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PALEOENVIRONMENTAL SETTING OF RUDISTS IN THE UPPER CRETACEOUS (SANTONIAN-CAMPANIAN) DEPOSITS FROM VALEA NEAGRĂ DE CRIŞ (BOROD BASIN)-NORTHERN APUSENI MTS, ROMANIA

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Abstract: The Upper Cretaceous deposits located in the eastern extremity of Borod Depression represent, for the Northern Apuseni Mountains, a well-known cropping out area for Gosau-type facies with rudists, which is similar to the typical Eastern Alps section. The investigated stratigraphic succession included both carbonate and siliciclastic deposits. The carbonate deposits with rudists (hippuritids) bioconstructions crop out in the base of the succession. The upper part is dominated by siliciclastic sequences that contain, at various levels, bioaccumulations mainly consisting of radiolitids. The rudist assemblages identified from these deposits include both species typical for the Gosau facies, as well as distinctive species (*Miseia, Gorjanovicia, Mitrocaprina)* characterising south-European, Mediterranean areas. These latter species are now first mentioned for the Upper Cretaceous deposits in the area under study.

Keywords: rudists, sedimentology, paleoenvironment, Upper Cretaceous, Borod Basin, Romania

1. Introduction

The studied deposits are located along the eastern extremity of Borod Depression, close to Valea Neagră de Criş locality, on the right flank of Pietrelor de Moară Brook (Fig. 1). The rudists bioconstructions in the area have been regularly investigated by several authors, as classical case studies for Gosau-type facies deposits in the Apuseni Mountains (Givulescu, 1954; Şuraru, 1972; Lupu, 1960; 1976). According to Lupu (1976), the Upper Cretaceous deposits from Valea Neagră are comparable with the middle (Upper Santonian–Lower Campanian) and upper (Upper Campanian–Maastrichtian) Gosau deposits, as evidenced by specific rudist associations. Currently, this subdivision of the Gosau facies types has been replaced by the one introduced by Wagreich and Faupl (1994), based on sedimentary facies; these authors have separated the Gosau Group into „Lower” and „Upper” Gosau subgroups. By taking into account the sedimentary facies types identified in the investigated succession, we have assigned the rudists deposits from Valea Neagră de Criş to the „Lower Gosau subgroup”. Cenozoic deposits (Sarmatian marls) overlay the Santonian-Campanian ones (Patrulius et al., 1973-geological map 1:50.000; Lupu, 1976).

Lupu (1970, 1976) has mentioned species *Colveraia secunda* LUPU and *Joufia silvaeregis* LUPU from the succession in Valea Neagră, as argument for the Maastrichtian age of these deposits. We did not identify these species in the succession cropping out along Pietrelor de Moară Brook. Because Lupu (1970, 1976) did not clearly indicate the detailed location of the samples containing the index species for Maastrichtian, this remains an open issue to be reconfirmed after more cropping areas will be investigated.

The aim of this study was the recognition of palaeoenvironments with rudists in the investigated deposits. Currently, in this area we had performed only paleontological analyses on rudists, without reconstructing the environment in which they have developed. The stratigraphical study of the succession has been based on a combination of field observations and sedimentological/palaeontological analyses. Microscopic analysis was performed on the thin sections, for defining the microfacies types; polished slabs have been used for rudists' identification. The characteristic features of the rudist associations were used for biofacies interpretation. By corroborating paleontological, microfacies, sedimentological and biostratigraphical data, we could propose the paleoenvironmental reconstruction for the Upper Cretaceous in the study area.

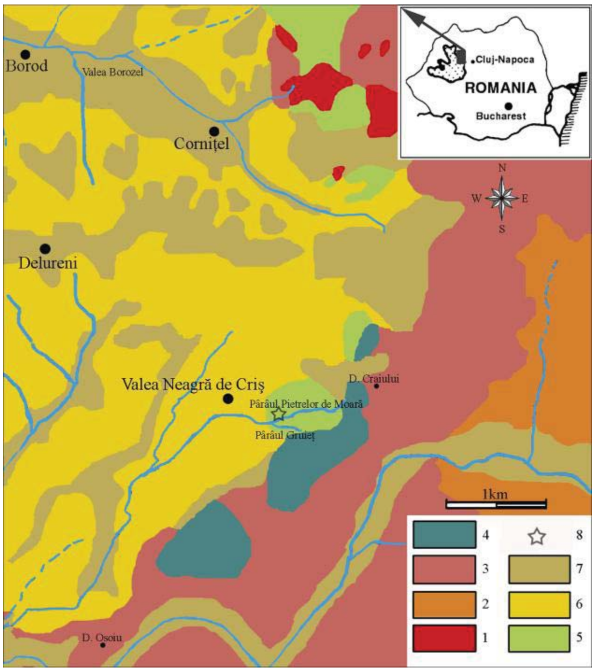

Fig. 1. Location of the studied area. Legend: 1-Magmatic rocks; 2-Proterozoic rocks (Seria de Somes); 3-Triassic deposits; 4-Jurassic deposits; 5-Upper Cretaceous deposits; 6-Miocene deposits; 7-Quaternary deposits; 8-location of the sedimentologic log in the Upper Cretaceous deposits from Valea Neagră de Criș.

2. Stratigraphy and sedimentary facies

The Upper Cretaceous deposits in Gosau facies along the right flank of Pietrelor de Moară Brook crop out along a stratigraphical succession of about 45 meters thick. The lower part of the profile is characterized by an alternation of conglomerate/microconglomerate levels and bioconstructions with *Vaccinites*. The sequence starts with a conglomerate horizon ~0.50 m thick, on the top of which, after a gap, the first bioconstructions with Vaccinites, 0.80 m thick, are installed. These are covered on top by another microconglomerate level of 0.50 m. The following two bioconstructions with *Vaccinites* (~2 and respectively 3 m thick) are also covered by conglomerate/microconglo-merate levels.

The median part of the profile is dominated by siliciclastic deposits. These deposits are represented by conglomerates, microconglo-merates and bioclastic sandstones, erosionally overlaid. In the upper part of the profile, a few levels with bioaccumulations dominated by radiolitids intercalated in siliciclastic deposits crop out.

Two facies types with rudists (Fig. 2) could be separated within the studied succession: 1) bioconstructions with *Vaccinites* (Fig. 3a-d) and 2) bioaccumulations dominated by radiolitids (Fig. 3e).

1) In the lower part of the profile, the bioconstruction consists of floatstone with *Vaccinites* and *Plagioptychus* and a fraction of small-sized biota (red algae, foraminifers, brachiopod fragments). The rudists' shells can be considered in growth-position. The *Vaccinites* skeletons are slender and reach more than 15-20 cm in length. Locally, between the clusters of *Vaccinites*, *Plagioptychus,* small radiolitids *(Lapeirousia* sp.*)* and small coral heads are intercalated.

The association of rudists is dominated by *Vaccinites* species: *V. gosaviensis* DOUVILLE (Fig. 4d), *V. sulcatus* DEFRANCE (Fig. 4a,b,c,d) and very rare specimens of *V. oppeli* DOUVILLE, *Vaccinites inaequicostatus* MUNSTER and *Hippurites nabresinensis* FUTTERER (Fig. 4c). At the base of the bioconstruction, *Plagioptychus paradoxus* MATHERON and *Plagioptychus* sp. are more abundant. This association points to the Upper Santonian–Lower Campanian interval.

2) In the upper part of the profile radiolitids are dominant. Radiolitid-rich bioaccumulations are present at various levels, interlayered within siliciclastic deposits. The internal sediment of the bioconstructions is represented by extraclastic-bioclastic wackestone-packstone with encrusting red algae, foraminifers encrusting rudist fragments, benthonic foraminifers and very rarely coral fragments.

Among the radiolitids, the following taxa have been recognized: *Miseia pajaudi* PATRULIUS (Fig. 4e), *Miseia* sp. (Fig. 4k), *Lapeirousia* sp. (Fig. 4h), *Radiolites subsquamosus* TOUCAS, *Radiolites mammilaris* MATHERON, *Praeradiolites aristidis* MUNIER-CHALMAS, *Praeradiolites subtoucasi* TOUCAS (Fig. 4l), *Sauvagesia tenuicostata* POLSAK, *Bournonia excavata* d'ORBIGNY, *Gorjanovicia polsaki* ÖZER, *Gorjanovicia costata* POLSAK (Fig. 4i). Among pla-

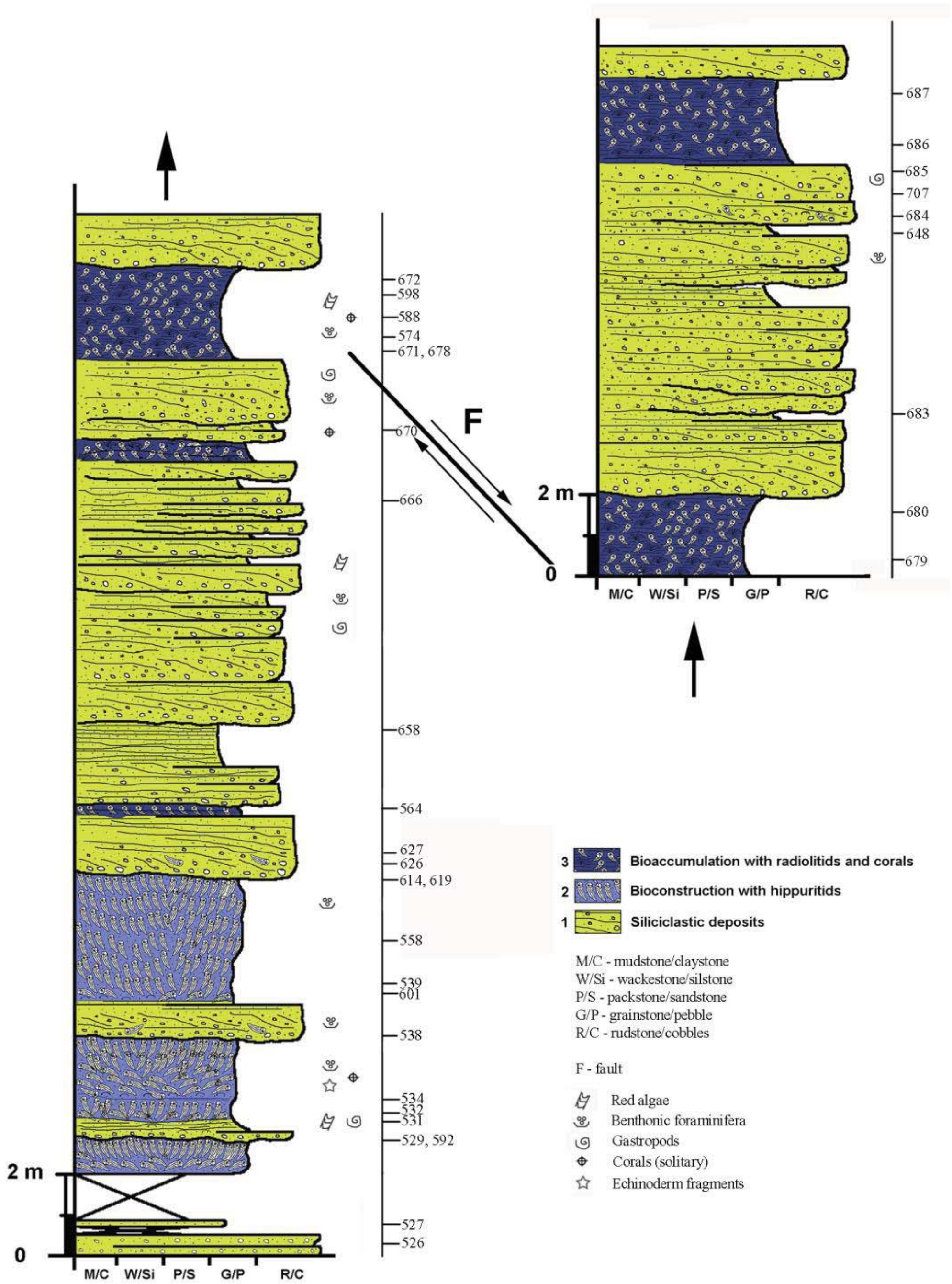

Fig. 2. Sedimentological log with the Upper Cretaceous deposits from Valea Neagră de Criş.

gioptychids: *Mitrocaprina* sp. (Fig. 4f), *Plagioptychus paradoxus* MATHERON. Locally, hippuritids may be occasionally present (*Vaccinites gosaviensis* DOUVILLÉ).

Small elevator radiolitids can be either solitary or forming clusters or thickets (*Gorjanovicia* or *Sauvagesia tenuicostata* POLSAK). *Plagioptychus paradoxus* MATHERON is a clinger rudist frequently identified in the base of the radiolitids' bioaccumulations.

Among the identified radiolitids, *Gorjanovicia costata* POLSAK represents a typical biostratigraphic marker for the Santonian–Lower Campanian interval. The species is widely distributed in central-southern Italy (Apulia-"Membro a Gorjanovicia") (Luperto-Sini and Borgomano, 1989; Simone et al., 2003). *Praeradiolites subtoucasi* TOUCAS is also a typical Campanian species. Accordingly, the identified rudists association characterizes the Santonian-Campanian interval.

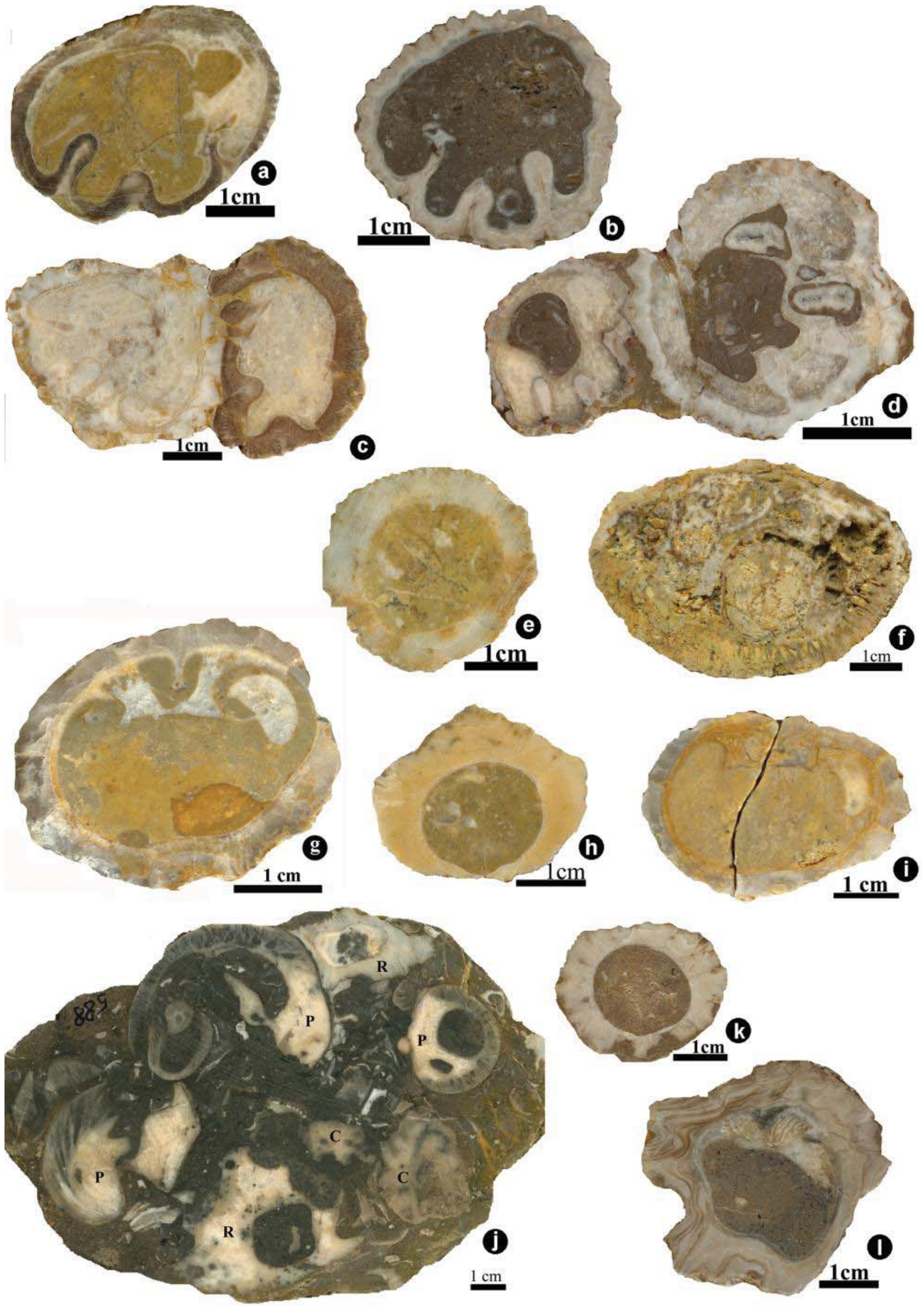

Fig. 4. Rudist assemblage: a –Adapical view of RV of *Vaccinites sulcatus* DEFRANCE (S.626); b – abapical view of RV of *Vaccinites sulcatus* DEFRANCE (S.527); c – abapical view of RV of *Vaccinites sulcatus* DEFRANCE (S.592a) and *Hippurites aff. nabresinensis* FUTTERER (S.592b); d –abapical view of RV of *Vaccinites gosaviensis* DOUVILLÉ (S.601a) and *Vaccinites sulcatus* DEFRANCE (S.601b); e – abapical view of RV of *Miseia pajaudi* PATRULIUS; f – transversal section of LV of *Mitrocaprina* sp.; g – adapical view of RV of *Gorjanovicia* sp. (S.648); h - abapical view of RV of *Lapeirousia* sp.(S.619); k - adapical view of RV of *Miseia* sp. (S.539); **i** – abapical view of RV of *Gorjanovicia costata* POLSAK (S.707); j – Facies with radiolitids (R), *Plagioptychus* sp. (P) and fragments of coral (C) (S.588); l –abapical view of RV of *Praeradiolites subtoucasi* TOUCAS (S.598).

Concerning the composition of the radiolitids assemblage, one can point out the wide diversity of species, typical for both the Gosau facies but also for the south-European, Mediterranean province: *Miseia* (Turkey-Karacabey-Öztemür, 1979; Özer, 1992), *Gorjanovicia* (Turkey-Özer, 1982), *Mitrocaprina* (Bulgaria–Tzankov, 1965; Turkey-Özer and Fenerci, 1993; Greece – Steuber, 1999). These species are now first mentioned from the Upper Cretaceous deposits cropping out in the study area.

In the studied deposits corals are isolated and completely subordinated; they occur as small colonies along the whole studied succession (Fig. 5e, f).

From rock fragments in slope aggregates in the same area, Şuraru (1972) has mentioned a coral fauna including: *Actinastrea* cf. *octolamellosa*, *Columnastrea striata, Heterocoenia verrucosa, Cunnolites* cf. *barrerei*, *Plesiocunnolites macrostoma,* and *Diplocterium* sp.

2.1. Micropaleontological assemblage

Within the studied succession, rudists represent the main biostratigraphic markers, microfossils being scarce, in general. However, within the biocon-

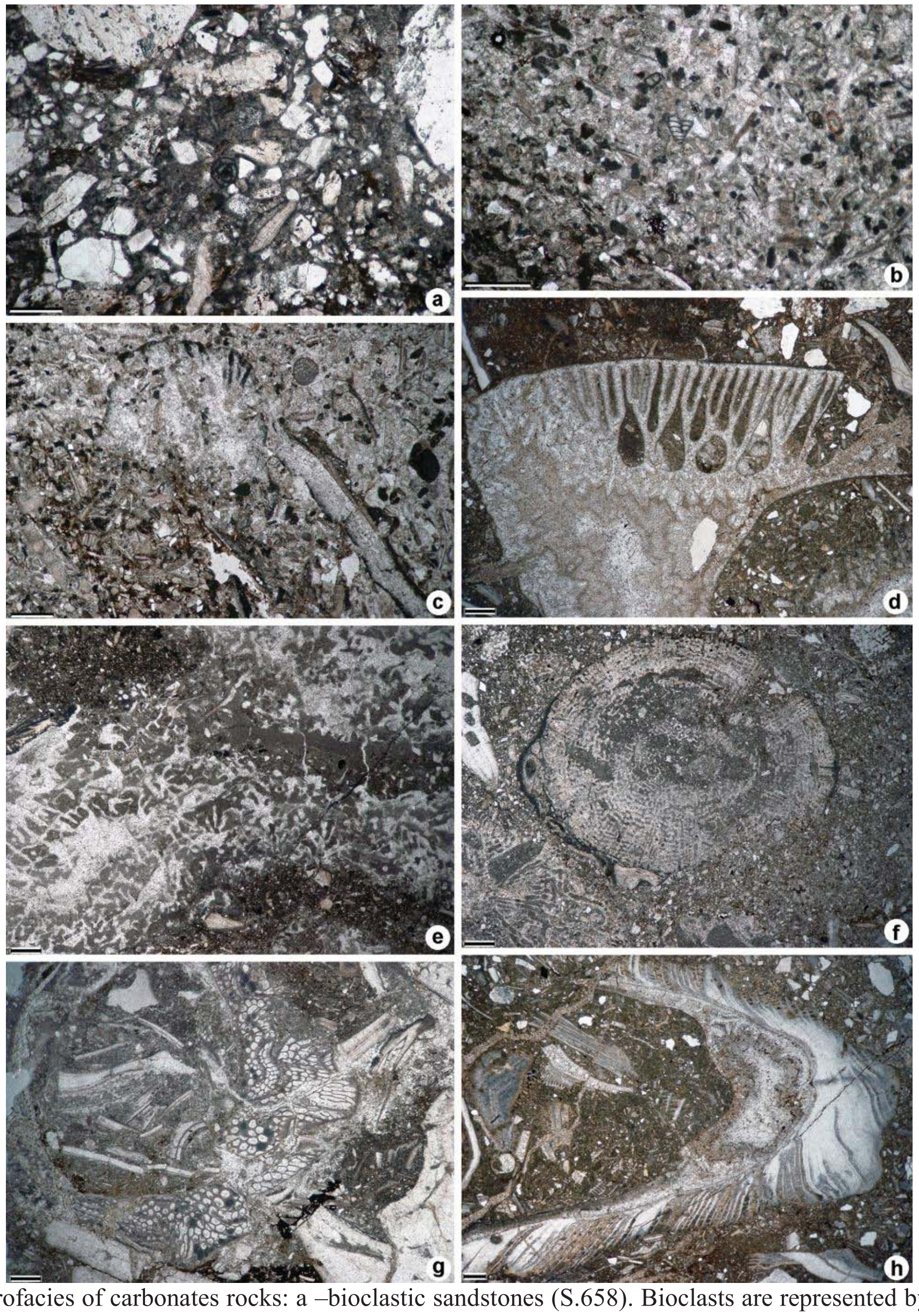

Fig. 5. Microfacies of carbonates rocks: a –bioclastic sandstones (S.658). Bioclasts are represented by fragments of rudists, corals, echinoid plates and benthonic foraminifers (miliolids); b-c – bioclastic-extraclastic grainstone/rudstone (S.526). Bioclasts are represented by large fragments of corals, red algae and benthonic foraminifers; d – bioclastic wackestone with plagioptychids (S.679); e-f – coralligenous bioconstructions; e, lamellar corals' colonies (S.534a); f, solitary corals (S:670); g-h – Bioaccumulations with radiolitids. Internal sediment consists of bioclastic extraclastic wackestone/packstone (S. 574 and 679). Scale bar is 1 mm.

structions with *Vaccinites* sp. we have identified several levels of peyssonneliacean and sporolithacean encrusting red algae: *Polystrata alba* (PFENDER) (Fig. 6h) and *Sporolithon* sp. (Fig. 6a-g). Besides, benthic foraminifers have been identified: ?*Dorothya* sp. (Fig. 6i), *Rhapydionina* sp. (Fig. 6j-k), miliolids (Fig. 6l), as well as encrusting and agglutinated foraminifers (Fig. 6m).

3. Paleoenvironmental setting of rudist facies

These mixed siliciclastic-carbonate sequences from the right flank of Pietrelor de Moară Brook consist of siliciclastic deposits (a) interlayered at several levels with rudists' limestones (b) (Bucur and Săsăran, 2008; Săsăran et al., 2009) (Fig. 2).

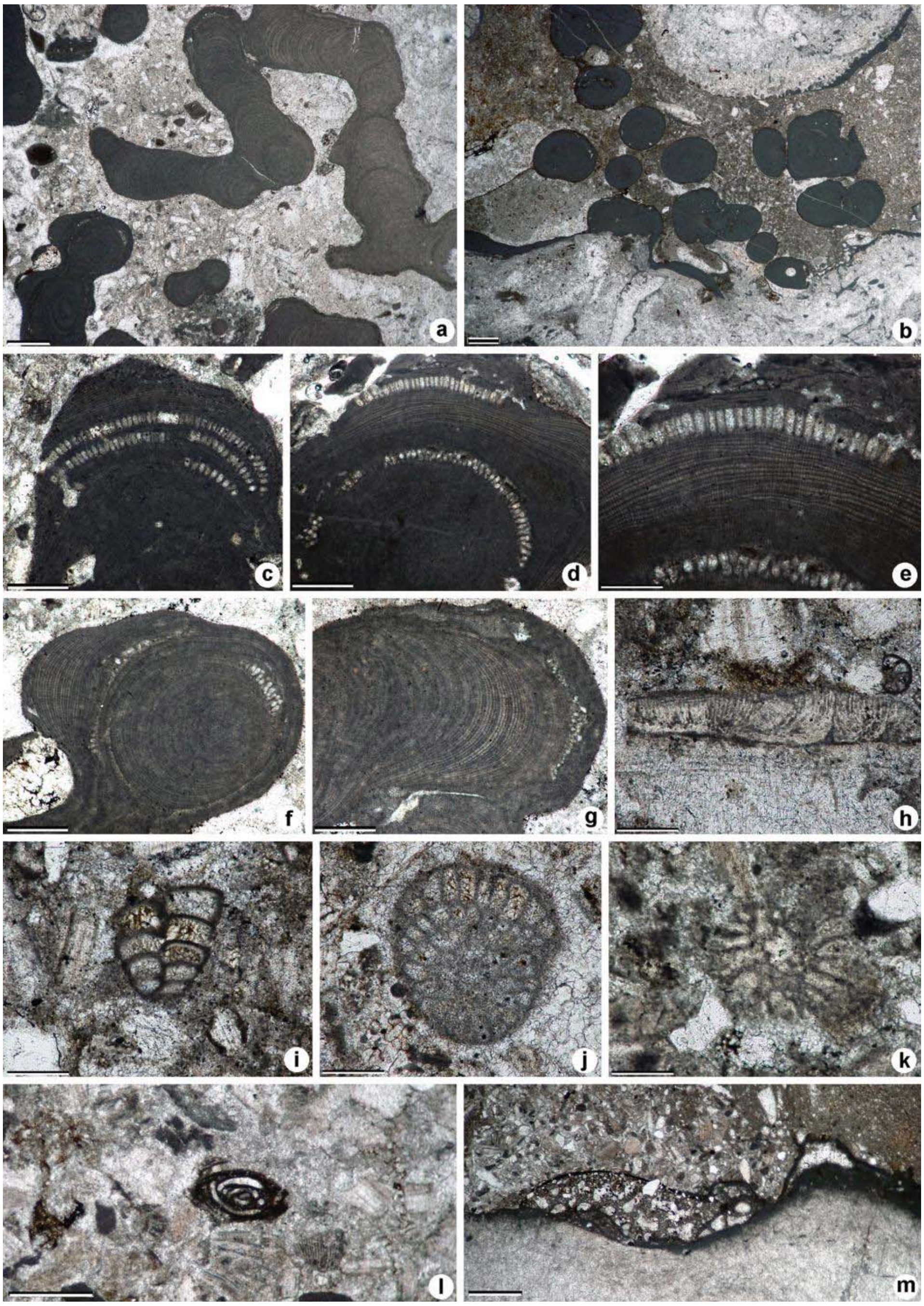

Fig. 6. Micropaleontological assemblage: a-b – Packstone with rhodoids (*Sporolithon* sp.) (S.531 and 678); c-g – *Sporolithon* sp. (S.529,531 and 532); h – *Polystrata alba* (PFENDER) (S.529); i – ?*Dorothya* sp.(S.529); j-k – *Rhapydionina* sp.(S.526 and 538); l – miliolid foraminifer (S.529); m – encrusting and agglutinated foraminifers (S.558) Scale bar is 1 mm (a-b), 0,5 mm (c, d, f, g, l, m) and 0,25 mm (e, h, I, j, k).

a) Siliciclastic deposits

Siliciclastic deposits are represented by conglomerates, microconglomerates and bioclastic sandstones, erosionally overlaid (Fig. 2; Fig. 3f, g). The bioclastic sandstones display a layered geometry, while conglomerates are present as lenses. Trough cross stratified and horizontal laminations has been identified within the sandstone beds. The pebbles consisting the conglomerates and microconglomerates are mainly represented by angular to subrounded fragments of metamorphic rocks (quartzites, micaschists and chloritic schists) (Fig. 3f, g; Fig. 5a). As a rule, conglomerates are poorly sorted, the ruditic pebbles being chaotically embedded by a bioclastic arenitic matrix. Both the sandstones and the conglomerates matrix contain fragments of rudists, red algae, gastropods, ostreids, echinoid plates and radioles, and benthic foraminifers (Fig. 5a).

These bioclasts point to a normal marine environment. On the other hand, the various sources for the pebbles within the conglomerates, as well as their heterogeneous shapes and sizes suggest the formation in an alluvial-fluvial environment followed by the accumulation of the deposits in proximal areas of a marine shelf (fan deltas). This model explains the mixture of typically marine bioclasts and pebbles originating from alluvial-fluvial fans discharging at the shelf margin.

The siliciclastic deposits within the succession represent submarine fan deltas accumulated in the marginal areas of the basin. These siliciclastic bodies built-up highland areas at the basin margins, providing proper conditions for the subsequent accumulation of carbonate deposits on their top. In this normal shallow marine environment with low hydrodynamics and favourable bioclastic substrate, the water deepening trend is accompanied by the presence of bioaccumulations with radiolitids as well as corals (as solitary specimens or as small-size clusters).

b) Rudist limestones

The carbonate deposits are represented by bioconstructed (Fig. 3a-d) and bioaccumulated (Fig. 3e) (the latter by the contribution of both rudists and corals) limestones. The identified rudists belong to the Hipuritidae, Radiolitidae and Plagioptychidae families. *Plagioptychus* sp. occur as isolated individuals like attached clingers (Skelton and Gilli 1991) at the base of the bioconstruction (Fig. 3d). In the bioconstructed limestones *Vaccinites* sp. occur as "clusters"-like associations of tens of specimens. These specimens have been identified living in position, showing elevator growth (Skelton and Gilli 1991) (Fig. 3a-d). They develop bioconstructions (build-ups) in the base of sedimentological log, clearly differentiated from the neighbouring facies types. The bioconstructions' internal sediment is represented by bioclastic-extraclastic grainstone, bioclastic-extraclastic rudstone and bioclastic wakestone/packstone (Fig. 5b-c, e-f). The internal sediment contains fragments of rudists and corals (Fig. 5c), of red algae, benthic foraminifers, echinoid plates and spines, and gastropods.

The bioaccumulated limestones with radiolitids are present at various levels, interlayered within siliciclastic deposits. The internal sediment consists of bioclastic extraclastic wackestone/packstone. Its matrix includes fragments of red algae, corals, rudists, echinoid plates and spines, and benthic foraminifers (miliolids and encrusting foraminifers) (Fig. 5g-h; Fig. 6m). The infilling, associated with the encrustations are arguments for low sedimentary rates, which favoured the installation and the development of the bioaccumulations with radiolitids.

4. Conclusion

The Upper Cretaceous deposits cropping out along the Pietrelor de Moară Brook (Valea Neagră de Criş – Borod Depression) consists of both carbonate and siliciclastic deposits; along the whole succession, the main biotic element is represented by rudists. The bioconstruction with *Vaccinites* sp. from the base of the studied succession indicates a depositional environment developed along a shelf margin with shallow marine water. On this shelf edge, the siliciclastic deposits represent submarine fan deltas accumulated in the marginal areas of the basin. The interlayered bioaccumulated limestones with radiolitids were deposited in a normal marine environment, with low sedimentary rates and lower energy.

Concerning the paleoenvironmental setting of rudists, a spatial distribution can be evidenced according to the depositional environments: *Vaccinites* sp. preferred shallower environments with higher energy, while the presence of radiolitids was favoured by deeper, lower energy ones. In both types of environments, rudists belonging to plagioptychids (*Plagioptychus* sp. and *Mitrocaprina* sp.) in the base of *Vaccinites* sp. bioconstructions or of the bioaccumulations with radiolitids have been identified, acting as substrate stabilisers.

These deposits are similar to those making up the „Lower Gosau Subgroup" from the Eastern Alps. Within the rudist association, besides species typical for the Gosau facies, also genera (*Miseia, Gorjanovicia, Mitrocaprina)* characteristic for south-European, Mediterranean region were identified. This is an argument for assuming the existence of a connection between these provinces during the Santonian–Campanian interval, which allowed species migration. According to Lupu (1976, 2002), the Senonian sea has transgressed in the Northern Apuseni Mountains from W-SW to E-NE.

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