Facies (2005) 51: 274–286
DOI 10.1007/s10347-005-0001-9

ORIGINAL ARTICLE

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Relationship between algae and environment: an Early Cretaceous case study, Trascău Mountains, Romania

Received: 12 December 2004 / Accepted: 22 April 2005 / Published online: 6 August 2005

Abstract The relationship between algae and depositional environment was studied in a limestone succession of Berriasian–Valanginian age. Several depositional environments were recorded from shallow subtidal to intertidal and supratidal, with salinity ranging from normal marine to fresh and/or supersaline water. The algal assemblages consist mainly of dasycladaleans, rivulariacean-type cyanobacteria and charophytes. *Nipponophycus* (Bryopsydales) and *Lithocodium-Bacinella* (microproblematicum), occur at some levels. Dasycladaleans are associated with subtidal, sometimes restricted (“lagoonal”) environments, while rivulariacean-like cyanobacteria and charophytes characterise intertidal-supratidal and fresh and/or supersaline environments, respectively. Among the dasycladaleans, *Salpingoporella annulata* is often related to restricted environments where it forms monospecific assemblages. Large dasycladaleans, such as *Selliporella neocomiensis*, *Macroporella praturloni* and *Pseudocymopolia jurassica* are found in subtidal high-energy deposits (bioclastic grainstones). The relationship between environment and algae, characteristic for each depositional unit, can be used to interpret the relative sea-level variations.

Keywords Calcareous algae · Palaeoecology · Lower Cretaceous · Apuseni Mountains · Romania

Introduction

Calcareous algae have traditionally been considered as very suitable ecological and palaeo-environmental indices (Wray 1977; Roux 1985; Bosence 1991; Berger and Kaever 1992; De Castro 1997). Their biostratigraphical value, with special reference to dasycladaleans, was gradually developed through detailed research and was defined by several synthesis papers (Barattolo 1991; Granier and Deloffre 1993; Masse 1993; Bucur 1999).

The present study emphasises attributes of fossil dasycladaleans and underlines the relationship between algae (or groups of algae) and depositional environment. The Early Cretaceous section studied provides an instructive example of the relationship between sedimentological features and biotic associations and allows a number of different algal facies associations to be distinguished. Dasycladaleans occur very prominent in the succession studied. In spite of several approaches in the last decades (Elliott 1968; Conrad 1977; Flügel 1977; Jaffrezo 1980; Roux 1985), their palaeoecology is still poorly known. Our approach aims to contribute to the understanding of algal palaeoecology and the relationships between algae and depositional environment by combining palaeontology with facies analysis.

Geological setting

The section studied is located in Dealul Mare, in the neighbourhood of Poiana Aiudului in the Trascău Mountains, southern Apuseni, Romania (Fig. 1); the material investigated consists of a large allochthonous block of limestone derived from the Upper Jurassic–Lower Cretaceous carbonate platform of the Trascău massif and that subsequently became incorporated within Upper Cretaceous flysch deposits (Fig. 2).

The Trascău Mountains represent a nappe structure. The remaining original carbonate platform that delivered the huge carbonate block is preserved in the Bedeleu Unit of the Transylvanides (Sandulescu 1984; Balintoni 1997). The Transylvanides are obduction nappes (Sandulescu 1984) composed of ophiolitic rocks and associated sedimentary successions. These nappes were generated during Austrian (Mid-Cretaceous) tectogenesis and were reactivated during the Laramian (Late Cretaceous–Palaeogene) phase.

The ophiolitic magmatism of the Trascău Mountains has been attributed to an island–arc-type structure (Nicolae

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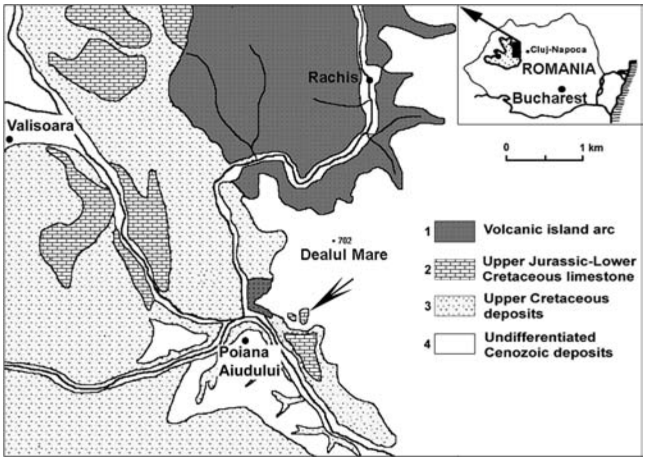


Fig. 1 Location of the section studied (*arrow*)

Fig. 2 Outcrop view of the limestone block from Dealul Mare—Poiana Aiudului (*arrow*). The limestone block is incorporated within Upper Cretaceous flysch deposits, covered by vegetation

1994), which developed during the Callovian. It generated a palaeo-topography favourable for the development of shallow-water carbonate platforms from the Oxfordian onward. Several carbonate platforms existed during the Oxfordian–Neocomian, separated by deeper basins. Closure of the sedimentary basins commenced in the Barremian and continued until the Late Cretaceous. These compressional movements generated the nappe structure. During the Late Cretaceous, the nappe movement caused partial destruction of the Upper Jurassic–Lower Cretaceous carbonate platforms. Huge blocks detached from these platforms were transported in the adjacent flysch basins. The limestones studied here from Dealul Mare belong to such a block.

Facies succession and micropalaeontological assemblages

The Dealul Mare limestones are about 145 m thick. They consist of shallow carbonate platform deposits mainly composed of calcareous algae. Three relatively distinctive intervals can be separated based on lithological and micropalaeontological features (Fig. 3).

Interval A: The lower interval (about 30 m thick) is dominated by bioclastic packstone with dasycladaleans (Fig. 4A and B) and interlayers of mudstone and peloidal packstone/grainstone (Fig. 4C). The micropalaeontological assemblage is mainly represented by dasycladaleans: *Salpingoporella annulata* Carozzi (Fig. 6A and B), *Clypeina sulcata* (Alth) (Fig. 5B), *Clypeina parasolkani* Farinacci and Radoicic (Fig. 5C and D), *Rajkaella bartheli* (Bernier) (Fig. 5R), *Actinoporella* cf. *podolica* (Alth) (Fig. 5A), *Clypeina* sp. 1 (Fig. 5E–G), *Humiella* sp. (Fig. 6K and L). *Thaumatoporella parvovesiculifera* (Raineri) was also noticed in the association. Among the foraminifers, *Pseudocyclammina lituus* (Yokoyama) is the most frequent species. Rare specimens of *Haplophragmoides* cf. *joukowskyi* Charollais, Broennimann and Zaninetti have also been identified, as well as rare *Favreina* sp.

Interval B: The middle interval (about 90 m thick) is dominated by micritic facies (mudstone, packstone) intercalated with peloidal-bioclastic grainstone with dasycladaleans (Fig. 4D) and peloidal-fenestral grainstone with rivulariacean-like cyanobacteria (Fig. 4E). Samples 1033–1034 represent mudstones with charophytes (Fig. 4I).

Most of the dasycladalean species present in the interval A are also present in the interval B. The main difference between A and B consists of the presence of locally large amounts of *Selliporella neocomiensis* (Radoicic) in the interval B (Fig. 6J, M and N), *Clypeina* cf. *isabellae* Masse, Bucur, Virgone and Delmasso, and *Salpingoporella katzeri* Conrad and Radoicic (Fig. 5S and 6C), and *Otternstella* cf. *lemmensis* (Bernier) (Fig. 5N). The presence of *Otternstella* cf. *lemmensis* (Bernier) at this level is unexpected because the stratigraphic range of this species is generally restricted to the Upper Jurassic (Granier and Deloffre 1993; Bassoullet 1997; Bucur 1999).

The foraminiferal assemblage is significantly richer in the interval B: *Pseudocyclammina lituus*, *Commaliama dobrogiaca* Neagu, *Haplophragmoides joukowskyi*, *Meandrospira* cf. *favrei* Charollais, Broennimann and Zaninetti, *Protopeneroplis ultragranulata* (Gorbachik), *Andersenolina alpina* (Leupold), *A. cherchiae* (Arnaud-Vanneau, Boisseau and Darsac), *A.* cf. *delphinensis* (Arnaud-Vanneau, Boisseau and Darsac), *A.* cf. *elogata* (Leupold), *A.* cf. *molesta* (Gorbachik) and *A.* cf. *sagittaria* (Arnaud-Vanneau, Boisseau and Darsac).

Interval C: The uppermost interval (about 30 m thick) is dominated by bioclastic grainstone or peloidal-bioclastic grainstone/packstone (Fig. 4F–H). The dasycladalean association differs from that of the previous intervals: *Pseudocymopolia jurassica* (Dragastan) (Fig. 5U), *Macroporella praturloni* Dragastan (Fig. 5K–M), *Salpingoporella* aff. *incerta* Sokac and Velic (Fig. 6D–I), *Clypeina* sp. 2 (Fig. 5H–J), *Terquemella* sp. (Fig. 5Q), *Suppiluliumaella* sp. (Fig. 6S), *Nipponophycus* sp. (Fig. 6Q) and *Bacinella-Lithocodium* (Fig. 6R) are present.

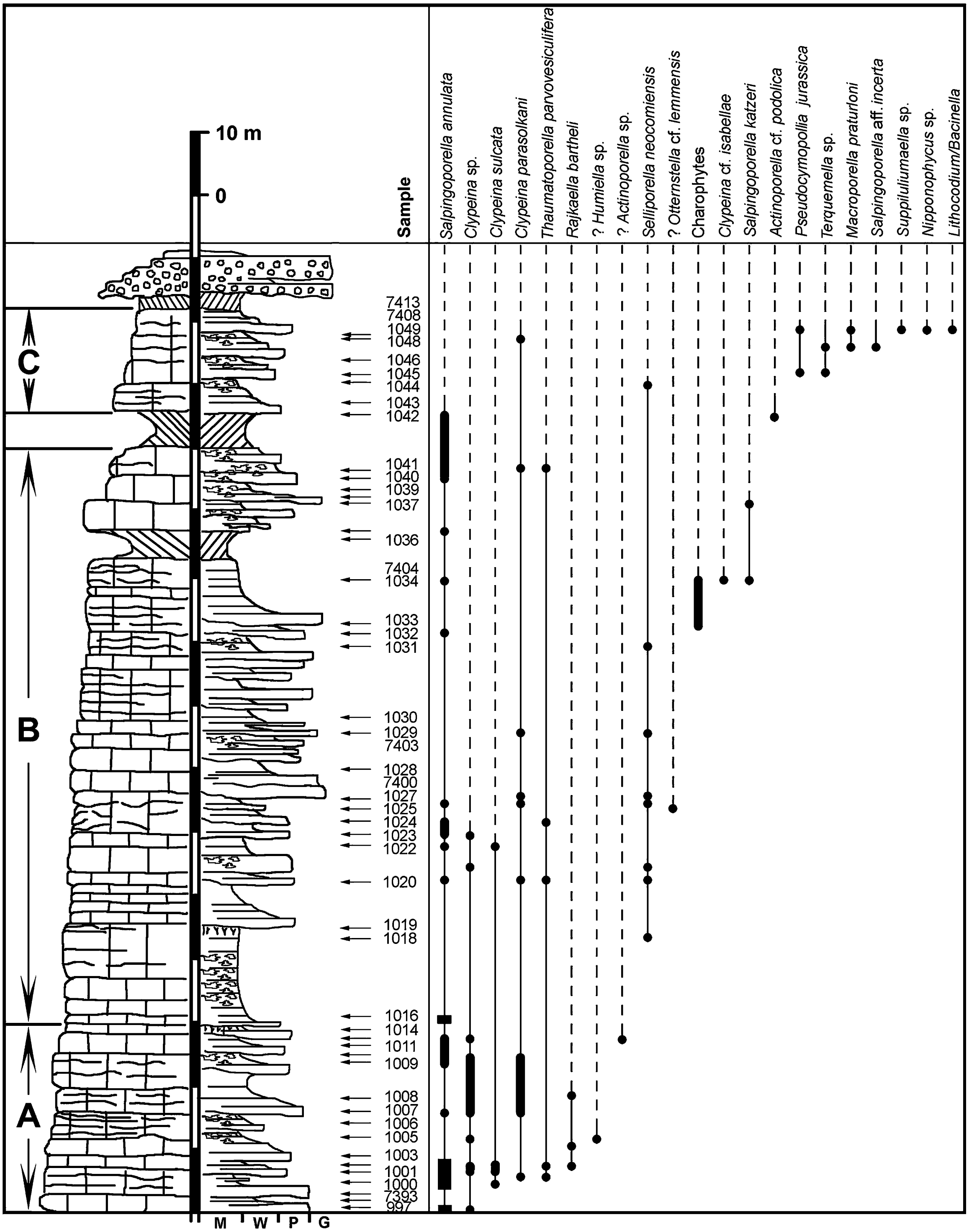


Fig. 3 Lithological and sedimentological succession of the limestones from Dealul Mare—Poiana Aiudului, with stratigraphical distribution of calcareous algae. A, B and C are the three intervals separated based on lithological and micropalaeontological features. M, W, P, G are abbreviations for the terms mudstone, wackestone, packestone and grainstone, respectively, in Dunham's classification of carbonate rocks

The foraminiferal assemblage is dominated by species of the genus *Andersenolina* that were also present in the previous interval: *Andersenolina alpina*, *A. cherchiae*, *A. delphinensis*, accompanied by *Protopeneroplis ultragranulata*. Other foraminifers present that were not identified in the preceding interval include *Nautiloculina cretacea* Peybernès, *Charentia cuvillieri* Neumann, *Andersenolina perconigi* Neagu and *Protopeneroplis banatica* Bucur.

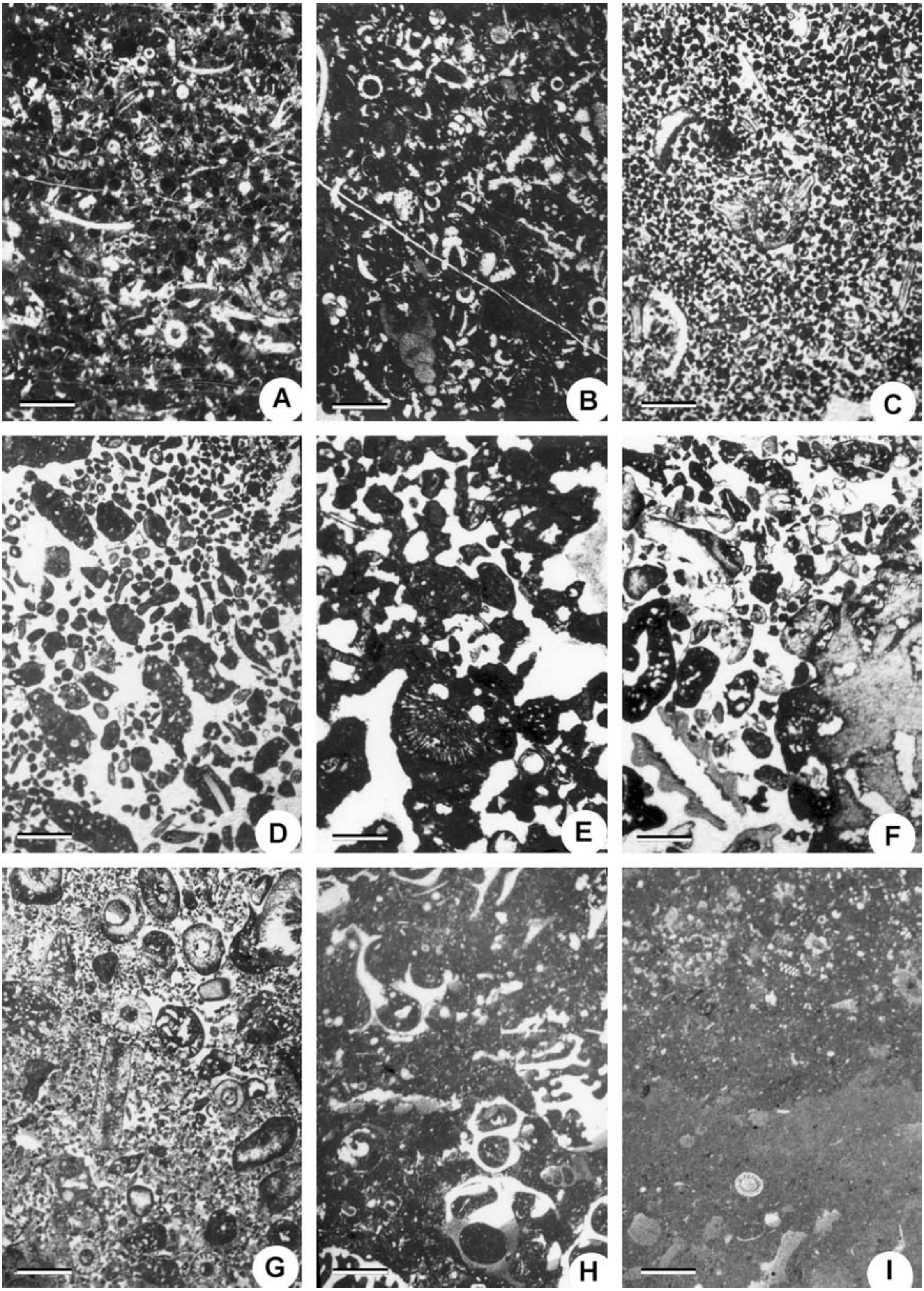


Fig. 4 Main facies types bearing calcareous algae in the limestone succession from Dealul Mare—Poiana Aiudului. (**A**, **B**) Dasycladalean packstone with abundant *Salpingoporella annulata* (A: sample 1001, B: sample 1000). (**C**, **D**) Peloidal-intraclastic-bioclastic grainstone with large *Selliporella neocomiensis* (C: sample 1020, D: sample 1027). (**E**) Peloidal-fenestral grainstone with rivulariacean-like cyanobacteria (sample 1040). (**F**) Bioclastic grainstone with mollusc and coral fragments and large dasycladaleans (*Pseudocymopolia jurassica*) (sample 7406). (**G**) Bioclastic-peloidal packstone/grainstone with abundant *Salpingoporella* aff. *incerta* (sample 7564). (**H**) Fenestral mudstone with dissolved gastropod shells (sample 1033). (**I**) Mudstone–wackestone with charophyte gyrogonites and rare foraminifera (sample 1034). For (**A**, **C**, **D**, **F**), and (**G**) the scale bar is 1.6 mm; for (**B**) the scale bar is 0.6 mm; for (**E**) and (**I**) the scale bar is 1.3 mm; for (**H**) the scale bar is 2.5 mm

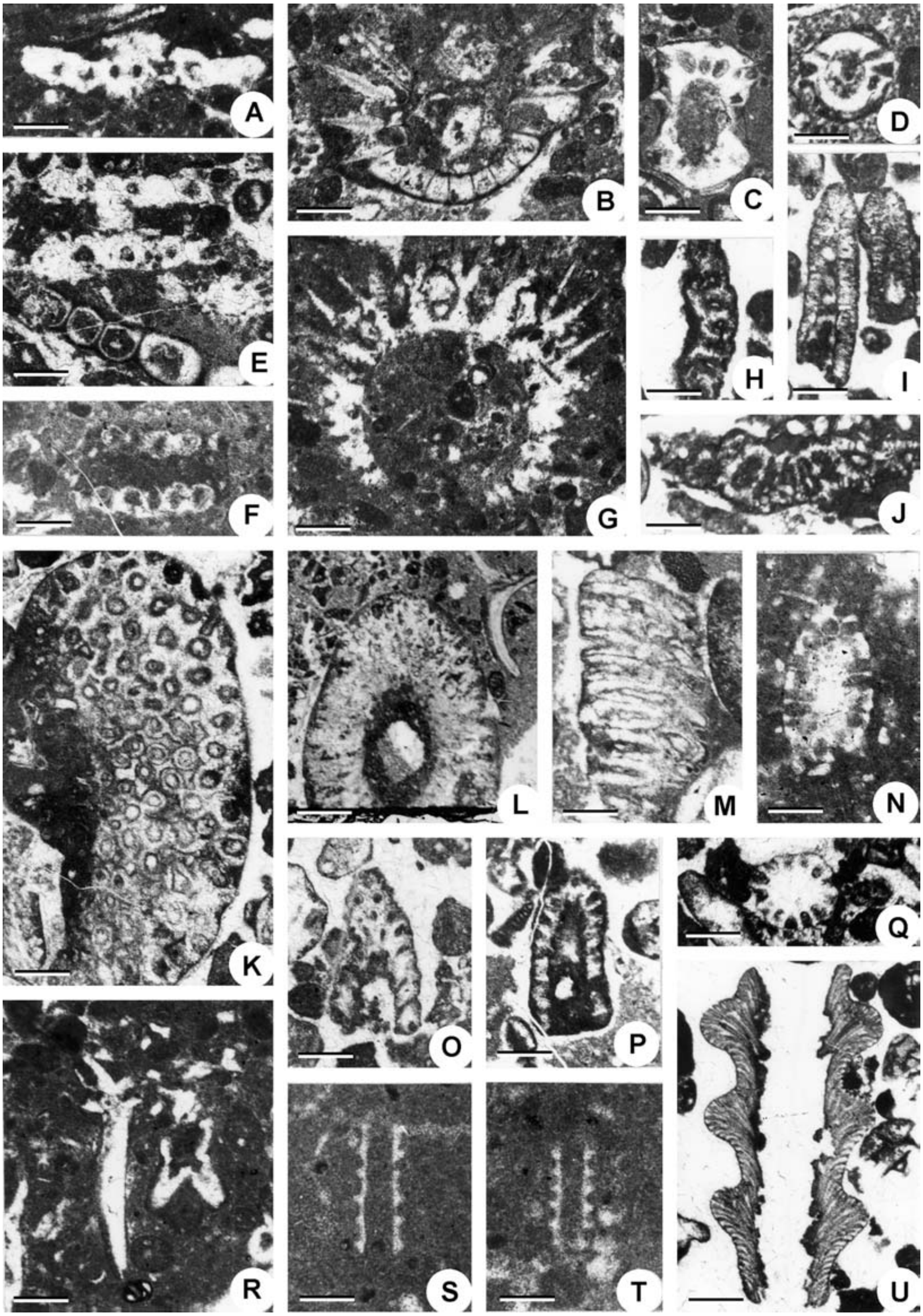


Fig. 5 Dasycladalean algae of the section studied. (**A**) *Actinoporella* cf. *podolica* (Alth) (tangential section through a verticil, sample 1001). (**B**) *Clypeina sulcata* (Alth) (oblique section through a verticil, sample 1001). (**C**, **D**) *Clypeina parasolkani* Farinacci and Radoicic (oblique and transverse-oblique sections, sample 1005). (**E**, **F**, **G**) *Clypeina* sp. 1 (**E**, **F**: tangential sections through a series of two verticils, **E**: sample 1000; F: sample 1001, **G**: transversal-oblique section through a verticil, sample 1000). (**H**, **I**, **J**) *Clypeina* sp. 2 (**H**, **J**: tangential sections through a verticil; **I**: longitudinal section through laterals, sample 7544). (**K**, **L**, **M**) *Macroporella praturloni* Dragastan (**K**: oblique section, sample 7547; **L**: oblique section, sample 7564; **M**: fragment of longitudinal section, sample 1047). (**N**) *Otternstella* cf. *lemmensis* (Bernier), sample 1025. (**O**) *Salpingoporella* sp. 1 (oblique section, sample 7564). (**P**) *Salpingoporella* sp. 2 (longitudinal-oblique section, sample 1047). (**Q**) *Terquemella* sp. (transverse section, sample 7545). (**R**) *Rajkaella bartheli* (Bernier) (longitudinal-oblique sections through laterals, sample 1001). (**S**) *Salpingoporella katzeri* Conrad and Radoicic (longitudinal section, sample 7451). (**T**) *Salpingoporella* sp. 3 (longitudinal section, sample 7541). (**U**) *Pseudocymopolia jurassica* (Dragastan) (longitudinal section, sample 7406). (**A**–**K**, **M**–**R**) scale bar is 0.3 mm; (**L**, **U**) scale bar is 0.6 mm; (**S**, T) scale bar is 0.1 mm

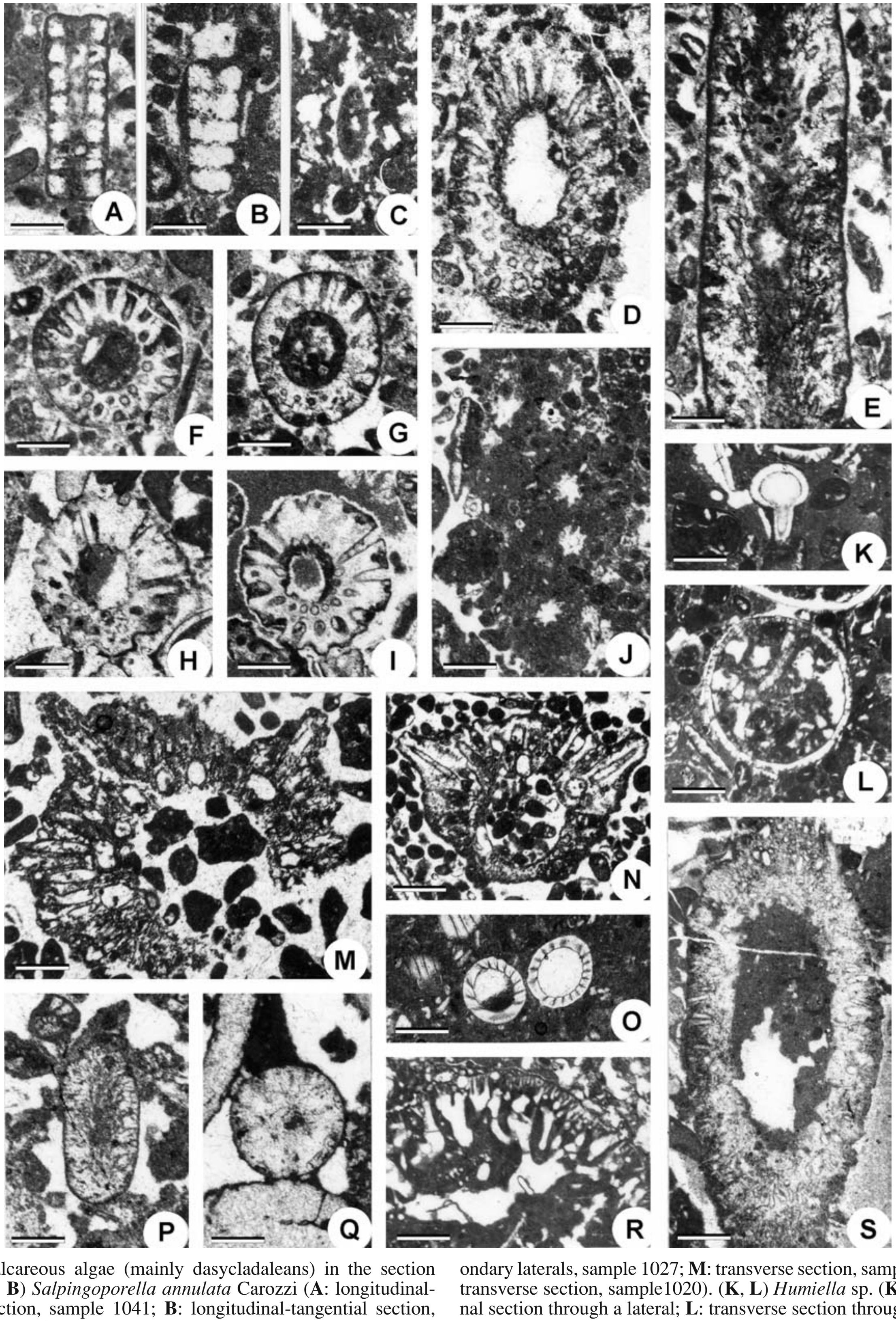


Fig. 6 Calcareous algae (mainly dasycladaleans) in the section studied. (**A**, **B**) *Salpingoporella annulata* Carozzi (**A**: longitudinal-subaxial section, sample 1041; **B**: longitudinal-tangential section, sample 7395). (**C**) *Salpingoporella katzeri* Conrad and Radoicic (oblique section, sample 1000). (**D**, **E**, **F**, **G**, **H**, **I**) *Salpingoporella* aff. *incerta* Sokac and Velic (**D**: oblique section; **E**: longitudinal section; **F**–**G**: transverse sections, sample 7564; **H**: transverse section, sample 1047; **I**: transverse section, sample 7547). (**J**, **M**, **N**) *Selliporella neocomiensis* (Radoicic) (**J**: tangential section cutting a series of secondary laterals, sample 1027; **M**: transverse section, sample 1027; **N**: transverse section, sample1020). (**K**, **L**) *Humiella* sp. (**K**: longitudinal section through a lateral; **L**: transverse section through the stipe, sample 1005). (**O**) Charophyte gyrogonites, sample 1034. (**P**) Halimedacean alga (oblique section, sample 1044). (**Q**) *Nipponophycus* sp. (transverse section, sample 7407). (**R**) *Lithocodium aggregatum* Elliott (sample 1049). (**S**) *Suppiluliumaella* sp. (oblique section, sample 1049). For (**A**–**I**, **O**, **Q**) the scale bar is 0.3 mm; (**J**–**N**, **R**, **S**) the scale bar is 0.6 mm

Age constraints

The micropalaeontological association present throughout the succession is typical for the Berriasian–Lower Valanginian. The benthic foraminifera are those usually used for age determinations of the carbonate platform deposits in this interval. A brief stratigraphical analysis of some of the species identified shows the following.

Pseudocyclammina lituus is known from the Upper Oxfordian to Lower Valanginian (Bassoullet 1997), and is frequently cited from the Berriasian–Lower Valanginian (Masse 1976; Jaffrezo 1980; Granier 1987; Bucur 1988; Chiocchini et al. 1994; Schindler and Conrad 1994; Bucur et al. 1995).

Nautiloculina cretacea is known from the Berriasian–Albian (Arnaud-Vanneau and Peybernès 1978), but frequently cited from the Berriasian–Valanginian interval (Darsac 1983; Salvini-Bonnard et al. 1984; Boisseau 1987; Altiner 1991).

Commaliama dobrogiaca is a recently described species (Neagu 2000) from the Upper Berriasian–Valanginian.

Haplophragmoides joukowskyi is known from the Berriasian–Lower Hauterivian deposits (Altiner 1991) and is frequently cited from the Upper Berriasian–Lower Valanginian interval (Darsac 1983; Boisseau 1987; Chiocchini et al. 1994; Bucur et al. 1995).

Protopeneroplis ultragranulata is known from the Middle Tithonian to the Lower Barremian (Bucur 1993, 1997), but the most frequent occurrence of this species has been recorded in the Berriasian–Valanginian (Septfontaine 1974; Boisseau 1987; Granier 1987; Chiocchini et al. 1988, 1994; Bucur et al. 1995).

Protopeneroplis banatica is also a recently described species (Bucur 1991, 1993) that is mainly documented in Valanginian deposits (Blanc et al. 1992; Bucur et al. 1995; Schlagintweit and Ebli 1999).

Species of the genus *Andersenolina* are well known for their stratigraphic distribution in the Berriasian–Valanginian interval (Arnaud-Vanneau et al. 1988; Neagu 1994; Bucur et al. 1995; Mancinelli and Coccia 1999), although some of them have also been identified in older stratigraphic intervals, e.g. *Andersenolina alpina* which is known to appear in the Kimmeridgian (Altiner 1991) and *Andersenolina delphinensis*, known from the Tithonian (Gorbachik and Mohamed 1997; Ebli and Schlagintweit 1998), or some even from younger deposits, e.g. *Andersenolina sagittaria*, recorded until the Aptian (Arnaud-Vanneau and Masse 1989; Bucur et al. 1995).

Except for the interval A, where only *Pseudocyclammina lituus* occurs, the foraminiferal assemblages from the other two intervals, B and C, are very similar. The same can be stated for the dasycladalean associations of the whole succession: *Salpingoporella annulata*, *Clypeina parasolkani*, *Rajkaella bartheli*, *Clypeina isabellae*, *Salpingoporella katzeri*, *Pseudocymopolia jurassica* and *Macroporella praturloni*. This is a typical association for the Berriasian–Lower Valanginian interval (Granier and Deloffre 1993; Masse 1993; Schindler and Conrad 1994; Bucur 1999).

However, for the biostratigraphic distinction of the intervals A–C, the dasycladaleans are the appropriate tools. Thus, *Selliporella neocomiensis* is restricted mainly to Middle- to Upper Berriasian rocks (Jaffrezo 1980; Granier and Deloffre 1993; Luperto-Sinni and Masse 1993; Masse 1993; Bucur 1999; Bucur and Săsăran 2003), and this age can be attributed to the interval B. The interval A, which still contains *Clypeina sulcata* (Fig. 3) may be attributed to the Lower Berriasian and the interval C to the Lower Valanginian.

Ecological significance of dasycladalean algae

As the case with other fossils, ecological considerations based on dasycladaleans are founded on the principle of uniformitarianism: the modern environment of dasycladalean development should be more or less similar to that of fossil dasycladaleans. However, Jaffrezo (1980) emphasised that the ecological information regarding present-day dasycladaleans is scarce and, apparently, often contradictory. Furthermore, Jaffrezo (1980) emphasised that recent dasycladaleans represent a relict group of organisms (only 11 genera are extant (Berger and Kaever 1992)) and that the relatively poorly understood ecology should not be invoked as an a priori interpretation of the palaeoenvironment. However, we consider that the uniformitarian perspective is valuable and necessary, as explained by the following information on modern dasycladaleans.

Some essential data on the ecology of modern dasycladaleans are provided in (Valet 1979; Berger and Kaever 1992). The ecology of living dasycladaleans is defined by the relationship with their substrate, temperature, light and salinity. As far as the *substrate* is concerned, Valet (1979) defines two types of facies: mobile and rocky. Based on their substrate relationships, dasycladaleans can be epilithic (attached to the rocks), zoophytic (attached on mollusc shells or corals), psammophytic (attached to a sandy substrate) or pelophytic (on muddy substrate) and epiphytic (attached to other plants).

However, according to Valet (1979), it is not the substrate that influences the distribution of living dasycladaleans, but water *temperature* determined by the climate. Recent dasycladaleans are tropical–subtropical forms and, even if some degree of variation occurs, they develop best in warm waters. According to Berger and Kaever (1992), the temperature tolerance of recent dasycladaleans is low with most genera occurring between the 20°C isocrymes (15°C according to Jaffrezo (1980)). One of the effects of low temperatures on dasycladaleans is the inhibition of calcification.

The *intensity of light* also plays an important role in calcification, as well as in the phenomena of heteromorphosis (Valet 1979; Jaffrezo 1980). Light dependence of dasycladaleans is related to photosynthesis. According to Valet

(1979), most living dasycladaleans can hardly tolerate strong light, even if photophyllous and sciaphyllous species may be separated. The latter can develop at shallow depth in protected environments such as caves, hanging walls and fissures of the rocky substrate. As far as bathymetry is concerned, most present-day dasycladaleans are known from the 0 to 10 m depth interval. However, some outstanding examples are known: specimens of the genus *Dasycladus* have been identified at 90 m depth (although in waters with temperatures surpassing 17°C even at that depth), while species of *Acetabularia* have been identified at 50–70 m depth (Jaffrezo 1980; Berger and Kaever 1992). It is worth noting that some littoral species tolerate short periods of emergence in tidal environments. Under these circumstances, they have to cope with a strong *salinity* gradient ranging from hypersaline to fresh water (i.e. euryhaline forms) conditions (Valet 1979). In spite of the fact that most present-day dasycladaleans prefer normal marine conditions, some of them are adapted to either hypersalinity (e.g. species of the genus *Acetabularia*), or hyposalinity (e.g. species of the genus *Batophora* that grow in mangroves or even brackish lakes with charophytes). Extrapolation of the salinity limits of modern species to fossil ones proved to be unsuccessful in some cases. As an example, Jaffrezo and Renard (1979), using trace element geochemistry, have shown that *Zergabriella embergeri* associated with charophytes is indicating a hypersaline environment and not a brackish one as would be suggested by biotic and facies data. Beyond these inconsistencies, we support the idea of Elliott (1968), Valet (1979), and Berger and Kaever (1992) that fossil dasycladaleans should have evolved under similar conditions with respect to substrate and temperature, as compared to the living ones. Many species might have been adapted to variable conditions of salinity. In order to accurately define the facies and facies associations as an important step in environmental reconstruction, the floral and faunal association must be considered in its entity in correlation with the nature of the sediment.

To summarise, the controls on ecology of modern dasycladaleans are comparable with fossil counterparts, so that application of modern ecological arguments are important in the interpretation of the fossils, and is developed in the next section of this paper, in relation to sedimentary facies characters.

Algae and palaeo-environment

The palaeoalgological literature includes several attempts to analyse the palaeo-environmental significance of calcareous algae (Elliott 1968; Abate et al. 1977; Conrad 1977; Flügel 1977; Jaffrezo 1980; Roux 1985). Most of the papers are based on the principle of uniformitarianism and start from ecological considerations of living algae; they also include the character of sediment, which defines the facies type because characteristic features give information on the relationship between certain groups of algae and the depositional environment. Our approach follows this trend.

Based on the sedimentological features and biotic associations from the succession studied, typical facies associations for shallow subtidal (including "lagoonal"), intertidal and supratidal depositional (sub)environments (Fig. 7) have been identified.

Shallow subtidal carbonates

Subtidal deposits occur both in the external platform area (e.g. bioclastic grainstone with large dasycladaleans, *Andersenolina* and various other bioclastic types in the interval C) (Fig. 4F) and the internal platform area (intervals A and B). The subtidal limestones from the internal platform are characterised by bioturbated peloidal-bioclastic muds (Fig. 7D). A diverse flora and fauna was noted, mainly represented by green algae (dasycladaleans), accompanied by cyanobacteria, large benthic foraminifers, fragments of corals and sponges, bivalves, gastropods and echinoids. All these features indicate a quiet, shallow-water environment. Based on the biotic associations and the structural and textural features, several stages of development could be identified: (a) subtidal, normal marine, (b) subtidal, restrictive ("lagoonal") and (c) subtidal, with intertidal ponds.

In the first stage, a diverse marine fauna and flora is characteristic, indicating open shallow-water environments. Due to the similarities with the intertidal facies, the last two stages may be included in the "lagoonal" and intertidal pond environments. Depending on the connection of the ponds to the open sea, a wide variety of facies is developed indicating normal marine to isolated/restricted conditions (Fig. 8A and B) with locally preserved emergence horizons (Fig. 9A and B). Under restrictive conditions, bioclasts underwent intense micritisation and the biota were less diverse, showing a dominance of cyanobacteria and few foraminifer species (Fig. 9D). The restrictive conditions are characterised by the presence of charophytes, cyanobacteria, gastropods and ostracods (Fig. 8A and B). Under these circumstances, rare terrigenous fragments may also be noticed. As a last stage, the sediment is emerged, with the formation of desiccation structures and palaeokarst surfaces (Fig. 9A and B). Subaerial exposure leads to an intense dissolution of both the cement and the components, while vadose silt accumulates and "dog tooth" cement precipitates in the corresponding voids (Fig. 8D).

The ponds represent the extension of the subtidal environment into the intertidal areas (Ginsburg 1975; Shinn 1983; Tucker and Wright 1990). The subtidal fauna occurring at various intervals in the succession indicates the age of the sediment, expresses the environmental conditions (open or restrictive), or suggests the variations in relative sea level.

Intertidal plains

These subenvironments are characterised by a clear influence of wave activity. Due to the similar texture and composition, they may be confused with the upper subtidal environments at places. Two types of facies

Fig. 7 Reconstruction of the carbonate platform showing the carbonate facies types characteristic of tidal environment. (**A**) Unfossiliferous mudstone, slightly laminated, intercalated with laminae of peloidal packstone. (**B**) Peloidal-bioclastic-intraclastic fenestrate packstone/grainstone. (**C**) Coarse intraclastic-bioclastic grainstone, intercalated with laminae of bioturbated peloidal packstone. (**D**) Bioclastic-intraclastic grainstone with dripstone (stalactitic) cement (arrows). (**E**) Fenestral bioturbated packstone with abundant *Salpingoporella annulata*. Scale bar is 1 mm

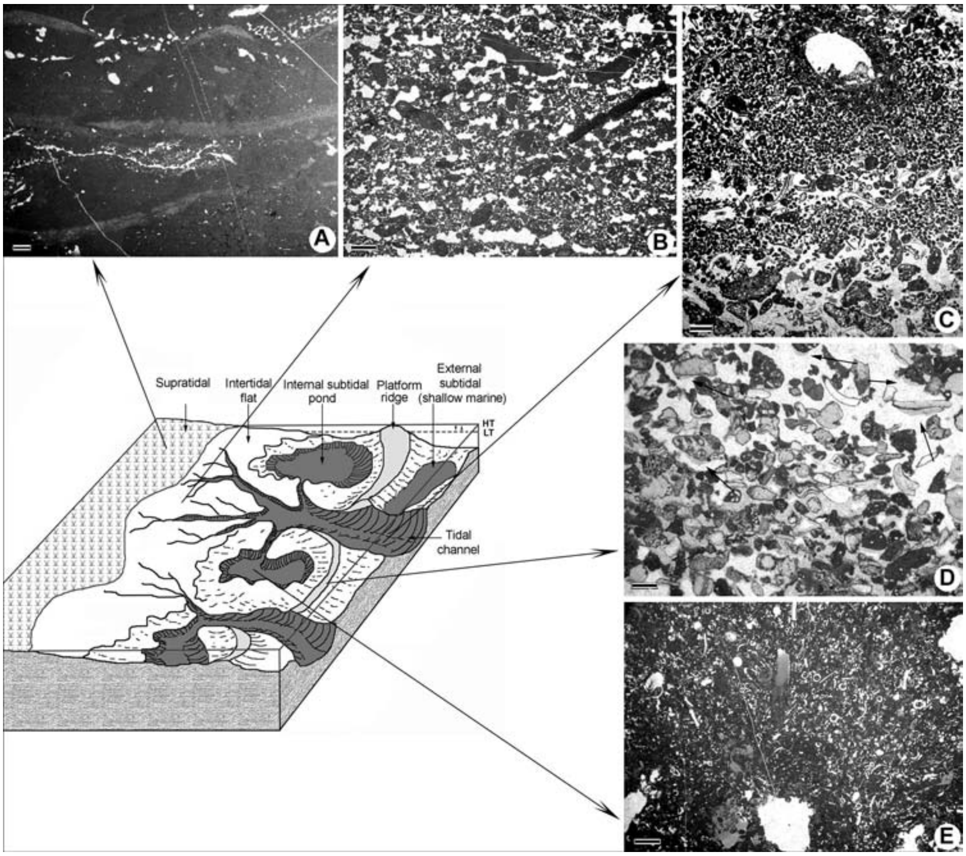
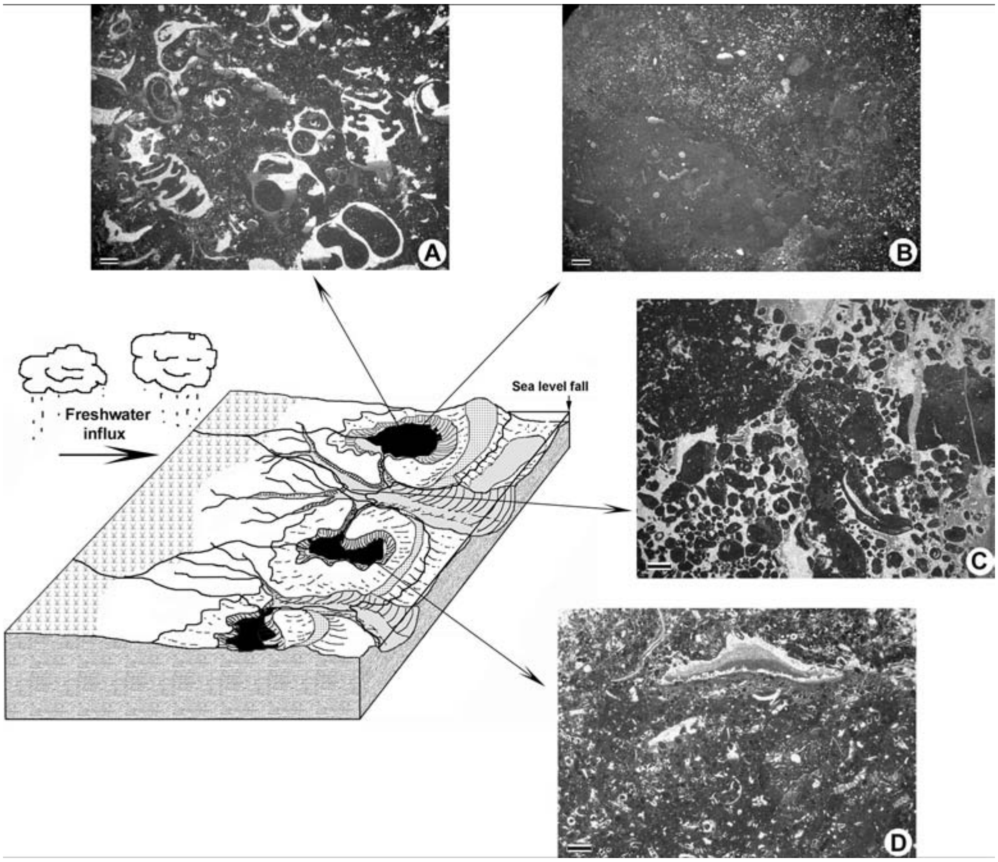


Fig. 8 Freshwater carbonate deposits. (**A**) Packstone with gastropods and charophytes with biomoldic-type porosity. Secondary cavities were filled with vadose silt. (**B**) Bioturbated bioclastic wackestone. The primary facies was a dasycladalean wackestone characteristic of subtidal marine environment. Subsequently it passed to a restricted environment with lacustrine fauna and flora (ostracodes and charophytes). (**C**) Microbreccia with intraclasts made up of bioclastic-peloidal wackestone. Intraclasts are cemented by a meteoric scalenohedral dogtooth cement. Intergranular voids are filled with vadose silt. (**D**) Dasycladalean-bearing fenestral wackestone. Scalenohedral dogtooth cement could be observed on the walls of the fenestrae which are filled with vadose silt. Scale bar is 1 mm



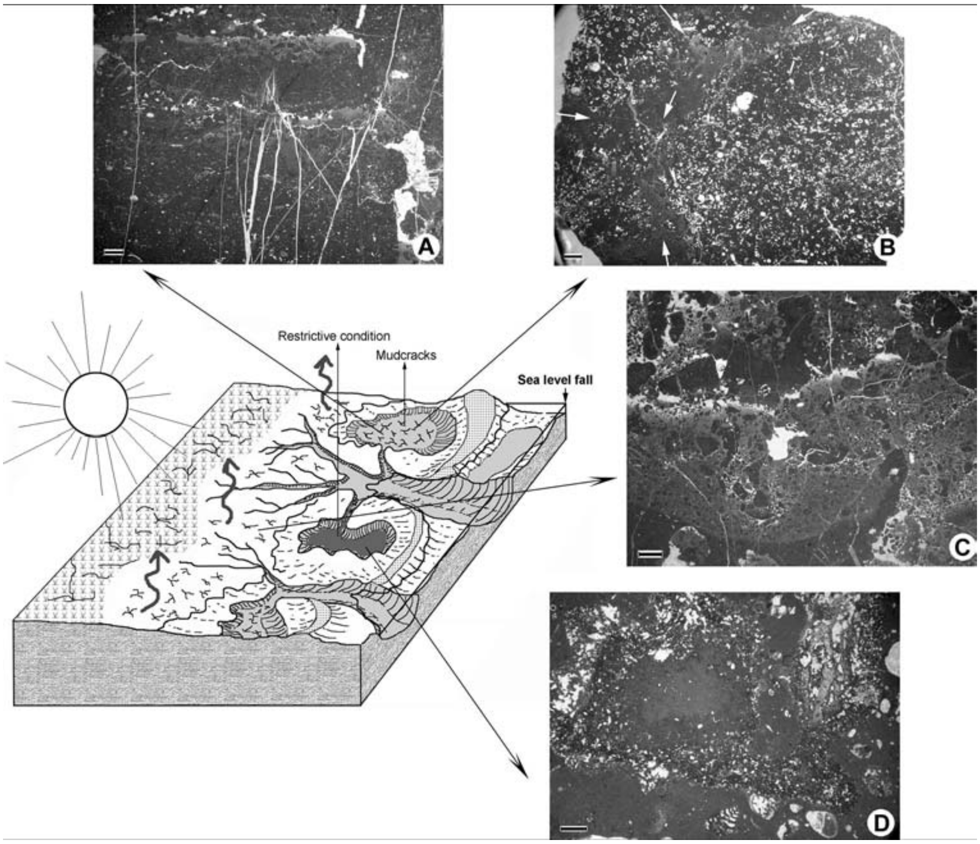


Fig. 9 Subaerial exposure and restrictive facies. (**A**, **B**) Different types of subtidal marine facies subarially exposed as shown by desiccation features in transverse (**A**) and longitudinal (**B**) section. (**C**) Microbreccia. (**D**) Bioclastic packstone with cyanobacteria (central part of the photo) and micritised bioclasts. Scale bar is 1 mm

can be separated: peloidal-intraclastic-bioclastic, fenestral packstone/grainstone (Fig. 7B) and peloidal-bioclastic, laminitic, sometimes bioturbated wackestone/packstone. The deposits contain intraclasts of non-fossiliferous mudstone with elongated and flattened shapes (chips) associated with the peloids and bioclasts. Most of the bioclasts consist of miliolids, besides which crustacean coprolithes (*Favreina* sp.), bivalves with small and thin tests, gastropods, ostracods and cyanobacteria may also be present.

Within these deposits, lenses of coarse intraclastic-bioclastic bodies, with decimetre thickness and metre lateral extensions have been identified. The lenses show an interlayering that consists of thicker intraclastic-bioclastic coarse grainstone and laminae of bioturbated peloidal-intraclastic packstone (Fig. 7C). The thicker levels contain typical marine bioclasts and intraclasts with subangular to rounded morphologies. Based on their geometry, grain-size distribution, biotic content and the association with intertidal facies, the aforementioned deposits are interpreted as tidal channels.

Supratidal carbonates

This category groups all the carbonate facies that show clear evidence for subaerial exposure (desiccation cracks and microbreccia, dog-tooth cement, vadose silt; Figs. 8C, 9A and B), as well as those represented by non-fossiliferous, sometimes laminated mudstone with interlayers consisting of laminae of fine peloidal packstone (Fig. 7A).

Relationship between the depositional subenvironments and the dasycladalean algae

When analysing the distribution of specific dasycladalean algae within the sedimentary units described earlier, two distinctive groups can be separated (Fig. 10). A first group is represented by the species *Salpingoporella annulata*, *Clypeina sulcata*, *Clypeina parasolkani*, *Clypeina* sp. 1, *Actinoporella* cf. *podolica* and *Salpingoporella katzeri*. These algae are indicative mainly for the internal platform domain, either open, or sometimes "lagoonal" (restrictive) to intertidal ponds. *Salpingoporella annulata*, in some cases very abundant, is characteristic for such restrictive environments. Most of the authors consider *Salpingoporella annulata* to be an index fossil for normal marine environments (Conrad 1977; Jaffrezo and Renard 1979; Jaffrezo 1980). However, in our opinion, the high frequency and the almost monospecific occurrence of this species in the succession studied, in association with charophytes, indicates restrictive environments, which represent brackish, as compared to present-day case studies (Valet 1979; Berger and Kaever 1992), or hypersaline conditions (cf. Jaffrezo and Renard 1979; Jaffrezo 1980).

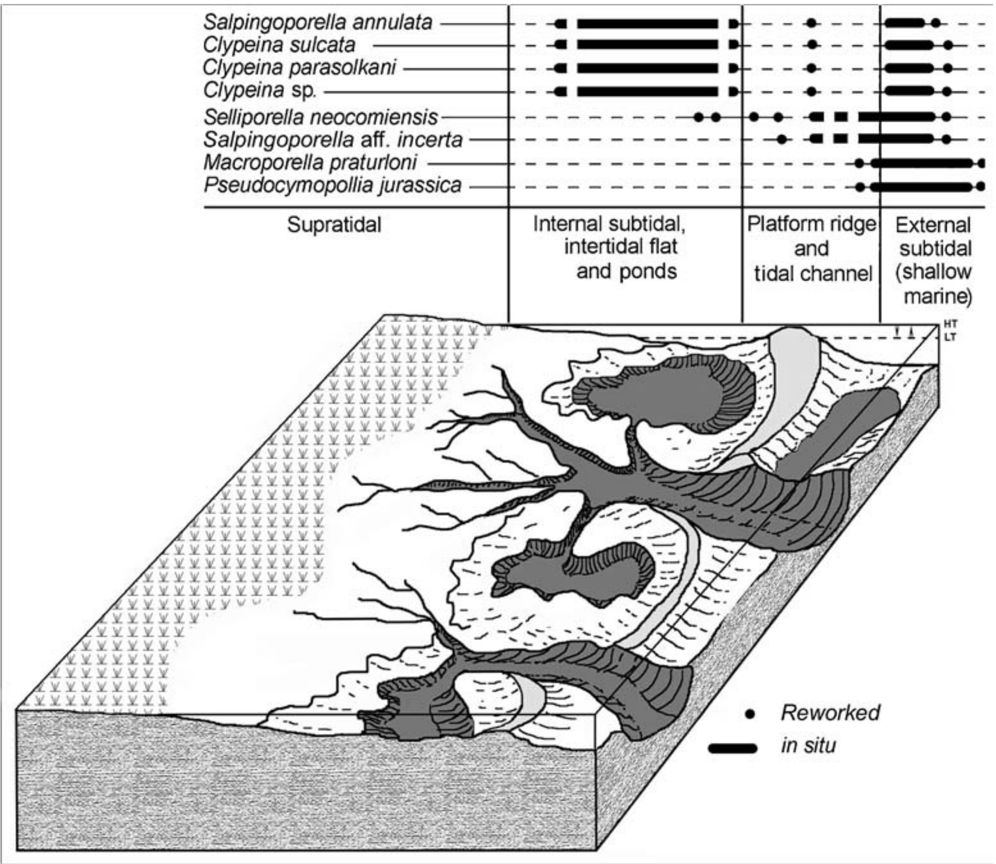


Fig. 10 Environmental distribution of some dasycladalean algae from the Berriasian–Valanginian limestones from Dealul Mare—Poiana Aiudului

The species of this group may be reworked in the platform margin environment or in the external platform area; in the external area they can also occur "in situ."

The second group is represented by species typical for the external platform environments: *Selliporella neocomiensis*, *Salpingoporella* cf. *incerta*, *Macroporella praturloni* and *Pseudocymopolia jurassica*. Some of the species (e.g. *Selliporella neocomiensis*) may also be present in internal environments, including tidal channels (as proved also by other occurrences in Trascău Mountains). Following Conrad (1977), the external infralittoral environment is an "environment encouraging the development of forms belonging to different genera and species, but having common morphological features (=dasycladalean species bearing tight whorls of numerous branches)." Notable also are the relatively large sizes of the dasycladaleans in this environment.

Conclusions

The limestones from Dealul Mare (Poiana Aiudului, Trascău Mountains) contain an assemblage of calcareous algae and benthic foraminifera of Berriasian–Valanginian age. Based on sedimentological features and biotic assemblages, typical facies associations for the external platform domain (shallow subtidal) and internal platform domain (from shallow subtidal to intertidal and supratidal) can be recognised.

Two distinctive groups of dasycladaleans characterise the subenvironments of the two domains: (1) *Salpingoporella annulata*, *Clypeina sulcata*, *Clypeina parasolkani* and *Clypeina* sp. 1 are typical for the internal platform, including some restrictive subdomains where *Salpingoporella annulata* is associated with charophytes. (2) The other group, represented by *Selliporella neocomiensis*, *Salpingoporella* cf. *incerta*, *Macroporella praturloni* and *Pseudocymopolia jurassica*, is characteristic for the external platform.

In order to obtain an accurate reconstruction of depositional environment, the ecological requirements of dasycladaleans—either interpreted in comparison with living dasycladaleans (Valet 1979; Berger and Kaever 1992), or based on analyses avoiding uniformitarianism (Jaffrezo and Renard 1979; Jaffrezo 1980)—have to be corroborated with data on facies analysis. Additionally, the biotic associations and the structural–textural features of the limestones formed in the internal platform area allow the recognition of facies sequences from normal marine subtidal, to restrictive subtidal and isolated subtidal (intertidal ponds). The sequence of these facies is, most probably, related to variations in relative sea level.

Acknowledgements This paper was written during a period of research by the two authors in Erlangen as guests of the IPAL. For financial and technical support we thank the Alexander von Humboldt Foundation (Bonn-Bad Godesberg) and Roman Koch and André Freiwald (IPAL, Erlangen). Thanks are also due to our colleague Dana Pop for the English translation and to Robert Riding and Steve Kershaw for English corrections. Baba Senowbari-Daryan and Michael Rasser reviewed the manuscript and provided valuable comments. The paper is partly a contribution to the CNCSIS research project 1690 (I.I. Bucur).

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