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FORAMINIFERAL ASSEMBLAGES AND FACIES ASSOCIATIONS IN THE UPPER JURASSIC CARBONATES FROM ARDEU UNIT (METALIFERI MOUNTAINS, ROMANIA)

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Abstract A rich association of benthic foraminifera was discovered in the Upper Jurassic carbonate sequence belonging to the Ardeu Unit of the Metaliferi Mountains. Large agglutinated species (mesoendothyrids, valvulinids and cyclamminids) are the most frequent, some of them being recorded for the first time in Romania. Many species are biostratigraphically important and allow us to assign a Kimmeridgian – Tithonian age for the studied carbonates. The foraminiferal assemblages also enable paleoenvironmental interpretations and facies zonation of the Ardeu Unit carbonates including five major facies associations assigned to most widespread lagoonal deposits (platform interior), patch-reef bioconstructions, reef-front debris and slope microbreccia (platform margin environments).

Keywords: agglutinated foraminifera, microfacies, inner-platform environments, platform-margin settings, Kimmeridgian-Tithonian.

INTRODUCTION

The central part of the Metaliferi Mountains is characterized by the presence of a small structural entity, the Ardeu Unit, composed entirely of carbonate deposits. This unit is overthrusting the large Mesozoic ophiolitic complex of the Căpîlnaș-Techereu Unit, the main nape of the Transilvanides nappe system (Balintoni, 1997). There are very few studies dealing with the calcareous deposits that crop out in this region, from which the work of Mantea & Tomescu (1986) being the most important. Beside the tectono-structural features of the Ardeu Unit, Mantea & Tomescu (1986) identified an association of micro- and macrofossils typical for the Upper Jurassic (Oxfordian-Tithonian) and Lower Cretaceous (Barremian-Aptian). Several depositional features were also documented.

The present paper encompasses the study of 234 samples collected from two sections belonging to the Ardeu Unit (Rudii Valley and Băcâia Gorges). They are located in the central part of the Metaliferi Mountains, between Balșa and Băcâia villages (Hunedoara County) (Fig. 1). Microfacies analysis revealed a very rich foraminiferal assemblage with species characteristic for different sedimentary settings. The identified assemblage enriches the Late Jurassic microfossil inventory known so far from this region. Also it reflects a new perspective of the facies zonation and depositional paleoenvironments throughout the Ardeu Unit carbonate platform**.**

FORAMINIFERAL ASSEMBLAGE

The foraminiferal assemblage from both studied areas (Rudii Valley and Băcâia Gorges) is dominated by large benthic agglutinated species. Some of them, which are the most abundant or stratigraphically relevant, are discussed in the chapters on micropaleontology and biostratigraphy. *Labyrinthina mirabilis* Weynschenk, *Parurgonina caelinensis* Cuvillier, Foury & Pignatti Morano, *Everticyclammina praekelleri* Banner & Highton and *Bramkampella arabica* Redmond represent the most common species. Besides, the following species were also identified: *Lituola*? *baculiformis* Schlagintweit & Gawlick, *Neokilianina rahonensis* (Foury & Vincent), *Pseudocyclammina lituus* (Yokoyama), *Redmondoides lugeoni* (Septfontaine), *Alveosepta jaccardi* (Schrodt), *Charentia evoluta* (Gorbachik), *Protopeneroplis striata* Weynschenk, *Mohlerina basiliensis* (Mohler), *Troglotella incrustans* Wernli & Fookes, *Coscinoconus alpinus* Leupold, *Coscinophragma* sp., *Haddonia* sp., *Ammobaculites* sp., *Everticyclammina* sp., *Gaudryina* sp. and *Lenticulina* sp.

MICROPALEONTOLOGY

Genus *Labyrinthina* Weynschenk, 1951
***Labyrinthina mirabilis* Weynschenk, 1951**
(Fig. 2a-h)

1956 – *Labyrinthina mirabilis* – Weynschenk, p. 283, pl. 1, fig. 8.
1896 – *Labyrinthina mirabilis* – Mantea & Tomescu, pl 4, figs. 1-9.
1988 – *Labyrinthina mirabilis* – Septfontaine, p. 243, pl. 1, figs. 10, 12.
2005a – *Labyrinthina mirabilis* – Bucur & Săsăran, p. 30, pl. 2, figs. 3, 4.
2005 – *Labyrinthina mirabilis* – Schlagintweit et al., p. 31, fig. 13 a, b.
2008 – *Labyrinthina mirabilis* – Omaña & Gonzalez-Arreola, p. 803, fig. 7a.

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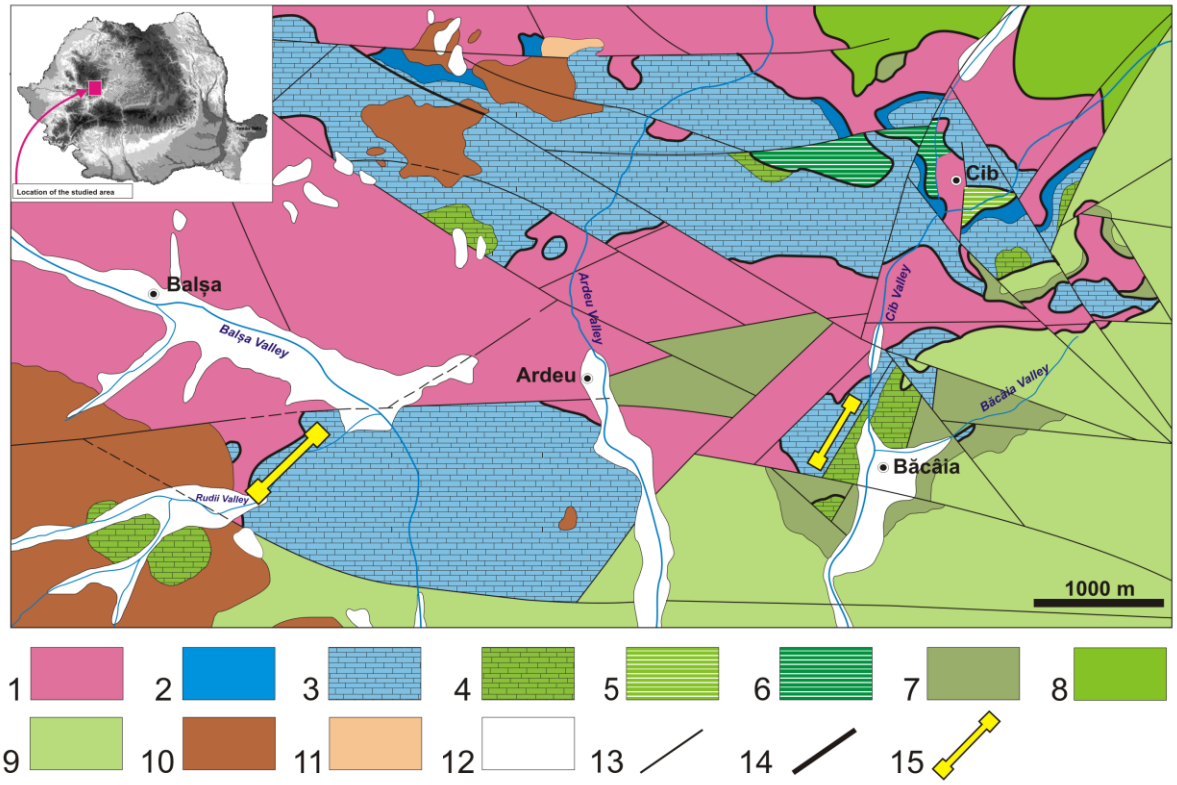


Fig. 1 Geological map of the Balşa-Ardeu-Băcâia region (modified after Mantea & Tomescu, 1986) **1** Mesozoic ophiolites (Căpâlnaş-Techereu Nappe); **2** Oxfordian limestones (Ardeu Unit); **3** Kimmeridgian-Tithonian carbonates (Ardeu Unit); **4** Barremian-Aptian limestones (Ardeu Unit); **5** Aptian conglomerates and sandstones (Căpâlnaş-Techereu Nappe); **6** Albian breccia and sandstones (Căpâlnaş-Techereu Nappe); **7** Coniacian-Santonian siltites and sandstones; **8** Santonian-Campanian marls; **9** Santonian-Maastrichtian flysch deposits; **10** ?Maastrichtian-Paleogene continental deposits; **11** Badenian limestones; **12** Quaternary deposits; **13** Faults; **14** Nappe; **15** Location of the studied sections.

Description: In early ontogenetic stage the test is planispirally coiled (up to 3 whorls), later becoming elongate, rectilinear up to 2.1 mm in lenght. The diameter of the coiled part ranges between 0.49 and 0.91 mm. Proloculus is globular. Chambers are separated by slightly convex septa. Vertical beams extend radially from the margins of the wall to the center, but not reaching it. Interseptal pillars are noticed in the adult uncoiled stage, mainly in the central part. They can be continuous from chamber to chamber (see Fig. 2c). Wall agglutinated. Aperture is simple and interiomarginal in the enrolled stage, becoming multiple in the adult rectilinear stage.

Remarks: In our samples, *Labyrinthina mirabilis* specimens are very abundant and identified in all ontogenetic stages. An important structural feature of this species is represented by the presence of the interseptal pillars. In early ontogenetic stages pillars are less evolved or absent, accounting for the simple morphology of the chambers and aperture. In the adult uncoiled part of the test, interseptal pillars are well formed and may develop a continuous trend throughout the chambers. The labyrinthic architecture of *L. mirabilis* can be the result of a random fusing process between beams and pillars in the adult stage. All of the *L. mirabilis* specimens are found free, in contrast to some encrusting forms illustrated by Weynschenk (1956). The non-encrusting feature of the species was documented soon after by several authors (Fourcade & Neumann, 1965; Gušić, 1968, Schlagintweit et al. 2005).

Stratigraphic range: *L. mirabilis* is a widespread taxon in the Upper Jurassic carbonates of the Tethyan realm. It was first described by Weynschenk (1951) from the Upper Jurassic deposits of the Sonnwend Mountains (Austria). Other occurrences are listed in Table 1. Loeblich & Tappan (1988) included the foraminifer *Lituosepta recoarensis*, described by Cati (1959) from Lower Jurassic limestones, into the synonymy list of *L. mirabilis*. Based on this fact, the authors extended the stratigraphic range of *L. mirabilis* from Lower to Upper Jurassic. Septfontaine (1988) in his evolutionary classification of Jurassic lituolids, clearly explains the main differences between the two taxa and restricts *L. mirabilis* to Upper Jurassic (as it was described) contrasting the Upper Sinemurian *Lituosepta recoarensis.* Bassoullet (1997) placed the stratigraphic position of this taxon between Uppermost Oxfordian and basal Tithonian.

Genus *Parurgonina* Cuvillier, Foury & Pignatti Morano, 1968

Table 1 *Labyrinthina mirabilis* Weynschenk occurences within the Tethyan realm.

Author	Region	Age
Gušić, 1968	Central Croatia	Kimmeridgian
Cuvillier et al., 1968	Cellina Valley, Italy	Oxfordian-Kimmeridgian
Azema et al., 1977	Sardinia, Italy	Tithonian
Steiger & Wurm, 1980	Plassen Limestone (Northern Calcareous Alps), Austria	Kimmeridgian
Altiner, 1991	Anatolia, Turkey	Kimmeridgian
Luperto Sinni & Masse, 1994	Gargano Massif, Italy	Kimmeridgian-Tithonian
Bouaouda et al., 2004	Agadir Basin, Morocco	Oxfordian-Kimmeridgian
Ivanova & Koleva-Rekalova, 2004	Slivnitsa Formation, Bulgaria	Oxfordian-Kimmeridgian
Schlagintweit & Gawlick, 2009	Plassen Carbonate Platform (Northern Calcareous Alps), Austria	Kimmeridgian-Tithonian

***Parurgonina caelinensis* Cuvillier, Foury & Pignatti Morano, 1968**
(Fig. 2i-p)

1968 – *Urgonina (Parurgonina) caelinensis* – Cuvillier, Foury & Pignatti Morano, 1968, p. 150, 152, 154, pl. 2, figs. 1-12; pl. 3, figs. 1-9.
1969 – *Lituonella dinarica* – Gušić, p. 69, 70, pl. 13, figs. 1, 2; pl. 14, figs. 1-4.
1975 – *Parurgonina caelinensis* – Schroeder et al., p. 320-325, pl. 1, figs. 1-4; pl. 2, figs. 3-5.
1987 – "primitive orbitolinids" – Bordea & Bordea, pl. 1, figs. 1-4; pl. 2, figs. 1-5.
2010a – *Parurgonina caelinensis* – Bucur et al., p. 32, figs. 4, 9.
2011 – *Parurgonina caelinensis* – Turi et al., p. 16, pl. 2, figs. 7, 10.

Description: The test is high conical starting with a spherical proloculus. A trochospiral stage can be noticed in the initial part, followed by an uniserial development in the main part of the test. The first chambers are undivided having punctured apertures. In the adult uniserial stage, numerous chamberlets are developing sepparated by successive septa and subconical / vertical pillars in the central part of the test. The wall is thick consisting of very fine canaliculated fibrous microstuctures (pseudo-keriothecal). The lenght of the test ranges from 1.79 mm up to 2.18 mm. The basal diameter is between 1,17 – 1,64 mm. The aperture is represented by multiple large pores over the terminal part.

Remarks: Most of the *P. caelinensis* specimens from our samples are well preserved and permit observations to both external and internal morphology of the test. The pseudo-keriothecal structure of the wall was possible to observe only in some specimens (Fig. 2k) due to recrystallization processes. In the original description of Cuvillier et al. (1968), this microstructural feature was not noticed. The presence of the pseudo-keriothecal wall-structure was observed soon after by Gušić (1968) in *Lituonella dinarica*, species which was consider synonym with *P. caelinensis*. A question mark was raised if this type of structure is really a taxonomical trait or an early diagenetic feature (Maync, 1972). Schroeder et al. (1975) presented some *P. caelinesis* specimens with a clearly developed pseudo-keriothecal wall and mainly by this argument excluded the species from the Orbitolinidae. Bordea & Bordea (1987) recorded the presence of numerous "primitive orbitolinids" in the Albioara Limestone (Upper Jurassic) from the southern part of Pădurea Craiului Mountains. These foraminifers illustrated by the authors in pl. 1 (figs. 1-4) and pl. 2 (figs. 1-5) are in fact well preserved specimens of *P. caelinensis*. It is also necessary to point the fact that *P. caelinensis* shows some resemblances with *Neokilianina rahonensis*, species known to share the same stratigraphic position and paleoenvironments. Septfontaine (1988) admitted the possibility that the two species could be taxonomically related or even synonyms. However, several structural features can be sometimes observed that can clearly separate the two taxa. The first is the thickened central zone of *N. rahonensis* compared with the trochospiral shaped central area of *P. caelinensis* observed in many basal/oblique sections (Fig. 2o-p). The subconical interseptal pillars in *N. rahonensis* associated with radial beams, are shaping most of inner structure of the adult stage in triangular chamberlets, as opposed to the cylindrical or semi-lunar chambers of *P. caelinensis*. Noujaim Clark & Boudagher-Fadel (2004) stated the fact that *P. caelinensis* has a bigger number of chambers per whorl in the adult stage and a more important pillar development than *N. rahonensis*. Kamoun & Peybernes (1993) have established a second species of the genus,

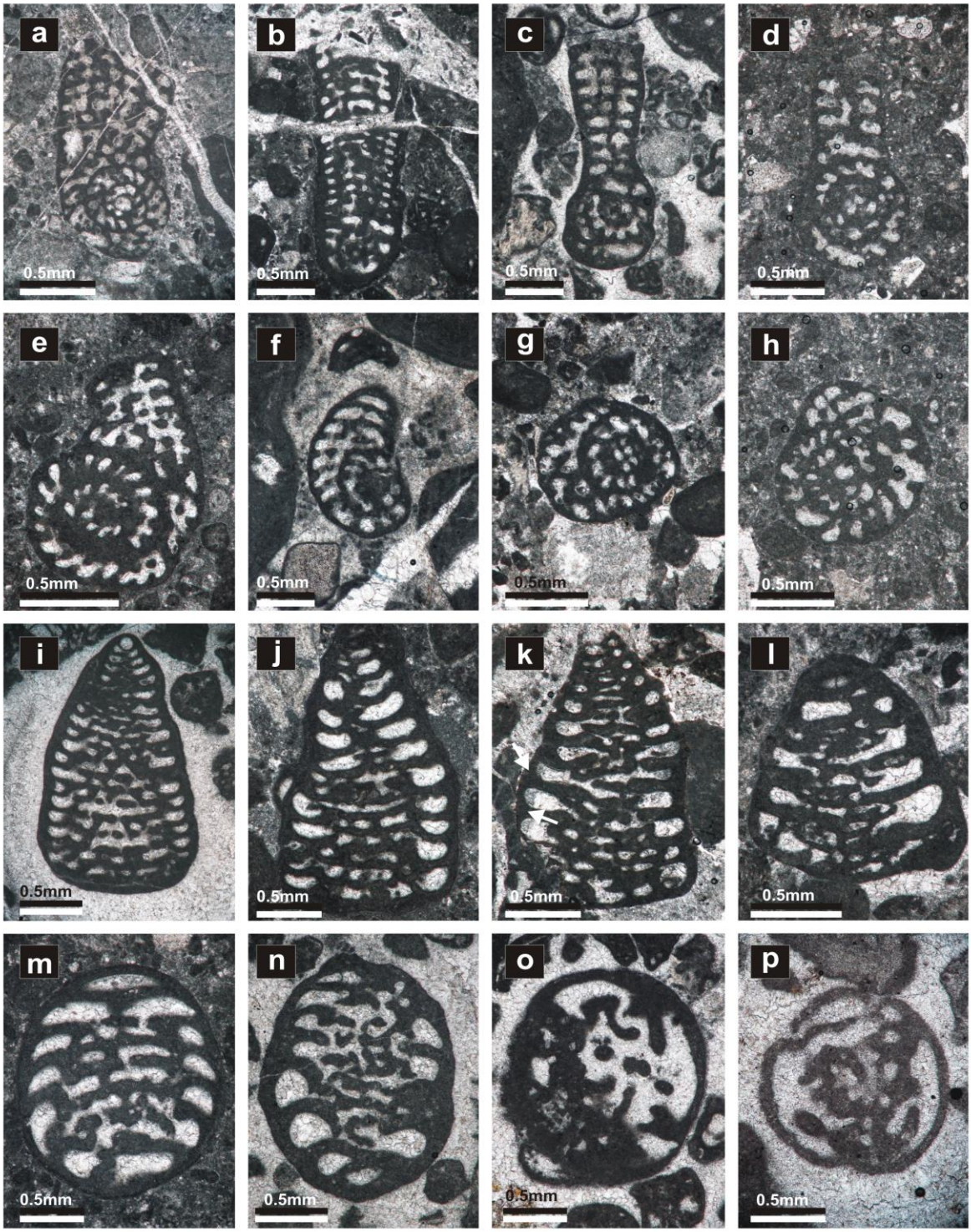


Fig. 2 Upper Jurassic foraminifers from the Ardeu Unit. **a-h** *Labyrinthina mirabilis* Weynschenk (a - Sample 153, b - Sample 27, c - Sample 64, d - Sample 165, e - Sample 33, f - Sample 21, g - Sample 159, h - Sample 55). **i-p** *Parurgonina caelinensis* Cuvillier, Foury & Pignatti Morano (i - Sample 65, j - Sample 36, k - Sample 129, l - Sample 30, m - Sample 23, n - Sample 65, o - Sample 38, p - Sample 64).

Parurgonina primaeva from the Middle Jurassic carbonates of southern Tunisia, characterized by a trochospirally development in both juvenile and adult stages.

Stratigraphic range: Cuvillier et al. (1968) described this species from the Upper Jurassic limestones (Kimmeridgian-Portlandian) of the Cellina Valley (Italy). Soon after it was cited by many authors from different Mesozoic deposits of Europe and Asia (Table 2). In the synthesis of Bassoullet (1997), *P. caelinensis* is dated from late Oxfordian to earliest Tithonian.

Genus *Everticyclammina* Redmond, 1964

***Everticyclammina praekelleri* Banner & Highton, 1990**

(Fig. 3f-h)

Table 2 *Parurgonina caelinensis* Cuvillier, Foury & Pignatti Morano occurences within the Tethyan realm.

Author	Region	Age
Azema et al., 1977	Sardinia, Italy	Tithonian
Tasli, 1993	Eastern Pontids, Turkey	Kimmeridgian
Luperto Sinni & Masse, 1994	Gargano Massif, Italy	Kimmeridgian-Tithonian
Pop & Bucur, 2001	Vâlcan Mountains, Romania	Kimmeridgian-Tithonian
Mancinelli & Coccia, 2002	Agry Valley, Italy	Tithonian
Bucur et al., 2004	Transylvanian Basin, Romania	Oxfordian-Tithonian
Noujaim Clark & Boudagher-Fadel, 2004	Kesrouane Formation,Lebanon	Oxfordian-Kimmeridgian
Bucur & Săsăran, 2005	Trascău Mountains, Romania	Kimmeridgian-Tithonian

1990 – *Everticyclammina praekelleri* – Banner & Highton, p. 8, 10; pl. 1, fig. 1; pl. 3, fig. 5; pl. 4, figs. 1-11.
2007 – *Everticyclammina praekelleri* – Krajewski & Olszewska, p. 299, fig. 5, C-D.
2008 – *Everticyclammina praekelleri* – Olszewska et al., fig. 8, K.

Description: The test is planspirally enrolled, involute and may develop trends to terminal rectilinearity. Wall is agglutinated, alveolar. The alveolar hypodermis is coated by a thin imperforate layer (epidermis) which seals the alveoli. The septa are slightly curved and non-alveolar with a thickness comparable to that of the chamber walls. Chambers are not flattened and irregular in shape and size. The last whorl is characterized by the development of coarse alveoli in the hypodermis. The aperture is single, terminal ("ammobaculitid"- type). In the posterior-lateral area of the hypodermis the alveoli are enlarged, elongated and closely spaced. Depending on the sectioning type they can appear ramified, fused together or subpolygonal. In the anterior-peripheral area, the alveoli are widely spaced given rise to a certain irregularity of the hypodermis. Dimensions: diameter of the enroled part of the test – 0.83 – 1.53 mm; lenght of the test – 1.59 – 1.86 mm; width – 0.51 – 0.71 mm.

Remarks: The main differences between *Everticyclammina praekelleri* and other representatives of the genus *Everticyclammina*, are associated with the development of alveolar structures. Many *E. praekelleri* specimens from our samples allowed observation of its inner structure, especially of the hypodermical layer. Elongated broadened alveoli are clearly noticed in the posterior-lateral parts of the hypodermis (Fig. 3f-h - arrows). Also, the anterior-peripherial alveoli are irregularly dispersed in most of the cases (Fig. 3f-h). The presence of an apparently multiple aperture in the *E. praekelleri* specimen illustrated in Fig. 3g, can be explained by the sectioning model. A closer look to several key studies (Hottinger, 1967; Loeblich & Tappan, 1988; Banner & Whittaker, 1991) points out the fact that multiple or cribrate types of aperture do not define any species of the genus *Everticyclammina*. All of these, together with other morphological features (the unflattened shape of the chambers or the reduction of chambers per whorl), represent key arguments in distinguishing *E. praekelleri* from *Everticyclammina virguliana* (Koechlin), the oldest species of the genus. Moreover, *E. virguliana* possess a distinctive row of subcircular hypodermal alveolar spaces in the posterior-lateral part of the chambers wall. The relatively close resemblance of *E. praekelleri* with its descendent *Everticyclammina kelleri* (Henson), can be excluded based on several traits. As opposed to *E. kelleri*, *E. praekelleri* has a much wider aperture, less structured wall, enlarged elongated lateral alveoli and a different stratigraphic position. More detailed arguments regarding this topic or the phylogeny of *Everticyclammina* can be found in the works of Redmond (1964) and Banner & Highton (1990).

Stratigraphic range: According to Banner & Highton (1990) and Banner & Whittaker (1991), the stratigraphic range of *Everticyclammina praekelleri* is restricted to the upper part of the Jurassic (Kimmeridgian-Tithonian). In the European Tethyan realm, the species was recorded in very few carbonate deposits, such as: the Tithonian of Crimeea Mountains, Ukraine (Krajewski & Olszewska, 2007), the Tithonian Cieszyn Beds from Polish Western Carpathians (Olszewska et al., 2008) or the Kimmeridgian lagoonal limestones of Paris Basin (Lefort et al., 2012). It is worth mentioning that the presence of *E. praekelleri* in the Ardeu Unit limestones, represents the first report of this species from Romania. Taking into account these arguments, we consider that *E. praekelleri*

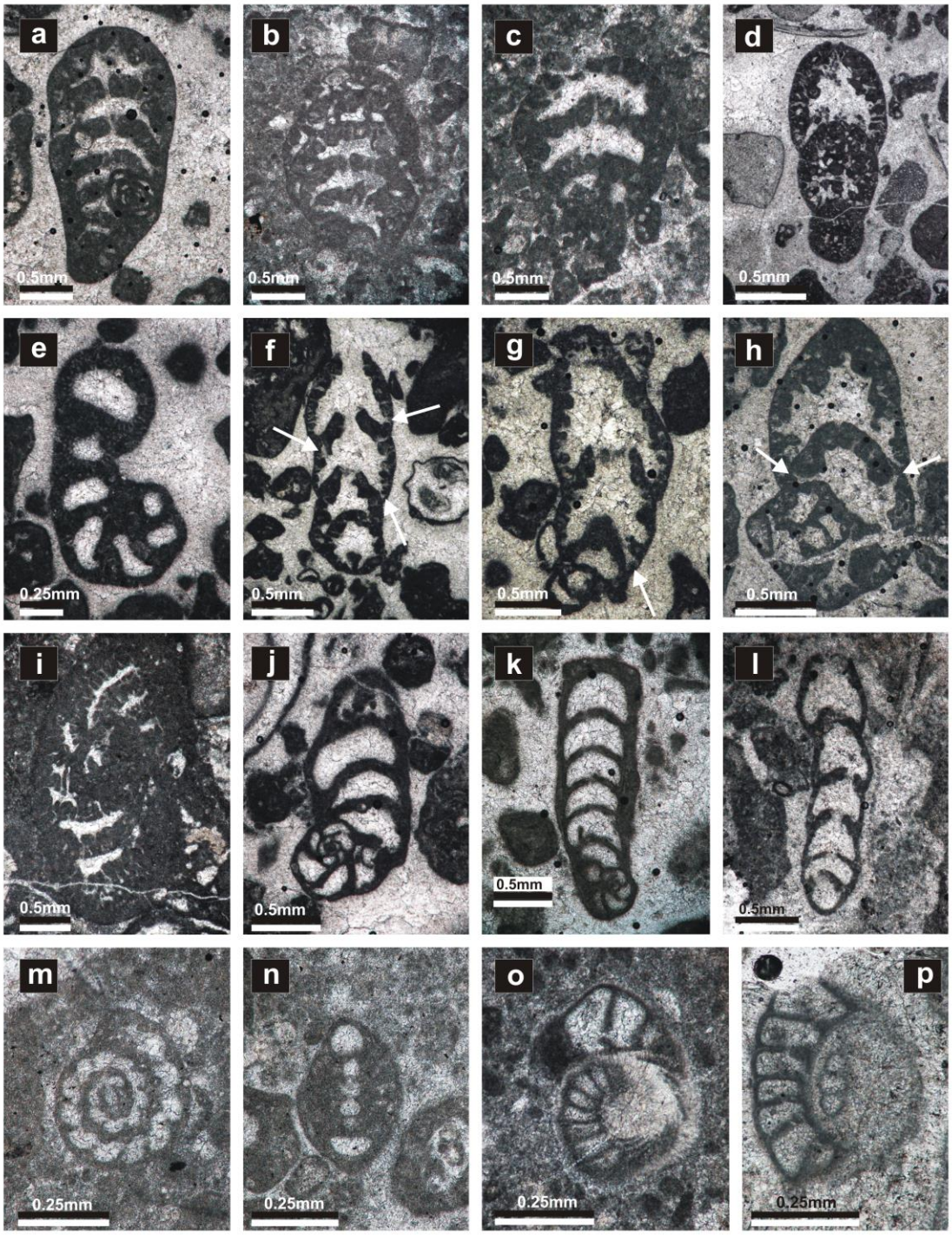


Fig. 3 Upper Jurassic foraminifers from the Ardeu Unit. **a-c** *Bramkampella arabica* Redmond (a - Sample 65, b - Sample 172, c - Sample 146). **d** Undetermined lituolid (Sample 41). **e** *Kaminskia*-type foraminifer with fine canaliculated wall (Sample 66). **f-h** *Everticyclammina praekelleri* Banner & Highton (Sample 65). **i** *Alveosepta jaccardi* (Schrodt) (Sample 49). **j-l** *Ammobaculites* sp. (j - Sample 65, k - Sample 110, l - Sample 95). **m-n** *Charentia evoluta* (Gorbachik) (m - Sample 32, n - Sample 45). **o-p** *Protopeneroplis striata* Weynschenk (o - Sample 153, p - Sample 212).

represents a typical Upper Jurassic taxon with a stratigraphic position ranging from early Kimmeridgian up to late Tithonian.

Genus *Bramkampella* Redmond, 1964
***Bramkampella arabica* Redmond, 1964**
(Fig. 3a-c)

1964 – *Bramkampella arabica* – Redmond, p. 409-414, pl. 1, figs. 26-29; pl. 2, figs. 19-20.
1988 – *Bramkampella arabica* – Loeblich & Tappan., p. 101-102, pl. 100, figs. 14-18.
1991 – *Bramkampella arabica* – Banner & Whittaker, p. 45, pl. 2, figs. 1-7.
1997 – *Bramkampella arabica* – Gorbachik & Mohamad, p. 347, pl. 1, figs. 8, 9, 11.

2005a – *Bramkampella arabica* – Bucur & Sasaran, pl. 2, figs. 6, 7.

Description: The test is subconical with a fine-grained imperforate agglutinated wall. In early ontogenetic stages, the test is planspirally-enrolled, involute. In the adult stage, the test begins to uncoil, finally becoming rectilinear, uniserial, up to 2.21 mm in lenght. In transversal section the test is circular in shape with a diameter size between 1.1 – 1.56 mm. The chambers are short and flattened, separated by strongly embowed septa. Beams and rafters are displayed as an interseptal alveolar network (septulae). The spetulae are elongated and radially developed inward up to the central part of the test. The aperture is terminal, multiple, represented as large pores on the central part of the septal surface.

Remarks: In our samples, *Bramkampella arabica* is frequently associated with the species described before (*L. mirabilis*, *P. caelinensis* and *E. praekelleri*). Several similarities with other cyclamminids, especially with *Rectocyclammina chouberti* Hottinger can be noticed sometimes. They are restricted mainly to the internal morphology of the species. Even so, the multiple aperture, the presence of interseptal pillars or the highly arched septa, clearly differentiate *Bramkampella arabica* from *Rectocyclammina chouberti* (Gorbachik & Mohamad, 1997).

Stratigraphic range: *Bramkampella arabica* was firstly described from Upper Jurassic-basal Cretaceous deposits from Arabia by Redmond (1964). Several lowermost Cretaceous (Berriasian-Valanginian) records of the species were documented by Gorbachik & Mohamad (1997) and Nouajim Clark & Boudagher-Fadel (2001). Due to these occurrences, mainly in lowermost Cretaceous carbonates, *B. arabica* was considered to be an index marker for the Berriasian-?Valanginian interval. However, Bucur & Săsăran (2005a) identified this species, besides the lowermost Cretaceous deposits, in Kimmeridgian-upper Tithonian limestones from Trascău Mountains. In the samples from Ardeu Unit, *B. arabica* is also found in association with typical Upper Jurasic foraminifera (*L. mirabilis* or *P. caelinensis*). Summarizing, the stratigraphic position of *Bramkampella arabica* is Kimmeridgian-?lower Valanginian.

BIOSTRATIGRAPHY

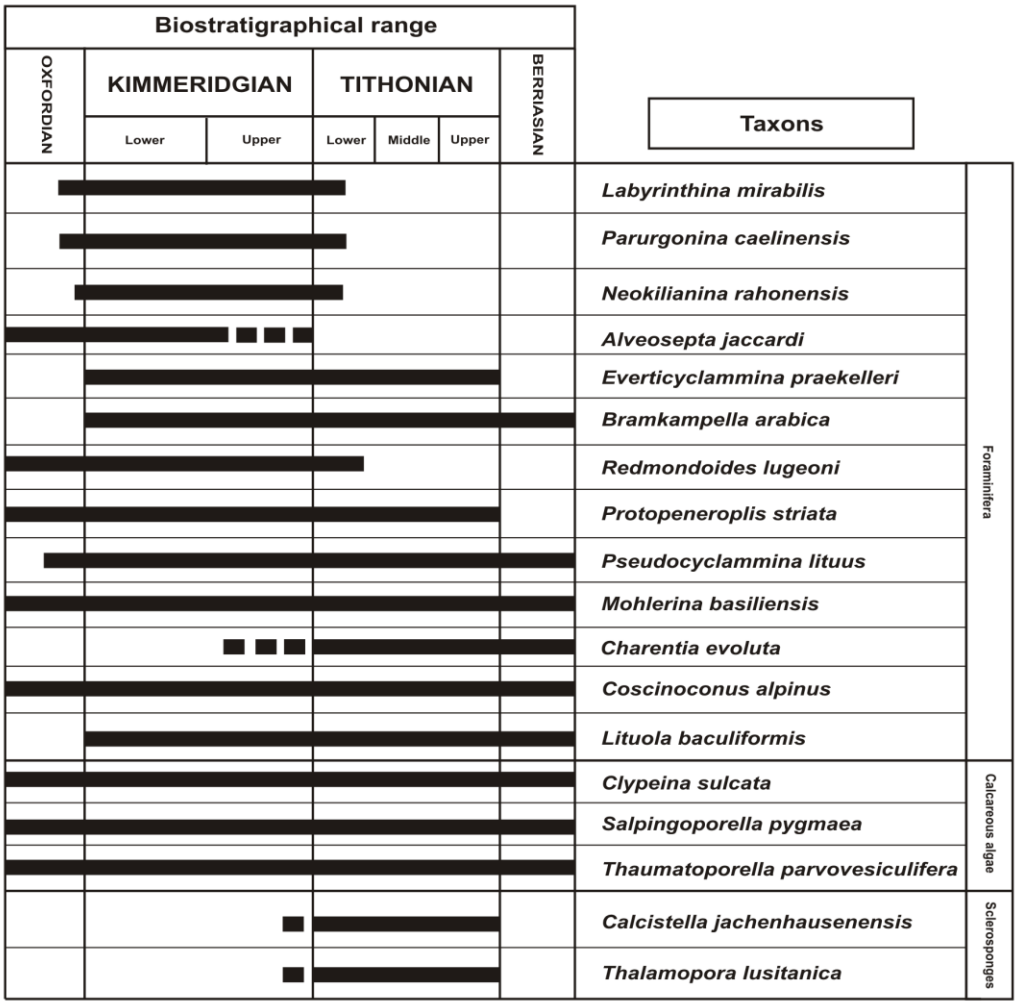
The biostratigraphical relevance of many microfossils (foraminifera and dasycladalean algae) enabled the age establishment of the studied carbonates. Besides the species described in the previous chapter, *Alveosepta jaccardi* (Fig. 3i) represent another important taxon. This foraminifer was considered an index microfossil for the late Oxfordian-Middle/late Kimmeridgian (Hottinger, 1967; Septfontaine, 1988; Altiner, 1991; Bassoullet, 1997; Pop & Bucur, 2001). In both of the studied sections, *A. jaccardi* was identified in association with *Labyrinthina mirabilis*, *Parurgonina caelinensis*, *Everticyclammina praekelleri*, *Bramkampella arabica*, *Redmondoides lugeoni* (Fig. 4j, k) and *Neokillianina rahonensis* (Fig. 4p). Even if most of these foraminifera are known also from the Oxfordian, species such as *E. praekelleri* and *B. arabica* do not indicate this stratigraphic interval (Table 3). They appear in the geological record starting with the Kimmeridgian (Banner & Whittaker, 1991; Bucur & Săsăran, 2005a). In respect with this argument we consider this association to be characteristic for the Kimmeridgian–early Tithonian interval. Also some species of dasycladalean algae association [*Clypeina sulcata* (Alth), *Salpingoporella pymaea* (Gümbel), and *Petrascula* sp.], pleads for this age of the studied deposits (Schlagintweit et al., 2005; Bucur & Săsăran, 2005b). Similar associations were documented from many Late Jurassic carbonate deposits of the Tethyan realm (Ivanova & Koleva-Rekalova, 2004; Bassoullet & Poisson, 1975; Darga & Schlagintweit, 1991). In Romania the association of *L. mirabilis*, *A. jaccardi*, *P. caelinensis* and *N. rahonensis* was partly identified in Pădurea Craiului Mountains (Bucur et al., 2010a), Trascău Mountains (Bucur & Săsăran, 2005a; Săsăran, 2006), Hăghimaș Massif (Dragastan, 1975), Vâlcan Mountains (Pop & Bucur, 2001) and Bihor Mountains (Bucur & Onac, 2000; Turi et al., 2011). Apart from these taxa, we have identified several other benthic foraminifera and sponges (*Lituola*? *baculiformis*, *Coscinophragma* sp. (Fig. 4n), *Mohlerina basiliensis* (Fig. 4a-c), *Troglotella incrustans* (Fig. 4g-i), *Thalamopora lusitanica* Termier & Termier, *Neuropora lusitanica* Termier & Termier and *Calcistella jachenhausenensis* Reitner) which often characterize the Tithonian (Schlagintweit & Gawlick, 2008; 2009; Pleș et al., 2013; Kaya & Altiner, 2015). In some cases they can be found associated with the previously mentioned taxa, but most of the time define external sedimentary settings. Given the fact that many species from the presented assemblage have a wide stratigraphic range (Table 3), none of the identified species is indicative for the lowermost Cretaceous (Berriasian-Valanginian). Summarizing, the sedimentary record of the analyzed sections from Ardeu Unit ranges from the Kimmeridgian to uppermost Tithonian.

FACIES AND PALEOENVIRONMENT

Five main facies associations were separated from internal to external sedimentary domains of the studied carbonate platform: high-energy open lagoonal deposits (F1), low-energy lagoonal deposits (F2), patch-reef bioconstructions (F3), reef-front debris (F4) and distal slope microbreccia (F5).

F1 – High-energy open lagoonal deposits (Fig. 6a-b)
Two main microfacies types were included in the deposits assigned to F1 based on the structural and

Table 3 Main identified fossils from the Ardeu Unit and their stratigraphic range.



textural features associated with the main components: bio-intraclastic grainstone/packstone and bio-oncoidal rudstone. These deposits were intercepted in both of the sampled carbonate sections from the Ardeu Unit. The micropaleontological association contains numerous species of benthic foraminifera (*Labyrinthina mirabilis*, *Parurgonina caelinensis*, *Bramkampella arabica*, *Everticyclammina praekelleri*, *Ammobaculites* sp., *Haddonia* sp. (Fig. 4o) and ?*Neokilianina rahonensis*) and dasyclad algae [*Salpingoporella pygmaea* (Fig. 5a-b), *Salpingoporella annulata* Carozzi (Fig.5f, i), *Petrascula* sp. (Fig. 5c), and microproblematicum *Thaumatoporella parvovesiculifera* (Fig. 5d). Micritic intraclasts, granular aggregates and echinoid spines and plates with syntaxial overgrowth cement are frequently noticed. Most of the clasts are rounded in shape and bordered by thin rims of isopachus early cements (Fig. 6a). Late diagenetetic features were also identified represented by spar-filled fractures and granular cement types (druzy and blocky). Sporadically, several peloidal levels with fenestrae and laminated microbial structures can be noticed.

Interpretation

These carbonates were developed in shallow-water high energy settings, accumulated most probably as tidal bars throughout the lagoon (Morsilli & Bosellini, 1997). The nature of some of the bioclasts together with the grain-supported facies and its structural characteristics, all serve as indicators for inner-platform paleoenvironment. High energy waters produced remobilization phenomena (represented mainly by intraclasts from the adjacent zones), the roundness of most of the main components and various-types of sorting. The deposits assigned to F1 are representative mainly for the subtidal domain associated in some cases with intertidal intercalations. The subtidal domain is defined in the present case by shallow-marine biota (large benthic foraminifera, dasycladalean calcareous algae, mollusks and echinoid fragments), granular aggregates and micritization processes. The intertidal environment is characterized by the appearance of fenestral structures, predominance of peloids and limited micropaleontological content (foraminifera and small-sized mollusks). Supratidal features were not observed.

F2 – Low-energy lagoonal deposits (Fig. 6c-d)

These deposits represent the most widespread carbonate sequence in the Upper Jurassic limestones from Ardeu Unit. The following microfacies were included in this main facies: bio-oncoidal wackestone/floatsone with benthic foraminifera, microbial floatstone with *Bacinella* and *Rivularia*-type cyanobacteria oncoids, bioturbated

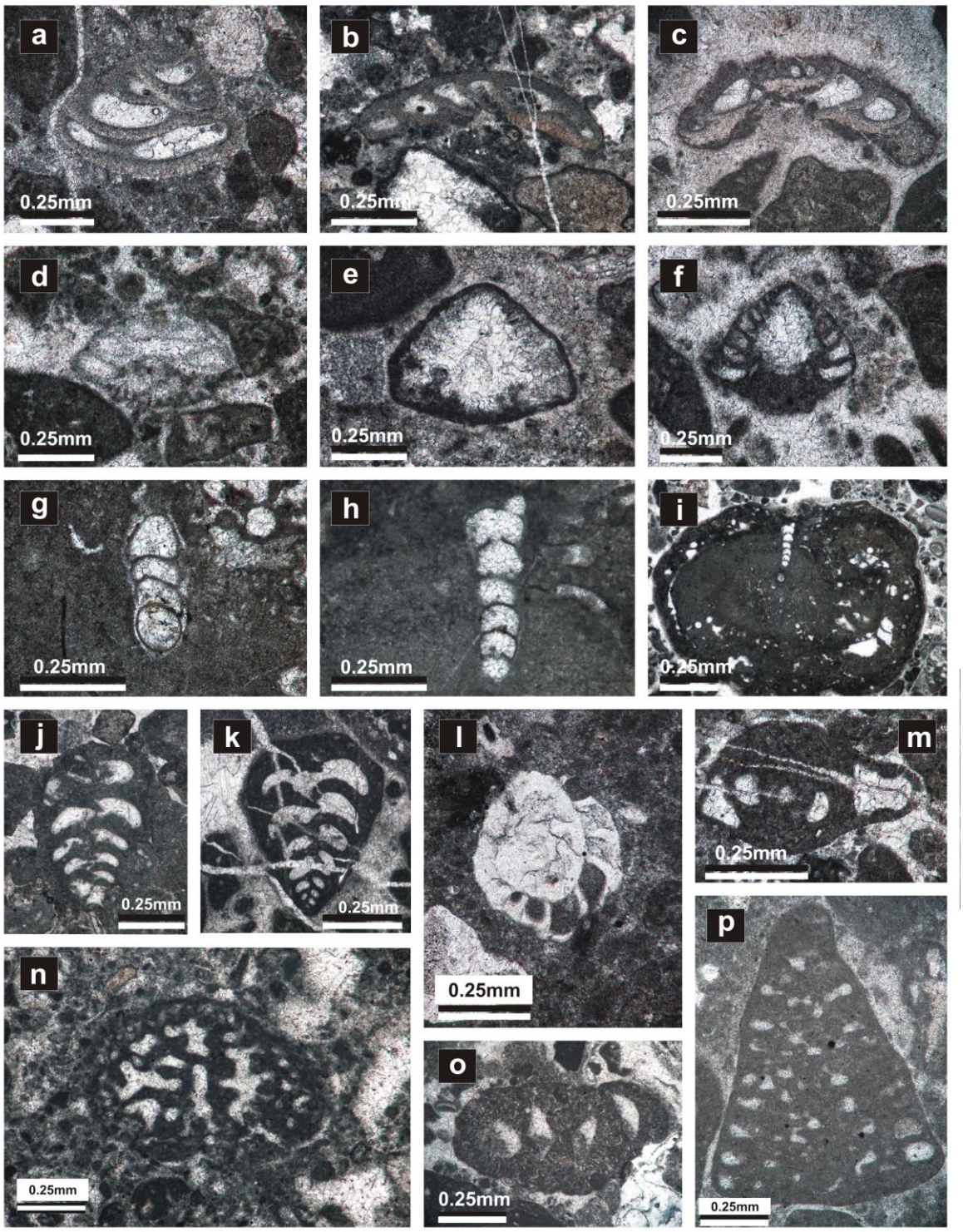


Fig. 4 Upper Jurassic foraminifers from the Ardeu Unit. **a-c** *Mohlerina basiliensis* (Mohler) (a - Sample 31, b - Sample 14, c - Sample 7). **d-e** *Coscinoconus alpinus* Leupold (d - Sample 17, e - Sample 21). **f** *Coscinoconus* sp. (Sample 110). **g-h** *Troglotella incrustans* Wernli & Fookes (g - Sample 10, h - Sample 85). **i** *Troglotella incrustans* associated with a *Lithocodium aggregatum* oncoid (Sample 85). **j-k** *Redmondoides lugeoni* (Septfontaine) (j - Sample 138, k - Sample 45). **l** *Lenticulina* sp. (Sample 145). **m** *Nautiloculina bronnimanni* Arnaud-Vanneau & Peybernès (Sample 174). **n** *Coscinophragma* sp. (Sample 182). **o** *Haddonia* sp. (Sample 53). **p** *Neokilianina rahonensis* (Foury & Vincent) (Sample 115).

bioclastic wackestone with foraminifera and echinoid fragments and floatstone with zoantharian fragments. Sometimes thin levels of micritized ooid packstones may occur. With respect to the micropalaeontological inventory, this facies contains a diverse foraminifera association with a dominance of benthic agglutinated forms (*Parurgonina caelinensis*, *Labyrinthina mirabilis*, *Bramkampella arabica* and *Everticyclammina praekelleri*). Besides, the following species were also identified: *Alveosepta jaccardi*, *Charentia evoluta*,

Protopeneroplis striata, *Redmondoides lugeoni*, *Troglotella incrustans* and *Ammobaculites* sp. Several species of calcareous green algae are found sporadically in the bio-oncoidal wackestones (*Salpingoporella pygmaea* and *Clypeina sulcata*). Medium-sized *Bacinella* oncoids accompanied by microbial-induced leiolitic structures are developing throughout the mud-dominated facies. Also various specimens of *Rivularia*-type cyanobacteria (Fig. 5h) and *Lithocodium aggregatum* Elliott crusts were identified. Most of the main components present micritic envelopes of different size. Corals are very rare, being developed as small isolated colonies associated most of the cases with cyanobacteria and microbial structures. Branching forms are absent.

Interpretation

The abundance of *Rivularia*-type cyanobacteria associated with *Bacinella*-type oncoids or *Lithocodium* crusts, can represent bio-indicators for shallow-subtidal lagoonal systems (Ginsburg, 1975; Flügel, 2004; Kaya & Altiner, 2015). Also several species such as *Parurgonina caelinensis* or *Alveosepta jaccardi*, generally dwell in inner-platform/lagoonal environments (Noujaim & Boudagher-Fadel, 2004; Gorbachik & Mohamad, 1997). Moreover, the intense microbial activity accompanied by bioturbation features can only be suported by low sedimentation rates in a protected low-energy lagoonal settings (Leinfelder et al., 1993; Pleș, 2015). The presence of several coral bioconstructed levels can be linked with the transition of the inner platform settings to the back-reef environments gradually passing to patch reef facies (F3). Similar sedimentary conditions were recorded in some Upper Jurassic deposits from the Apuseni Mountains (Săsăran, 2006; Turi et al., 2011).

F3 - Patch-reef bioconstructions (Fig. 6e)

This facies type was identified in some parts of the analyzed areas (especially in the Rudii Valley sector) associated mainly with the coarse grainstones assigned to the reef-front debris (F4). In terms of microfacies, stromatoporoid-microbial boundstones, coral-microencruster boundstones, and stromatolitic-microencruster bindstones, are dominating. The bioconstructions are relatively small and they are made of corals and sclerosponges [*Perturbatacrusta leini* Schlagintweit & Gawlick, *Calcistella jachenhausenensis* (Fig. 5j), *Murania reitneri* Schlagintweit, *Thalamopora lusitanica* (Fig. 5k), *Actinostromaria* sp.] intensely encrusted by worm tubes, *Lithocodium* crusts, *Crescentiella morronensis* (Crescenti) and *Radiomura cautica* Senowbari-Daryan & Schäfer. Scarce foraminifera (*Charentia evoluta*, *Mohlerina basiliensis*, *Coscinoconus alpinus*, *Coscinophragma* sp.) and calcareous algae [*Salpingoporella pygmaea* or *Neoteutloporella socialis* (Praturlon)] were also identified within the intra-reefal sediment.

Interpretation

The association of stomatoporoids and corals with micro-encrusters and microbial mesostructures, allow this facies to be interpreted as a reef environment developed most probably as patch-reefs on the platform margin (Longman, 1981; Morsilli & Bosselini, 1997). Small reefs like these don't exhibit well-developed rigid frameworks with branching corals and coarse skeletal sands. In this case, the main structural feature of these boundstones is the microencruster framework which generates crustose fabrics with cement rims. These micro-organisms accompanied by syndepositional cements are in fact the main enforcers of the bioconstructions during their development.

F4 - Reef-front debris (Fig. 6f)

Several levels of coarse bio-intraclastic grainstones/rudstones were intercepted in both of the analyzed areas (Rudii Valley and Băcâia Gorges). The main components of this facies are represented by zoantharian or stromatoporoid/sclerosponge fragments (*Murania reitneri* and *Neuropora lusitanica*), echinoid plates, foraminifera (*Mohlerina basiliensis*, *Lenticulina* sp., *Lituola*? *baculiformis*), crustacean fragments [*Carpathocancer* sp. (Fig. 5l)], *Crescentiella*-type structures and reefal intraclasts. Agglutinated microbial microstructures are frequently noticed binding the small-sized bioclasts. Early marine fibrous cements (radiaxial and isopachus) are dominant.

Interpretation

The sub-angular shape and the random orientation of the components point to small debris flows followed by resedimentation processes in the proximity of the reef-front. These features can be related with storm erosion of the patch-reefs crest (Morsilli & Bosselini, 1997) or with abrasion produced by boring micro- and macroorganisms (Longman, 1981). Several species such as *Lituola*? *baculiformis*, *Lenticulina* sp. or *Crescentiella morronensis* were found in fore-reef depositional settings throughout the Intra-Tethyan realm (Turnšek et al., 1981; Schlagintweit & Gawlick, 2008; Gawlick & Schlagintweit, 2009; Pleș et al., 2013). Moreover, *Mohlerina basiliensis* was reported many times from high-energy facies (Schlagintweit, 2012). The absence of shallow-water internal-platform benthic foraminifera (*Parurgonina caelinensis*, *Bramkampella arabica*) can also be an argument in recognizing the external-margin sedimentary settings of the Ardeu Unit carbonate platform.

F5 – Distal slope microbreccia (Fig. 6g, h)

This facies association was identified only in Băcâia Gorges and consists of two main microfacies types: intra-skeletal rudstone/floatstone and bio-intraclastic packstones. The intraclasts, which represent the main components, show various types of forms and facies. Peloidal packstones, oolitc grainstones, bio-oncoidal wackestones, stromatolitic packstones or biconstucted

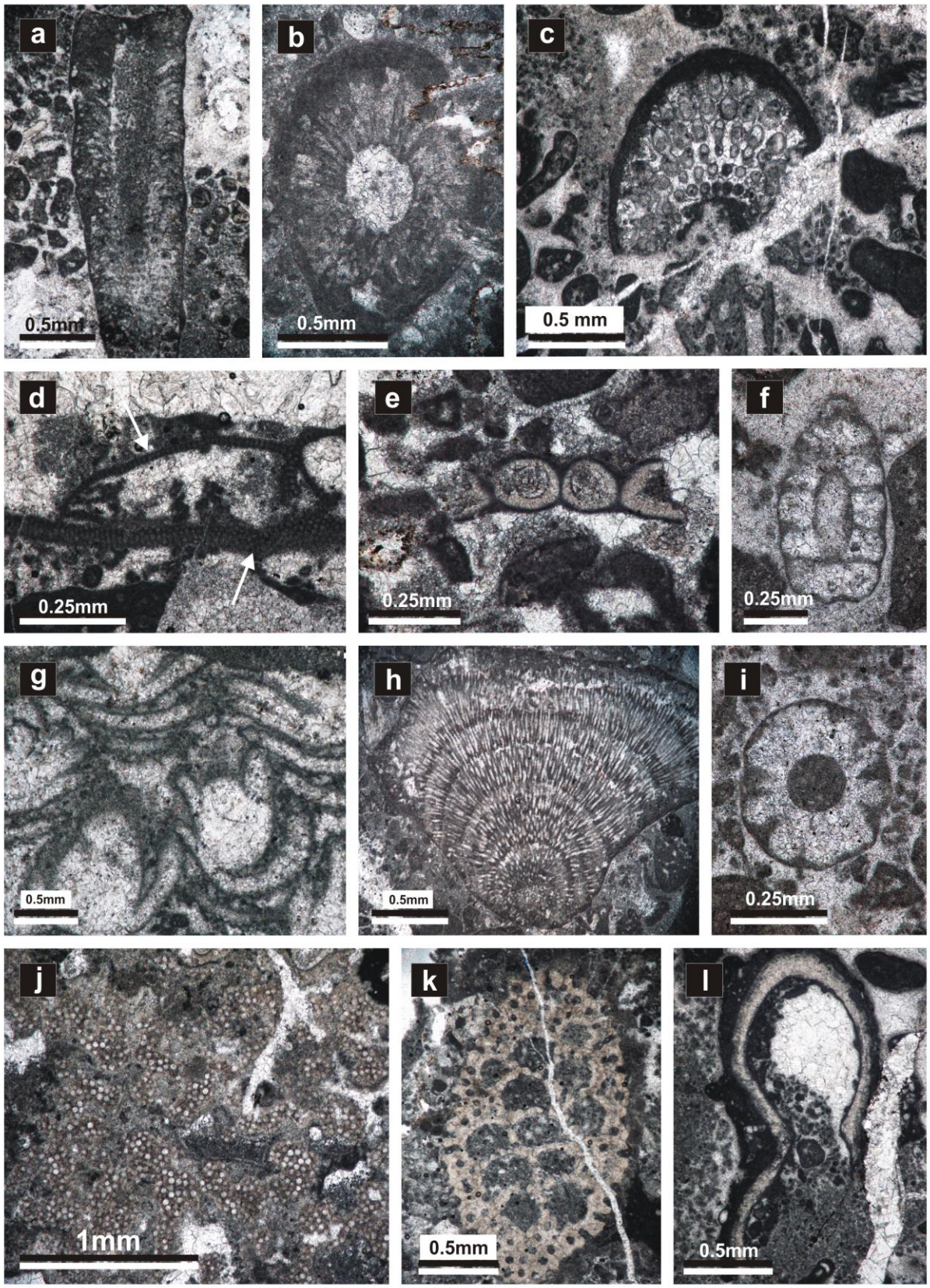


Fig. 5 Upper Jurassic dasycladalean algae (a-c, e-g), incertae sedis (d), cyanobacteria (h), sponges (j-k), and crustaceans (l) from the Ardeu Unit. **a, b** *Salpingoporella pymaea* (Gümbel) (a - Sample 39, b - Sample 167). **c** *Petrascula* sp. (Sample 7). **d** *Thaumatoporella parvovesiculifera* (Raineri) (arrows) (Sample 56). **e** *Clypeina sulcata* (Alth) (Sample 159). **f-i** *Salpingoporella annulata* Carozzi (f - Sample 67, i - Sample 41). **g** *Neoteutloporella socialis* (Praturlon) (Sample 193). **h** *Rivularia*-type cyanobacteria (Sample 69). **j** *Calcistella jachenhausenensis* Reitner (Sample 19). **k** *Thalamopora lusitanica* Termier & Termier (Sample 79). **l** *Carpathocancer* sp. (Sample 61).

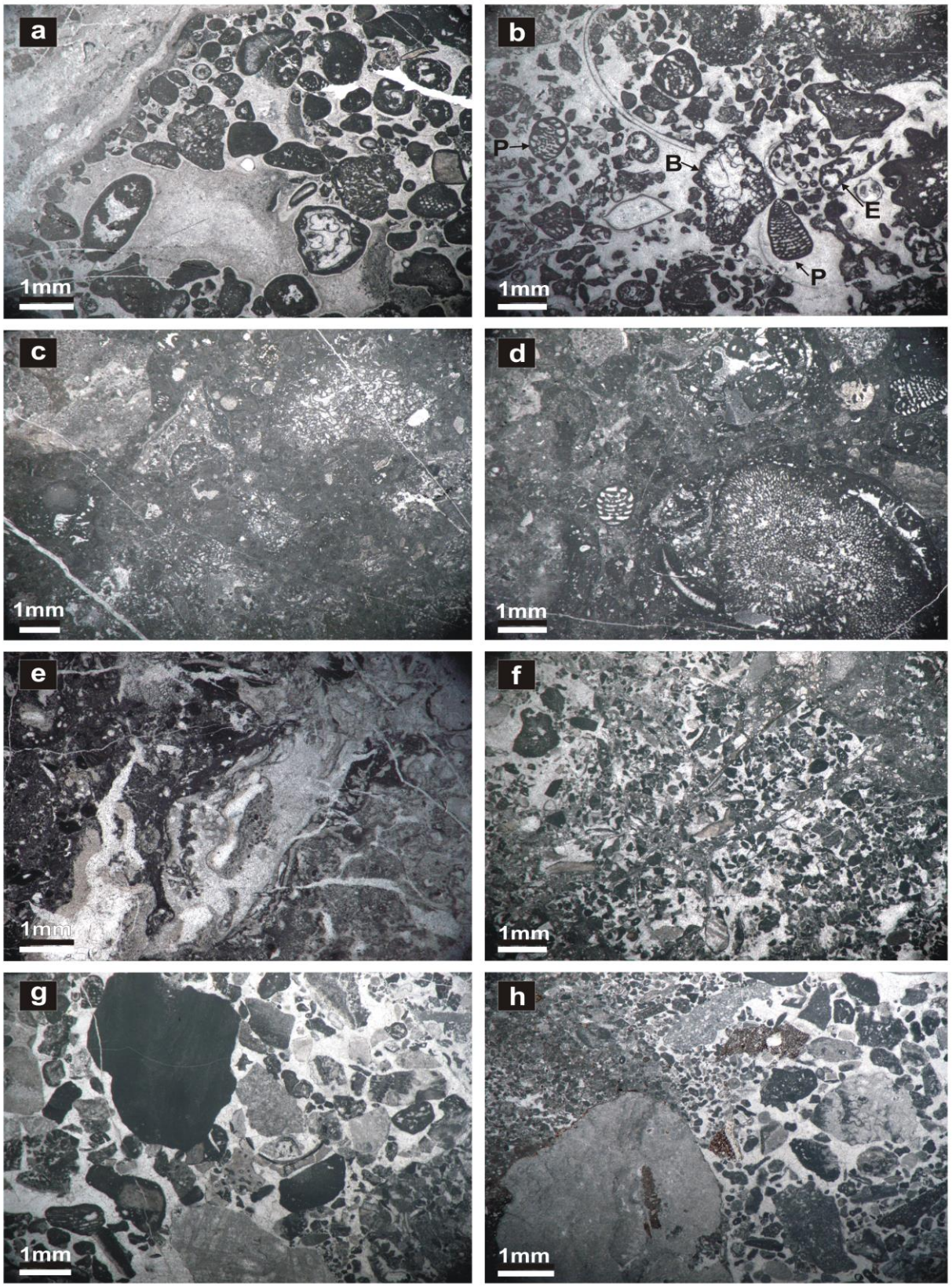


Fig. 6 Main facies associations of the carbonates from the Ardeu Unit. **a** Bio-oncoidal grainstone (F1) (Sample 48). Notice the thin rims of isopachus fibrous early cement bordering most of the bioclasts. **b** Bio-intraclastic grainsote/rudstone with *Parurgonina caelinensis* (P), *Everticyclammina praekelleri* (E) and *Bacinella*-type oncoids (B) (F1) (Sample 64). **c** Oncoidal wackestone/floatstone with numerous *Bacinella*-type oncoids, *Thaumatoporella parvovesiculifera* bridges and scarce foraminifera (F2) (Sample 5). **d** Bio-oncoidal floatstone with *Rivularia*-type cyanobacteria oncoids and *Parurgonina caelinensis* (F2) (Sample 23). Most of the oncoids are encrusted by *Lithocodium aggregatum*. **e** Coral-microbial-microencruster boundstone (F3) (Sample 183). **f** Brecciated bio-intraclastic grainstone with reef fragments (F4) (Sample 194). **g** Intraclastic rudstone (F5) (Sample 161). The intraclasts characterize different facies zones. **h** Intra-extra-bioclastic packstone/rudstone with different grain sorting and various intraclasts (F5) (Sample 160).

fragments were evidenced within the ruditic intraclasts. The skeletal debris is represented by fragments of reef-builders (micro-encruster crusts, corals and sclerosponges) and broken mollusk shells. *Lenticulina* sp., *Crescentiella morronensis*, sponge spicules, calpionellids and calcareous dinoflagellate cysts occur associated with the main components. Normal and reversed grain sorting are characterizing these rudstones. The most common diagenetic features are represented by processes of silicification, fractures and granular late cements.

Interpretation

Based on compositional and structural features presented above, we consider these deposits to be the result of different types of gravitational flows, from low-density to high-concentrated (turbiditic character) (Morsilli & Bosselini, 1997; Bucur et al., 2010b). The primary source of these micro-breccias must have been represented by platform-margin carbonates (reflected by the skeletal debris) followed by inner-platform sediments identified within the intraclasts. Open water-circulation conditions should have existed in some parts of the carbonate platform to permit detachment and mixture of components from both internal and marginal facies zones. The presence of calpionellids identified together with the main clasts points the fact that resedimentation took place in distal slope settings. The presence of some cherty nodules (silicification) can come as an additional argument in supporting this fact.

CONCLUSIONS

1 – The carbonate deposits analyzed in this paper, are characterized by Kimmeridgian-Tithonian "Štramberk"- or "Plassen"-type limestones with a diverse fauna and flora. Besides zoantharian, stromatoporoids, calcareous green algae and micro-encrusters, a well preserved foraminifera assemblage was identified in both of the analyzed sections from Ardeu Unit. The most abundant species are represented by agglutinated forms belonging to the Mesoendothyridae, Valvulinidae and Cyclamminidae. Some of the species presented in this paper are identified for the first time in Romania (e. g. *Everticyclammina praekelleri*), and may represent important arguments in age establishment and paleoenvironmental reconstructions.

2 – The identified foraminifera assemblage and calcareous green algae indicate a Late Jurassic age of both studied sections. Even if some species have a broad stratigraphical position throughout the Jurassic-lowermost Cretaceous, many of them represent typical taxa for the final stages of the Upper Jurassic. Taking this into account, we conclude that the carbonate deposits analyzed in this paper were developed during the Kimmeridgian-Tithonian interval.

3 – Facies analysis together with the main biota (especially the foraminifera associations), provided support in distinguishing five major facies associations for the Ardeu Unit carbonate platform. Each of these associations is represented by typical components, microfacies and sedimentary processes corresponding to different depositional paleoenvironments. The first two (high- and low-energy lagoonal deposits) indicate internal sedimentary settings, contrasting the marginal environments defined by patch-reef bioconstructions (F3) and reef-front debris (F4). The slope microbreccia (F5) mark the transition to more external domains of the carbonate platform margins.

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