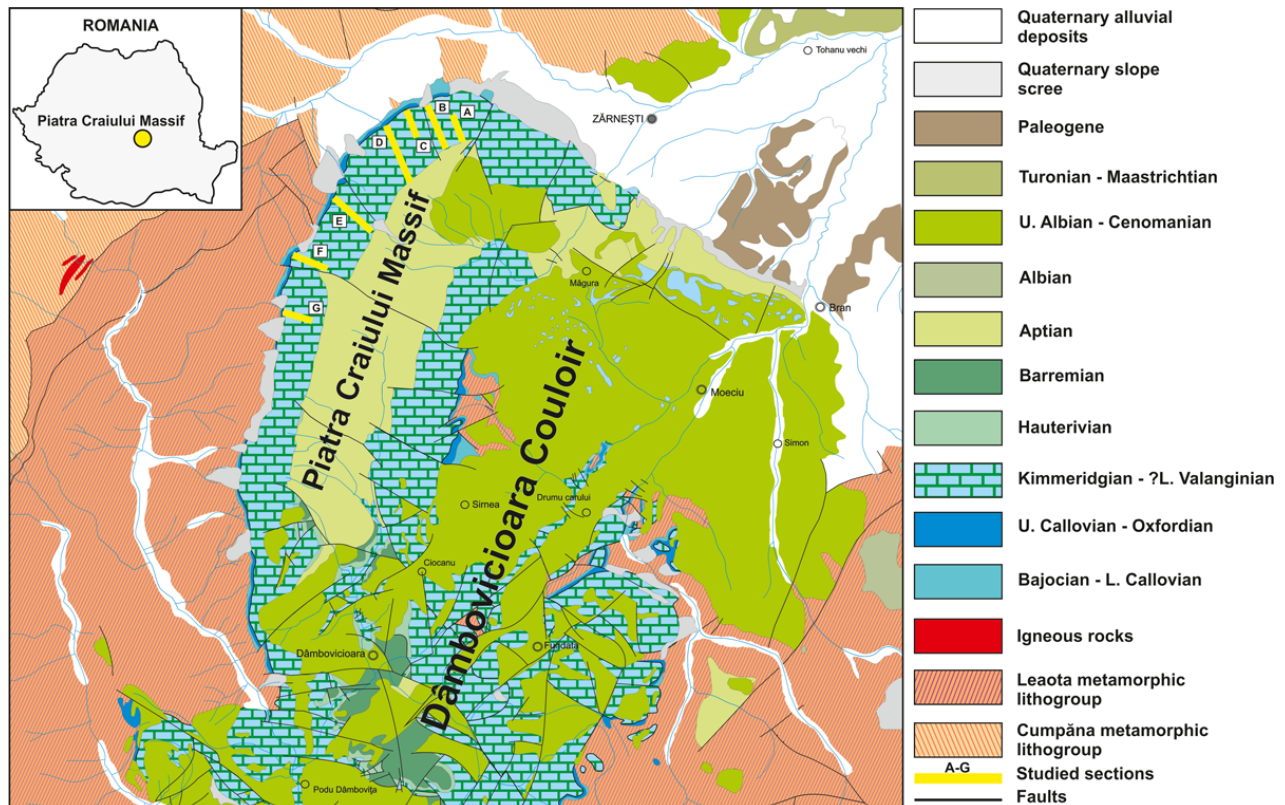


Figure 2: Location of studied sections on the geological map of the Piatra Craiului Massif (modified from DIMITRESCU *et al.*, 1971, 1974; PATRULIUS *et al.*, 1971; SÂNDULESCU *et al.*, 1972) (A-Curmătura-Turnu; B-Padina Închisă-Drumul lui Lehmann; C-Padina Popii; D-Ciorânga Mare-Vf. Ascuțit-Padinile Frumoase; E-Vlădușca de Vest-Vlădușca de Est; F-Zaplaz-Lanțuri; G-Padina Lăncii).

5. Micropaleontology

This chapter focuses on the systematic description of the most abundant and biostratigraphically important foraminiferal species, identified in 120 samples. Apart from these, other associated species are represented including *Nodosaria* sp. (Fig. 3), *Lenticulina* sp. (Fig. 3), *Lituola baculiformis* SCHLAGINTWEIT & GAWLICK, 2007 (Fig. 4.E), *Frentzenella involuta* (MANTSUROVA & GORBATCHIK, 1982) (Fig. 4.B), *Bulbobaculites* sp. (Fig. 5.A), *Scythiolina* sp. (Fig. 6.J), and *Freixialina planispiralis* RAMALHO, 1969 (Fig. 6.O). Taxonomy of benthic foraminifera follows SEPTFONTAINE (1988), RIGAUD *et al.* (2013) and KAMINSKI (2014). Taxonomy of calcareous algae follows that of BASSOULLET *et al.* (1978).

Class Foraminifera ORBIGNY, 1826
Order Lituolida LANKESTER, 1885
Suborder Nezzazatina KAMINSKI, 2004
Superfamily Nezzazatoidea
HAMAOU & SAINT-MARC, 1970
Family Nautiloculinidae
LOEBLICH & TAPPAN, 1985
Genus Nautiloculina MOHLER, 1938

Nautiloculina cf. broennimanni ARNAUD-VANNEAU & PEYBERNÈS, 1978

(Fig. 6.F)

1978 - *Nautiloculina broennimanni* n. sp. - ARNAUD-VANNEAU & PEYBERNÈS, p. 81, Pl. 2, figs. 4-11.

1991 - *Nautiloculina broennimanni* ARNAUD-VANNEAU & PEYBERNÈS, 1978 - ALTINER, p. 194, Pl. 7, figs. 15-16.

1997 - *Nautiloculina broennimanni* ARNAUD-VANNEAU & PEYBERNÈS, 1978 - KOŁODZIEJ & DECROUZÉ, p. 149, Pl. 1, fig. 3.

Description: The test is lenticular in shape, planispirally coiled, made of agglutinated carbonate particles. The inner structure is simple, characterized by numerous chambers that expand in a very short distance from the proloculus to the end of the last whorl. An additional micritic layer coats the septa as a new chamber develops. The aperture is equatorial/low interior-marginal.

Remarks: *N. broennimanni* differs from *Charentia cuvillieri* in not having a developed pseudoalveolar layer and canalculated wall structures. The identified specimens are smaller than the original specimens described by ARNAUD-VANNEAU & PEYBERNÈS, 1978.

Stratigraphic range: Tithonian-?Albian.

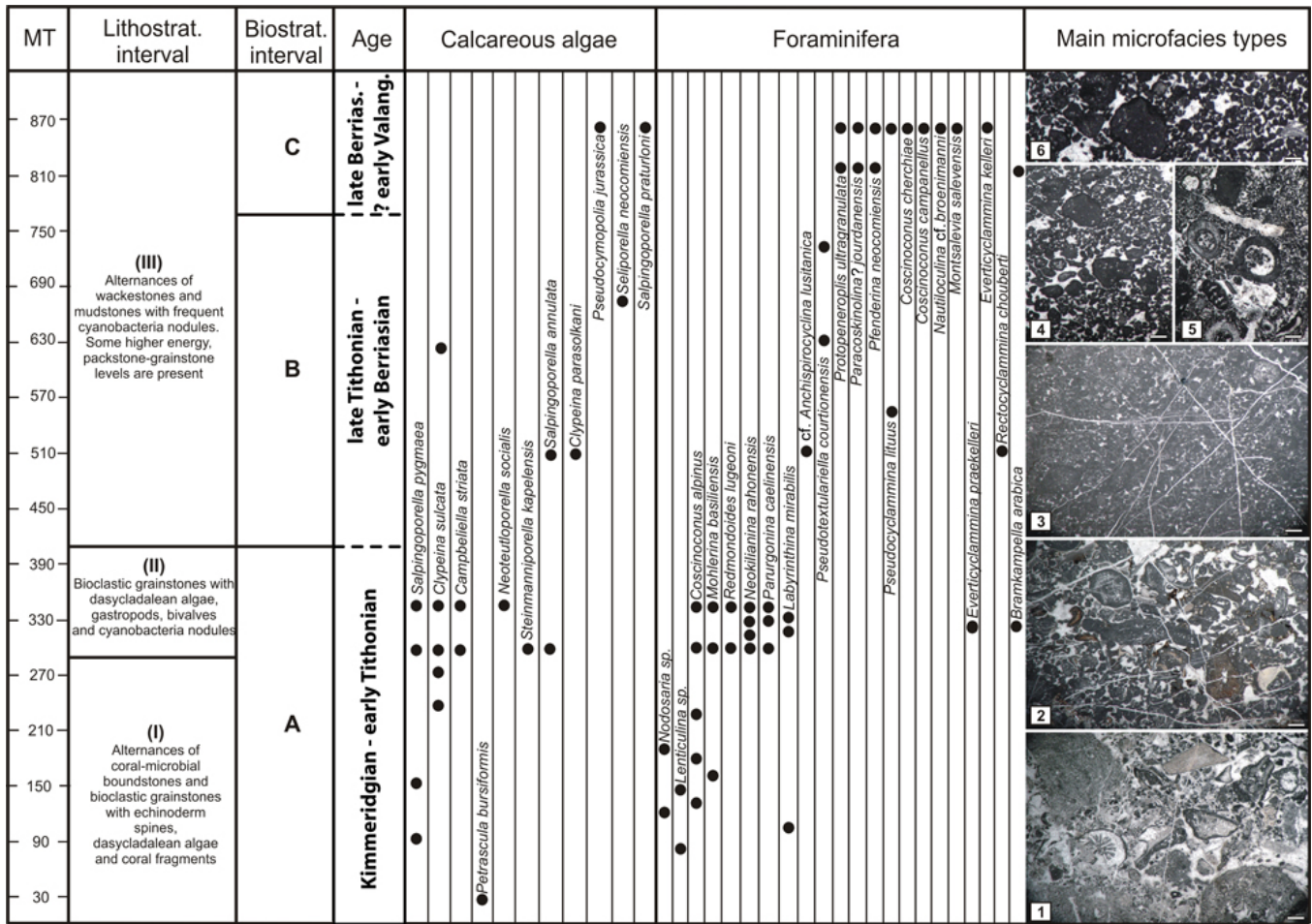


Figure 3: Lithostratigraphic and micropaleontological characteristics of the carbonate succession from the Piatra Craiului Massif [1-Bioclastic rudstone with coral fragments, echinoderm spines, dasycladalean algae (*Salpingoporella pygmaea*) and encrusting organisms (*Crescentiella morronensis*); 2-Coarse bioclastic intraclastic grainstone with cyanobacteria nodules, dasycladalean algae (*Neoteutloporella socialis*; *Campbeliella striata*) and gastropods. Black pebbles consist of blackened cyanobacteria nodules; 3-Peloidal fenestral packstone with cyanobacteria nodules; 4-Peloidal intraclastic grainstone with cyanobacteria nodules and angular/subangular micritic intraclasts; 5-Peloidal bioclastic intraclastic grainstone. Bioclasts: foraminifera (*Bramkampella arabica*), dasycladalean algae (*Pseudocymopolia jurassica*); 6-Peloidal grainstone with cyanobacteria nodules] (Scale bar: 1 mm).

Order Loftusiida
KAMINSKI & MIKHALEVIC, 2004
Suborder Loftusiina
KAMINSKI & MIKHALEVIC, 2004
Superfamily Loftusioidea BRADY, 1884
Family Mesoendothyridae
VOLOSHINOVA, 1958
Subfamily Labyrinthinae
SEPTFONTAINE, 1988
Genus *Labyrinthina* WEYNSCHENK, 1951
Labyrinthina mirabilis
WEYNSCHENK, 1951

(Fig. 4.D)

- 1951 - *Labyrinthina mirabilis* n. sp. - WEYNSCHENK, p. 798, Pl. 112, figs. 4, 6-7, 9.
- 2005 - *Labyrinthina mirabilis* WEYNSCHENK, 1951 - SCHLAGINTWEIT *et al.*, p. 31, Fig. 13.a-b.

Description: The test is characterized by a planispiral development juvenile stage and an uncoiled rectilinear adult stage. Wall is fine agglutinated, imperforated. The interseptal pil-

lars and vertical beams of the uncoiled part form a particular labyrinthic inner structure, best observed in longitudinally sectioned specimens. Aperture is simple in early ontogenetic stages, later becoming multiple.

Stratigraphic range: uppermost Oxfordian-lower Tithonian.

Family Everticyclamminidae
SEPTFONTAINE, 1988
Genus *Everticyclammina*
REDMOND, 1964
Everticyclammina praekelleri
BANNER & HIGHTON, 1990

(Fig. 4.F-G)

- 1990 - *Everticyclammina praekelleri* n. sp. - BANNER & HIGHTON, p. 8, 10; Pl. 1, fig. 1; Pl. 3, fig. 5; Pl. 4, figs. 1-11.
- 2015 - *Everticyclammina praekelleri* BANNER & HIGHTON, 1990 - PLEŠ *et al.*, p. 46, Fig. 3.f-h.

Description: The test is planispirally coiled in early ontogenetic stages, later starting to uncoil reaching terminal rectilinearity in most speci-

mens. Wall is alveolar, imperforate made of agglutinated carbonate grains. In the adult stage, the hypodermis is characterized by the presence of elongated broadened alveoli in the posterior-lateral area and widely spaced alveoli in the anterior-peripheral area. The aperture is single, terminal.

Remarks: The differences between *Everticyclammina praekelleri* and *E. kelleri* are related mainly to the development of the alveolar structures. *E. praekelleri* has much enlarged lateral alveoli compared with *E. kelleri*. The presence of this foraminifer in the Piatra Craiului Massif is mentioned for the first time in this study.

Stratigraphic range: lower Kimmeridgian-upper Tithonian.

***Everticyclammina kelleri*
(HENSON, 1948)**

(Fig. 6.H)

1948 - *Pseudocyclammina kelleri* n. sp. - HENSON, p. 16-17, Pl. 9, figs. 4-5, 7.

1990 - *Everticyclammina kelleri* (HENSON, 1948) - BANNER & HIGHTON, p. 5, Pl. 1, figs. 2-6; p. 7, Pl. 2, figs. 1-4; p. 9, Pl. 3, figs. 1-2.

Description: Planispirally enrolled test in early ontogenetic stages, involute. In several specimens, in the adult stage, the last two chambers can be uncoiled. Wall is thick, alveolar, with agglutinated particles. The inner structure of the foraminifer is composed of networks of bifurcated alveoli, mostly in the lateral parts of the hypodermis. The chambers are flattened; the septa are thick, non alveolar, pierced by a simple-type aperture.

Remarks: In comparison with *E. praekelleri*, *E. kelleri* specimens possess a more developed planispiral stage.

Stratigraphic range: ?Tithonian-Valanginian.

**Genus *Rectocyclammina*
HOTTINGER, 1967
? *Rectocyclammina* sp.**

(Figs. 5.D & 6.G)

Description: The test is conical, tall, elongated with a relatively short planispiral early stage. The adult stage consists of inflated chambers that rapidly increase in height as they successively develop. The chambers are separated by thick septa. Wall is alveolar (alveoli network), agglutinated. The aperture seems to be circular, in the center of the apertural face.

**Family Cyclamminidae MARIE, 1941
Subfamily Choffatellinae MAYNC, 1958
Genus *Bramkampella* REDMOND, 1964
Bramkampella arabica REDMOND, 1964**

(Fig. 4.C)

1964 - *Bramkampella arabica* n. sp. - REDMOND, p. 410, Pl. 1, figs. 26-29.

1991 - *Bramkampella arabica* REDMOND, 1964 - BANNER & WHITTAKER, p. 45, Pl. 2, figs. 1-7.

2005 - *Bramkampella arabica* REDMOND, 1964 - BUCUR & SĂSĂRAN, Pl. 2, figs. 6-7.

Description: Medium-sized robust subconical test, planspirally enrolled in early stage. The test uncoils in a short distance and progressively gains size in the adult stage. Wall is alveolar, agglutinated. A network of elongated interseptal alveoli radially developed defines the inner structure of the foraminifer. The septa are high-arched, pierced by many openings (multiple aperture type).

Remarks: The highly curved septa and the multiple aperture type, differentiate this species from *Rectocyclammina chouberti*. The presence of this foraminifer in the Piatra Craiului Massif is mentioned for the first time in this study.

Stratigraphic range: Kimmeridgian-lower Valanginian.

**Suborder Ataxophragmiina
FURSENKO, 1958**

**Superfamily Ataxophragmioidea
SCHWAGER, 1877**

Family Montsaleviidae

ZANINETTI *et al.*, 1987

Genus *Montsalevia*

ZANINETTI *et al.*, 1987

Montsalevia salevensis

(CHAROLLAIS *et al.*, 1966)

(Fig. 6.I)

1966 - *Pseudotextulariella salevensis* n. sp. - CHAROLLAIS *et al.*, p. 28, Pl. 1, figs. 1-5.

1966 - *Pseudotextulariella salevensis* - BRÖNNIMANN, Pl. III, fig. 4.

1987 - "*Montsalevia*" *salevensis* - ZANINETTI *et al.*, p. 166

1988 - *Pseudotextulariella salevensis* CHAROLLAIS *et al.*, 1966 - BUCUR, p. 387, Pl. 2, figs. 11-12.

1991 - *Montsalevia salevensis* - ALTINER, p. 170, Fig. 3; p. 173-177, Pl. 11, figs. 1-23.

2010 - *Montsalevia salevensis* (CHAROLLAIS *et al.*, 1966) - IVANOVA & KOŁODZIEJ, p. 25, Pl. 2, fig. 10.

2016 - *Montsalevia salevensis* (CHAROLLAIS *et al.*, 1966) - GRĂDINARU *et al.*, Fig. 14.G-K.

Description: Small-sized conical test that is trochospirally enrolled in the initial stage, later becoming biserial. The inner-structure is divided by radial partitions in numerous small flattened chamberlets. The wall is microgranular (finely agglutinated), imperforated. Aperture is interiomarginal.

Stratigraphic range: Berriasian-Hauterivian.

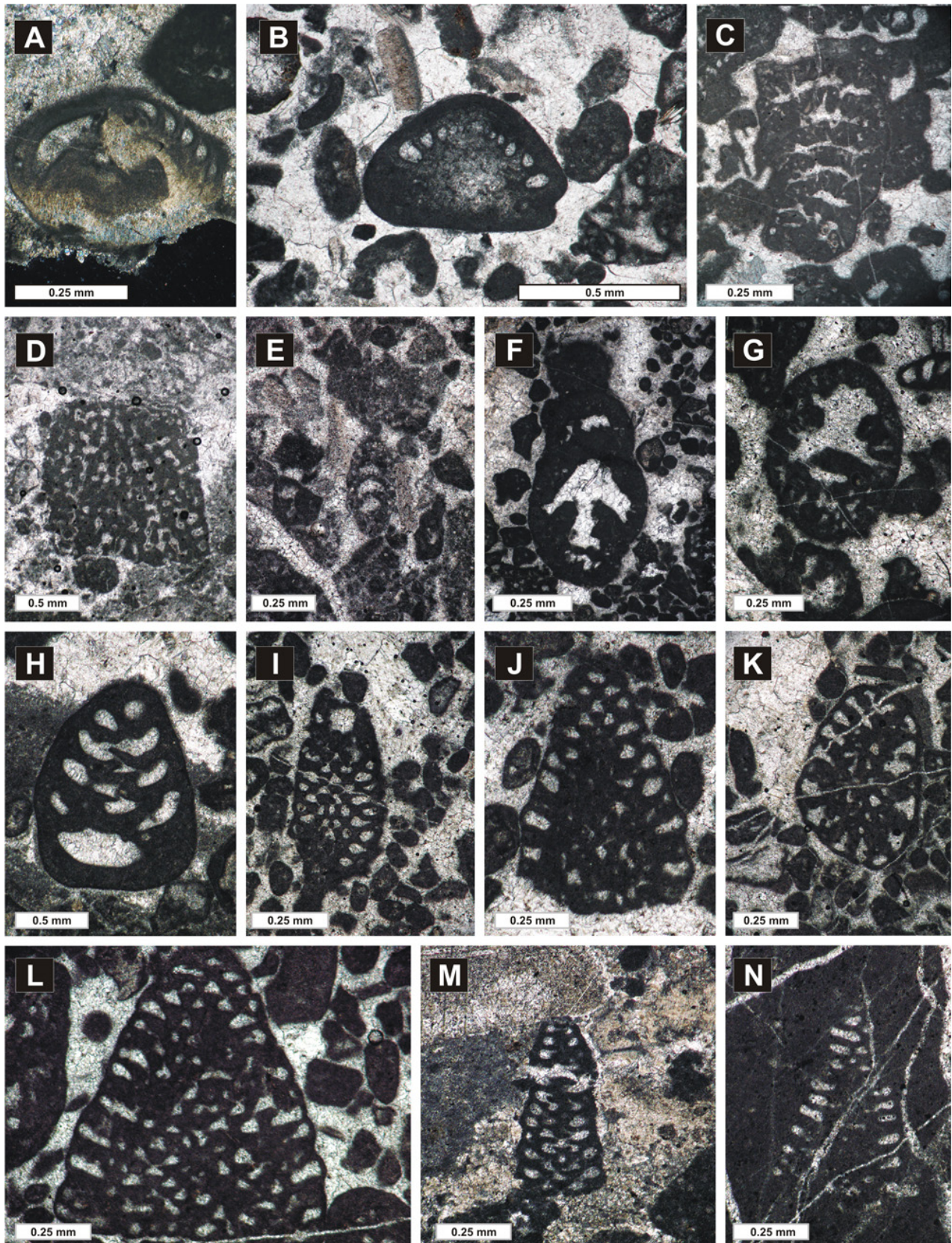


Figure 4: Foraminiferal assemblage identified in biostratigraphic interval A (A: *Mohlerina basiliensis*; B: *Frentzenella involuta*; C: *Bramkampella arabica*; D: *Labyrinthina mirabilis*; E: *Lituola baculiformis*; F-G: *Everticyclamina prae-kelleri*; H: *Redmondoides lugeoni*; I-L: *Neokilianina rahonensis*; M-N: *Parurgonina caelinensis*) (A: Sample 216, Vlădușca de Vest-Vlădușca de Est section; B: Sample 17, Zaplaz-Lanțuri section; C: Sample 92, Padina Popii section; D: Sample 743, Padina Lăncii section; E: Sample 18, Zaplaz-Lanțuri section; F: Sample 634, Zaplaz-Lanțuri section; H: Sample 630, Zaplaz-Lanțuri section; I-J, L: Sample 633, Zaplaz-Lanțuri section; K: Sample 628, Zaplaz-Lanțuri section; M: Sample 650, Zaplaz-Lanțuri section; N: Sample 652, Zaplaz-Lanțuri section).

Family Cuneolinidae SADOIVA, 1981
Subfamily Cuneolininae SADOIVA, 1981
Genus *Pseudotextulariella*
BARNARD, 1953

Pseudotextulariella courtionensis
BRÖNNIMANN, 1966

(Fig. 5.C)

- 1966 - *Pseudotextulariella courtionensis* n. sp. - BRÖNNIMANN, p. 267-276, Figs. 1-8; Pl. I, figs. 1-5; Pl. II, figs. 1-2; Pl. III, fig. 3.
 1977 - *Pseudotextulariella courtionensis* BRÖNNIMANN, 1966 - AZÉMA *et al.*, p. 137, Pl. 3, figs. 13-14.
 1983 - *Pseudotextulariella courtionensis* BRÖNNIMANN, 1966 - DARSAC, Pl. 5, figs. 1-8.
 2016 - *Pseudotextulariella courtionensis* BRÖNNIMANN, 1966 - GRÄDINARU *et al.*, Fig. 14.B.

Description: The initial stage of the test is trochospirally developed, subsequently becoming triserial and biserial in the adult stage. Shape of the test is low to high conical. The internal structure is composed of horizontal and vertical partitions. Wall is finely agglutinated. Aperture face is flattened with a slit-type opening at the base.

Stratigraphic range: Berriasian.

Suborder Orbitolinina KAMINSKI, 2004
Superfamily Pfenderinoidea
SMOUT & SUGDEN, 1962
Family Pfenderinidae
SMOUT & SUGDEN, 1962
Subfamily Pfenderininae
SMOUT & SUGDEN, 1962
Genus *Pfenderina* HENSON, 1948
Pfenderina neocomiensis
(PFENDER, 1938)

(Fig. 6.M-O)

- 1938 - *Eorupertia neocomiensis* n. sp. - PFENDER - p. 236, Pl. XVI, figs. 1-7.
 1961 - *Pfenderina neocomiensis* (PFENDER, 1938) - SMOUT & SUGDEN, p. 585-588, Pl. 73, figs. 1-9; Pl. 74, figs. 1-3; Pl. 75, fig. 1.
 1995 - *Pfenderina neocomiensis* (PFENDER, 1938) - BUCUR *et al.*, p. 369, Pl. 6, figs. 4-6.

Description: The test is high trochospiral with a thickened (columellar) central zone. The chambers are small and numerous separated by oblique septa. The wall is agglutinated/microgranular imperforate. Primary aperture is multiple, secondary one being represented by an intercameral passage (groove), spiraling around the thick axial zone.

Stratigraphic range: upper Berriasian-Valanginian.

Family Hauraniidae SEPTFONTAINE, 1988
Subfamily Amijellinae
SEPTFONTAINE, 1988
Genus *Anchispirocyclus*
JORDAN & APPLIN, 1952
cf. *Anchispirocyclus lusitanica*
(EGGER, 1902)

(Fig. 5.E-F)

- 1902 - *Dicyclus lusitanica* n. sp. - EGGER, p. 585, Pl. 6, figs. 3-5.
 1967 - *Anchispirocyclus lusitanica lusitanica* (EGGER, 1902) - HOTTINGER, p. 74, Pl. 13, figs. 6-8.
 1987 - *Anchispirocyclus lusitanica* (EGGER, 1902) - GRANIER, Pl. 48, fig. k.
 2005 - *Anchispirocyclus lusitanica* (EGGER, 1902) - SCHLAGINTWEIT *et al.*, p. 25, Fig. 5.a-c.

Description: Test large, compressed, planispirally to asymmetrically coiled in juvenile stage, in adult stage spreading becoming peneropliform or circular. The wall is imperforate, finely agglutinated. Reticulate layers of beams and rafters characterize the hypodermis. The central part of the test is represented by a multitude of radial interseptal pillars. The chambers are elongated, especially in adult stages, separated by highly curved septa. Aperture is cribrate, extending across the apertural face.

Remarks: The specimens identified in Piatra Craiului are poorly preserved, and the above-described characteristics are difficult to observe. The presence of this foraminifer in the Piatra Craiului Massif is mentioned for the first time in this study.

Stratigraphic range: Tithonian-lower Berriasian.

Genus *Pseudocyclamina*
YABE & HANZAWA, 1926
Pseudocyclamina lituus
(YOKOYAMA, 1890)

(Figs. 5.B & 6.A-B)

- 1890 - *Cyclamina lituus* n. sp. - YOKOYAMA, p. 26, Pl. 5, fig. 7.
 1926 - *Pseudocyclamina lituus* (YOKOYAMA, 1890) - YABE & HANZAWA, p. 10, Pl. 2, figs. 3-6.
 1995 - *Pseudocyclamina lituus* (YOKOYAMA, 1890) - BUCUR *et al.*, p. 358, Pl. 1, figs. 3-4.
 2006 - *Pseudocyclamina lituus* (YOKOYAMA, 1890) - KOBAYASHI & VUKS, p. 840, Figs. 5, 7-14.

Description: Planispirally enrolled medium to large-sized test tending to uncoil in advanced ontogenetic stages. Wall alveolar, coarsely agglutinated with layers of thick alveoli in the hypodermis; septa are very thick. Aperture is areal, multiple, across the apertural face.

Stratigraphic range: Kimmeridgian-lower Valanginian.

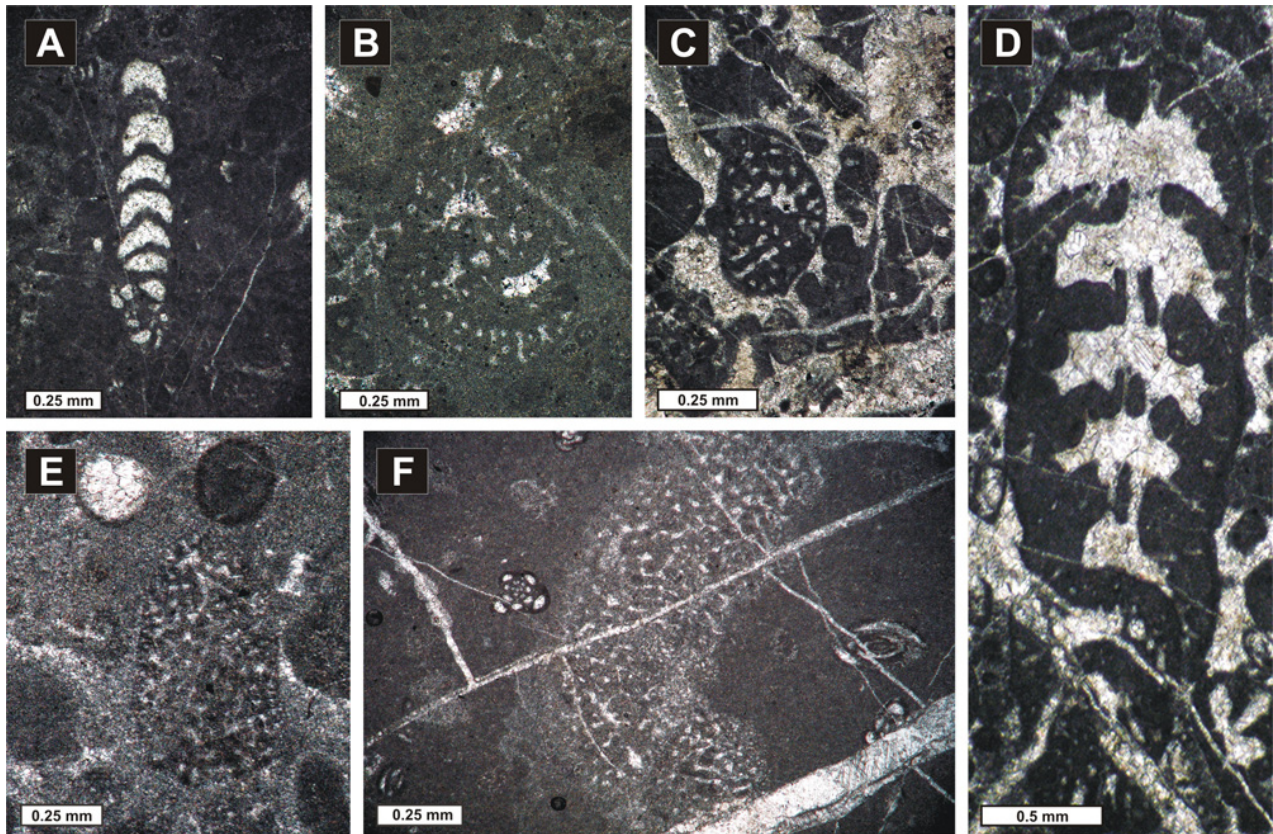


Figure 5: Foraminiferal assemblage identified in biostratigraphic interval B (A: *Bulbobaculites* sp.; B: *Pseudocyclammina lituus*; C: *Pseudotextulariella courtionensis*; D: *Rectocyclammina* sp.; E-F: cf. *Anchispirocyclina lusitani-ca*) (A: Sample 394, Padina Închisă-Drumul lui Lehmann section; B: Sample 269, Vlădușca de Vest-Vlădușca de Est section; C: Sample 464, Padina Închisă-Drumul lui Lehmann section; D: Sample 464, Padina Închisă-Drumul lui Lehmann section; E-F: Sample 46, Zaplaz-Lanțuri section).

Family Parurgoninidae
SEPTFONTAINE, 1988
Genus Parurgonina
CUVILLIER *et al.*, 1968
Parurgonina caelinensis
CUVILLIER *et al.*, 1968

(Fig. 4.M-N)

1968 - *Urgonina (Parurgonina) caelinensis* n. sp. - CUVILLIER *et al.*, p. 151, Pl. 2, figs. 1-12.

1975 - *Parurgonina caelinensis* CUVILLIER *et al.*, 1968 - SCHROEDER *et al.*, p. 320-325, Pl. 1, figs. 1-4; Pl. 2, figs. 3-5.

2014 - *Parurgonina caelinensis* CUVILLIER *et al.*, 1968 - MIRCESCU *et al.*, p. 13, Pl. 1, fig. 1.

Description: Test is conical, trochospirally developed in the initial part, later becoming uniserial. The chambers are cylindrical/semi-lunar in shape, separated by vertical pillars and low-arched septa. The wall is pseudo-keriothecal, made of fine fibrous microstructural elements. Aperture is multiple.

Remarks: *P. caelinensis* differs from *Neokilianina rahonensis* by internal structural features (pillar development and the shape of the chamber lumen).

Stratigraphic range: uppermost Oxfordian-lower Tithonian.

Genus Neokilianina SEPTFONTAINE, 1988
Neokilianina rahonensis
(FOURY & VINCENT, 1967)

(Fig. 4.I-L)

1967 - *Kilianina rahonensis* n. sp. - FOURY & VINCENT, Pl. 2, figs. 1-14.

1988 - *Neokilianina rahonensis* (FOURY & VINCENT, 1967) - SEPTFONTAINE, p. 249.

2005 - "*Kilianina*" *rahonensis* FOURY & VINCENT, 1967 - SCHLAGINTWEIT *et al.*, p. 29, Fig. 11.a-d.

Description: Medium sized conical test, with numerous chambers in the adult stage. The shape of the chamber lumen in longitudinal sections is more or less triangular (oblique stolons/low arched septa). Closely spaced interseptal pillars are developed in the central part of the test. Wall is finely agglutinated with canaliculate structure; aperture multiple.

Remarks: The presence of this foraminifer in the Piatra Craiului Massif is mentioned for the first time in this study.

Stratigraphic range: uppermost Oxfordian-lower Tithonian.

Superfamily Orbitolinoidea
MARTIN, 1890
Subfamily Praedictyorbitolininae
SCHROEDER, 1990
Genus *Paracoskinolina* MOULLADE, 1965
Paracoskinolina* ? *jourdanensis
(FOURY & MOULLADE, 1966)

(Fig. 6.K-L)

- 1966 - *Meyendorffina* (*Paracoskinolina*) *jourdanensis* n. sp. - FOURY & MOULLADE, p. 252, Pl. 1, figs. 1-6.
 1980 - *Paracoskinolina* ? *jourdanensis* (FOURY & MOULLADE, 1966) - ARNAUD-VANNEAU, Pl. 102, figs. 1-4.
 2008 - *Paracoskinolina* ? *jourdanensis* (FOURY & MOULLADE, 1966) - MICHETIUC *et al.*, p. 226, Pl. 3, fig. 3.
 2014 - *Paracoskinolina* ? *jourdanensis* (FOURY & MOULLADE, 1966) - BRUCHENTAL *et al.*, p. 36, Fig. 3.a.
 2016 - *Paracoskinolina* ? *jourdanensis* (FOURY & MOULLADE, 1966) - GRÄDINARU *et al.*, Fig. 14.A.

Description: High conical test, some specimens with an apical bulb (a short juvenile spire), followed by rectilinear development. Long intercameral vertical pillars characterize the internal structure of the foraminifer. Also two sets of radial beams are present in the subepidermal region. Wall is microgranular, imperforated. Aperture is composed of multiple pores on the basal side.

Stratigraphic range: upper Berriasian-lower Barremian.

Order Textulariida
DELAGE & HÉROUARD, 1896
Suborder Textulariina
DELAGE & HÉROUARD, 1896
Superfamily Chrysalidinoidea
NEAGU, 1968
Family Paravalvulinidae
BANNER *et al.*, 1991
Subfamily Paravalvulininae
BANNER *et al.*, 1991
Genus *Redmondoides*
BANNER *et al.*, 1991
Redmondoides lugeoni
(SEPTFONTAINE, 1977)

(Fig. 4.H)

- 1977 - *Valvulina lugeoni* n. sp. - SEPTFONTAINE, p. 612-613, Pl. 2, figs. 2-5.
 1987 - *Valvulina lugeoni* SEPTFONTAINE, 1977 - GRANIER, Pl. 14, fig. g.
 1991 - *Redmondoides lugeoni* (SEPTFONTAINE, 1977) - BANNER *et al.*, p. 127, figs. 46-54.
 2016 - *Redmondoides lugeoni* (SEPTFONTAINE, 1977) - GRANIER *et al.*, p. 259, Pl. 1, fig. 17.

Description: Large-sized conical, trochospiral test with thick microgranular/agglutinated walls and septa. The test is quadriserial throughout most ontogenetic stages. The microgranular material that forms the test walls and septa

may develop canalculated features in some specimens. Aperture is interiomarginal (slit-type) enclosed by a flat lip (Fig. 4.G).

Stratigraphic range: upper Bathonian-lower Tithonian.

Order Involutinida
HOHENEGGER & PILLER, 1977
Suborder Involutinina
HOHENEGGER & PILLER, 1977
Superfamily Involutinoidea
BÜTSCHLI, 1880
Family Trocholinidae
KRISTAN-TOLLMANN, 1963
Subfamily Trocholininae
KRISTAN-TOLLMANN, 1963
Genus *Coscinoconus* LEUPOLD, 1936
Coscinoconus campanellus
(ARNAUD-VANNEAU *et al.*, 1988)

(Fig. 6.C-D)

- 1988 - *Trocholina campanella* n. sp. - ARNAUD-VANNEAU *et al.*, p. 371, Pl. 3, figs. 9-15.
 1994 - *Andersenolina campanella* (ARNAUD-VANNEAU *et al.*, 1988) - NEAGU, p. 143, Pl. 13, figs. 19-20.
 2013 - *Coscinoconus campanellus* (ARNAUD-VANNEAU *et al.*, 1988) - RIGAUD *et al.*, p. 330.
 2016 - *Coscinoconus campanellus* (ARNAUD-VANNEAU *et al.*, 1988) - GRÄDINARU *et al.*, Fig. 14.U.

Description: Large-sized *Coscinoconus* representative with a bell-shaped (or piriform), trochospirally coiled test and a convex base. The chambers are tubular, undivided. Apical angle ranges between 60 and 70 degrees. Wall (originally aragonitic) is hyaline, perforated. Aperture located at the end of the tubular chambers.

Remarks: This species differs from the other *Coscinoconus* representatives by the apical angle and by the pyriform shape of the test.

Stratigraphic range: upper Berriasian-Valanginian.

Coscinoconus cherchiai
(ARNAUD-VANNEAU *et al.*, 1988)

(Fig. 6.E)

- 1988 - *Trocholina cherchiai* n. sp. - ARNAUD-VANNEAU *et al.*, p. 369, Pl. 2, figs. 9-21.
 1994 - *Andersenolina cherchiai* (ARNAUD-VANNEAU *et al.*, 1988) - NEAGU, p. 126, Pl. 5, figs. 1-14.
 2013 - *Coscinoconus cherchiai* (ARNAUD-VANNEAU *et al.*, 1988) - RIGAUD *et al.*, p. 330.
 2016 - *Coscinoconus cherchiai* (ARNAUD-VANNEAU *et al.*, 1988) - GRÄDINARU *et al.*, Fig. 14.V.

Description: The test is medium in size characterized by variations of shape during ontogeny. In the initial stage, the test is low to high conical in shape (40-50 degrees apical angle), and in advanced ontogenetic stages, the test becomes more cylindrical and elongated. Chambers are broader than those of *C. campanellus* and triangular in shape in longitudinal sections.

Stratigraphic range: upper Berriasian-Valanginian.

Family Ventrolaminidae

WEYNSCHENK, 1950

Genus *Protopenneroplis*

WEYNSCHENK, 1950

Protopenneroplis ultragranulata

(GORBATCHIK, 1971)

(Fig. 6.P)

1971 - *Hoeglundina* ? *ultragranulata* n. sp. - GORBATCHIK, p. 135, Pl. 5, fig. 2.a-c.

1974 - *Protopenneroplis trochangulata* n. sp. - SEPT-FONTAINE., p. 608, Pl. 1, figs. 1-18.

1987 - *Protopenneroplis trochangulata* SEPTFONTAINE, 1974 - GRANIER, Pl. 3, figs. g-j; Pl. 44, figs. a, d.

1993 - *Protopenneroplis ultragranulata* (GORBATCHIK, 1971) - BUCUR, p. 221, Pl. 2, figs. 1-2, 5, 8, 11-12.

1997 - *Protopenneroplis ultragranulata* (GORBATCHIK, 1971) - BUCUR, Pl. 6, figs. 1-14.

2016 - *Protopenneroplis ultragranulata* (GORBATCHIK, 1971) - GRÄDINARU *et al.*, Fig. 14.S-T.

Description: Small-sized trochospirally enrolled, lenticular test, involute, with a two layered calcareous wall. The inner layer is microgranular, protected by a hyaline outer layer. Aperture is areal.

Remarks: The trochospiral model of coiling of *P. ultragranulata* differentiates it from *P. striata* WEYNSCHENK.

Stratigraphic range: middle Tithonian-Barremian (acme in Berriasian-Valanginian).

Order Rotaliida LANKESTER, 1885

Suborder Rotaliina

DELAGE & HÉROUARD, 1986

?Family Rosalinidae REISS, 1963

Genus *Mohlerina* BUCUR *et al.*, 1996

***Mohlerina basiliensis* (MOHLER, 1938)**

(Fig. 4.A)

1938 - *Conicospirillina basiliensis* n. sp. - MOHLER, p. 27, Pl. 4, figs. 4-5.

1987 - "*Conicospirillina*" *basiliensis* MOHLER, 1938 - GRANIER, Pl. 3, figs. g-j; Pl. 44, fig. e.

1996 - *Mohlerina basiliensis* (MOHLER, 1938) - BUCUR *et al.*, p. 74, Pl. 3, figs. 3-6.

2012 - *Mohlerina basiliensis* (MOHLER, 1938) - SCHLAGINTWEIT, p. 639, Fig. 2.a-j.

Description: The test is generally low conical in shape, trochospirally coiled. The test wall is calcareous bilamellar (microcrystalline layer and radial-fibrous calcitic layer). Aperture is possibly slit-type.

Remarks: *M. basiliensis* is considered to be the single species of the genus *Mohlerina*.

Stratigraphic range: middle Bathonian-lower Valanginian.

6. Biostratigraphy of the Upper Jurassic-Lower Cretaceous transition

Three biostratigraphic intervals (A-C) were differentiated in the Upper Jurassic-Lower Cretaceous carbonate succession from Piatra Craiului Massif based on the occurrence of several species of foraminifera and dasycladalean algae (Fig. 3).

6.A. Biostratigraphic interval A (Kimmeridgian-lower Tithonian)

The first interval contains the following algae and foraminifera (Fig. 3): *Campbelliella striata* (CAROZZI, 1954), *Clypeina sulcata* (ALTH, 1882), *Neoteutloporella socialis* (PRATURLON, 1963), *Petrascula bursiformis* (ETALLON, 1859), *Salpingoporella annulata* CAROZZI, 1953, *S. pygmaea* (GÜMBEL, 1891), *Steinmanniporella kapelensis* (SOKAČ & NIKLER, 1973), *Bramkampella arabica* REDMOND, 1964 (Fig. 4.C), *Everticyclammina praekelleri* BANNER & HIGHTON, 1990 (Fig. 4.F-G), *Frentzenella involuta* (MANTSUROVA & GORBATCHIK, 1982) (Fig. 4.B), *Labyrinthina mirabilis* WEYNSCHENK, 1951 (Fig. 4.D), *Lituola baculiformis* SCHLAGINTWEIT & GAWLICK, 2007 (Fig. 4.E), *Lenticulina* sp., *Mohlerina basiliensis* (MOHLER, 1938) (Fig. 4.A), *Neokilianina rahonensis* (FOURY & VINCENT, 1967) (Fig. 4.I-L), *Nodosaria* sp., *Parurgonina caelinensis* CUVILLIER *et al.*, 1968 (Fig. 4.M-N), and *Redmondoides lugeoni* (SEPT-FONTAINE, 1977) (Fig. 4.H). The microfossil assemblage identified in this interval (0-410 m) is characteristic of the Kimmeridgian-lower Tithonian interval.

Although some species of algae (*e.g.*, *Salpingoporella pygmaea* or *Clypeina sulcata*) have longer stratigraphic distributions, most taxa provide valuable biostratigraphic information:

- Several authors mentioned *Campbelliella striata* from Kimmeridgian-lower Berriasian limestones (CAROZZI, 1954; FARINACCI & RADOIČIĆ, 1964). However, it is more common in Kimmeridgian-Tithonian deposits (JAFFREZO, 1970; BERNIER, 1971).
- *Clypeina sulcata* is characteristic of the Kimmeridgian-Berriasian interval. It was mostly described from Upper Jurassic, Kimmeridgian-Tithonian sedimentary rocks (BASSOULLET *et al.*, 1978).
- *Petrascula bursiformis* and *Neoteutloporella socialis* are two algal species that are common in the Upper Jurassic. They have been identified in many Kimmeridgian-Tithonian deposits of the Tethyan realm (DRAGASTAN, 1975; SCHLAGINTWEIT & EBLI, 1999; BUCUR *et al.*, 2005; MEINHOLD *et al.*, 2009; SCHLAGINTWEIT, 2011).
- *Salpingoporella pygmaea* is known from Bajocian-Aptian carbonate deposits (GRANIER & DELOFFRE, 1993; BUCUR, 1999; CARRAS *et al.*, 2006) and it is most frequently reported in the Upper Jurassic (Kimmerid-

gian-Tithonian) (FARINACCI & RADOIČIĆ, 1991; SENOWBARI-DARYAN *et al.*, 1994).

- *Steinmanniporella kapelensis* is a rare species known only from Tithonian deposits (SOKAČ & NIKLER, 1973; SCHLAGINTWEIT & EBELI, 1999; BUCUR & SĂSĂRAN, 2012; MIRCESCU *et al.*, 2014).

Regarding the foraminiferal assemblage, *Neokilianina rahonensis*, *Parurgonina caelinensis* and *Labyrinthina mirabilis* represent the most biostratigraphically important taxa for this interval. They were reported mainly from Kimmeridgian-Tithonian strata (CUVILLIER *et al.*, 1968; SEPTFONTAINE, 1988; TASLI, 1993; POP & BUCUR, 2001; VELIĆ, 2007; PLEŠ *et al.*, 2015).

Considering this, the whole micropaleontological assemblage identified in this biostratigraphic interval (Fig. 3) represents the Kimmeridgian-lower Tithonian interval. Although some species of foraminifera (*Labyrinthina mirabilis*, *Neokilianina rahonensis*, and *Parurgonina caelinensis*) appear lower in the geological record in the uppermost Oxfordian (SEPTFONTAINE, 1988; BASSOULLET, 1997; VELIĆ, 2007; PLEŠ *et al.*, 2015), well-dated Oxfordian radiolarites (MÉSZÁROS & BUCUR, 1980; BECCARO & LAZĂR, 2007) are directly below the limestones of interval A. Moreover, many microfossils of the assemblage (*Clypeina sulcata*, *Petrascula bursiformis*, *Salpingoporella pygmaea*, *Coscinoconus alpinus*, *Everticyclammina praekelleri*, *Mohlerina basilienensis*, *Redmondoides lugeoni*) represent typical Kimmeridgian-Tithonian biota (BUCUR, 1999; SCHLAGINTWEIT *et al.*, 2005), and most of the mentioned taxa are known from carbonates no older than lower Kimmeridgian (BASSOULLET, 1997). In addition, the presence of *Steinmanniporella kapelensis* and several sclerosponge species (*Calcistella jachenhausenensis* REITNER, 1992, *Neuropora lusitanica* TERMIER, 1985, and *Thalamopora lusitanica* TERMIER *et al.*, 1985) confirms the Tithonian age of the upper part of biostratigraphic interval A.

6.B. Biostratigraphic interval B (upper Tithonian-lower Berriasian)

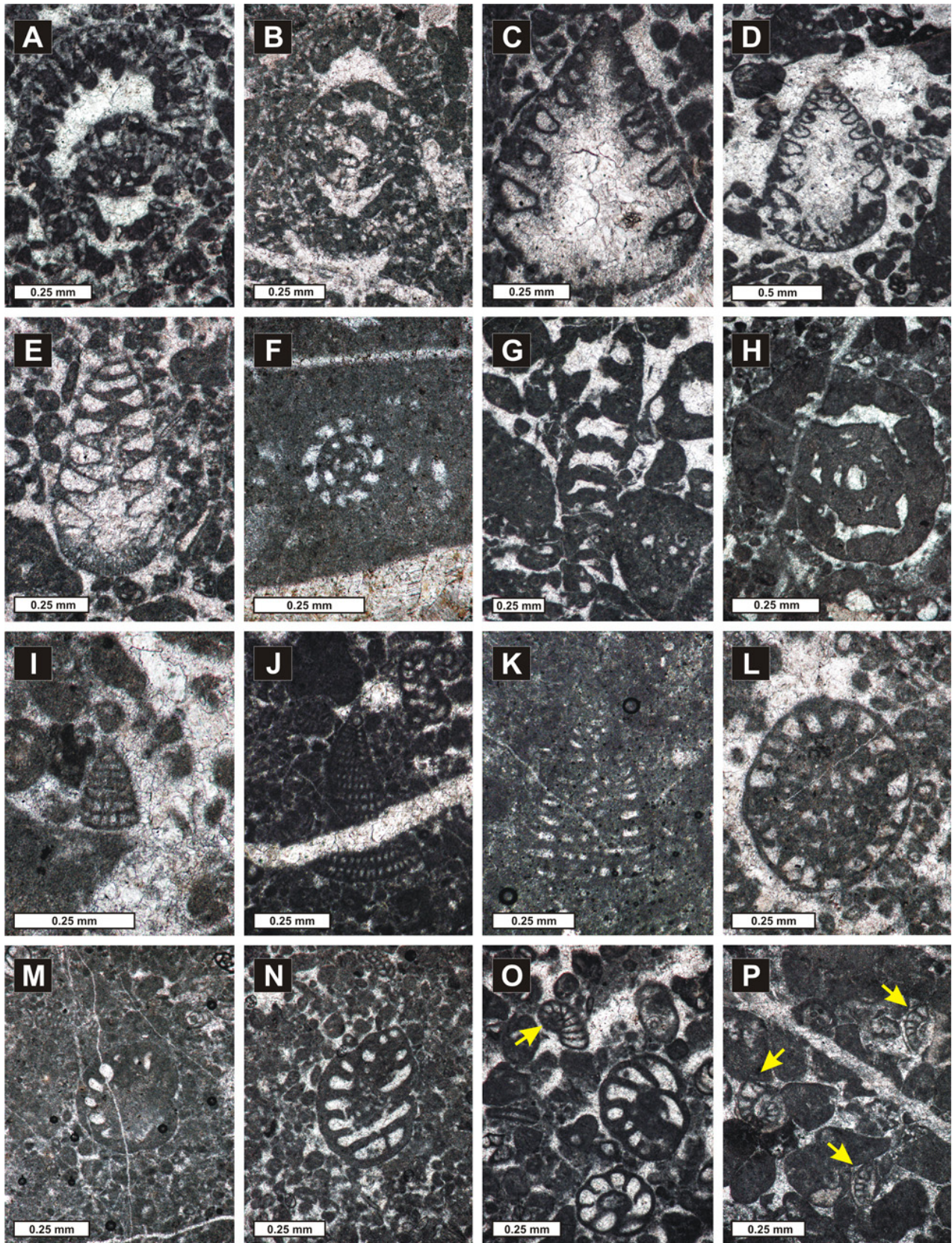
In the second biostratigraphic interval (B), the total number of species of dasycladalean algae decreases compared to that of the foraminifera species (Fig. 3). The following species have been identified in this interval: *Clypeina parasolkani* FARINACCI & RADOIČIĆ, 1991, *Salpin-*

goporella annulata CAROZZI, 1953, *Selliporella neocomiensis* (RADOIČIĆ, 1963), cf. *Anchispirocyclina lusitanica* (EGGER, 1902) (Fig. 5.E-F), *Bulbobaculites* sp. (Fig. 5.A), *Pseudocyclammina lituus* (YOKOYAMA, 1890) (Fig. 5.B, *Pseudotextulariella courtionensis* BRÖNNIMANN, 1966 (Fig. 5.C), and *Rectocyclammina* sp. HOTTINGER, 1967 (Figs. 5.D & 6.G).

- FARINACCI and RADOIČIĆ (1991) described *Clypeina parasolkani* from upper Tithonian-Berriasian deposits from Turkey (Pontides). It is common in similar deposits from Sardinia (DIENI & RADOIČIĆ, 1999), Italy (Apennines) (BRUNI *et al.*, 2007), and Switzerland (GRANIER *et al.*, 2014).
- *Selliporella neocomiensis* is a typical species of Berriasian shallow water carbonates (PEYBERNÈS, 1976; LUPERTO-SINNI & MASSE, 1986; GRANIER & DELOFFRE, 1993; BUCUR, 1999; SĂSĂRAN & BUCUR, 2001).
- *Anchispirocyclina* spp., including *A. lusitanica*, have been reported by several authors mostly from Tithonian-lowermost Berriasian deposits (FOURCADE, 1970; JAFFREZO, 1980; DYA, 1992; SCHLAGINTWEIT *et al.*, 2005).
- *Pseudocyclammina lituus* has a Kimmeridgian-lower Valanginian distribution and is most common in Tithonian-Berriasian deposits (DARGA & SCHLAGINTWEIT, 1991; MOSHAMER & SCHLAGINTWEIT, 1999).
- *Pseudotextulariella courtionensis* is a Berriasian foraminifer commonly found in Lower Cretaceous limestones from Switzerland (BRÖNNIMANN, 1966), France (DARSAC, 1983) and Spain (Pyrenees) (SCHROEDER *et al.*, 2000).

The lower part of the biostratigraphic interval B is probably still Tithonian in age. The first occurrence of "cf. *Anchispirocyclina lusitanica*" is recorded near the base of biostratigraphic interval B (Fig. 3) where this foraminifer is associated with the alga *Clypeina parasolkani*. *Pseudocyclammina lituus* appears slightly higher in the same interval of the sections studied. The first primary evidence for a Berriasian age is brought by the first occurrence of *Selliporella neocomiensis* (Fig. 3), followed by that of *Pseudotextulariella courtionensis*. Thus the upper part of the biostratigraphic interval B can definitely be ascribed to the lower Berriasian (GRANIER & BUCUR, 2011).

► **Figure 6:** Foraminiferal assemblage identified in biostratigraphic interval C [(A-B: *Pseudocyclammina lituus*; C-D: *Coscinoconus campanellus*; E: *Coscinoconus cherchiaie*; F: *Nautilocolina* cf. *broennimanni*; G: *Rectocyclammina* sp.; H: *Everticyclammina kelleri*; I: *Montsalevia salevensis*; J: *Scythiolina* sp.; K-L: *Paracoskinolina* ? *jourdanensis*; M-O: *Pfenderina neocomiensis*; O: *Freixialina planispiralis* (arrow); P: *Protopenneroplis ultragranulata* (arrows)] (A: Sample 11828, Ciorânga Mare-Vf. Ascuțit-Padinile Frumoase section; B: Sample 11879, Ciorânga Mare-Vf. Ascuțit-Padinile Frumoase section; C-D: Sample 11867, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; E: Sample 11868, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; F: Sample 11821, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; G: Sample 11843, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; H: Sample 11867, Zaplaz-Lanțuri section; Sample 11867, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; I: Sample 11867, .../...



Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; J: Sample 287, Vlădușca de Vest-Vlădușca de Est section; K: Sample 331, Vlădușca de Vest-Vlădușca de Est section; L: Sample 11830, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; M: Sample 9, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; N: Sample 11830, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; O: Sample 12831, Ciorânga Mare- Vf. Ascuțit -Padinile Frumoase section; P: Sample 411, Padina Închisă-Drumul lui Lehmann section).

It is impossible to identify the Tithonian-Berriasian boundary in interval B, because none of the markers, either primary or secondary, or proxies are present in our material. The micropaleontological assemblage of this stratigraphic interval (Fig. 3) merely indicates the Upper Jurassic-Lower Cretaceous transition.

6.C. Biostratigraphic interval C (upper Berriasian-? lower Valanginian)

As in interval B (Fig. 3), the total number of foraminiferal species in interval C exceeds that of other taxa such as dasycladalean algae. The main microfossils are represented by: *Pseudocymopolia jurassica* (DRAGASTAN, 1968), *Salpingoporella praturloni* (DRAGASTAN, 1978) (Fig. 3), *Coscinoconus campanellus* (ARNAUD-VANNEAU *et al.*, 1988) (Figs. 3 & 6.C-D), *C. cherchiaie* (ARNAUD-VANNEAU *et al.*, 1988) (Figs. 3 & 6.E), *Everticyclammina kelleri* (HENSON, 1948) (Fig. 6.H), *Freixialina planispiralis* RAMALHO, 1969 (Fig. 6.O, arrow), *Montsalevia salevensis* (CHAROLLAIS *et al.*, 1966) (Figs. 3 & 6.I), *Nautiloculina* cf. *broennimanni* (ARNAUD-VANNEAU & PEYBERNÈS, 1978) (Figs. 3 & 6.F), *Paracoskinolina ? jourdanensis* FOURY & MOULLADE, 1966 (Figs. 3 & 6.K-L), *Pfenderina neocomiensis* (PFENDER, 1938) (Figs. 3 & 6.M-O), *Protopenneroplis ultragranulata* (GORBATCHIK, 1971) (Figs. 3 & 6.P), *Pseudocyclammina lituus* (YOKOYAMA, 1890) (Fig. 6.A-B), and *Scythiolina* sp. (Fig. 6.J).

Dasycladalean algae (*Pseudocymopolia jurassica*, *Salpingoporella praturloni*) are rare. They were identified in a stratigraphic level in the uppermost part of this interval. Foraminifera (*Coscinoconus campanellus*, *C. cherchiaie*, *Montsalevia salevensis*, *Nautiloculina* cf. *broennimanni*, *Paracoskinolina ? jourdanensis*, *Pfenderina neocomiensis*, *Protopenneroplis ultragranulata*) are abundant in the same level (Fig. 3).

- *Pseudocymopolia jurassica* and *Salpingoporella praturloni* are generally known from Berriasian-lower Valanginian deposits (DRAGASTAN, 1975; JAFFREZO, 1980; BUCUR, 1985; FARINACCI & RADOIČIĆ, 1991; BUCUR & SĂȘĂRAN, 2005).
- *Coscinoconus campanellus* and *C. cherchiaie* are commonly found in upper Berriasian-lower Valanginian carbonate rocks in Italy (MANCINELLI & COCCIA, 1999), Serbia (BUCUR *et al.*, 1995), Romania (NEAGU, 1994), and Bulgaria (IVANOVA, 2000).
- *Montsalevia salevensis* is known from numerous Valanginian deposits throughout Europe (CHAROLLAIS *et al.*, 1966; VELIĆ & SOKAČ, 1983; BOISSEAU, 1987; CHIOCCHINI *et al.*, 1988; BUCUR, 1988; SCHROEDER *et al.*, 2000).
- *Paracoskinolina ? jourdanensis* was described for the first time from lower Barremian deposits by FOURY and MOULLADE (1966).

However, it is common in upper Berriasian-lower Valanginian deposits in association with *Pfenderina neocomiensis* (BUCUR *et al.*, 1995).

- *Protopenneroplis ultragranulata* has a long stratigraphic range (middle Tithonian-Barremian) with an acme in the Berriasian-Valanginian (ALTINER, 1991; CHIOCCHINI *et al.*, 1994; BUCUR, 1997).

Some foraminifera found in this assemblage (*e.g.*, *Protopenneroplis ultragranulata*) extend up into the Barremian (BUCUR, 1997; GRANIER & BUCUR, 2011). However, most algae or foraminifera listed above do not extend higher than the Valanginian and some have never been reported from Upper Valanginian strata. In conclusion, the above mentioned assemblage indicates a late Berriasian-early Valanginian age for biostratigraphic unit C.

The exact position of the Berriasian-Valanginian boundary is difficult to identify on the sole basis of the micropaleontological assemblage. However, based on ammonite and calpionellid finds, the lowermost strata of the transgressive Dâmbovicioara Formation that directly overlie limestones of interval C are dated as Early Valanginian (GRĂDINARU *et al.*, 2016). At this point, only two options are considered: 1) the uppermost strata of lithostratigraphic unit III and biostratigraphic unit C could be earliest Valanginian in age, or 2) the hiatus at the boundary with the overlying Dâmbovicioara Formation spans the stage boundary and the uppermost strata of lithostratigraphic unit III and biostratigraphic unit C are Late Berriasian in age.

7. Paleoenvironmental implications of benthic foraminifera and calcareous algae

The Upper Jurassic-Lower Cretaceous succession from Piatra Craiului contains mainly benthic foraminifera. Various factors, such as salinity, water temperature, and nutrients (REISS & HOTTINGER, 1984; HUGHES, 2000), play an essential role in the diversity and abundance of the benthic microfauna and the associated calcareous algae. Therefore, paleoecological information can be derived from their assemblages and their analysis may contribute to improving the depositional model of the carbonate succession.

The lowermost part of the carbonate succession corresponding to lithostratigraphic interval I (Fig. 3) consists of interbedded reef rudstones and coral microbial boundstones, *i.e.*, a gradual transition from reef slope areas to reef margin environments with bioconstructions becoming dominant towards the top. Carbonate material was transported from the bioconstructions and reworked on the deeper fore-reef slope where coral fragments and echinoderm plates are the most important bioclasts (Fig. 7) (PLEȘ *et al.*, 2013). Lithostratigraphic interval I (0-289 m)

(Fig. 3) contains *Lenticulina* sp., *Nodosaria* sp. (Fig. 3) and other foraminiferal species characteristic of the lower and middle parts of biostratigraphic interval A (Fig. 3). They are associated with fragments of juvenile ammonites and encrusting organisms (mainly *Crescentiella morronensis*) (Fig. 7). The presence of *Lenticulina* sp. in the assemblage with other bioclasts points to a moderately deep, open-marine environment (HUGHES, 2000; REOLID *et al.*, 2008a, 2008b; NIKITENKO *et al.*, 2013).

Lithostratigraphic interval II (290-408 m) (Fig. 3) contains foraminifera from the upper part of biostratigraphic interval A (Fig. 3). The number of specimens of *Neokilianina rahonensis* and *Parurgonina caelinensis* gradually increases between 290-340 m. Their abundance is higher at 340 m compared with their isolated occurrence 50 meters below. According to HUGHES (2000), "the progressively ascending appearance of certain species" and the gradual increase of "their vertical extent and abundance until a consistent presence" up section reflects a "possible gradual shallowing" of the depositional environments. These foraminifera are in coarse bioclastic grainstones (lithostratigraphic interval II) associated with reworked black-pebbles and dasycladalean algae (*Steinmanniporella kapeleensis* and *Neoteutloporella socialis*) (Fig. 7), which define high-energy, shallow-water platform margin environments. *Redmondoides lugeoni*, *Coscinoconus alpinus* and *Everticyclammina praekelleri* are also present in lithostratigraphic interval II (Fig. 3). Several authors (PÉLISSÉ *et al.*, 1984; TYSZKA, 1994; SVELIEVA *et al.*, 2014) have described these species from similar high-energy facies (bioclastic grainstones) and depositional settings (Fig. 7). Further discussion regarding the lithostratigraphy of these deposits can be found in MIRCESCU *et al.* (2014). The facies identified in lithostratigraphic interval II point to the presence of elevated carbonate margin deposits where coarser sediments were accumulating under high-energy conditions within a shallow-water environment (Fig. 7). Coral fragments are common which suggests that reworking has occurred either from the underlying bioconstructions or from adjacent and coeval bioconstructions. The presence of micritic-rimmed bioclasts indicates that the calcareous sand bars were probably adjacent to a lagoonal area where the micritisation occurred under more restrictive conditions. Subsequently, the micritised bioclasts were reworked in high-energy deposits.

Lithostratigraphic interval III (Fig. 3) is composed of interbedded intertidal/supratidal peloidal wackestone-packstone and homogeneous mudstone with cyanobacteria nodules. Cyanobacteria are forming the main bioclasts. The intertidal conditions are indicated by abundant laminoid fenestral structures (Fig. 7).

Carbonate sediment was accumulating in intertidal ponds where cyanobacteria were the main sediment producers. The supratidal environment is indicated by the presence of abundant cyanobacteria, plant roots and fine, micritic sediment (Fig. 7). As the carbonate platform was prograding, the accommodation space was reduced and cyanobacteria became the main carbonate producers (SĂSĂRAN *et al.*, 2013). However, high-energy bioclastic packstones-grainstones in the uppermost part of the interval at 865 m contain foraminifera and dasycladalean algae (Fig. 3). *Pseudocymopolia jursica* and *Salpingoporella praturloni* are commonly associated with well oxygenated, shallow-water, subtidal environments (BUCUR & SĂSĂRAN, 2005). Other species (*Coscinoconus campanellus*, *C. cherchiaie* and *Nautiloculina* cf. *broennimanni*) usually also reflect similar palaeoecological conditions (ARNAUD-VANNEAU & PEYBERNÈS, 1978; ARNAUD-VANNEAU, 1980; SIMMONS 1990). In addition, presence of large dasycladalean algae (*Pseudocymopolia jursica*, *Salpingoporella praturloni*) in this lithostratigraphic interval indicates a shallow-water environment. These sediments were probably carried through a network of tidal channels crossing the intertidal and supratidal areas where cyanobacteria were growing in restricted conditions (Fig. 7). The Upper Jurassic-Lower Cretaceous foraminiferal assemblage from Piatra Craiului Massif comprises mainly subtropical forms (*Everticyclammina*, *Labyrinthina*, *Nautiloculina*, *Protopenneroplis*, and *Pseudocyclammina*) with very few tropical exceptions (*Bramkampella*, *Paracoskinolina*, and *Redmondoides*) (KUZNETSOVA *et al.*, 1996).

8. Conclusions

1. The Kimmeridgian-Berriasian (? Lowermost Valanginian) limestones from Piatra Craiului Massif correspond to an overall regressive depositional sequence that is subdivided into three informal lithostratigraphic units labelled I to III.
2. The foraminiferal and algal assemblages identified in the studied interval provide supplementary information regarding the depositional environments that range from fore-reef to innermost platform settings.
3. In addition, these assemblages allow subdivision of the studied interval into three successive chronostratigraphic units.
4. The first and second lithostratigraphic units, *i.e.*, units I and II, correspond to a single biostratigraphic unit, *i.e.*, unit A. They are probably Kimmeridgian to early Tithonian in age.
5. The position of the Kimmeridgian – Tithonian stage boundary cannot be precisely located.

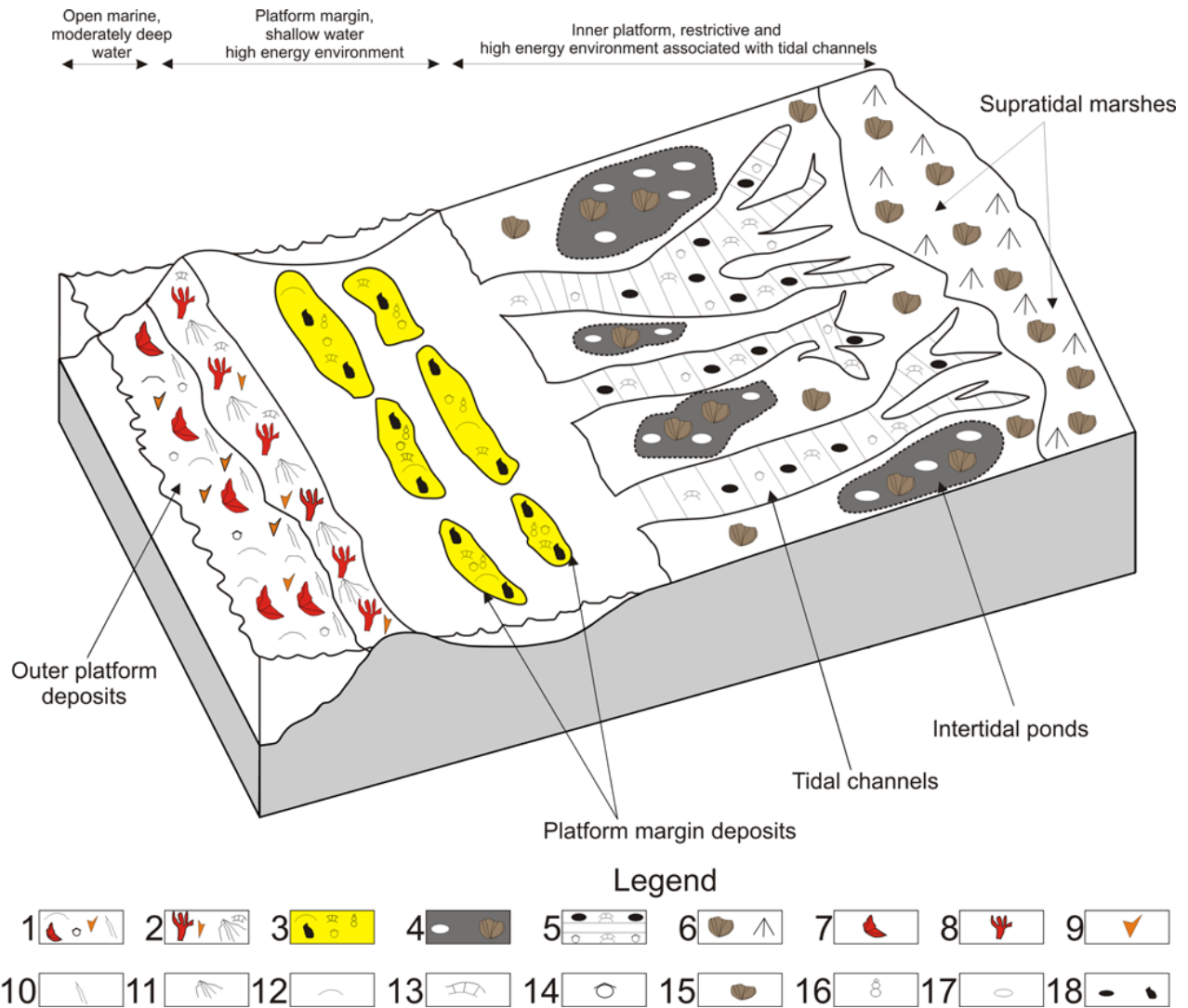


Figure 7: Conceptual depositional model of the Upper Jurassic-Lower Cretaceous carbonate succession from the Piatra Craiului Massif (1: Fore-reef rudstone facies; 2: Platform margin coral-microbial bioconstructions; 3: Platform margin sand-bar grainstone facies; 4: Intertidal pond fenestral wackestone facies; 5: Tidal channel grainstone facies; 6: Supratidal marsh, mudstone-wackestone facies; 7: Coral fragments; 8: Corals; 9: Echinoderm plates; 10: Microbial crust fragments; 11: Microbial crusts; 12: Pelecypods; 13: Dasycladalean algae; 14: Benthic foraminifera; 15: Cyanobacteria nodules; 16: Gastropods; 17: Fenestral structures; 18: Peloids and black pebbles).

6. The third lithostratigraphic unit, *i.e.*, unit III, spans two biostratigraphic units, *i.e.*, units B and C. They are probably late Tithonian to Berriasian in age, although an early Valanginian age cannot be excluded for its uppermost strata.
7. The Tithonian-Berriasian stage boundary is located in biostratigraphic unit B, but its exact position within the interval cannot be identified.
8. The Berriasian-Valanginian stage boundary is possibly located in biostratigraphic unit C, near the top of this unit, which is also the top of the lithostratigraphic unit III and which coincides with the basal discontinuity of the Dâmbovicioara Formation (or of Barremian- Aptian breccias/conglomerates).
9. There is an alternative hypothesis for the location of this last stage boundary, *i.e.*, the hiatus associated with the basal discon-

tinuity of the Dâmbovicioara Formation (or of Barremian-Aptian breccias/conglomerates) that possibly spans the boundary. Such discontinuities tied either to a major relative sea-level fall (VAIL's hypothesis), a drowning event (SCHLAGER's hypothesis), or a combination of both have been reported from several localities around the world near the Berriasian-Valanginian (*e.g.*, GRANIER, 1994; GRANIER *et al.*, 1995, 2006).

10. To summarize, biostratigraphers have difficulty in clearly identifying stage or substage boundaries in shallow-water carbonate settings of the Jurassic-Cretaceous transition. An holostratigraphic approach, integrating sequence stratigraphy, will hopefully provide refined results. In any case, further investigations should be carried out because, for instance, they could help to better locate the Berriasian-Valanginian boundary.

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