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UPPER JURASSIC-LOWER CRETACEOUS DEPOSITS FROM THE NORTHERN PART OF PĂDUREA CRAIULUI MASSIF (NORTHERN APUSENI MOUNTAINS): FACIES AND BIOSTRATIGRAPHY

Summary of the PhD thesis

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Key words: Upper Jurassic, Lower Cretaceous, microfacies, microfossils, Pădurea Craiului

INTRODUCTION

The aim of this PhD thesis is the study of the Upper Jurassic-Lower Cretaceous deposits from the northern part of Pădurea Craiului Massif. The main objectives are to analyze the facies and the biostratigraphy of these deposits. This analysis enabled us to determine the depositional environment, diagenesis or where possible sea-level changes.

The Pădurea Craiului Mountains are part of the Apuseni Mountains. They are located in the northwestern part of the latter (Fig. 1) between the Crișul Repede Valley in the north and the Crișul Negru Valley to the south, being separated from the Vlădeasa and Bihor Mountains to the east and south-east by the Iada and Meziad Valleys (Pop, 2000).

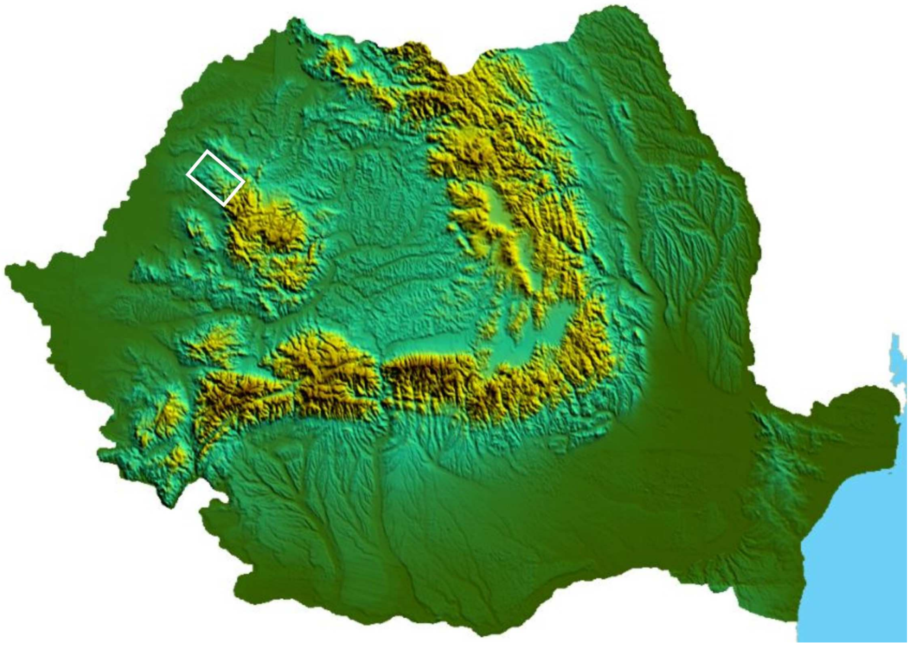

Fig. 1 Location of Pădurea Craiului Mountains on the map of Romania.

Due to the location of the outcrops the area under study was split in two parts, namely Vadu Crișului area and Aștileu-Subpiatră area.

1. HISTORICAL APPROACH

The first geological studies concerning Pădurea Craiului were performed in the ninetieth century. The outcome of these studies was the rough separation of the Mesozoic and Neogene deposits and the mapping of certain parts of the Pădurea Craiului Mountains. Palfy (1916) reached to the conclusion that the Bihor Mountains and Pădurea Craiului have similar Mesozoic cover. He is the first to recognize the Codru facies thrust over the Bihor "Autochthon" in the south-western part of Pădurea Craiului and presumed that the age of the thrusting is mid-Cretaceous.

The unconformity between the Malm and Lower Cretaceous limestones was noticed by Rozlosnik (1917), stating that the bauxites are accumulated in the topographic lows of the Upper Jurassic limestones.

The facies difference between the northern and southern part of the Upper Jurassic-Lower Cretaceous deposits of the Pădurea Craiului Mountains was recognized by Fisch (1924).

The first studies concerning the microfacies and micropalaeontological content of the limestones from Pădurea Craiului were performed by Dragastan (1966, 1967).

Patrulius in Ianovici et al. (1976) established the formal lithostratigraphic units of the Upper Jurassic deposits: the Vad Formation (former Vad Limestone), the Farcu-Cornet Formations with three members (Farcu, Cornet and Aștileu), the Albioara Formation (former Albioara Limestone). Regarding the Lower Cretaceous deposits, Patrulius splits the succession in the following lithostratigraphic terms: (1) bauxites, (2) "the limestone with characeans", (3) "the limestone with gastropods" (all these terms represent at least partially the "Neocomian"), 4) "the lower limestone with pachyodonts" (Barremian-Lower Aptian), (5) the Ecleja Beds, (6) "the middle limestone with pachyodonts" (Aptian), (7) "the complex of the glauconitic sandstones and the upper limestones with pachyodonts" (Aptian-Albian), (8) sandstones, siltites, red or green argillaceous shales (likely of Cenomanian age).

Jurcsak and Popa (1978) described for the first time in Pădurea Craiului dinosaurs remains.

Dragastan et al. (1988, 1989) integrated the first four members of the Lower Cretaceous deposits separated earlier by Patrulius in Ianovici et al. (1976) into the Blid Formation.

Bucur (1981-2012) performed many studies in the area, most of them concerning the biostratigraphy and mentioned numerous microfossils for the first time from Pădurea Craiului. He also described several new algal species from the Upper Jurassic-Lower Cretaceous deposits of Pădurea Craiului.

Cociuba (1995, 1997, 1999, 2000) brought a series of new data concerning the Upper Jurassic-Lower Cretaceous deposits and established formal lithostratigraphic units for the Lower Cretaceous ones.

2. GEOLOGICAL FRAMEWORK

Geologically Pădurea Craiului belongs to the Northern Apuseni Mountains, part of the Tisza Mega-Unit. The Northern Apuseni Mountains consist of Bihor Unit overthrust by two nappe systems: Codru Nappe System and Biharia Nappe System. Bihor Unit outcrops on almost all of the Pădurea Craiului area, including the northern part. Its sedimentary cover includes Permian, Triassic, Jurassic and Cretaceous deposits. Upper Jurassic deposits consist basically of the following formations: Vad Formation, Cornet Formation, Albioara Formation. The Lower Cretaceous deposits are separated into the following formation: the Blid Formation with two members, namely the Dobrești Member (Valanginian-Hauterivian), the Coposeni Member (Hauterivian-Early Aptian); the Ecleja Formation (Early Aptian), the Valea Măgurii Formation (?late Early Aptian), the Vârciorog Formation which includes the Subpiatră Limestone (Late Aptian-Albian).

3. MATERIAL AND METHODS

In order to do this study we made many field trips (2005-2012) mapping the areas of interest and collecting many samples of which more than 800 were used for this PhD thesis. Where we deemed necessary and the field reality made it possible, vertical sections were raised. All the sections were described in the field including the lithology, bedding thickness and surface, geometric relationship between them, sedimentary structures and facies. The samples were analyzed, before collecting with the help of a 10x hand lens. Thin sections or occasionally polished sections were made from the samples collected. When needed, more thin sections were made from the same sample as is the case with what we believe to be a new *Triploporella* species, or with important orbitolinids. The taxonomy of orbitolinids is largely based upon the internal structures and especially the embryonic apparatus (Schroeder, 1975, Schroeder et al. 2010). As a consequence their determination was made on specimens with embryonic apparatus cross-cut in axial sections.

The microfacies analysis with the help of the microscope allowed determination of the ratio between matrix and components, the composition and grain size of the skeletal and nonskeletal components. Facies were described using Dunham's classification (1962), extended by Embry and Klovan (1971).

4. SECTIONS ANALYSIS

4.1 Vadu Crișului Area

Upper Jurassic and Lower Cretaceous deposits outcrop on tens of square kilometers in this area. Upper Jurassic deposits are better represented but there are very few places where the succession can be observed in vertical sections. One of these places is Birtin Hill in the south-west of Vadu Crișului. The Lower Cretaceous deposits are relatively well exposed along the Crișului Repede Valley between the localities of Vadu Crișului and Şuncuiuș.

A total of six vertical sections were raised from Vadu Crișului area, but some of them are very short as is the case with the bauxite lenses. As there was no detailed geological map for this area or the existing maps were obsolete, a new map was required. The new map was made at a scale of 1: 10 000 and the vertical sections are represented on this map (Fig. 2).

4.1.1 Birtin Hill Section

The section starts from the base of the hill and then goes up, on a small torrent, passes Birtin Cave, and then crosses the road between localities of Vadu Crișului and Birtin, ending 35 meters above the road because of the lack of outcrops (GPS coordinates N 46°58'49.5''; E 22°29'11.4''). The entire section is around 94 meters. The sampling interval for the thin sections was around 3 meters because of the monotonous facies, but numerous other samples were analyzed in the field by using a 10 times magnification hand lens.

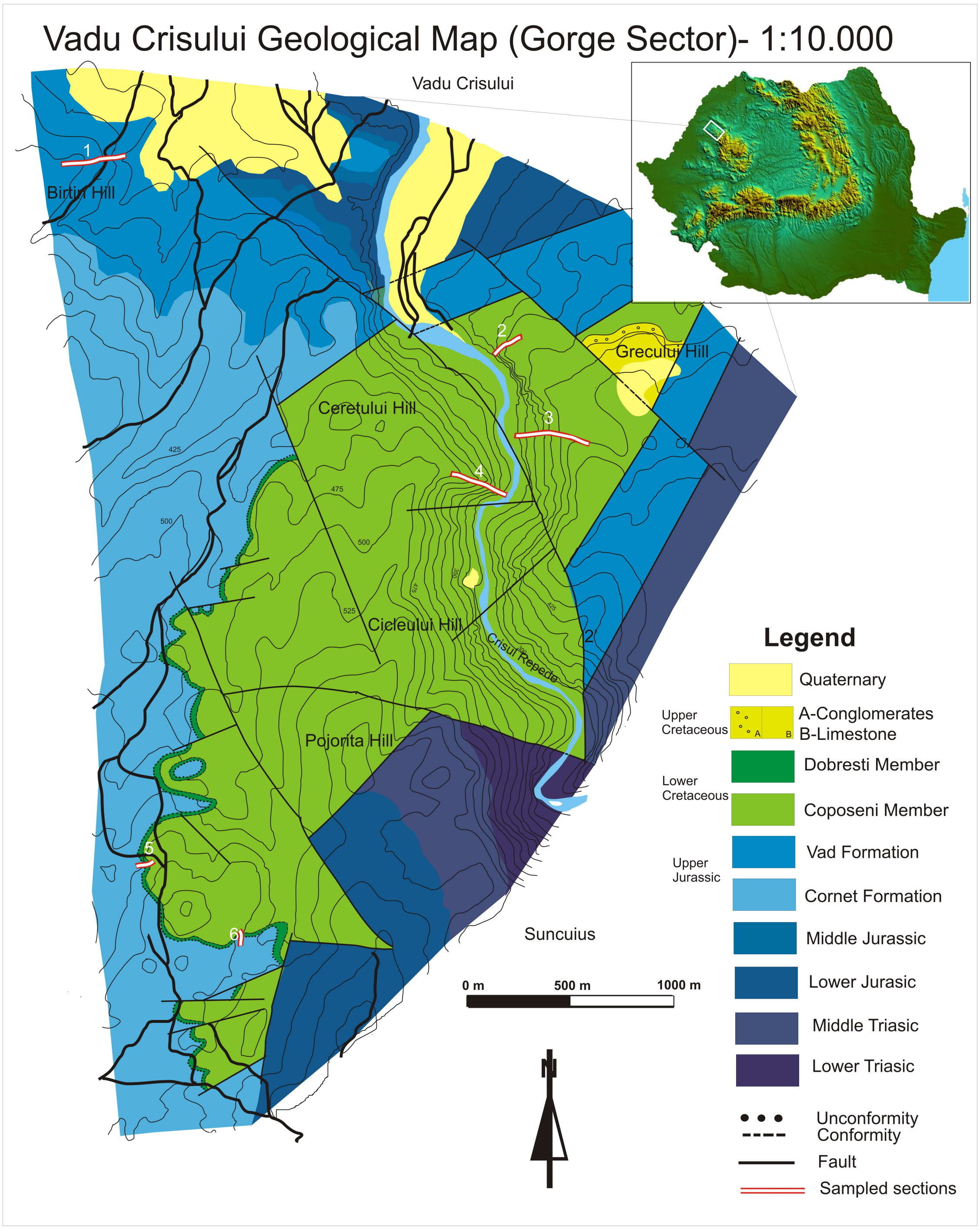

Fig. 2 The geological map of Vadu Crişului area and the location of the sampled sections: 1-Birtin Section, 2-Gorge Entrance Section, 3-Canton CFR Section, 4-Tunnel Section, 5-Bauxite lens, 6-Bauxite lens.

The outcrop appears as dark grey, coarse bedded limestones with numerous intercalations of nodular or lenticular cherts. The section is relatively easy to access, only the vegetation being an impediment at its base.

Microfacies of the limestones from the Birtin Section

The microfacies of this section consist almost entirely of (1) peloidal packstone/fine peloidal grainstone. The bioclasts are weakly represented and consist of echinoderm debris (spines and plates, crinoid arm elements, antler shape Saccocomma), lamellibranchiate remains, ostracods, rare radiolarians, rare sponge spicules, rare bryozoans, worm tubes, hemipelagic foraminifers (*Lenticulina* sp.), very rare miliolids. (2) Mudstone/wackestone with echinoderm debris is found as small interlayers in the previous microfacies type. This microfacies is weakly represented throughout the succession. (3) Bioclastic grainstone occurs as small interlayers towards the top of the succession. The grains are represented by bioclasts, ooids, peloids and intraclasts. The bioclasts consist of dasyscladalean algae, benthic foraminifera, echinoderm debris, sponges, *Crescentiella* sp., *Lithocodium* sp. and *Bacinella*-type structure consortium.

The micropalaeontological association and the age of the limestones.

These deposits are very scarce in algae or foraminifers except for the bioclastic intercalation found in the upper part of the section. The microfossils determined are poorly preserved dasyclads: *Salpingoporella pygmea* (Gümbel), *Petrascula bursiformis* Pia, or foraminifera: *Everticyclammina* sp., *Mohlerina basilensis* (Mohler), *Protopleneroplis striata* Weynschenk, *Labyrinthina mirabilis* Weynschenk, *Charentia evoluta* Gorbatchik. *Lenticulina* sp. occurs throughout the section. From the above mentioned species the most important one is *Labyrinthina mirabilis* - Latest Oxfordian to Early Tithonian (Bassoullet, 1997 in the Tethys region) or Late Oxfordian to Early Kimmeridgian (Velić, 2007 in the Dinaric karst). Taking this argument into account we can presume that the upper limit for the deposition of the Birtin section and implicit for the Vad Formation of this area is between Late Oxfordian to Early Tithonian (most likely Kimmeridgian).

Remarks

For almost the entire succession the environment was characterized by low hydrodynamics, with sediments formed at or bellows the fair weather wave base probably on a gentle slope. No slump structure or turbidite limestones were noticed. Towards the top of the succession bioclastic shoals formed small interlayers as a result of the decrease of the relative water depth. The biota and facies from these bioclastic shoals are typical of Cornet Formation. *Protopleneropis*, a double wall foraminifer found in these shoals is common in the upper slope environments (Flügel, 2004). The cherts from the Vad Formation might have resulted from the diagenesis of the sponge spicules or radiolarians as badly preserved radiolarians were noticed occasionally.

4.1.2 The limestones from the bauxite lenses

These deposits from the bauxite lenses are located south-west of the Vadu Crișului locality, south-west of Pojorâta Hill. They show similar facies and are treated together as very few samples were collected from the second bauxite lens.

The microfacies of the limestones from the bauxite lenses

The microfacies of the limestones from the bauxite lenses are represented by:

(1) Peloidal-bioclastic packstone/grainstone. The bioclasts consist of echinoderm debris, foraminifers, dasycladalean algae [*Clypeina sulcata* (Alth), *Salpingoporella pygmea* (Gümbel)], and bryozoans. The bioclasts are badly preserved, usually as fragments and with their edges micritised.

(2) Charophycean algal wackestone. This microfacies is by far the most common one. The charophyte remains are represented most of the time by fragments of thallus internodes and only occasionally by gyrogonites. This fact shows that the charophytes have accumulated in situ. Other microfossils are ostracods, microgastropods, sometimes very small foraminifers (probably adapted to fresh or brackish environments) and very rarely by dasycladalean algae (*Salpingoporella katzeri* Conrad & Radoičić). This microfacies is associated with wackestone with cyanobacteria and gastropods, ostracod wackestone and fenestral mudstone. The sections ends with (3) wackestone with foraminifers (miliolids basically) and rare charophyte fragments.

Remarks

Above the bauxite lenses the facies reveal an environment dominated by lacustrine condition (fresh water) that is passing to a brackish one and finally to a marine environment towards the top of the sections (wackestone with foraminifers). These changes of depositional environments and water salinities are characteristic for the

Dobrești Member. Stylolites and other chemical dissolution features are abundant in the Dobrești Member.

4.1.3 Cornet Formation from Vadu Crișului area

A few samples were taken from the south-west of Vadu Crișului area (on the Jurassic-Cretaceous limit) for mapping purposes. The microfacies consist of (1) bioclastic intraclastic packstone/grainstone with dasycladalean algae [*Clypeina sulcata* (Alth), *Salpingoporella pygmea* (Gümbel)], *Crescentiella moronensis* (Crescenti), echinoderm debris (mostly crinoids), foraminifers, *Thalamopora lusitanica* Termier & Termier, sponge spicules, brachiopods and (2) peloidal packstone/grainstone with crinoid remains, bivalve fragments, and *Crescentilla moronensis* (Crescenti). Most of the grains are sand sized, subangular to subrounded and present small micrite envelopes. Where patches of packstone are present, the grains are slightly deformed, due to mechanical and chemical compaction. The existing intergranular pores were probably closed. The facies represent an environment with high hydrodynamics, above the fair weather wave base forming external shoals.

4.1.4 The Lower Cretaceous limestones from the gorge sector area

Three sections were raised along the Crișului Repede Valley (Fig. 2), namely Gorge Entrance Section (GPS coordinates N 46°58'20.6"; E 22°30'40.8"), Canton CFR Section (GPS coordinates N 46°58'06.5" E 22°30'50.9") and Tunnel Section (GPS coordinates for the beginning of the section are N 46°57'56.4"; E 22°30'47.5"). The first two are close to each other, but the last one is across the Crișului Repede Valley and it is very likely to be separated through a fault by the first two sections. The microfacies and micropalaeontological content are very similar, and for this reason they were treated together. A ten meters spacing sample interval was kept along the Crișului Repede Valley to check for lateral continuity of the facies and also for mapping purposes. The limestones from the gorge area were the subject of a recent article published by Bruchental et al. (2014) as part of this PhD thesis, and as a consequence almost all the data in this part are from this paper.

The micropalaeontological content and the age of the limestones

The micropalaeontological assemblage indentified in all three sections includes both algae and foraminifers. The foraminifers are represented by *Paracoskinolina*? *jourdanensis* (Foury & Moullade), *Paracoskinolina maynci* (Chevalier), *Pfenderina globosa* Foury, *Nezazatinella* sp., *Bellorusiella* sp., *Vercorsella* sp., *Vercorsella camposauri* (Sartoni & Crescenti), *Vercorsella scarselai* (de Castro), *Nautiloculina* sp., *Pseudolituonella* sp., *Glomospira urgoniana* Arnaud-Vanneau, *Paleodictyoconus* sp., *Novalesia* sp., *Orbitolinopsis* sp., *Orbitolinopsis buccifer* Arnaud-Vanneau & Thieuloy, *Neotrocholina* sp., *Neotrocholina friburgensis* Guillame & Rechel, *Coscinophragma* sp., *Sabaudia minuta* (Hofker), *Sabaudia auruncensis* Chiocchini & Di Napoli Alliata, *Nautiloculina cretacea* Peybernes, *Derventina filipescui* Neagu, *Siphovalvulina* sp., *Charentia cuvillieri* Neumann.

The algae assemblage consists of *Salpingoporella* sp., *Clypeina* sp., *Salpingoporella* cf. *hasi* Conrad, Radoičić & Rey, *Salpingoporella muehlbergii* (Lorenz), *Salpingoporella melitae* Radoičić, *Salpingoporella genevensis* (Conrad), *Salpingoporella urladanasi* Conrad, Peybernes & Radoičić, *Salpingoporella biokovensis* Sokač & Velić, *Salpingoporella heraldica* Sokač, *Cylindroporella ivanovici* (Sokač), *Clypeina solkani* Conrad & Radoičić, *Falsolikanella danilovae* (Radoičić), *"Halimeda" misiki* Schlagintweit, Dragastan & Gawlick, *Juraella bifurcata* Bernier, *Thaumatoporella* sp., *Conradella bakalovae* Conrad & Peybernes, *Actinoporella podolica* (Alth).

Rivulariacean-like cyanobacteria are very frequent in the first two parts of the sections, whilst *Lithocodium aggregatum* Elliot appears in the facies with *Palorbitolina lenticularis*. Bacinellid structures were occasionally observed and they are associated most often with *Lithocodium*. Species of the crustacean Carpathocancer are locally abundant in the same facies.

From the above mentioned species important age indicators are: *Paracoskinolina*? *jourdanensis*, *Pfenderina globosa* (Upper Hauterivian to Lower Barremian, but *P*.? *jourdanensis* was identified in the basal Upper Barremian by Clavel et al. 2010; Granier et al. 2013) found only at the base of the Tunnel Section and a few samples taken along the Crişul Repede Valley, and *Palorbitolina lenticularis* (Late Barremian-Bedoulian) appearing in the third part of all the sections, except for the Canton CFR Section, the longest section, where *P. lenticularis* appears since the middle part. Dragastan et al. (1988) considered the Blid Formation from Pădurea Craiului as including the Lower Aptian substage but without unequivocal proofs, hence its upper limit was considered Upper Barremian by other researchers (Cociuba, 2000 and reference therein). In the facies with *Palorbitolina lenticularis* of Canton CFR Section species of *Praeorbitolina cormyi* was recognized for the first time in the Blid Formation. This species has its first occurrence in the Early Aptian (Arnaud-Vanneau et al., 1998; Schroeder et al., 2010), and therefore it represents a compelling evidence for regarding the upper limit of the Blid Formation from Vadu Crișului area in the Early Aptian.

Microfacies of the Lower Cretaceous limestones from the gorge sector area

The microfacies types (MFT) were separated based on depositional texture, grain size and grain composition. Early diagenetic characteristics with environmental significance were also considered.

The following microfacies types were distinguished:

MFT1. Fenestral nonlaminated / laminated mudstone / wackestone. Biota is of reduced diversity and is represented by foraminifera (miliolids, textulariids, and occasionally cuneolinids) ostracods, gastropods, and rivulariacean-like cyanobacteria. Lamination, when present, is supposed to be of microbial nature. Most of the time the finer laminae correspond to micrite layers while the coarser one consists of very small peloids or sparry calcite. Desiccation cracks were sparsely observed. This MFT is quite frequent in the first part of all the sections, and occasionally in the middle part. Because these fenestral fabrics frequently underlie short early exposure surfaces, cavities often form geopetal structure with vadose microsparitic silt (sensu Dunham 1969).

MFT 2. Peloidal intraclastic packstone/grainstone. The grains consist almost entirely of peloids and micrite intraclasts or micritised cyanobacteria. Most peloids are probably fine micrite intraclasts. They are well to moderately sorted and most of them are moderately to well rounded. *Rivularia*-like cyanobacteria, miliolids, textulariids, green algae, rudist fragments and gastropods occur occasionally and could be locally important. In a few samples from the Gorge Entrance Section rare charophyte remains are also present. Keystone vugs are common feature, occasionally with vadose silt infilling. This microfacies often alternates with fenestral laminated mudstone/wackestone, the limit between them being a discontinuity surface (probably firmground) which could be the result of erosion or partial lithification. The grains above the discontinuity surface commonly show micrite envelopes.

MFT 3. Charophycean algal wackestone. Algal fragments are represented by gyrogonites and fragments of thallus internodes. The fragments of thalus internodes are small and often badly preserved. Sometimes problematic small rounded structures occluded by calcite spar are present. A few circumgranular cracks are present in the Tunnel Section and the facies has a mottled appearance. It occurs at the end of the first part in the Tunnel Section and inside the first part of the Canton CFR Section. We identified this MFT in a few samples taken along the Crişul Repede Gorge as well. This means it has also an important lateral extent, and it could help to correlate the sections studied. This microfacies is associated with thin layers (up to 10 cm) of mottled, brecciated limestone with red clay matrix.

MFT 4. Ostracods wackestone. This MFT occurs at several levels within the lower and middle part of the sections. Apart from ostracods, rare foraminifers can be found occasionally. As in the two previous mentioned MFT mottled micrite and geopetal structures sometimes with vadose microsparitic silt are common.

MFT 5. Wackestone with green algae. Besides algae, small benthic foraminifera are common. The most abundant green algae are represented by dasycladaleans *Salpingoporella* sp., *S.* cf. *hasi*, *S. muehlbergii*, *S. melitae*, *Clypeina* sp. This MFT is common in the middle part of Gorge Entrance Section and Tunnel Section and in the lower part of Canton CFR Section.

MFT 6. Bioclastic packstone/grainstone. Bioclasts are represented by (a) benthic foraminifera, rare green algae and rudist debris. These deposits show evidence of intense reworking and probably formed high energy internal shoals, but overall they are very weakly represented. In other cases (b) bioclasts are represented by echinoderm debris, foraminifera (*Orbitolinopsis* sp., *Palorbitolina lenticularis*, textulariids, *and Lenticulina* sp.), *Lithocodium* sp. (occasionally associated with bacinellid-like structures), bryozoans, corals and microbial structures. These deposits were heaped up by waves and could have formed weak external shoals. They were noticed only in the Tunnel section.

MFT 7. Wackestone/packstone with orbitolinids and echinoderm debris. These deposits are common in the middle part of the Canton CFR Section and in the upper part of the other two sections. The fauna is of low diversity; beside orbitolinids there are rare textulariids, sponge spicules, *Carpathocancer* sp., and the hemipelagic foraminifer *Lenticulina*. Trocholinid foraminifera are locally abundant in the Gorge Entrance Section and Canton CFR Section. This MFT is dominant in the facies with *Palorbitolina lenticularis*.

MFT 8. Wackestone/packstone with abundant sponge spicules. Echinoderm fragments are locally abundant. This MFT type is encountered in the third part of the Tunnel Section. In the field, these deposits overlie 2-3 meters of covered surface (no outcrops). Throughout the limestone with sponge spicules nodular cherts are very common. Two levels of bedded cherts were also recognized.

Diagenetic overprint

The studied sediments were affected by early marine and meteoric diagenetic processes. A clear distinction is difficult to make between them. Marine diagenesis is represented by micritic envelopes around grains and micritised grains. Occasionally thin isopachous fringes of bladed or fibrous cements border the grains or pore spaces between grains. Peloidal microcrystalline cement appears locally, filling the center of the voids. Borings on shell fragments (usually rudists) are quite common.

Vadose diagenesis is represented by thin isopachous rims around grains and meniscus cement. The remaining pore spaces are usually filled with blocky calcite cement. Crystal silt is found sometimes inside dissolution cavities of subtidal deposits (wackestone rich in dasycladaleans and benthic foraminifers). The upper parts of the cavities are usually filled with sparitic calcite.

Rarely, dolomitisation/feruginisation processes are present superimposed on the ostracods wackestone. The dolomite may have two origins: early formed peritidal dolomite and diagenetic dolomite.

Very thin layers of mottled, brecciated grayish limestone with red clay matrix are present at several levels in the lower part of the sections. They are associated with charophycean algal wackestone when the latter is present. The nodular aspect is probably due to desiccation and subsequent formation of planar to curved fissures (Freytet 1973, Alonso-Zarza 2003).

In the middle part of the Tunnel Section within the peritidal deposits diagenetic processes went further resulting in incipient paleosoil horizons. *Microcodium* was clearly recognized in one sample. *Microcodium* presumably represents intracellular calcification of roots (Wright et al., 1988, Alonso-Zarza, 2003, Flügel, 2004). Cavities filled with sparite calcite and bordered by laminae with irregular thickness, have probably a pedogenic origin, possibly related with root activity (Tucker, 2003). They were observed at several levels.

In the Tunnel section silica for the chert nodules is probably derived from the siliceous sponge spicules as it is associated only with the limestone with abundant sponge spicules.

Occasionally arguments for deep burial diagenesis were observed. Stylolites, dissolution seams and other pressure solution structures are present but not abundant. In rare cases breakage and distortion of grains due to physical compaction were noticed.

Sedimentary environment

The Lower Cretaceous deposits from Vadu Crisului (Blid Formation-Coposeni Member) can be assigned to inner, middle, and outer shelf environments. Inner shelf deposits are represented by fenestral laminated mudstone/wackestone (MFT 1), peloidal intraclastic packstone/grainstone (MFT 2), charophycean algal wackestone (MFT 3), ostracod-bearing wackestone (MFT 4), and occasionally wackestone with green algae (MFT 5). Fenestral carbonates which are often finely laminated formed extensive tidal flats. Abundant charophyte remains testify for supratidal ponds and lakes. These charophyte remains were associated with breccias and red clay suggesting intermittent exposure of the inner platform. More than that, in the Tunnel section *Microcodium* and other specific soil features appear at several levels. The inner shelf deposits are dominant in the first two parts of the Gorge Entrance Section and Tunnel Section but only in the first part of Canton CFR Section, being characterized by shallowing-up peritidal deposits, capped sometimes by red clay.

Middle shelf deposits are weakly represented, and are difficult to separate from the inner shelf ones. Most common microfacies are wackestone with green algae (MFT 5) and bioclastic packstone/grainstone (MFT 6a).

Outer shelf deposits dominate the upper part of the sections. They are represented by wackestone of MFT 7, MFT 8, or MFT 6b. As in other parts of the Tethys *Palorbitolina lenticularis* is associated with muddy environments being indicative of warm waters and relatively shallow environments (Vilas et al., 1995). As a rule, the average beds thickness inside peritidal deposits is thinner than in the facies with *Palorbitolina lenticularis.*

In the Tunnel sections during the main transgression wackestone/packstone with abundant sponge spicules (MFT 8) are dominant. Bioclastic packstone/grainstone of MFT 6b could have formed external shoals but it is unlikely they were effective barriers against wave energy. This and the lack of framebuilders lead us to presume a slight change in morphology of the carbonate shelf during the dominance of the facies with *Palorbitolina*, as noted in other parts of the Tethys (Vilas et al., 1995, Masse and Fenerci-Masse 2011). The flat-topped shelf became closer to a ramp type. Pomar (2001) argue that oligophotic producing biota like large foraminifera generate distally steepened ramp. The change of shelf morphology has not occur before, because sediments specific to carbonate ramps are lacking in the first two parts of the sections (for instance ooids are lacking almost completely or when present they are only superficial). Carbonate ramps form during the drowning of shelves or during the early stages of platform formation (Flügel, 2004).

Sea-level changes

In all three sections analyzed two large scale depositional trends could be recognized.

(1) In the first part in all the three sections the sediment production kept pace with created accommodation space. The sediments are shallow water deposits, from shallow subtidal, intertidal to supratidal settings. The overall trend in these deposits is progradational to aggradational. Early exposure surfaces are quite frequent and are usually short lasting. In the middle part of the Tunnel section incipient paleosoil started to develop. This incipient paleosoil is stratigraphically above *Paracoskinolina*? *jourdanensis* but bellow the facies

with *Palorbitolina lenticularis*. The paleosoil formation is an unambiguous proof of sea-level drop (Flügel, 2004; Schlager, 2005). The paleosoil deposits were later covered by shallow water deposits.

(2) The upper part of the sections shows a transgressive trend, being more obvious in the Tunnel Section. Sedimentary transgressive sequence starts with wackestone with large orbitolinids (*Palorbitolina lenticularis* - the most abundant one, and *Preorbitolina cormyi*) and echinoderm debris. In the Tunnel Section this MFT is followed by wackestone/packstone with abundant sponge spicules. They start to decrease in importance towards the top of the section, and the wackestone/packstone with abundant orbitolinids takes its place showing a decrease in water depth. The Gorge Entrance section and the Tunnel section end with a slight shallowing upward trend. In the longest section, which is Canton CFR, the water depth is fluctuating on the last 50 m. After a shallowing trend which corresponds with the end of the other two sections, it ends with a deepening trend. The onset of the facies with *Palorbitolina lenticularis* marks the incipient drowning of the shallow carbonate platform. In the Gorge Entrance Section and Canton CFR Section this incipient drowning event is not that well marked, but there is a clear evidence of the change from shallow water facies to deeper ones.

4.2 AŞTILEU-SUBPIATRĂ AREA

In this area four vertical sections were raised, one of them of Upper Jurassic and the rest of Upper Aptian-Albian age (Fig. 3).

4.2.1 Şerbota Hill Section (Aștileu)

The section was raised on the eastern side of Șerbota Hill, south of the locality of Aștileu. The GPS coordinates are N 47°00'663"; E 22°24'418" for the beginning of the section and N 47°00'612'; E 22°24'212" for the end of the section. The eastern side of Şerbota Hill represents a pastureland with small occurrences of limestones, with the lateral continuity difficult or most often impossible to follow. The same continuity problems were encountered uphill, partly due to thorn bushes, and as a consequence the section contains many gaps and the vertical scale is not accurate. In the field, the base of the section consists of limestones of dark grey color, resembling the limestones from the Vad Formation. The rest of the section is represented by light grey limestones, with sandy texture.

The base of the section is formed by peloidal bioclastic packstone/wackestone similar with the upper part of the Vad Formation formed in low energy environments and represents the distal shelf (offshore). This facies gradually pass upwards into intraclastic-bioclastic packstone/grainstone and then to ooid bioclastic grainstone/ooid-pisoid bioclastic grainstone, representing shallow water bioclastic shoal deposits (Bucur & Săsăran, 2012). Broken bioclasts and tangential ooids are evidence of high depositional environments. Radial ooids and pisoids in the upper part of the section point to adjacent environments with low hydrodynamics.

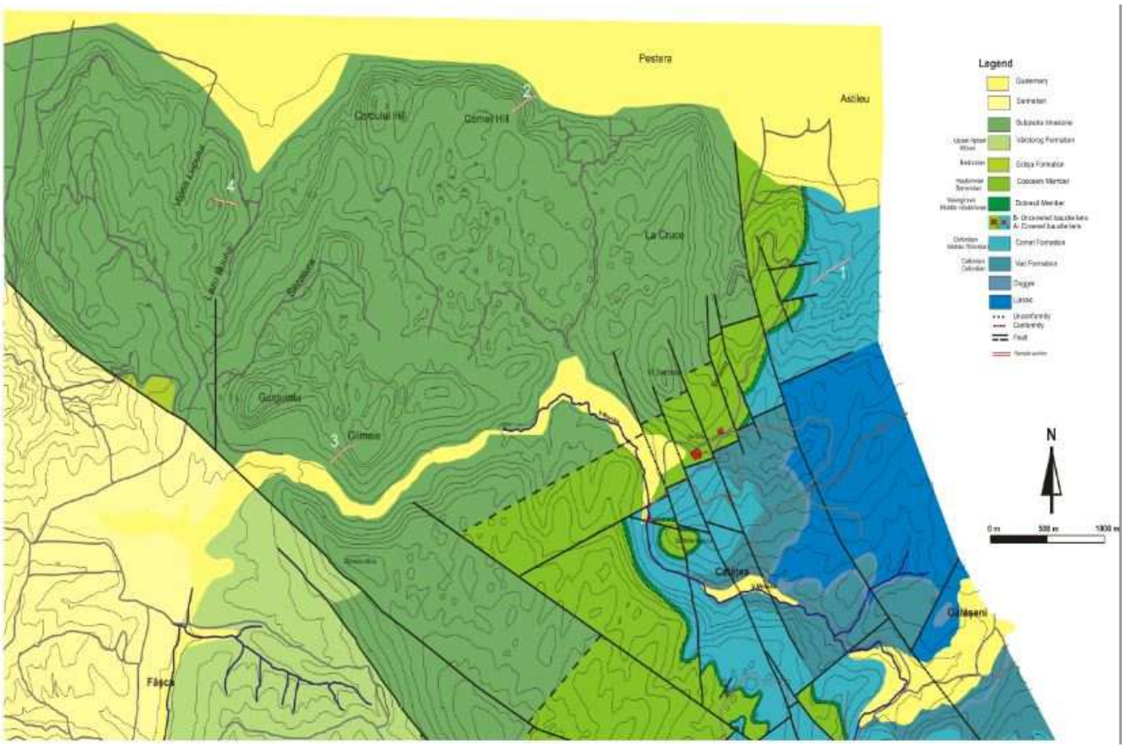

Fig. 3 The geological map of Aștileu-Subpiatră area. 1-Şerbota Section; 2-Peștera Section; 3-Glimeii Hill Section; 4-Valea Lupului Section.

In the middle part of the section *Labirinthina mirabilis* was identified which is an important age indicator (Latest Oxfordian-Early Tithonian).

4.2.2 Peștera Section

The section is located south-east of the Peștera locality, east of the Igrițu Cave, on a hill called by the locals "Cornet". The GPS coordinates are N 47°01'264"; E 22°22'444" for the beginning of the section. The section is quite easy to access being used as a pastureland. It starts at 7-8 meters from the right corner of the last house. In the field, the deposits appeared as thickly bedded limestones (0.5-1 m), with some very thick beds in the upper part of the section (more than 1.5m), with the color of the limestones from grey to dark grey.

The micropalaeontological content and the age of the limestones

The identified foraminifers are: *Sabaudia minuta* (Hofker), *Sabaudia auruncensis* (Chiocchini and Di Napoli Alliata), *Nautiloculina cretacea* Peybernes, *Nezzazata* sp., ?Nezzazata isabellae Arnaud-Vanneau & Sliter, *Nezzatinella* sp., *Vercorsella* sp., *Vercorsella scarcellai* (De Castro), *Bancilina* sp., *Mayincina* sp., Spiroloculina sp., *Glomospira urgoniana* Arnaud Vanneau, *Patellina* sp., *Patellovalvulina* sp., *Mesorbitolina texana* Roemer, *Meandrospira* sp., *Amobaculites* sp., *Pseudolituonella* sp., *Coscinophragma* sp. *Novalesia* sp.. The green algae identified are *Cilindroporella ivanovici* Sokač, *Salpingoporella urladanasi* Conrad, Peybernes & Radoičić, Salpingoporella sp..

These deposits were considered previously as part of "the lower limestones with pachyodonts" of Barremian-?Early Aptian age but the presence of the foraminifer *Mesorbitolina texana* is an argument for the Upper Aptian-Albian age. Deposits of the same age are found in the Vârciorog Formation (Cociuba 1999). As a consequence the limestone from Peștera Section can be regarded as part of the Subpiatră Limestone.

The microfacies consist of (1) fenestral mudstone/wackestone with rare foraminifers, (2) wackestone with green algae, (3) wackestone with charophytes, (4) intraclastic packstone/grainstone, (5) laminoid fenestral bindstone, (6) wackestone with sponge spicules, (7) wackestone/packstone with abundant orbitolinids, (8) bindstone with Bacinella-like structures.

Remarks

The section consists of shallow peritidal carbonates for most of its part. The base of the section is dominated by micrites, often peloidal micrites, with the exception of high energy intraclastic grainstone formed in the intertidal zone. In the outcrops, two conspicuous features are easily observed: well bedded limestones and the abundance of fissures filled most of the time with calcite spar. Although orbitolinids are present from the middle part of the succession they are only minor components of the biota until the last part. The vertical arrangement of the facies suggests peritidal cycles dominated by the intertidal component in the base of the section and starting from the middle section the subtidal component becomes more and more important. In the final 20 meters of the section there is a clear deepening of the water, expressed by abundant orbitolinids, wackestone with sponge spicules, rare corals and more diversified microfauna in general. The thickness of the beds is considerably increasing in the same part too. The depositional environment for this part of the section is almost exclusively subtidal with low hydrodynamics. No facies that could have formed an external barrier was observed in this part of the section. As a result of chemical compaction and pressure solution stylolites and horse tail dissolution seams are locally abundant.

4.2.3 Glimeii Hill Section

This section is located NNE of Fâșca locality, at around 200 meters east of the last house, on a hill called by locals Glimeii and SE of the Gurguiatu Hill which is adjacent to it. The GPS coordinates for the beginning of the section are N 46°59'92.2"; E 22°20'90.9". The section is a pastureland with mild slopes, with grey to light grey limestones. The average bed thickness is between 0.3-0.5 meters, except for the upper middle part where the beds are thicker.

The micropalaeontological content and the age of the limestones from Glimeii Hill.

The identified foraminifers are: *Sabaudia minuta* Hofker, *Vercorsella* sp., *Vercorsella scarcellai* (de Castro), *Meandrospira* sp., *Pseudolituonella* sp., *Patellina* sp., *Coscinophragm*a sp., *Amobaculites* sp., *Mesorbitolina texana* Roemer, *Bdelloidina urgonensis* Wernli & Schulte. The algae present are very scarce. *Triploporella n.* sp., described briefly by Bucur et al (2012) is the most important one, and it occurs only in the bioclastic rudstone in the middle upper part of the succession. In the same bed occur *Cylindroporella ivanovici* (Sokač).

Bacinella-like structures are very abundant. It is very often associated with *Lithocodium* sp.. *Carpathoporella occidentalis* Dragastan occurs in a few samples from the base of the section.

Mesorbitolina texana identified in this section and from samples collected 500 m west point to an Upper Aptian-Albian age. The facies characteristic are very similar with those found in the middle part of the Subpiatră Limestone.

Remarks

Glimeii Hill Section is dominated by shallow subtidal environments and consists of the following facies: bioclastic intraclastic wackestone/packstone with rudists, peloidal intraclastic packstone with rudists, bindstone with bacinellid structures, bindstone with *Bdelloidina urgonensis*, wackestone with foraminifers and sponge spicules. These facies can be split further into low energy environments and relatively high energy environments (bioclastic intraclastic packstone/grainstone). The intertidal deposits consist of intraclastic bioclastic grainstone formed in environments with high hydrodynamic and fenestral non laminated/laminated mudstone/wackestone formed in environments with low hydrodynamic. Often the bioclasts from the intertidal environments are partly dissolved. The geopetal structures have sometimes crystal silt at the bottom as a result of the vadose diagenesis. Clear criteria for assigning facies to supratidal environments were not observed. In the middle upper part of the section bioclastic rudstone or coarse grainstone formed high energy shoals.

4.2.4 Valea Lupului Section

The section is located on the right side of "Valea Lupului" (Wolf Valley), SE of Subpiatră locality. The GPS coordinates for the beginning of the section are N 47°00'882"; E 22°20'290". The outcrop is formed by grey to dark grey bedded limestones, with the average bed thickness around 0.5 meters. The hill itself present mild slopes, easy to access, and is used as a pastureland.

The micropalaeontological content and the age of the limestones from the Valea Lupului Section.

As in the previously analyzed section the determinable microfossils are relatively scarce. However, the following foraminifers were identified: *Sabaudia minuta* Hofker, *Sabaudia auruncensis* (Chiocchini and Di Napoli Alliata), *Glomospira urgoniana* Arnaud-Vanneau, *Patellina* sp., *Vercorsella* sp., *Mesorbitolina texana* Roemer. The algae present are *Triploporella* sp., and *Salpingoporella* sp..

Bacinellid structures are abundant, sometimes together with *Lithocodium* sp.. *Crescentiella* sp. occurs rarely. The crustacean *Carpathocancer* sp. is associated with peloidal bioclastic packstone with orbitolinids.

These limestones were considered before as Barremian-?Early Aptian but the presence of *Mesorbitolina texana* is an argument for the Upper Aptian-Albian age.

Remarks on the sedimentary environment

The deposits from this section formed peritidal cycles, with the subtidal component becoming more and more important in the last part of the section. This characteristic resembles somehow Peștera Section, but the distribution of the microfossil is different. The orbitolinids are by far more abundant and the dasycladalean algae *Triploporella* although not abundant is nevertheless present at several levels, being associated with the peloidal bioclastic packstone/grainstone with abundant orbitolinids. The subtidal deposits are represented by peloidal bioclastic packstone/grainstone with orbitolinids and bindstone with bacinellid structures. Some of these deposits may have formed in restrictive environments as shown by the common micritization of the orbitolinids, or the abundance of cyanobacteria. The intertidal deposits consist of fenestral mudstone/wackestone with miliolids and ostracods formed in low hydrodynamic environments and fenestral intraclastic peloidal packstone/grainstone formed in high hydrodynamic environments. The supratidal deposits are represented by wackestone with charophytes and occasionally fenestral mudstone/wackestone with ostracods that are associated with. Stylolites are locally present as a result of chemical compaction. They are often found between two different facies.

5. SEDIMENTARY EVOLUTION OF THE STUDIED AREA

During the Upper Jurassic-Lower Cretaceous interval the area corresponding today to Pădurea Craiului was generally characterized by carbonate sedimentation. There are differences in facies between the northern and southern part throughout this time. There is no continuous section in the field where the whole succession can be observed and the tectonics complicated the matters further. As a result, there were numerous stratigraphic columns made by different researchers. The stratigraphic column and sedimentary evolution proposed by Patrulius in Ianovici et al. (1976) stood the test of time. Since then numerous studies were performed and adjustments have been made to the stratigraphic column. A new sedimentary evolution was proposed by Bucur and Cociuba (1998), Cociuba (1999), Cociuba (2000). Based on the new data, including this study and data from the Tethys region we propose a slightly changed sedimentary evolution especially for the northern part of Pădurea Craiului, the studied area. Our attempt is based on the previous work of Bucur and Cociuba (1998) and subsequent works (Cociuba, 1999, 2000) and also on our own observations.

The carbonate platform sedimentation starts in the Upper Callovian with external slope deposits, hemipelagic type facies, which covers the condensed deposits of the Middle Jurassic. These deposits consisting mainly of peloidal packstone/grainstone of the Vad Formation are lacking slumping or turbidites at least in the study area. This could be the result of sediments accumulated on a very low angle depositional slope, with sediments bellows the fair weather wave base or close to it but within the reach of storms. In the upper part of the Vad Formation there are bioclastic interlayers that show the decrease of the relative water depth in the future ridge area. Possibly the Vad Formation formed in an outer ramp position, and then as the relative water depth decreased and the external barrier developed (bioclastic shoals, reefs of the Cornet Formation) the external morphology of the depositional environment changed to a rimmed shelf as ramp morphology are transient features in warm climate (Schlager, 2005). These bioclastic shoals became the dominant component for a few tens of meters in our study area (Aștileu Limestone, and probably in the rest of the Cornet Formation). On top of the bioclastic shoals in central area (Cornet) of Pădurea Craiului bioconstructions with corals, sponges and microbialits were installed (Săsăran et al. 2008a). In the southern part behind these barriers shallow water sedimentation took place with fenestral limestone or limestone with oncoliths of the Albioara Formation (Cociuba, 1999). As a result of the sea-level drop Pădurea Craiului has been subaerially exposed from the end of Middle Tithonian to Berriasian. Pădurea Craiului became a low carbonate plateau with favorable conditions for diaspore bauxite to accumulate in the palaeodolines. The cause of this sea-level drop is two folded: tectonic and eustatic. The tectonic cause is probably related to the closure of the Vardar Ocean by the end of Jurassic causing the Bihor-Getic-Serbo-Macedonian microcontinent to collide with the internal Dinaric-Western Carpathian margin (Csontos & Vörös, 2004). On the other hand a sea-level drop was noticed in other parts of the Tethys and also globally (Hardenbol et al. 1998; Haq & Al Qahtani curve A, 2005). In the Tethys region this sea-level fall starts at the Kimmeridgian/Tithonian boundary and continues to Berriasian (Hardenbol et al. 1998).

The deposits that follow over the bauxite or directly over the Upper Jurassic limestones are composed of limestones with gastropods, ostracods and charophytes formed in a lacustrine environment to start with, that changes to brackish and finally to a normal marine one (Patrulius, in Ianovici et al., 1976; Cociuba, 1999; Bucur et al. 2010). Their age is regarded as Valanginian-Hauterivian (Bucur & Cociuba, 1996).

The Barremian stage is characterized by vast tidal flats, with frequent short lived exposure surfaces, or lacustrine deposits in the adjacent supratidal areas. The drop in sea-level is marked out by paleosoil formation (Bruchental et al. 2014).

The late Barremian stage and the Early Aptian in the northern part of Pădurea Craiului features thick to very thick-bedded limestones indicating deepening of the environment. The dominant facies is wackestone/packstone with *Palorbitolina lenticularis* and locally wackestone with abundant sponge spicules. In the area with abundant sponge spicules cherts were formed as a result of their diagenesis (Bruchental et al. 2014). The sea-level rise that started in the late Barremian or Early Aptian is known from many parts of the Tethys Ocean. This is one of the most widespread drowning events in the geological history (Jenkyns, 1980; Schlager, 1981) and according to Jaquin et al. (1998) it is known from different tectonic settings: on passive margins (Australia, Austria, southern France, northern Spain, Mexico), on isolated oceanic platforms (Apulia, Pacific guyots), within the intracontinental basins (Arabia), and within active margins (Venezuela, Maracaibo lake). Therefore this sea-level drop is not solely caused by local tectonic movements as previous works suggested. In the central area of Pădurea Craiului the Early Aptian is represented by marls and limestones with *Palorbitolina lenticularis* on higher grounds (Cociuba, 1999). Possibly the Blid Formation is diachronous in Pădurea Craiului. The upper limit of this formation is situated in the Early Aptian in Vadu Crișului area and we did not identify the Ecleja Formation on top of it. In the southern part, the Blid Formation is overlain by the Ecleja Formation and its age is considered not younger than Barremian.

Southern of our study area, the upper part of the Early Aptian (Upper Bedoulian) shows features of a regression with shallow subtidal or fenestral limestone (Valea Măgurii Formation). In the Vadu Crișului area, the upper part of the Blid Formation formed in an environment with decreasing relative water depth but any correlation stops here as we do not have any hard data to rely on.

The Upper Aptian-Albian deposits encountered in the studied area are part of the Subpiatră Limestone. It is difficult to make assessments on the sedimentary evolution based on the deposits encountered alone. In the Upper Aptian probably the tectonic movements intensified. These movements may have lead to uplifts in certain parts of Pădurea Craiului. As a consequence the landscape has to adapt to a new equilibrium profile. It is very likely that the "Gugu Breccia" formed at this time as it is figured by Bucur et al. (2012). The higher places were eroded leading to intense deposition with terrigenous sediments in the lower ones. In the same time, in adjacent areas (to the north) genuine carbonate platform might have existed, their remains being the Subpiatră Limestone (Bucur et al., 2008; Lazăr et al., 2012). They were the source for the allodapic intercalation in the terrigenous sediments of the Vârciorog Formation.

CONCLUSIONS

The main goal of this PhD thesis was to perform a detailed investigation of the Upper Jurassic-Lower Cretaceous deposits from the northern part of Pădurea Craiului Massif. In order to achieve this objective we sampled the study area collecting more than 800 samples, from which more than 900 thin sections were made, and a few polished slabs.

Upper Jurassic-Lower Cretaceous deposits outcrops in the area under investigation in two locations: Vadu Crișului and Aștileu-Subpiatră. These two areas were also mapped at 1:10 000 scale.

In **Vadu Crișului area** three stratigraphical units were identified: Vad Formation, Cornet Formation and Blid Formation.

The **Vad Formation** consists of a monotonous succession of grey to dark grey limestone, with nodular or bedded chert. The facies is dominated by peloidal packstone/grainstone. The environment was characterized by low hydrodynamics, with sediments formed at or bellows the fair weather wave base probably on a gentle slope. In the final part contains a bioclastic intercalation from which *Labyrinthina mirabilis* (Late Oxfordian-Early Tithonian) was identified.

The **Cornet Formation** consists of intraclastic bioclastic packstone/grainstone or peloidal packstone/grainstone that probably formed external shoals.

The **Blid Formation** is composed of two members: Dobrești and Coposeni. The Dobrești Member was formed in an environment dominated by lacustrine condition (fresh water) with charophytes, that is passing to a brackish one and finally to a marine environment towards the top of the section (wackestone with foraminifers). The lower part of the Coposeni Member is made of peritidal carbonate deposits that formed extended tidal flats with frequent ephemeral exposure surfaces. The presence of *Microcodium* and other pedogenic features evidence the relative fall in sea-level during Barremian. The upper part indicates a deepening event. The facies with *Palorbitolina lenticularis* mark the beginning of this transgression (in Canton CFR Section occur from the middle part) that led to the incipient drowning of the platform and to the installation of the Aptian conditions. During the main transgression a short-term deposition of limestones with abundant sponge spicules and cherts occur in the Tunnel Sections. The cherts are similar to the ones from the Vad Formation and are for the first time mentioned from the Lower Cretaceous of Pădurea

Craiului. The micropalaeontological content of the Coposeni Member is very rich and some of the specimens were mentioned for the first time in this formation. One of these specimens is *Praeorbitolina cormyi* which point to an Early Aptian upper limit of the Blid Formation from Vadu Crișului.

In **Aștileu-Subpiatră** area four vertical sections were analyzed. One of them is on the eastern side of Şerbota Hill and it represents mainly Aștileu Member (of Cornet Formation). However, the base of the section is a transition between the Vad Formation and the Aștileu Limestone. The facies of the base of the section consists of peloidal bioclastic packstone/wackestone representing the distal shelf. This facies is passing upwards to intraclastic-bioclastic packstone/grainstone and then to ooid bioclastic grainstone/ooid-pisoid bioclastic grainstone. These facies record the transition from distal shelf environment to shallow water with bioclastic shoals. The bioclastic shoals with ooids are typical for the Aștileu Member. *Labyrinthina mirabilis* (Late Oxfordian-Early Tithonian) was identified in the middle part of the section.

The other three sections raised represent the **Subpiatră Limestone** of Vârciorog Formation. The analysis of the sections revealed different environments from shallow peritidal environments with fenestral limestones and charophytes to dominantly subtidal environments with abundant orbitolinids and occasionally sponge spicules to high energy environments with coarse grainstone or rudstone with corals and sponges that formed bioclastic shoals. These limestones were considered before as Barremian-?Early Aptian but we identified the foraminifer *Mesorbitolina texana* (Upper Aptian-Albian) in all sections. *Triploporella* n. sp. was briefly described from one of the section (Glimeii Hill Section).

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