Dasycladalean algae from Upper Jurassic-Lower Cretaceous limestones of Piatra Craiului Massif (South Carpathians, Romania) and their relationship to paleoenvironment

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Abstract. The Mesozoic limestones of Piatra Craiului Massif were deposited in the Dâmbovicioara sedimentary area, at the easternmost part of the Getic carbonate platform. In order to study the microfacies and to provide a more detailed biostratigraphy, we sampled the carbonate succession from Piatra Craiului Massif along several sections. Identified microfacies point to reef slope, carbonate platform margin and restricted, lagoon-type internal depositional environments. Some of the identified microfossils are biostratigraphic markers for the Tithonian-Lower Valanginian. The calcareous algae form associations typical for reef slopes and internal platforms. The latter can be subdivided into: (1) restricted environments (low-energy subtidal-intertidal) dominated by rivulariacean-type cyanobacteria, and (2) open-marine environments (moderate to high-energy subtidal) where dasycladalean algae are more frequent.

Keywords: dasycladalean algae, paleoenvironment, platform carbonates, Upper Jurassic-Lower Cretaceous

INTRODUCTION

During the Late Jurassic-Early Cretaceous, the dasycladalean algae flourished, with some species recording acmes during relatively short stratigraphic intervals (Bassoulet et al., 1978; Barattolo, 1991; Berger and Kaever, 1992; Granier and Deloffre, 1993; Bucur, 1999). As a rule, fossil algae ecology can be deduced by extrapolating environmental observations made on present-day calcareous algae. The latter populate various marine environments, from high-energy reefs to low-energy lagoons. They prefer tropical warm waters, around 20°C annual average values (Roux, 1995; De Castro, 1997; Valet, 1979).

Our study focuses on the relationship of some dasycladalean algae with their depositional environment. Based on sedimentary features and associated microfossils, we evidenced several depositional environments. Each of them favored the development of a variable number of species controlled by several ecological key-factors.

We have sampled four sections in the Piatra Craiului carbonate succession: Padina Închisă-Lehmann's trail, West Vlăduşca-East Vlăduşca, Zaplaz-Lanţuri, and Padina Lăncii (Fig. 1). All the samples from these sections were investigated in order to describe the main type of microfacies and microfossils.

GEOLOGICAL FRAMEWORK

The 25 km-long, NE-SW oriented calcareous mountain crest forming the Piatra Craiului Massif is located in eastern part of the Southern Carpathians (Fig. 1), forming the western flank of a large synclinal unit (Popescu, 1966; Patruşiu, 1969). On the top of the crystalline basement assigned to the Cumpăna and Leaota

formations, a sedimentary succession consisting of Kimmeridgian-Lower Valanginian calcareous deposits is found in the Piatra Craiului Syncline (Bucur et al., 2009). Bajocian-Oxfordian terrigenous and carbonate rocks consisting of microconglomerates, sandstones and marly-limestones passing towards the top into radiolarites with marl and calciturbidite interlayers, and jaspers form the base of this succession (Popescu, 1966; Bucur, 1978; Bucur, 1980; Mészáros and Bucur, 1980; Beccaro and Lazăr, 2007). Next in the succession are white, massive or stratified limestones; when present, the layers are in the order of meter- to centimeter-decimeter- thick. The massive limestones consist of coral bioconstructions and fore-reef rudstones (Fig. 2a-b). They crop-out in lower part of the carbonate succession and correspond to the platform margin. Meters to centimeter-thick layered (peritidal) limestones developed in the upper part of the succession are rich in bioclasts (Fig. 2c-e; g-h) and show frequent fenestral structures (Fig. 2f). Within these peritidalites, we could identify all of the three depositional subenvironments (subtidal, intertidal and supratidal) described below. They migrate laterally and may present typical variations within the calcareous massif.

On the whole, the succession is interpreted as a shallowing upward prograding megasequence of Kimmeridgian-Lower Valanginian age (Bucur et al., 2009; Mircescu et al., 2013; Pleş et al., 2013) (Fig. 3).

Microfacies and microfossils

A number of 720 thin sections have been made and microscopically investigated; they allowed the separation of eight major microfacies types (MF type 1-MF type 8) (Table 1): coarse bioclastic rudstone, coral-microbial boundstone,

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Fig. 1. Location of sampled sections from Piatra Craiului Massif on the geological map of Piatra Craiului-Dâmboviara area (modified after the geological map of Romania, scale 1: 50000, sheets I10a-d, Dimitrescu et al., 1971; Patrulius et al., 1971; Săndulescu et al., 1972 and Dimitrescu et al., 1974). A) Padina Închisă-Lehmann's Trail section; B) Western Vlădușca-Eastern Vlădușca section; C) Zaplaz-Lanțuri section; D) Padina Lăncii section; 1-3) Quaternary deposits 4,5) Cenozoic deposits 6) Turonian-Maastrichtian 7) Uppermost Albian-Cenomanian 8) Albian 9) Aptian 10) Barremian 11) Hauterivian 12) Kimmeridgian-Lower Valanginian 13) Callovian-Oxfordian 14) Bajocian-Callovian 15) Magmatic rocks 16) Leaota metamorphic formation 17) Cumpăna metamorphic formation 18) Fault 19) Sampled sections.

Table 1. The main microfacies identified in the studied zone and their relationship with the paleoenvironment.

MF number	Microfacies description	Paleoenvironment	Illustration
1	Coarse bioclastic rudstone	Reef slope and platform margin	Plate II, Figs. 1-4
2	Coral-microbial boundstone	Reef slope and platform margin	Plate II, Figs. 5-8
3	Bioclastic intraclastic grainstone with black pebbles	High energy internal platform subtidal	Plate III, Figs. 1-6
4	Grainstone with regenerated ooids	High energy internal platform subtidal	Plate III, Figs. 7-8
5	Fenestral bioclastic wackestone	Low energy internal platform subtidal	Plate IV, Figs. 1-6
6	Bindstone with cyanobacteria	Intertidal-supratidal	Plate V, Fig. 1
7	Fenestral bioclastic packstone-grainstone	Intertidal-supratidal	Plate V, Figs. 7-8
8	Homogenous non-fossiliferous mudstone	Supratidal	

bioclastic-intraclastic grainstone with black pebbles, grainstone with regenerated ooids, fenestral bioclastic wackestone, bindstone with cyanobacteria, fenestral-bioclastic packstone/grainstone, and homogenous non-fossiliferous mudstone. MF type 1 and MF type 2 are the main component of reef slope and platform margin environments while MF type 3-MF types 8 are characteristic for peritidal environments (internal platform with high and low

Fig. 2. Outcrop aspects of the Upper Jurassic-Lower Cretaceous limestones from Piatra Craiului. A) Massif limestones in the lower part of Vlădușca section; B) Coral bioconstructions; C) Peritidal limestones in the middle-upper part of the Padina Închisă section; D) Rudist-bearing bioclastic wackestone, Padina Închisă section; E) Meter bedded limestones in the middle-upper part of the Vlădușca section (Scale: 1 m); F) Laminoid-fenestral limestones, Vlădușca section; G) Decimeter to meter bedded limestones in the upper part of the Zaplaz-Lanțuri section; H) Bioclastic limestones with gastropods, Zaplaz-Lanțuri section.

energy, intertidal, supratidal). The most important microfossils (foraminifera and dasycladalean algae) are shown in Pl. I-VIII.

Microfacies type 1 (coarse bioclastic rudstone)

In the lower part of the studied sections, Kimmeridgian limestones are built-up of the typical rudstones of reef slope environments (Pleș et al., 2013). They are frequently associated with coral-microbial boundstones (MF type 2). Within the rudstones, poorly sorted angular-subangular clasts indicate limited transportation (Pl. II, Figs. 1, 2). Bioclasts consist of bivalve shells, gastropod fragments, corals, echinoderm plates, bryozoans, worm tubes, juvenile ammonites and foraminifers (Pl. II, Figs. 3, 4).

Dasycladalean algae (*Salpingoporella pygmaea* and *Clypeina sulcata*) are also present, but with a relatively reduced species diversity. They seem to be dispersed into the bioconstructions internal sediment, or they occur as small fragments mixed with the reef detritus along the fore-reef slope.

Microfacies type 2 (coral-microbial boundstone)

The boundstones display peloidal bioclastic packstone-wackestone-type internal sediment (Pl. II, Figs. 5-7). Microbial crusts and encrusting organisms are important constituents, contributing significantly to the reinforcement of the reef

Fig. 3. Generalized stratigraphic succession of the Kimmeridgian-Lower Valanginian limestones from Piatra Craiului. 1) Corals; 2) Coral fragments; 3) Microbial crusts; 4) Echinids; 5) Peloids; 6) Bivalves; 7) Bryozoans; 8) Gastropods; 9) Dasycladalean algae; 10) Rivulariacean-type cyanobacteria; 11) Foraminifers; 12) Rudists; 13) Regenerated ooids; 14) Fenestral structures; 15) Black pebbles; 16) Roots; 17) Latest Albian-Cenomanian conglomerates; 18) Aptian breccia; 19) Oxfordian radiolarites.

framework (Pleş et al., 2013). In some cases, they build-up networks between the coral colonies, or they form associations of encrusting organisms within the sediment between corals (Pl. II, Fig. 8). The bioconstructions occur as intercalations, being installed and developing on top of the rudstone type deposits. Bioconstructions did not merge into large-scale vertical frameworks that could explain the reefal paleoslope. Pleş et al. (2013) considered that the shelf paleoslope derived from the inherited geometry of the carbonate platform basement.

The micropaleontological assemblage identified consists of encrusting organisms [*Crescentiella morronensis* (Crescenti), bacinellid structures, *Lithocodium aggregatum* Elliott, *Koskinobullina socialis* Cherchi & Schroeder, *Iberopora bodeuri* Granier & Berthou, *Radiomura cautica* Senowbari-Daryan & Schäfer, interpreted by Senowbari-Daryan (2009) as a sponge], sponges (*Murania reitneri* Schlagintweit, *Neuropora lusitanica* Termier, *Perturbatacrusta leini* Schlagintweit & Gawlick,

Thalamopora lusitanica Termier & Termier, *Calcastella jachenhausenensis* Reitner), foraminifers [*Coscinocoma alpinus* Leupold, *Labyrinthina mirabilis* Weynschenk, *Mohlerina basiliensis* (Mohler), *Parurgonina caelinensis* Cuivillier, Foury & Pignatti Morano] and dasycladalean algae [*Clypeina sulcata* (Alth), *Salpingoporella pygmaea* (Gümbel), *Petrascula bursiformis* (Etallon)].

The bioconstructions are followed by peritidal Tithonian-Berriasian-Lower Valanginian limestones. They display a wide range of microfacies (MF type 3-MF type 8): bioclastic-intraclastic grainstone with black pebbles, grainstone with regenerated ooids, fenestral bioclastic wackestone, bindstone with cyanobacteria, fenestral-bioclastic packstone/grainstone, and homogenous non-fossiliferous mudstone.

Microfacies type 3 (bioclastic-intraclastic grainstone with black pebbles)

Dasycladalean algae, rivulariacean-type cyanobacteria (*Rivularia piae*), gastropods, coral fragments, sponges, and *Bacinella*-type structures are the biota identified in the bioclastic-intraclastic grainstones (Pl. III, Figs. 1-6). A millimeter-thick micritic rim is present around the dasycladalean fragments (Pl. III, Figs. 2, 3). We assume that the micritization took place in a low-energy, quiet environment, under the influence of microendoliths (Bathurst, 1966; Flügel, 2004). Subsequently, the dasycladalean algae were reworked and re-deposited in higher-energy environments.

The black pebbles (Pl. III, Figs. 1, 6) indicate stages of subaerial exposure of the carbonate platform as well as relative fluctuations of the sea level. According to Strasser (1984), three models apply to the formation of black pebbles: the first assumes that a black film could form around carbonate clasts in anoxic microenvironments within peritidal areas. A second model considers that organic matter in the sediments blackens the carbonate clasts during the uplift stages of the carbonate platform (Strasser, 1984; Leinfelder, 1987). A third scenario also involves organic matter, but this is adsorbed at the surface of calcretes during pedogenetic micritization processes (Strasser, 1984; Săsăran, 2006). The black pebbles may be reworked, or may be found *in situ*. In the studied deposits, the pebbles were reworked in the subtidal sediments.

In the Zaplaz-Lanțuri and Padina Lăncii sections, we have identified limestone levels pigmented with iron oxides. They are probably subaerially exposed subtidal carbonate deposits. Dasycladalean algae (frequent *Clypeina sulcata* and seldom *Campbeliella striata*) and rare foraminifers are the typical bioclasts in these deposits. Here we have also remarked a second black pebbles level.

Microfacies type 4 (grainstone with regenerated ooids)

The grainstones with broken and regenerated ooids are frequent in Padina Închisă section. They build-up a 10 m-thick level located on top of the black pebbles-bearing deposits. No bioclasts are present in these sediments (Pl. III, Figs. 7, 8). These limestones formed in high-energy environments, in marginal or internal areas of the shallow carbonate platform (Flügel, 2004).

Microfacies type 5 (fenestral bioclastic wackestone)

This type of microfacies contains the following sub-types: wackestone with dasycladalean algae, bioclastic wackestone with diceratid rudists and gastropods, bioclastic mudstone/wackestone (Pl. IV, Figs. 1-6). The bioclasts, represented by large

gastropods, rudists and cyanobacteria nodules are embedded in a muddy, micritic sediment (Pl. IV, Figs. 1, 2). The micritic sediment is intensely bioturbated. The abundance of gastropods and cyanobacteria nodules (Pl. IV, Figs. 1-4) indicates a lagoon-type, quiet, shallow environment (low energy internal platform subtidal environment).

Microfacies type 6 (bindstone with cyanobacteria)

In the Padina Închisă section, the cyanobacteria may form small bioconstructions (Pl. V, Fig. 1). These contain laminitic stromatolitic structures consisting of very fine peloids alternating with very fine, laminitic, black micrite. Skeletal cyanobacterial stromatolites are associated with the micritic laminites; sometimes they may also build-up thrombolytic fabrics (Pl. V, Fig. 1).

Microfacies type 7 (fenestral-bioclastic packstone/grainstone)

The following sub-types are characteristic for MF type 7: fenestral peloidal bioclastic wackestone/packstone, packstone with cuneolinid foraminifers, grainstone/packstone with micritized ooids and intraclasts (Pl. IV, Figs. 7-8; Pl. V, Figs. 2-8). The top of the studied sections consists of intertidal-supratidal limestones. On western flank of the Piatra Craiului Massif, these deposits are more than 300 m-thick, while on the eastern side they are only 250 m-thick. The bioclastic wackestone/packstone dominates (Pl. V, Figs. 2, 3). Abundant rivulariacean-type cyanobacteria are the main bioclasts present (Pl. V, Figs. 4, 5, 8) and they indicate restrictive environments. Rare bivalves, gastropods and cuneolinid foraminifers are also present. We have also noticed grains formed under high energy condition (ooids) that were afterwards reworked into intertidal environments and micritized (Pl. V, Fig. 6). In similar depositional environments, micritization processes are often associated with low carbonate sediment accumulation rates (Enos, 1983; Flügel, 2004).

Microfacies type 8 (homogenous non-fossiliferous mudstone)

This type of microfacies lacks microfossils almost entirely. Sometimes dolomitization is present, mainly located along fissures. In addition, we noticed diffuse structures resembling calcretes in the East Vlădușca section; they may include root tracks.

The micropaleontological assemblage includes foraminifers [*Pseudotextulariella courtionensis* Brönnimann, *Coscinoconus cherchiai* (Arnaud-Vanneau, Boisseau & Darsac), *Conicopfenderina? balkanica* Peybernès, *Haplophragmoides joukowskyi* Charollais, Brönnimann & Zaninetti, *Pfenderina neocomiensis* (Pfender), *Protopeneroplis ultragranulata* (Gorbachik), *Vercorsella camposauri* (Sartoni & Crescenti)], rivulariacean-type cyanobacteria [*Rivularia piae* (Frollo), *Rivularia moldavica* (Frollo)], and dasycladalean algae [*Campbelliella striata* (Carozzi), *Steinmanniporella kapelensis* (Sokač & Nikler), *Clypeina sulcata* (Alth), *Clypeina parasolkani* Farinacci & Radoičić, *Salpingoporella praturloni* (Dragastan), *Pseudocymopolia jurassica* Dragastan, *Salpingoporella annulata* Carozzi, *Salpingoporella pygmaea* (Gümbel)].

The age of the studied deposits

The micropaleontological assemblages identified in the white limestones from Piatra Craiului Massif (Pls. I, VI-VIII) point to a Kimmeridgian-Lower Valanginian age. Table 2 includes the identified foraminiferal and dasycladalean species, together with their generalized stratigraphic distribution.

The foraminifers *Labyrinthina mirabilis* and *Parurgonina caelinensis* are typical species for the Kimmeridgian-Lower

Tithonian interval (Cuvillier et al., 1968; Bassoullet, 1997). They are associated with the algae *Salpingoporella pygmaea*, *Clypeina sulcata*, *Steinmanniporella kapelensis*, *Campbelliella striata* and *Petrascula bursiformis*, another typical Kimmeridgian-Tithonian association (Fenninger and Hötzel, 1967; Granier and Deloffre, 1993; Senowbari-Daryan et al., 1994; Bucur, 1999; Schlagintweit and Ebli, 1999; Schlagintweit, 2004; Schlagintweit and Gawlick, 2005; Carras et al., 2006; Schlagintweit, 2011).

The foraminiferal association identified at the top of the succession is characterized by Berriasian-Lower Valanginian species such as *Protopeneroplis ultragranulata*, *Pseudotextulariella courtionensis*, *Haplophragmoides joukowskyi*, *Pfenderina neocomiensis*, or *Conicopfenderina? balkanica* (Altiner, 1991; Bucur et al., 1995; Bucur, 1997; Peybernès, 2004; Ivanova and Kolodziej, 2010). The accompanying calcareous algae also indicate a Berriasian-Valanginian age: *Clypeina parasolkani*, *Salpingoporella annulata*, *Pseudocymopolia jurassica*, *Salpingoporella praturloni* (Farinacci and Radoičić, 1991; Granier and Deloffre, 1993; Masse, 1993; Schindler and Conrad, 1994; Bucur, 1999; Dieni and Radoičić, 1999; Moshhammer and Schlagintweit, 1999; Schlagintweit et al., 2009).

Relationship between dasycladalean algae and paleoenvironment

Based on the identified microfacies types and the microfossils, we could separate three principal depositional environments: reef slope and platform margin, internal platform subtidal, intertidal and supratidal.

Reef slope and platform margin environment

In the lower part of the sampled sections, reef slope carbonate deposits were identified. They are represented by bioclastic rudstone, and boundstone with packstone-wackestone type internal sediment.

Most probably, the algal species identified in the reef rudstone deposits (*Clypeina sulcata*, *Salpingoporella pygmaea*) were reworked, as they are dispersed within the mass of grain flows along the fore-reef slope (Pl. VI, Figs. 1-4). We have identified *Petrascula bursiformis* only in the Padina Lăncii section. Because it is present in packstone-type internal sediment of a coral bioconstruction, we assume that this species is *in situ* (Pl. VI, Figs. 5-8). Other authors (Schlagintweit, 2011; Bucur and Săsăran, 2012) have described similar large dasycladaleans from similar depositional environments.

Internal platform subtidal environment

Internal platform subtidal limestones identified in the studied sections formed in both high- and low energy platform environments. High energy subtidal carbonate rocks consist of bioclastic-intraclastic grainstones with black pebbles, or grainstones with regenerated ooids. In the Padina Închisă, West Vlădușca, and Zaplaz-Lanțuri sections, these deposits are about 60 m-thick. This marker level located on top of the reef limestones can be followed along the whole western flank of the Piatra Craiului Massif.

In the internal platform high energy subtidal deposits, we have identified the following dasycladalean algae: *Campbelliella striata*, *Clypeina sulcata*, *Salpingoporella annulata*, *Salpingoporella pygmaea* and *Steinmanniporella kapelensis* (Pl. VII). A micritic rim often surrounds *Clypeina sulcata* and *Salpingoporella pygmaea*. We assume that the micritization took place in a low-energy, quiet environment, under the influence of microendoliths. Subsequently, the dasycladalean algae were reworked and re-deposited in higher-energy environments.

Table 2. Stratigraphic distribution of foraminifera and dasycladalean algae identified in Piatra Craiului Massif.

Range Taxa	Kimmeridgian	Tithonian	Berriasian	Valanginian	Illustration
Foraminifera					
<i>Parurgonina caelinensis</i> Cuvillier, Foury & Pignatti Morano, 1968	←				Pl. I, Fig. 1
<i>Labyrinthina mirabilis</i> Weynschenk, 1951	←				Pl. I, Fig. 2
<i>Protopenneroplis ultragranulata</i> (Gorbachik, 1971)			→		Pl. I, Fig. 3
<i>Pseudotextulariella courtionensis</i> Broennimann, 1966					Pl. I, Fig. 4
<i>Haplophragmoides joukowskyi</i> Charollais, Broennimann & Zaninetti, 1966					Pl. I, Fig. 5
<i>Pfenderina neocomiensis</i> (Pfender, 1938)					Pl. I, Fig. 6
<i>Conicopfenderina ? balkanica</i> Peybernes, 2004				→	Pl. I, Fig. 7
Dasycladalean algae					
<i>Salpingoporella pygmaea</i> (Gümbel, 1891)	←			→	Pl. VI, Figs. 3-4 Pl. VII, Fig. 1
<i>Salpingoporella annulata</i> Carozzi, 1953	←			→	Pl. VII, Figs. 2-3 Pl. VIII, Figs. 3-4
<i>Petrascula bursiformis</i> (Etallon, 1859)					Pl. VI, Figs. 5-8
<i>Campbelliella striata</i> (Carozzi, 1954)					Pl. VII, Figs. 7-8
<i>Chypeina sulcata</i> (Alth, 1882)					Pl. IV, Figs. 5-6 Pl. VI, Figs. 1-2 Pl. VII, Fig. 5-6 Pl. VIII, Figs. 1,2,6
<i>Steinmanniporella kapelensis</i> (Sokač & Nikler, 1973)					Pl. VII, Fig. 4
<i>Chypeina parasolkani</i> Farinacci & Radoičić, 1991					Pl. VIII, Fig. 5
<i>Pseudocymopolia jurassica</i> (Dragastan, 1968)					Pl. VIII, Fig. 7
<i>Salpingoporella praturloni</i> (Dragastan, 1978)					Pl. VIII, Fig. 8

As a rule, *Steinmanniporella kapelensis* is present in deposits formed on carbonate platform margins (Bucur and Săsăran, 2012), as it is also the case in the Piatra Craiului area.

Salpingoporella annulata was identified in both normal marine (Jafrezo and Renard, 1979), and restrictive (Bucur and Săsăran, 2005) environments. Similarly, in Piatra Craiului this species is present in both open sea deposits (platform margin), and in restrictive, internal platform deposits.

In the upper part of the studied sections the limestones show typical features for restrictive environments (internal platform subtidal with low energy) with rare intercalations of higher energy deposits. The dasycladalean algae dominate the wackestone and fenestral packstone/grainstone facies types. They are represented

by four main species: *Chypeina sulcata*, *Chypeina parasolkani*, *Salpingoporella praturloni* and *Pseudocymopolia jurassica* (Pl. VIII, Figs. 1-8). The micritic sediment is intensely bioturbated. In these limestones, we have identified numerous specimens of *Chypeina sulcata*. They occur in abundance as monospecific, whole-fossils in a wackestone microfacies and can be interpreted as being *in situ*. This species frequently prefers restrictive environments with high salinity (Conrad, 1977).

Favre and Richard (1927) have described *Chypeina sulcata* (as *Chypeina jurassica*) from lagoonal limestones, a typical restrictive environment.

Salpingoporella praturloni and *Pseudocymopolia jurassica* prefer external platform environments (Bucur and Săsăran, 2005), but they seem also to occur in high-energy open-marine internal platform settings; they have been identified at the top of the Padina Inchisă- Lehmann's trail section, in bioclastic wackestones, probably reworked from areas of higher energy sedimentation.

The intertidal and supratidal environments

The top of the studied sections consists of intertidal-supratidal limestones. On the western flank of the Piatra Craiului Massif, these deposits are more than 300 m-thick, while on the eastern side they are only 250 m-thick. Dasycladalean algae are almost completely absent. Within the micritic sediment, the rivulariacean-type cyanobacteria are either isolated, or incorporated in the fenestral sediment (Pl. VIII, Fig. 5). Occasionally, the cyanobacteria incorporate peloids or ostracods. *Rivularia moldavica* is the dominant species (Pl. VIII, Fig. 4). According to Săsăran et al. (2013), in the intertidal limestones from Piatra Craiului the rivulariacean-type cyanobacteria are the main producers of carbonate, under the circumstances of a progressive decrease of the accommodation space rate of formation in parallel with the progradation of the carbonate platform.

The limestones formed in supratidal environments almost lack microfossils. One microfacies type characterizes this depositional environment: non-fossiliferous mudstone.

CONCLUSIONS

The Kimmeridgian-Lower Valanginian carbonate succession from the Piatra Craiului Massif consists of deposits formed in a wide range of depositional environments. They indicate a general transition from platform margin to internal platform carbonate deposits. Jointly with the progradation of the carbonate platform, the water became shallower. Therefore, in the internal areas of the carbonate platform, restrictive, lagoon- or intertidal

pond-type environments developed. The relative sea level changes have directly influenced the flora and fauna development. In the restrictive environments, cyanobacteria have flourished, while some dasycladalean algae such as *Clypeina sulcata*, *Salpingoporella annulata*, or *Clypeina parasolkani* developed optimally in the lagoons. More frequently dasycladaleans have been identified in the carbonate platform margin. In spite of the relatively reduced diversity, dasycladaleans, in association with other fossils and the microfacies are useful tools in the reconstruction of the evolution of the Piatra Craiului carbonate platform during the Upper Jurassic-Lower Cretaceous.

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Plate I. The most important foraminifera identified in the Upper Jurassic-Lower Cretaceous limestones from Piatra Craiului. Scale: 0.5 mm (Figs. 1-2); 0.25 mm (Figs. 3-7).

Fig. 1. *Parurgonina caelinensis* Cuvillier, Foury & Pignatti Morano, longitudinal section; Zaplaz-Lanțuri section, sample 652;

Fig. 2. *Labyrinthina mirabilis* Weynschenk, longitudinal-tangential section; Padina Lăncii section, sample 743;

Fig. 3. *Pseudotextulariella courtionensis* Brönnimann, oblique section; Padina Închisă section, sample 464;

Fig. 4. *Protopeneroplis ultragranulata* (Gorbatchik), subaxial and tangential sections; Lehmann's Trail section, sample 621;

Fig. 5. *Haplophragmoides joukowskyi* Charollais, Brönnimann & Zaninetti, subequatorial section; Padina Închisă section, sample 464. Scale: 0.25 mm;

Fig. 6. *Pfenderina neocomiensis* (Pfender), oblique section; East Vlădușca section, sample 350;

Fig. 7. *Conicopfenderina? balkanica* Peybernès, longitudinal-oblique section; Lehmann's Trail section, sample 411.

PLATE I

Plate II. Slope and platform edge deposits in the lower part of the carbonate succession in Piatra Craiului. Scale: 1 mm.

Fig. 1. Bioclastic-peloidal rudstone with encrusting organisms and echinoderm plates; Padina Închisă section, sample 50 P;

Fig. 2. Coarse bioclastic grainstone/rudstone with microbial structures, encrusting organisms and bryozoans; West Vlădușca section, sample 125;

Fig. 3. Bioclastic rudstone. Bioclasts consist of encrusting organisms (*Crescentiella morronensis*), agglutinated-walled worm tubes, and bivalves; Zaplaz-Lanțuri section, sample 591;

Fig. 4. Bioclastic rudstone. Bioclasts consist of echinoderm plates, gastropods, bivalves, recrystallized coral fragments and encrusting organisms [*Crescentiella morronensis* (Crescenti)]; Padina Lăncii section, sample 686;

Figs. 5, 6. Coral-microbial boundstone with *Crescentiella morronensis*. Encrusting organisms are present together with the sediment between corals; Fig. 5: Padina Închisă section, sample 40 P; Fig. 6: West Vlădușca section, sample 138;

Fig. 7. Microsolenid boundstone with peloidal wackestone as internal sediment. Corals are bioeroded; Zaplaz-Lanțuri section, sample 582;

Fig. 8. Coral-microbial boundstone. Superposed crusts of calcareous sponges (*Calcistella jachenhausenensis*) and stromatolitic-microbial structures on a coral; Padina Lăncii section, sample 717 b.

PLATE II

Plate III. Characteristic microfacies of the high-energy internal platform subtidal carbonate deposits. Scale: 1 mm.

Fig. 1. Bioclastic-intraclastic grainstone with black pebbles; West Vlădușca section, sample 212c;

Fig. 2. Coarse bioclastic grainstone. Bioclasts consist of cyanobacteria, sponge fragments, bivalves and dasycladalean algae (*Chypeina sulcata*). A micritic envelope around bioclasts is developed; West Vlădușca section, sample 213;

Fig. 3. Bioclastic-intraclastic, fenestral packstone-grainstone with dasycladalean algae (*Salpingoporella pygmaea*) and bivalve fragments; Zaplaz-Lanțuri section, sample 630;

Figs. 4, 5. Coarse bioclastic grainstone with cyanobacteria, nerineid gastropods, bivalves and corals. Micritic envelopes around bioclasts; West Vlădușca section, sample 630;

Fig. 6. Bioclastic-intraclastic, fenestral grainstone with black pebbles; West Vlădușca section, sample 632;

Figs. 7, 8. Oolitic grainstone with broken and regenerated ooids. Rare bioclasts are represented by gastropods; Padina Închisă section, sample 490.

PLATE III

Plate IV. Microfacies of low-energy internal platform subtidal carbonate deposits. Scale: 1 mm.

Fig. 1. Bioclastic-fenestral, bioturbated wackestone with gastropods; Padina Închisă section, sample 435;

Fig. 2. Bioclastic wackestone with diceratid rudists and other bivalve fragments and gastropods. Some cavities are filled with geopetal sediment; Padina Închisă section, sample 468;

Figs. 3, 4. Bioclastic wackestone/floatstone with coral fragments, dasycladalean algae, gastropods and cyanobacteria; Lehmann's Trail section. Fig. 3: sample 621; Fig. 4: sample 621;

Figs. 5, 6. Bioclastic-intraclastic wackestone with dasycladalean algae (*Chypeina sulcata*); West Vlădușca section. Fig. 5: sample 197; Fig. 6: sample 197;

Figs. 7, 8. Bioclastic-intraclastic packstone-grainstone. Main bioclasts are represented by foraminifera. Intraclasts contain cyanobacteria nodules; East Vlădușca section, sample 288.

PLATE IV

Plate V. Microfacies of intertidal-supratidal carbonate deposits. Scale: 1 mm.

Fig. 1. Microbial laminitic (stromatolitic) structures; Padina Închisă section, sample 454;

Fig. 2. Peloidal fenestral wackestone; West Vlădușca section; sample 245;

Fig. 3. Peloidal fenestral wackestone sharply overlain by a bioclastic-intraclastic grainstone with cyanobacteria; Lehmann's Trail section, sample 415;

Fig. 4. Rivulariacean-type cyanobacteria (*Rivularia moldavica* Frolo); West Vlădușca section, sample 242;

Fig. 5. Rivulariacean-type cyanobacteria in a fenestral fabric, West Vlădușca section, sample 245;

Figs. 6, 7. Bioclastic-fenestral packstone-grainstone with micritized ooids and rivulariacean fragments; East Vlădușca section, sample 315;

Fig. 8. Intraclastic-bioclastic, fenestral packstone-grainstone with rivulariaceans and gastropods, East Vlădușca section, sample 316;

PLATE V

Plate VI. Dasycladalean algae from the reef limestones. Scale: 0.25 mm (Figs. 1-2; Fig. 4); 0.5 mm (Fig. 3; Figs. 7-8); 1 mm (Figs. 5-6).

Fig. 1. *Clypeina sulcata* (Alth), transverse section; Padina Închisă section, sample 30 P;

Fig. 2. *Clypeina sulcata* (Alth), tangential section; West Vlădușca section, sample 79;

Fig. 3. *Salpingoporella pygmaea* (Gümbel), oblique section; Padina Închisă section, sample 40 P;

Fig. 4. *Salpingoporella pygmaea* (Gümbel), transverse-oblique section; West Vlădușca section, sample 100;

Figs. 5-8. *Petrascula bursiformis* (Etallon); Padina Lăncii section, sample 721; Fig. 5: oblique and oblique-transverse sections; Fig. 6: tangential and oblique sections; Fig. 7: tangential section; Fig. 8: longitudinal section of a head fragment.

PLATE VI

Plate VII. Dasycladalean algae from the high-energy internal platform subtidal carbonates. Scale: 0.25 mm (Figs. 1-2, Fig.5); 0.5 mm (Figs. 3-4; Figs. 6-8).

Fig. 1. *Salpingoporella pygmaea* (Gümbel), oblique section; Padina Închisă section, sample 71 P;

Figs. 2, 3. *Salpingoporella annulata* Carozzi. Fig. 2: oblique section; Padina Închisă section, sample 464; Fig. 3: transverse and longitudinal oblique sections; Zaplaz-Lanțuri section, sample 628;

Fig. 4. *Steinmanniporella kapelensis* (Sokač and Nikler), transverse-oblique section; West Vlădușca section, sample 218;

Figs. 5, 6. *Chypeina sulcata* (Alth), Zaplaz-Lanțuri section. Fig. 5: transverse section, sample 650; Fig. 6: transverse and tangential sections, sample 651;

Figs. 7, 8. *Campbelliella striata* (Carozzi), Zaplaz-Lanțuri section. Fig. 7: oblique section, sample 630; Fig. 8: longitudinal-tangential section, sample 631.

PLATE VII

Plate VIII. Dasycladalean algae from the low-energy internal platform subtidal carbonates. Scale: 0.25 mm (Figs. 1-5; Figs. 7-8); 0.5 mm (Fig. 6).

Figs. 1, 2. *Clypeina sulcata* (Alth), tangential-oblique section; West Vlădușca section, sample 197;

Figs. 3, 4. *Salpingoporella annulata* (Carozzi), Padina Închisă section. Fig. 3: oblique section, sample 464; Fig. 4: transverse-oblique section, sample 464;

Fig. 5. *Clypeina parasolkani* Farinacci & Radoičić, tranverse-oblique section; Padina Închisă section, sample 464;

Fig. 6. *Clypeina sulcata* (Alth), longitudinal section cutting five verticils; West Vlădușca section, sample 197;

Fig. 7. *Pseudocymopolia jurassica* Dragastan, longitudinal section; Lehmann's Trail section, sample 621;

Fig. 8. *Salpingoporella praturloni* (Dragastan), fragment of longitudinal section and *Protopeneroplis ultragranulata* (Gorbachik), transverse section; Lehmann's Trail section, sample 621;

PLATE VIII