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Development of a *Lithocodium* (syn. *Bacinella irregularis*)-reef-mound-A patch reef within Middle Aptian lagoonal limestone sequence near Nova Gorica (Sabotin Mountain, W-Slovenia)

Alga *Lithocodium* (syn. *Bacinella irregularis*)-graditelj krpastih grebenov znotraj srednjeaptijskega lagunskega apnenca, Sabotin pri Novi Gorici

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Abstract

A Middle-Aptian (zone of *Palorbitolina lenticularis*) „patch reef“ of about 40 m maximum thickness with marked morphology was analyzed at the Sabotin Mountain near Nova Gorica. It is developed above an basal unit of superficial oolites within lagoonal sediments and is overlain by shallow subtidal to intertidal sediments which reveal short time periodically subaerial exposure and early diagenetic freshwater influxes (birds eyes, vadose silt, characeans). Above these sediments within the zone of *Salpingoporella dinarica* fine-bedded to platy, laminated bituminous limestones occur.

The central part of the reef structure reveals an alternation of individual lenses of *Lithocodium*-boundstones and of rudist-beds (up to 4 m thickness) which are separated by coarse- to medium-grained, moderately to poorly sorted bioclastic sands. These facies types show also lateral interfingering and are concentrated in the central part of the buildup where the greatest thickness can be observed and where packstones, grainstones and boundstones prevail. The neighbouring lagoonal sediments which consist of mudstones and wackestones predominantly were analyzed in the so-called Sabotin-standard-profile which is located north of the patch reef at a lateral distance of about 300 m.

Three vertical profiles (A = 90 m, B = 100 m, C = 64 m thickness) were analyzed. The middle profile B of greatest thickness is taken as reference profile and documents best the vertical facies development within the patch reef directly overlying a basal unit of peloidal packstones with superficial ooids. The patch reef itself is characterized by the faunal associations within the unit rich in *Lithocodium* and rudists. It is overlain by a subtidal unit of peloidal mudstones with very minor biogenic allochems. An intertidal unit above rich in birds-eyes and vadose silt is followed by fine-laminated black shales which are covering the general seqeunce of interfingering patch-reef – lagoonal sediments.

Using different time lines (marker horizons) for correlation it can be shown that already very early differential compaction of fine-grained uncemented sediments in comparison to the core area of the patch reef is of great importance.

The greater thickness of the patch reef itself is caused by an intensive early diagenetic marine phreatic cementation within the core zone and by the early fixing of sediment by *Lithocodium aggregatum* (syn. *Bacinella irregularis*) resulting in a greater resistivity against compaction. Furthermore a lagoonal side and an more open marine side of the patch reef can be determined. *Lithocodium aggregatum* is the main constructing organism within the buildup investigated, beginning with the incrustation of varying substrates and biogenic particles. Finally, a dense network of encrustation-sequences is formed interfingering with the general sedimentary textures intensively and resulting in larger „biogenic-cemented“ patches within the sediment.

The correlation of the three profiles A, B, and C allows to reveal the history of differential compaction of the associated lagoonal sediments in comparison to the more massive patch reef limestones. It becomes obvious that the main compaction must have occurred within the time span of about 50 m sediment-deposition overlying the patch reef. Differential compaction resulted in differences in thickness of about 10 m from the patch reef (profile B) to the more lagoonal influenced sediments (profile A) within a lateral distance of about 50 m.

Kratka vsebina

V vzhodnem pobočju Sabotina pri Novi Gorici smo raziskali do okoli 40 m debel, morfološko lepo izražen srednjeaptijski (cona *Palorbitolina lenticularis*) krpasti greben (patch reef). Razvit je med lagunskimi apnenci nad bazalno enoto, sestavljeno iz nepopolno razvitih oolitov (supeficial oolites). Prekrivajo ga sedimenti nastali v plitvem morju in v medplimski coni, ki razkrivajo kratkotrajne periodične okopnitve in zgodnje diagenatski dotok sladke vode (teksture ptičjega očesa, vadozni melj, haraceje). Nad temi sedimenti, znotraj cone *Salpingoporella dinarica,* so razviti tanko plastnati do ploščasti laminirani bituminozni apnenci.

V osrednjem delu grebena se menjavajo leče apnenca z algami *Lithocodium* in strukturo boundstone z do 4 m debelimi plastmi z rudistnimi školjkami, ki jih ločujejo pasti debelo do srednjezrnatega, srednje do slabo sortiranega biokastičnega apnenca. Ti faciesi se tudi lateralno prepletajo in so koncentrirani v osrednjem delu grebena. V tem delu je greben najdebelejši. V njem prevladujejo apnenci s strukturo packstones, grainstones in boundstones. Obdajajoče lagunske sedimente, ki jih sestavljajo apnenci s prevladujočo strukturo mudstone in wackstone, smo raziskali v tako imenovanem standardnem profilu Sabotin, ki je 300 m severno od obravnavanega grebena.

Raziskali smo tri vertikalne profile, ki zajemajo debelino 64 do 100 m (A = 90 m, B = 100 m, C = 64 m). Srednji profil B, ki obsega največjo debelino in najbolje prikazuje vertikalni facialni razvoj znotraj krpastega grebena, smo določili kot referenčni profil. Ta zajema tudi neposredno bazalno enoto iz peloidnih apnencev s packstone strukturo, ki vsebujejo tudi ne popolnoma razvite ooide. Za sam krpasti greben je značilna favnistična združba enot bogatih z algami *Lithocodium* in rudistnimi školjkami. Prekriva ga enota plitvomorskih peloidnih apnencev s strukturo packstone in z zelo malo biogenih alokemičnih komponet. Nad njimi je enota bogata s teksturami ptičjega očesa in vadoznim meljem, nastala v medplimski coni. Sledijo tanko laminirani črni muljevci, ki prekrivajo splošno zaporedje prepletanja grebenskih in lagunskih sedimentov.

Pri korelaciji z uporabo različnih časovnih črt (vodilnih horizontov), se pokaže velik vpliv in pomembnost, že zelo zgodnje diferencialne kompakcije ne cementiranih drobnozrnatih sedimentov v primerjavi z jedrom krpastega grebena. Večja debelina samega krpastega grebena, je posledica zgodnje diagentske morske freatske cementacije osrednjega dela grebena in zgodnje vezave sedimenta z algami *Lithocodium aggregatum* (syn. *Bacinella irregularis*), kar je povzročilo manjšo stopnjo kompakcije.

Nadalje smo lahko, glede na položaj krpastega grebena, določili smer raztezanja lagune in odprtega morja. Alge *Lithocodium aggregatum* so glavni sestavni organizem raziskovanega krpastega grebena, ki se pričenja z inkrustacijami različne podlage in biogenih drobcev. Končno se je izoblikovala gosta mreža zaporedja inkrustacij, ki se intenzivno prepletajo s splošnimi sedimentnimi teksturami in grade znotraj sedimentov velik »biogenocementiran« krpasti greben.

Korelacija treh profilov A, B in C nam dovoljuje razkritje zgodovine diferencialne kompakcije sosednjih lagunskih sedimentov v primerjavi z bolj masivnim apnencem krpastega grebena. Izkaže se, da je glavnina kompacije potekala v času odlaganja okoli 50 m sedimentov krovnine krpastega grebena. Diferencialna kompakcije je povzročila razliko v debelini od krpastega grebena (profil B) proti sedimentom z večjim lagunskim vplivom (profil A) za okoli 10 m na lateralni razdalji približno 50 m.

Introduction

Rudists, corals, and sponges (stromatoporoids, chaetetids) are the most important reef-forming elements of Cretaceous carbonate platforms (Wilson 1975). Within the photic zones of carbonates platforms numerous mono- to multispecific types of bioconstructions are formed by these potential (classic) constructional organisms including local individual occurrences as biostroms, mounds, patchreefs and even extended barrier-like reef-systems (Masse & Philipp 1981, Kauffman & Johnson 1988, Moussavian 1992, Höfling 1997, Sanders & Höfling 2000, Höfling & Scott

2002). Two essential basic reef-types are characteristic for the Cretaceous time interval. These are (1) mono- to paucispecific rudist-buildups and (2) coral-sponge-algae/coral-algae reefs. The rudist-population (mainly monopleurids, caprinids, radiolitids, hippuritids) commonly grows in bouquet-like buildups within a reduced commonly lagoonal environment with low diversity.

Coral or coral-sponge-dominated bioconstructions are best developed with highest diversity in a normal marine environment (open platform) of deeper water compared to the locations of the formation of rudists-buildups (Moussavian 1992, Höfling 1997, Voigt et al. 1999, Kauffman et al. 2000, Höfling & Scott 2002). But generally they can be found in a lagoonal environment too. The worldwide expansion of these main reef types was developed during the Lower Cretaceous (pre-Barremian), subsequently to a time of reorganisation of carbonate platforms and reef communities.

Lithocodium (syn. *Bacinella*; Segonzac & Marin 1972) is an incrusting organism living generally in reef facies. Already during the Upper Triassic and Jurassic it plays an important role within reef communities. During the Berriassian to Aptian *Lithocodium* reached its greatest expansion worldwide resulting in the formation of reef-like buildups.

It is obvious that a higher reduced energy environment is most favourable for the growth of *Lithocodium* as also valid for the occurrence of rudists. Therefore *Lithocodium*-buildups are valuable indicators for these specific environments in which only some very spezialized groups of organisms occur.

In the recent study a characteristic Lithocodium-mound in W-Slovenia is analyzed (Pl. 1/1-3). It has a thickness of about 40 m, a lateral extension of about 200 m and is characterized by a marked morphology in comparison to the adjacent lagoonal bedded sediments (Plate 1/1). Furthermore characteristic are thin platy, laminated black shales (Pl. 1/4) which cover the structure (Koch 1988, Koch & Zimmerle 1996). Comparative analyses dealing with the facial and diagenetic development of Cretaceous beds in neighboured areas (Nanos and Trnovo) were carried out by Koch (1978), Koch et al. (1989), Koch & Ogorelec (1990) and by Koch et al. (1998). Cretaceous beds of the Trieste – Komen Plateau were investigated by Jurkovšek et al. (1996) and L. Šribar (1995).

The methods used for the recent study are (1) field analysis by taking three vertical profils over the vertical walls of the structure (A – 90 m, B – 100 m, C – 64 m) and (2) microscopic thin section analysis including semiquantitative estimation of the most important groups of organisms. The results of analysis are representatively documented by the analysis of the middel profile B (Fig. 2) in the description of thin sections, in the microfossil list and in photoplate 2-4 documenting the most important microfossil elements (foraminifera and algae), microfacies-types as well-as textural and diagenetic characteristics.

Geological setting

The Cretaceous strata studies are situated in the high Karst area of the Outer Dinarides in W-Slovenia and belong to the Dinaric Carbonate Platform (Buser 1976, 1987). In NW- and W-Slovenia where the northern part of the platform occurs, small tectonic units form overthrusts with a lateral movement of 30 km or less (Mlakar 1969, Placer 1981, 1999).

The Cretaceous sequence at the Sabotin (thickness about 800 m) which is situated north of Nova Gorica just at the Slovenian-Italian border belongs to the overthrust anticline of Sabotin Mountain, which passes towards the east to the Trnovo overthurst (Buser 1973). A standard section of about 600 m thickness (Hauterivian – Turonian) was analyzed in comparison to the neighboured profiles (Trnovo, Nanos, Fig. 1). An obvious sequence of more massive limestones (Pl. 1/1-3) with a total thickness of about 40 m and of indivudual beds of 2-4 m in the middle part is of Aptian age.

Due to the marked morphology it was interpreted as patch-reef in general terms already during field work. Following the W-Flank of the Sabontin it becomes obvious that the patch reef is unique in this part of the Sabotin Mountain. Laterally the thick-bedded part is developed as normal-bedded limestones (bed thickness predominantly 5 – 15 cm) of lagoonal facies which are analyzed in the so-called Sabotin standard profile positioned about 300 m north of the patch reef (Pl. 1/1).

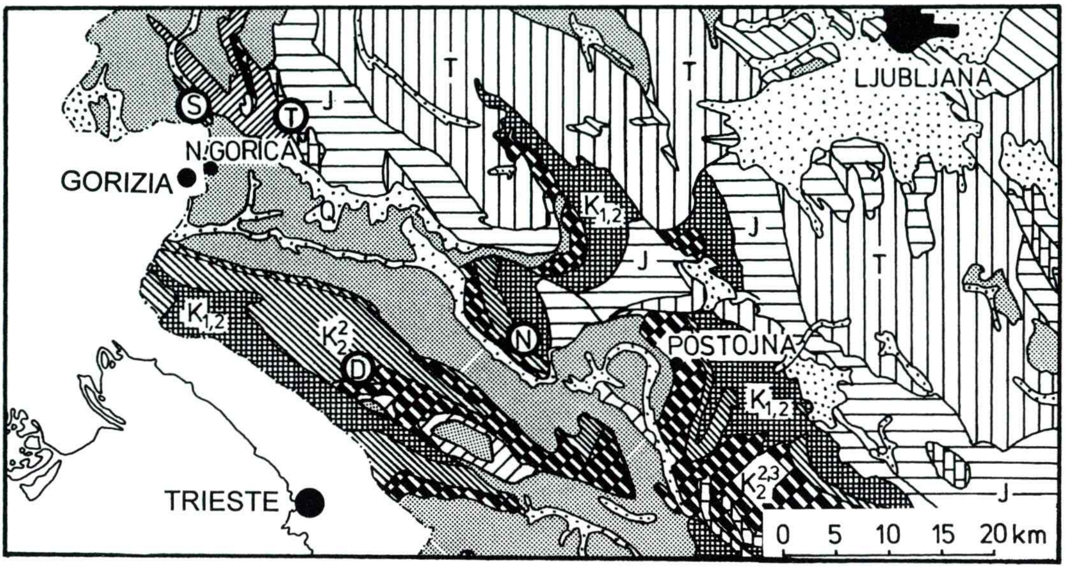


Fig.1: Detail of the geological map of W-Slovenia with location of the Sabotin profile (S). Other profiles analyzed in this area are the Trnovo profile (T: Koch et al. 1989, Koch & Ogorelec 1990) and the Nanos profile (N: Koch 1978, Koch et al. 1998). The Trnovo overthrust is characterized by the Sabotin and Trnovo sections and the Hrušica overthrust by the Nanos section. Modified from „Geological map of Slovenia". T = Triassic, J = Jurassic, K_1 = Lower Cretaceous, K_1^1 = Berriasian/Valanginian, K_1^2 = Hauterivian, $K_1^{3,4}$ = Barremian/Aptian, K_1^5 = Albian, $K_{1,2}$ = Lower-Upper Cretaceous, K_2^1 = Cenomanian, $K_2^{1,2}$ = Cenomanian-Turonian, K_2^2 = Turonian, $K_2^{2,3}$ = Turonian-Senonian, K_2^3 = Senonian (Koch 1988; modified from Buser 1986).

Biostratigraphy

The whole assemblage of microfossils (appendix) indicate an Early Aptian (Bedoulian) age (Schroeder 1975, Arnaud-Vanneau 1980, Arnaud-Vanneau & Chioccini 1985, Luperto Sinni & Masse 1993). Macrofauna was recently not used for age determination. Most elements of the foraminiferal fauna are characteristic for urgon facies and indicate a Late Barremian to Early Aptian age. The most precise data given, are due to the occurrence of orbitolinids i.e. *Palorbitolina lenticularis* (Blumenbach) which indicate Early Aptian age.

Salpingoporella dinarica which has a general stratigraphic range from Valanginian to Albian (Granier & Deloffre 1993, Bucur 1999) is known in this region as beeing indicative for Aptian time interval (upper part of the Lower Aptian and lower part of the Upper Aptian (Farinacci & Radoičić 1994, Velić 1977, Sokač et al. 1978, Lj. Šribar 1979, Turnšek & Buser 1966, Koch et al., 1989, Koch et al. 1998, Jurkovšek et al.1996, L. Šribar 1995).

Facies development, distribution pattern of biota

Three profiles were analyzed in order to characterize the patch-reef which is best developed in profile-B, as indicated by the most thick-bedded limestones (up to 4 m bed thickness). About 300 m north of profile-A, fine-bedded lagoonal sediments are found and samples in the Sabotin standard section (Pl. 1/1).

Five characteristic litho- and microfacial units can be distinguished in the profiles (Fig. 2). These are well-bedded limestones (unit-SO) at the base which contain superficial ooids (Pl. 2/1), the central unit-LBR which is rich in *Lithocodium* (Pl 2/2-4), forming the core of the patch-reef, an overlying unit-ST of peloidal mud- wackestones with very minor biogenic allochems, and a unit-IT rich in mudstones and wackestones with birds-eyes and vadose silt (Pl. 2/6) reflecting predominantly an intertidal depositional environment.

The structure is covered by thin-bedded to platy, laminated black shales rich in *Sal-*

pingoporella dinarica (Pl. 2/7) and ostracod mudstones (Pl. 2/8) which grade upwards in normal lagoonal well-bedded sediments (Fig. 2 and 3).

Besides the correlation in the field which was carried out be tracing single beds through all four profiles, the semiquantitative estimation of fauna elements is another base for the correlation of the profiles (Fig. 3). The bioigenic constitutents are nearly exclusively composed of foraminifera, *Lithocodium*, molluscs (predominantly rudists), echinoid fragments and green algae.

Dasycladaceans occur in two horizons. The first one (unit-SO) in the lower part of the sequence contains predominantly *Salpingoporella muehlbergi* (Lorenz). The second one (unit-IT) in the upper part contains the

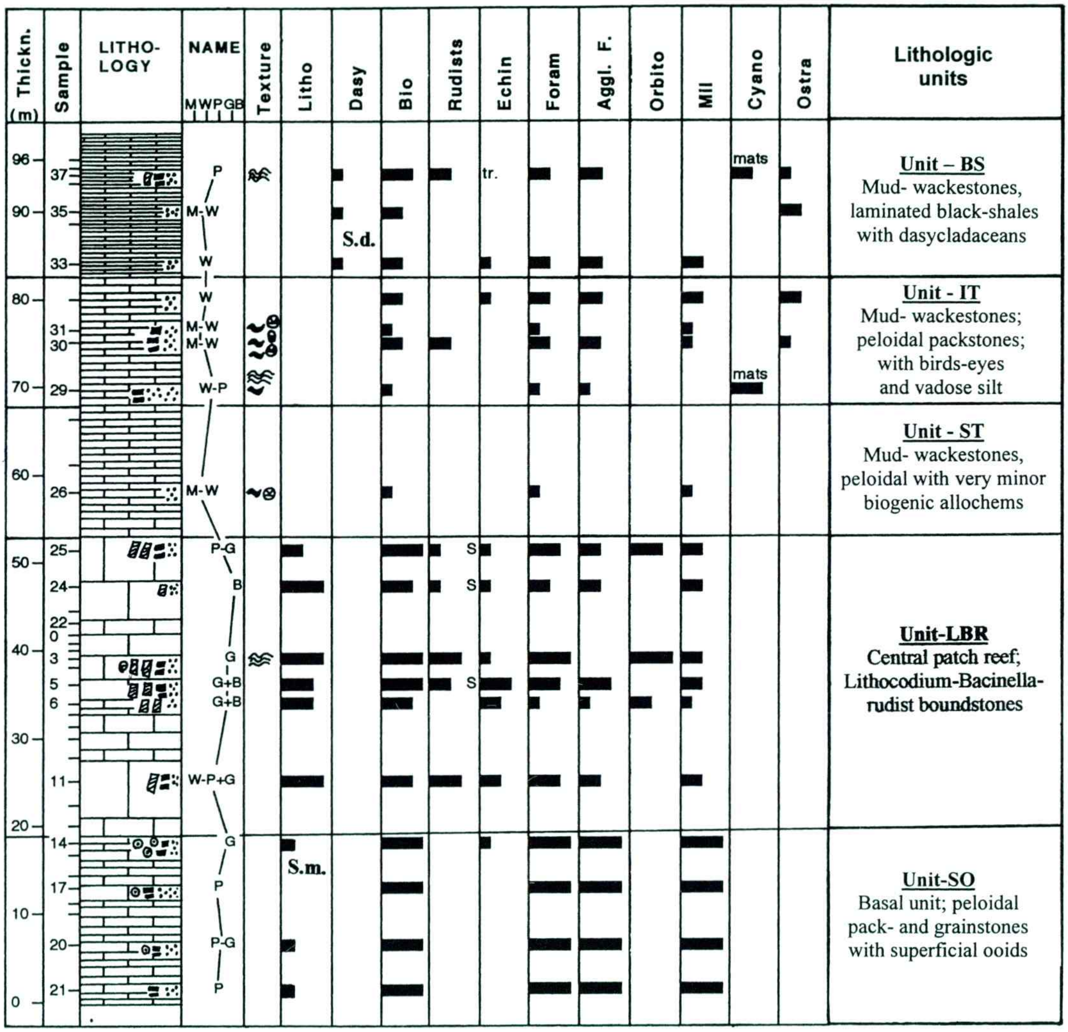


Fig. 2: The middle profile B of the Sabotin patch reef is taken as example for the vertical distribution of varying faunal elements. In the lithologic column rudist fragments, lithoclasts, peloids and ooids are indicated as well as the measured thickness of individual beds. Textures comprise algal laminations, birds-eyes and vadose silt as well as geopetal fillings. *Lithocodium* means occurrence of undifferentiated *Lithocodium-Bacinella*. Furthermore dasycladaceans (dasy; S.m. = *Salpingoporella muehlbergi*; S.d. = *Salpingoporella dinarica*) general amounts of biogenic allochems (bio), rudists, echinoids (echin), foraminefera (foram), orbitolinids (orbito; *Palorbitolina lenticularis*), miliolids (mil), cyanobacteria mats (cyano) and ostracods (ostra) are indicated in relative abundance.

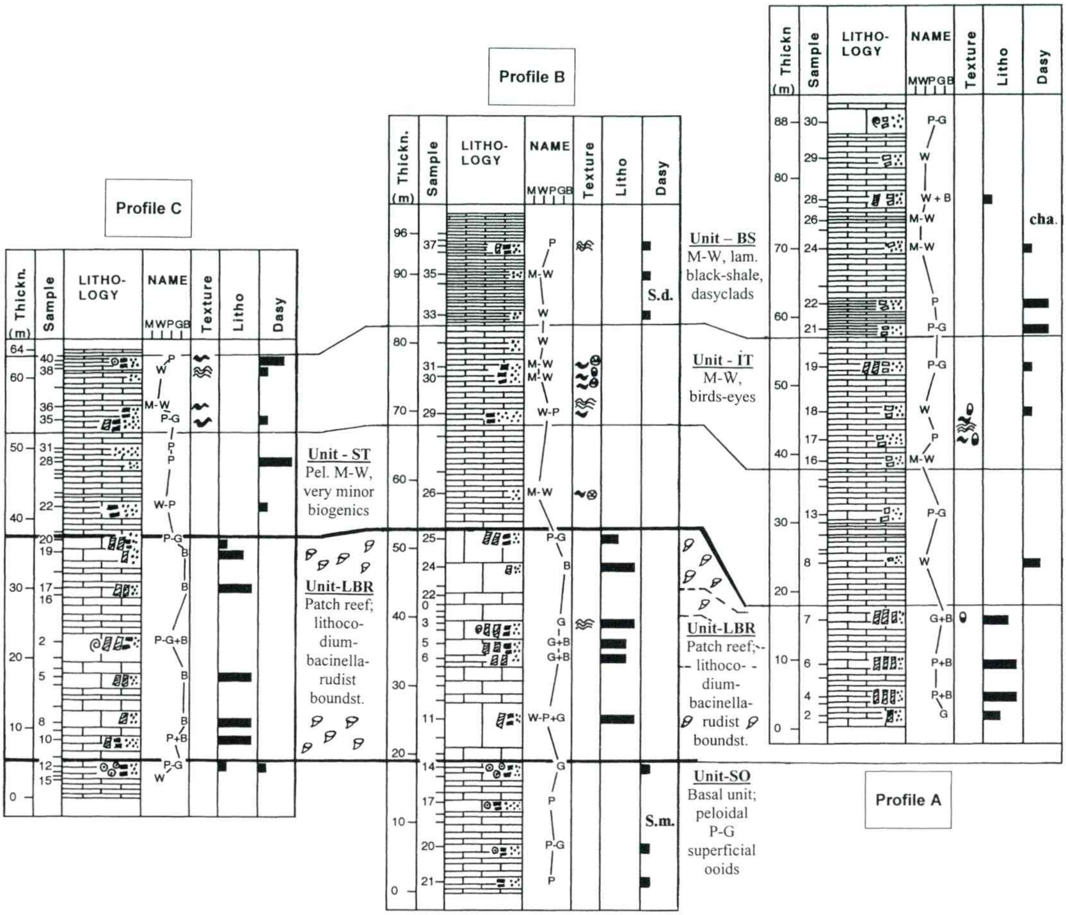


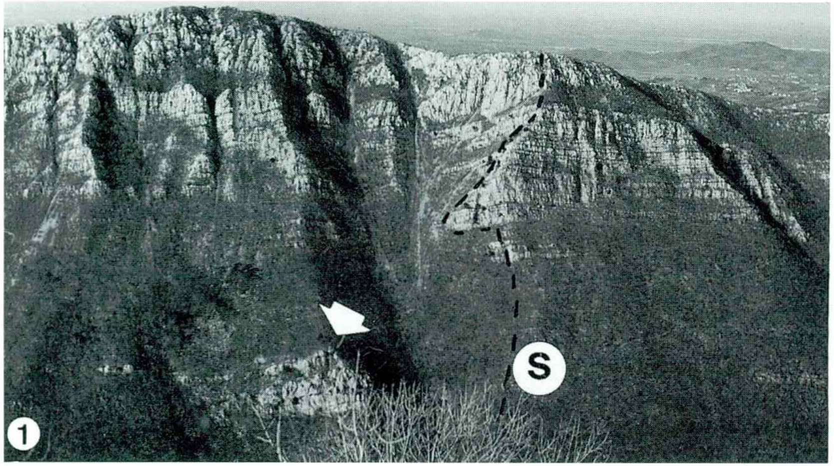
Fig. 3: Correlation of the profiles A, B and C from North to South, i.d. from the lagoonal influenced part of the patch reef in direction to the more open marine side rich in biogenic debris. Note thickness variations of different beds due to early cementation, organigenic reef growth and differential compaction. For explanation see text.

Plate 1

1 The Sabotin profile; view from the S-side with position of the Aptian patch reef with marked morphology within the Cretaceous sequence.

2,3 Detail of the Aptian patch reef with position of the three profiles (A, B, and C) studied. Marked facial boundaries (1, 2, and 3) are separating the base of pack- to grainstones with superficial ooids (unit-SO), the zone rich in *Lithocodium* (unit-LBR), the zone with intertidal sediments (unit- ST and unit-IT), and the overlying limestones containing fine-bedded black shales with Salpingoporella (unit-BS) from eachother.

4 Detail of the overlying fine-bedded, laminated black shales show deformation structure at a small fault. Thickness of individual beds is some mm to 10 cm.



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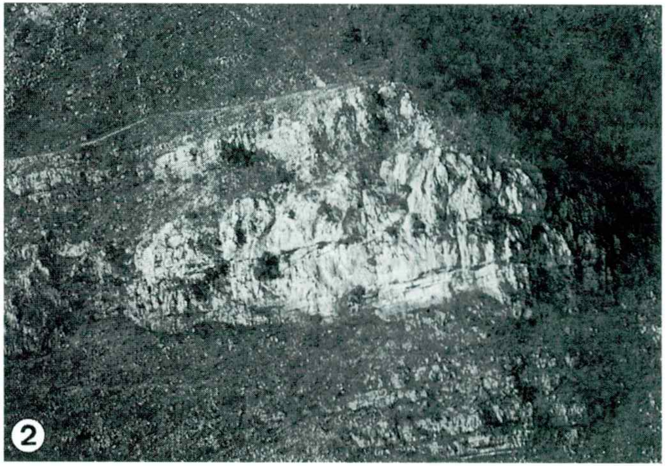

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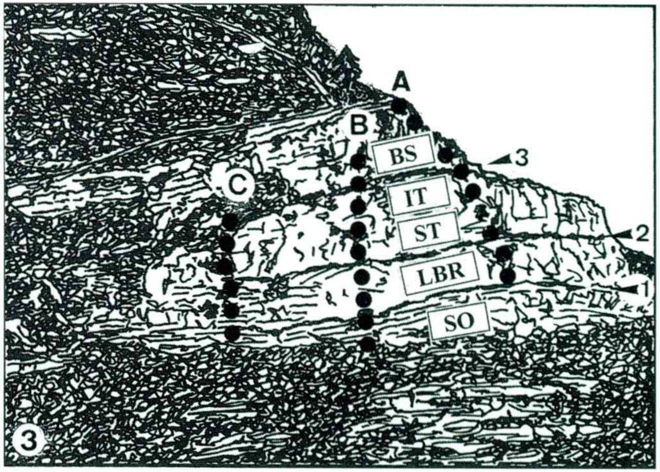

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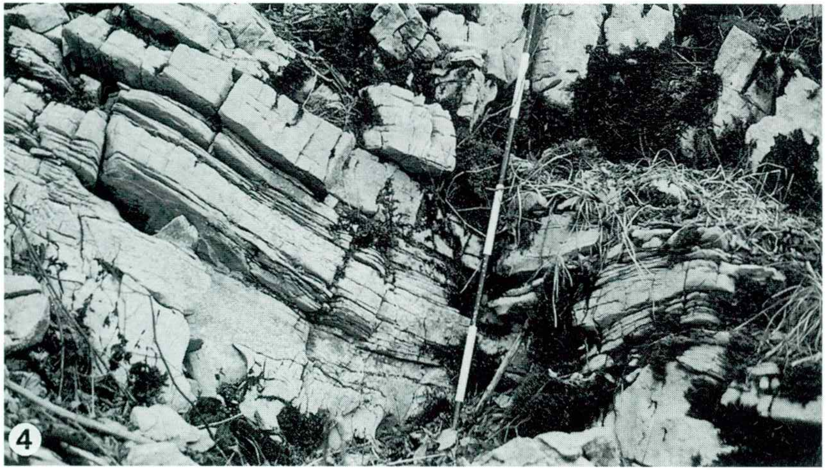

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single species *Salpingoporella dinarica*. As indicated by the slightly reduced fauna of the unit-IT dasycladaceans lived in a more restricted environment compared to the underlying beds, rich in *Lithocodium*. Red algae are represented only by one species (*Polystrata alba*) too, which occur very rarely within the *Lithocodium* boundstones (profile C). *Lithocodium aggregatum* is found in unit-LBR exclusively forming the monospecific reef mound. Corals, stromatoporoidsd and chaetetids are quantitatively not significant and only occur in some horizons with lowered diversity.

Predominantly fragments of rudists are abundant in unit-LBR, within the *Lithocodium* boundstones. Only in more massive beds of profile-B, rudists (up to 5 cm in size) are commonly in life position revealing biostromal growth forms and some small bundles (bouquets sensu Höfling 1997).

Benthic foraminifera are the main biogenic components in thin sections analyzed. Agglutinated and porcellaneous families are predominant. The first group mentioned consist of Ataxiophragmiids, Textulariids and Lituolids mainly. More complex agglutinated groups (as Cuneolinids and Charentiids) generally occur in minor amounts throughout the sequence and are enriched only in some horizons. Orbitolinids show similar distribution patterns and are represented by *Palorbitolina*. Miliolids and other porcellaneous foraminifera show a relatively homogeneous composition when occurring abundantly.

For the description of the profile only the most characteristic fossil elements are documented in profile B (Fig. 2) and in plates 3 and 4.

Profile-A has a thickness of about 90 m and consists of intercalations of thin-bed-

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Plate 2

1 Unit-SO: Sample C – 12
Oobiopelsparite predominantly rich in superficial ooids besides ooids with thicker cortices (arrow). Besides common small benthic foraminifera also some dasycladaceans occur (right). The grains are surrounded by marine phreatic cements.

2 Unit-LBR: Sample C – 5
In this *Lithocodium*-biolithite from the centre of the patch reef fragments of rudists and some orbitolinids are bound together by *Lithocodium/Bacinella*. The chamber walls of *Lithocodium* are lined by interior isopacheous rims of bladed crystals indicating an early marine phreatic cementation by high Mg-calcite.

3 Unit-LBR: Sample C – 2
Lithocodium-orbitolina biosparit-boundstone with tight, inclusion-rich cements. This limestone type is characteristic for the central part of a thick bed rich in rudist fragements.

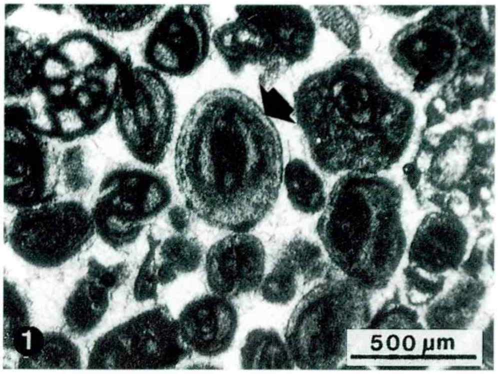
4 Unit-LBR: Sample C – 17
Peloidal sediments are stabilized by a combination of *Lithocodium* type with vertical perforations (arrows) and also by a *Lithocodium* type which reveals more microbial growth forms.

5 Unit-ST: Sample A – 13
A bed of foraminiferal biopelsparite is intercalated in the fine-bedded limestones of unit-ST which are generally nearly barren of fossils. Besides abundant small foraminifera also some larger foraminifera as e.g. ?*Praecrysalidina* sp. can be found. The sediment is lithified by fine granular cements.

6 Unit-IT: Sample B – 30
The intertidal sediments of unit-IT are characterized by birds-eyes which commonly show geopetal filling by peloidal, slightly recrystallized internal sediments (1). The upper part of the pores is often filled by granular calcite (2). Late fractures are cutting through cements and fillings.

7 Unit-BS: Sample A – 22
In thin layers within the fine-bedded to platy black shales of unit-BS which is covering the complete structure, *Salpingoporella dinarica* commonly occurs (1). Furthermore some rudist fragments can be found (2).

8 Unit-IT: Sample B – 32
The Upper part of the intertidal unit-IT in profile-B reveals completely preserved ostacods which are floating in the micritic matrix together with miliolids and other small fossil fragments.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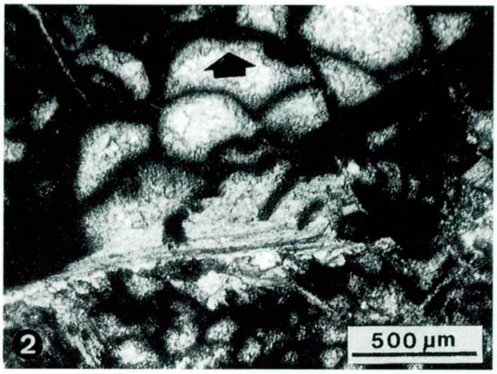
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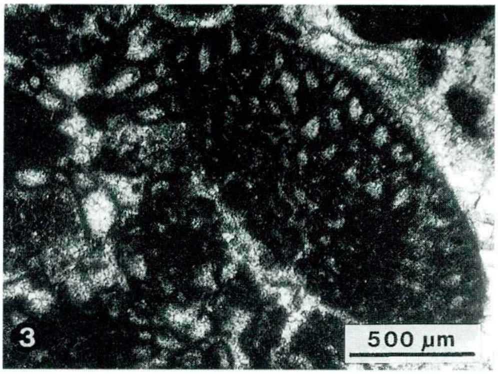
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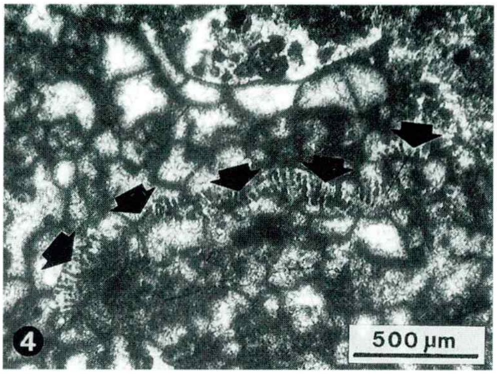
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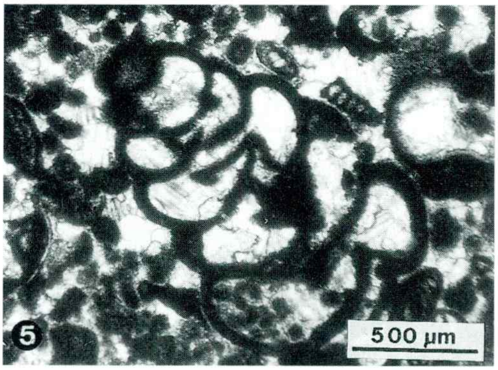
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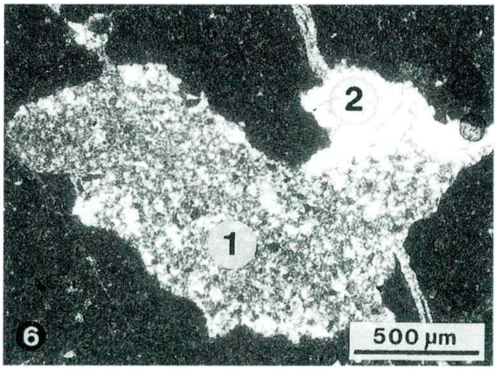
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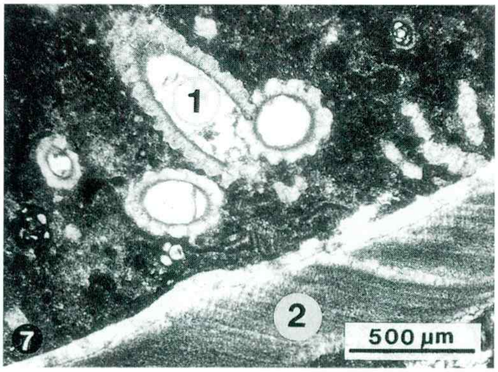
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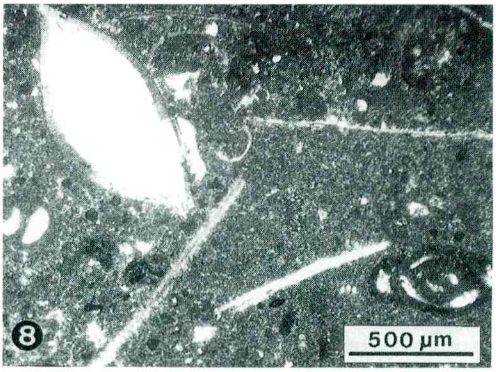
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500 µm

ded limestones in the lower and middle part, indicating lateral interfingering of the more massive patch-reef sediments (profile B) with the normal-bedded (5 – 10 cm) lagoonal sediments which occur northwards in the standard section. Intercalated are beds of up to 2m thickness which are rich in molluscs occur representing interfingering with the reefal sediments. The microfacial development reveals the *Lithocodium*-rich unit-LBR with abundant orbitolinids at the base.

Marine conditions are indicated also by the presence of locally abundant echinoid fragments and by isopacheous cements surrounding the allochems in packstones and grainstones. Fragments of requienid rudists occur commonly. At the top of unit-I requienids built biostrom-like thickets. The overlying unit-ST and unit-IT consists of a mixture of facies types (predominantly mudstones and wackestones) indicating close alternation of shallow subtidal to intertidal conditions. Chracateristic sedimentary features are birds-eyes, internal sediments and microbial laminations. Echinoids occur in traces. The strongly reduced diversity of the foraminiferal fauna, dominated by a few agglutinated forms, indicate reduced, probably more brackish conditions.

The overlying unit-BS starts with fine-laminated to platy, bituminous limestones very rich in *Salpingoporella dinarica*. The restricted marine conditions change periodically into episodic short time freswater influxes. Predominantly mudstones with small ostracods and charcophytes (oogonia) were deposited.

Profile-B (thickness about 100 m) cuts through the central part of the reef mound investigated. The basal unit-SO is characterized by beds rich in small superficial ooids (Pl. 2/1) overlying foraminiferal packstones and grainstones with subordinate ooids. This unit shows well-bedded limestones (Fig. 2) with beds of about 10 – 20 cm thickness. It is overlain by unit-LBR, the core of the *Lithocodium* reef-mound which has a thickness of 34 m and consists of succeccive *Lithocodium* boundstones with a thickness of individual beds up to 4m.

Besides *Lithocodium*, echinoid fragments, foraminifera (mainly orbitolinids) and rudists (in life position) occur. Between samples B-13 and B-25 (32 m thickness) the section is characterized by several rudist banks composed of requienid forms of up to 5 cm size.

The amount of rudists in most layers is up to 20% of total rock volume. The shells of

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Plate 3

1, 2 *Salpingoporella muehlbergii* (Lorenz).
Obliques sections.
1-sample B14, x 50; 2-sample B20-44276, x 25.

3 *Cylindroporella ivanovici* (Sokač).
Oblique section through the lower part of the thallus. Sample A30-44265, x 25.

4 *Cylindroporella* sp.
Oblique section. Sample B14, x 50

5, 9 *Salpingoporella dinarica* Radoičić.
5-Longitudinal-oblique section. Sample A22-44262, x 25 ; 9-Specimens in longitudinal, oblique and transverse sections. Sample C28-44270, x 12.

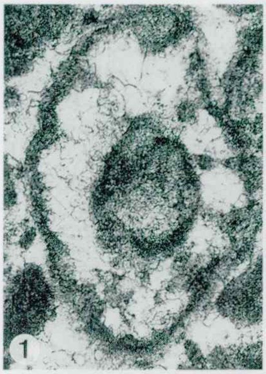
6, 7 *Carpathocodium anae* (Dragastan).
Longitudinal-tangential (6) and transverse-oblique (7) sections. Sample A28-44233, x 50.

8 *Bacinella irregularis* Radoičić growing on a bivalve shell. Note the perforations of *Bacinella* threads (films) inside the bivalve shell. Sample B5-44289, x 12.

10 *Bacinella* threads (films) binding diferent grain types (bioclasts, peloids). Sample B20-44276, x 25.

11 Polystrata alba (Pfender).
Sample A28-44233, x 50.

12 *Lithocodium aggregatum* Elliott-*Bacinella irregularis* Radoičić assemblage growing around a bivalve shell fragment. Sample C5-44290, x 12.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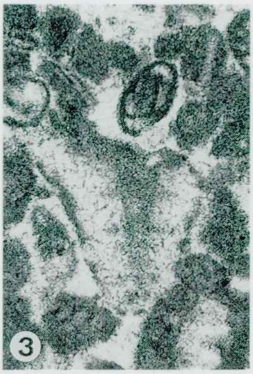
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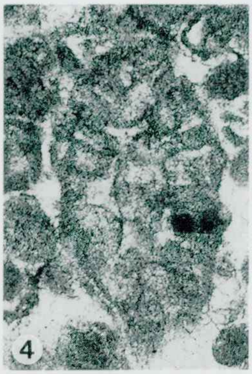
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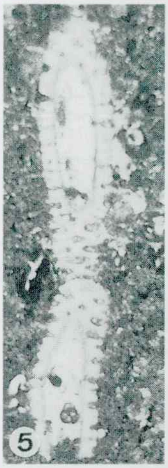
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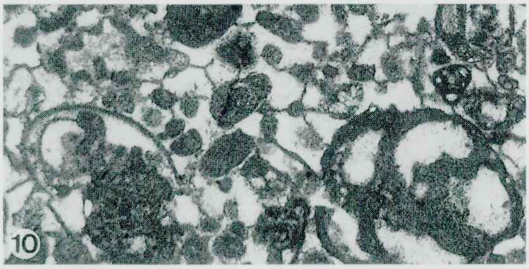
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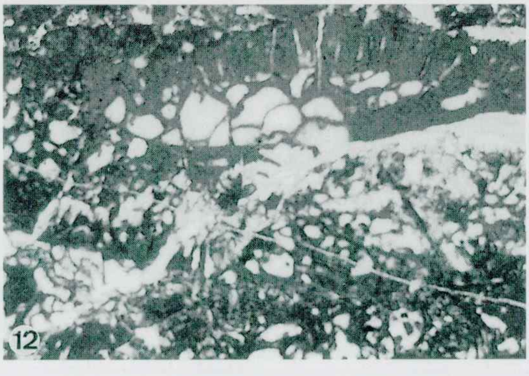
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the rudists are mostly black coloured. Brown micritic beds are commonly found intercalated between beds rich in rudists.

The overlying unit-ST consists of peloidal mud- to wackestones with very minor biogenic allochems. It is overlain by the unit-IT which reveals intertidal sediments and a reduced faunal composition in comparison to the standard-profile-A. Increasing intertidal (brackish ?) conditions are indicated by abundant birds-eyes and by vadose silt-fillings (Pl. 2/6).

In the overlying unit-BS renewed normal marine conditions are indicated by the frequency of *Salpingoporella dinarica* and minor amounts of echinoid fragments, found in the fine-laminated bituminouis marker beds. Thin micritic beds with octracods (Pl. 2/8) are intercalated in the bituminous beds.

Profile-C (thickness about 64 m) begins with the basal grainstone layer rich in superficial ooids (Pl. 2/1), forming the top of unit-SO. In the *Lithocodium* zone (unit-LBR) less massive limestones with a maximum bed-thickness up to 2 m occur. They are rich in rudists, commonly in life position. The top of the unit is characterized by the scattered occurrence of solitary corals and a single species of peryssonneliacean red algae.

Similar to the neighbouring sections the overlying unit-ST indicates more marine conditions (dasycladaceans; shallow subtidal-intertidal). It is followed by unit-IT with more intertidal conditions as indicated by birds-eyes and microbial carbonates.

Characteristics of the *Lithocodium* reef-mound

As mentioned above, the „reef“ was first noted due to it's marked and massive morphology in comparison to the bedded lagoonal facies of adjoining areas (Plate 1). In the central part it attains a thickness of up to 40 m. The massive central part laterally changes in increasing thin-bedded facies, although the boundaries at the top and the base are constantly developed.

Sampling the vertical walls of the outcrop it can observed that within the boundstones rudists in life position occur at different levels. Orbitolinid foraminifera, which are characteristic for this interval too, occur also in varying amounts within the unit-LBR (Fig. 2). All other small biogenic components show a relative homogeneous distribution pattern. Opposite to this, the rela-

Plate 4

1-3 *Palorbitolina lenticularis* (Blumenbach).
1-Vertical section through a specimen showing the embrionar apparatus. Sample A4-44257, x 25; 2, 3-Sections through the embrionar apparatus, 2: sample C10-44297, x 50, 3: sample C5-44290, x 50.

4 *Vercorsella laurentii* (Sartoni & Crescenti).
Longitudinal-oblique section. Sample B30-44260, x 25.

5 *Pseudolituonella conica* Luperto Sinni & Masse.
Subaxial section. Sample C20-44282, x 50.

6 *Debarina hahounerensis* Fourcade, Raoult & Vila.
Subaxial section. Sample A13-44271, x 50.

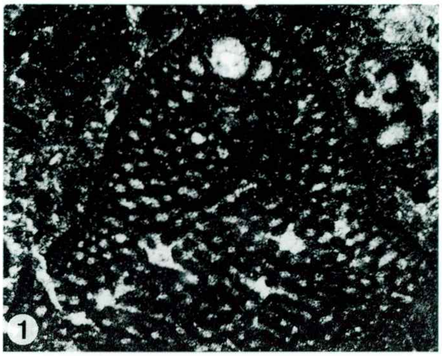
7 *Vercorsella arenata* Arnaud-Vanneau.
Longitudinal section. Sample B32-44271, x 50.

8-9 *Sabaudia minuta* Hofker.
8-axial section. Sample A30-44265, x 60; 9-transverse section. Sample A28-44233, x 50.

10 *Spiroloculina cretacea* (Reuss).
Subaxial section. Sample B24-44298, x 50.

11 *Pseudolituonella gavonensis* Foury.
Axial section. Sample B21-44255, x 50.

12-13 *Voloshinoides murgensis* Luperto Sinni & Masse.
12-transverse-oblique section; 13-Longitudinal-oblique section. Sample C28-44270, x 50.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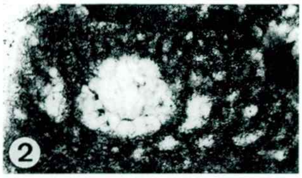
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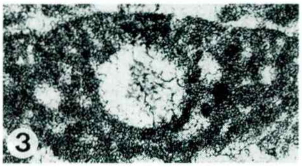
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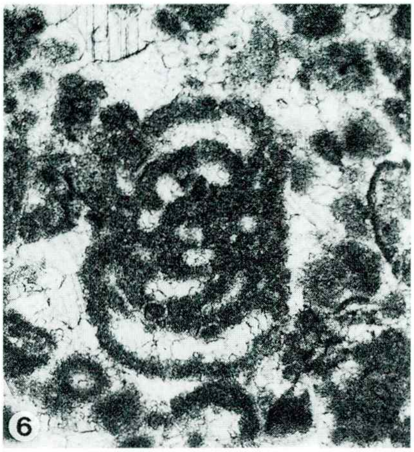
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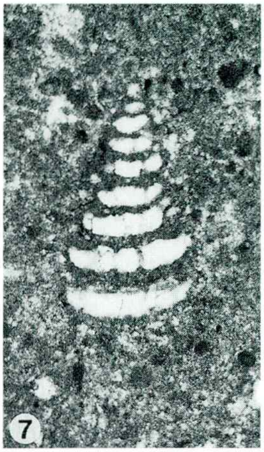
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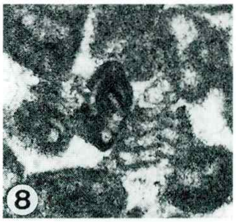
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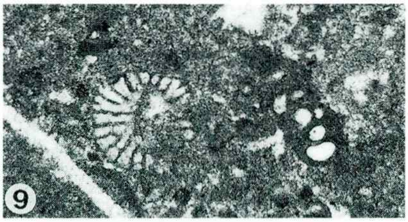
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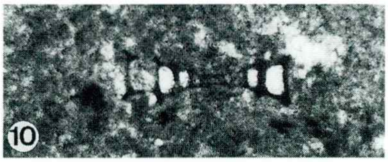
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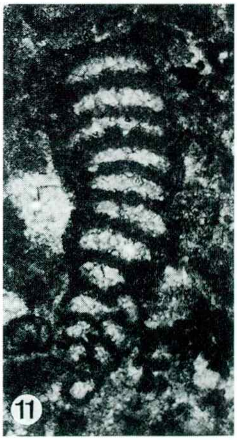
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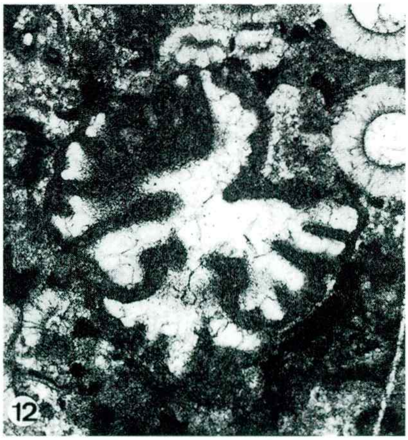
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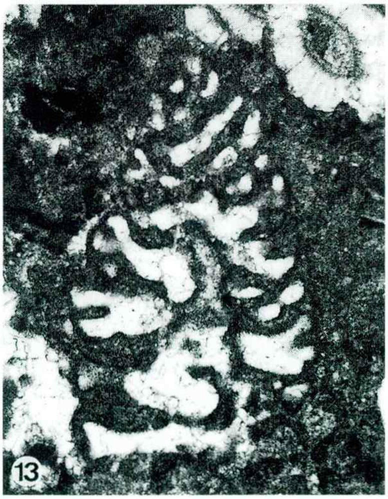
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tive amount of *Lithocodium*, forming boundstones predominantly, can be correlated within the profiles in a well-defined level (Fig. 3).

Therefore, it is interpreted that the accumulation of biogenic debris composed of varying amounts of different organisms is one important parameter for the formation of a *Lithocodium* reef mound. The small benthic organisms, especially foraminifera, probably did not live in this environment. Most of them and their fragments were transported by weak bottom currents. These piles of bioclastic debris (rich in pellets) probabaly formed shallow marine, subtidal sand bars which subsequently to their deposition were fixed at the top by cyanobacterial layers during periods of lower or even non-sedimentation.

In contrast, *Lithocodium* (*Bacinella*) bound these particles together in the sand piles forming *Lithocodium*- (*Bacinella*) boundstones, marking periods of lowered or non-sedimentation too. The lithification of the carbonate constituents occurred very early, probably before the sedimentation of the next overlying sediment of varying composition took place. Thus *Lithocodium* togther with an early diagenetic cementation in inter- and intraparticle pores is responsible for the greater stability of the sediments in the central part of the positive structure, forming a shelter against later campaction.

This together with differential compaction being more intensive in the neighboured lagoonal sediments, results in the marked positive morphology of the central part of the buildup revaling also laterally decreasing degrees of primary porosity and cementation.

Remarks on systematic affinity of *Lithocodium*

The systematic position of *Lithocodium* (*Bacinella*) is still uncertain and was often discussed in literature.

Several species and five genera were established from the time-span Triassic – Upper Cretaceous: *Lithocodium* Elliott 1956, *Bacinella* Radoičić 1959, *Pseudolithocodium* Misik 1979, *Bacinellacodium* Dragastan 1985 and *Radoicicinellopsis* Banner et al. 1990 which all seem to be synonymous. Since Elliott (1956) interpreted *Lithocodium* to be a green algae and Radoičić (1959) regarded it as a microptroblematicum, such morphotypes were repeatedly attributed to different systematic groups, mainly of following systematic positions: Codiacean green algae (Banner et al. 1990), cyanobacteria/microbes/porostromata (Masse 1979, Maurin et al. 1985, Camoin & Maurin 1988), and multispecific cyanobacteria/algae/foraminifera associations (Johnson 1969, Leinfelder et al. 1993). Schmid & Leinfelder (1996) interprete it as a foraminifer.

Based on systematic and paloecological studies on Triassic to Cretaceous specimens by E. Moussavian it is interpreted to be a complex, encrusting organism of sheet-like basic growth form primarily, which is able to penetrate deeply in e given substrate. In association with other organisms it forms a dense network of incrustation-sequences living in an environment with general common microbial activity.

Due to the dense, micritic preservation of the cell-walls, it was probably originally formed by tiny Mg-calcite crystals of < 1 ?m size which are slightly recrystallized to micrite (< 4 ?m). The skeleton of a juvenil *Lithocodium aggregatum* was built of a network-like mat which shows a structural differentiation from the surface (cortical zone) to the basal zone. Fine and branched channels are changing to somewhat larger canals from the periphery of the cortical zone towards the inner part of the tuissue. The larger channels alter to basin-like cavities (chambers) of different shape and size (see illustrations at Elliott 1956, Misik 1979, Banner et al. 1990).

Canals beginnign in the chambers and ending at the base occur only in very minor amounts. During the autogenetic growth stages an increasing number of canals and chambers is formed. In the late stages neighbouring chambers can be fused to a system of chambers which are separated from each other only by lamellar-like walls. In mature forms the internal structure under the cortex likes a loose network, whereas the canals and chambers in the oldest parts of the iorganism became „impregnated" by micritic Mg-calcite.

These characteristics resemble more to sponge than to any other organism. The new observations show that the systematic affinity of *Lithocodium* remains an open question inspite the frequent hypothesis as disccussed above.

Constructional type of *Lithocodium* buildup

The primary mode of life of Lithocodium is encrusting various substrates and sedimentary particles, due to genetic and ecological controls. Therefore *Lithocodium* can be defined as typical „plano-occupant“ (Moussavian 1995) within the „binder guild“ (Fagerstrom 1987, 1988).

Covering a facies of oolitic-bearing sands (unit-SO with superficial ooids), *Lithocodium* led to local fixing of fossil-rich wackestones and packstones. Micritic rims around biogenic particles generally indicate a high microbial acivity in this environment which was favourable for the initiation of the massive growth of *Lithocodium aggregatum* by encrusting and binding various substrates and particles (compare also Neuweiler & Reitner 1992).

Thus a growth-sequence was formed which interfingers intesively with sedimentary textures. Also important in this environment, but generally subordinate, other encrusters as microbial/cyanobacterial associations, agglutinating foraminifera and probably non-skeletal organisms occured too.

The intensive encrustation took place periodically and diachronous, interrupted by short-term higher energy bioclastic environments.Thus a vertical alternation and lateral interfingering of bioclastic sediments and massive encrusted carbonate-sands with rudist-biostroms are formed which all together make up the complete buildup.

Therefore the obvious patchreef is interpreted as a vertical pile of *Lithocodium*-encrustation sequences and associated rudist-lenses separated from each other by bioclastic sands. All sediments are lithified by early diagenetic marine phreatic cements.

Depositional environment

The central part of the buildup analyzed, rich in *Lithocodium*, has a thickness od about 40 m occurring within a complete positive structure of total thickness of about 100 m. The general sahallow subtidal depositional environment in which this structures has been formed is characterized by the predominance of agglutinating and porcellaneous foraminifera throughout.

Above a basal oolitic unit, bioclastic sand bars were deposited periodically. In periods of reduced or interrupted sedimentation they were fixed at their top by cyanobacteria-mats, whereas *Lithocodium* was responsible for the internal stabilization of these sand bodies at the same time. Additonally early marine phreatic cements were formed in open pores of the packstones and grainstones. Lenses of small rudist-biostroms formed which are sepatered laterally by bioclastic sands. Thus the complete buildup is constructed by a vertical and lateral alternation of bioclastic sands, fixed by *Lithocodium*, by small rudist biostroms (up to 4 m thickness) and by bioclastic sands without *Lithocodium*. The marked morphology of the buildup is additonally forced by diffrential compaction of the neighboured lagoonal sediments which are more micritic and therefeore probably not so intensively lithified as the pack- and grainstones of the buildup.

Within the Triassic to Cretaceous *Lithocodium* is found more commonly in generally reduced internal platform settings than in external platform areas (Elliott 1956, Radoičić 1959, Misik 1979, Flügel 1979, Alsharan 1985, 1987, Banner et al. 1990, Neuweiler & Reitner 1992, Höfling 1997). The massive „reef-like“ constructions of *Lithocodium* are characteristic for restricted, internal platform areas with reduced diversity. During the Cretaceous these were also the best locations for requieniid rudists (Moussavian 1992). But due to adaptive strategy and constructional morphology requienids could not form „reefs“. Therefore *Lithocodium* was the only successful organism, in the formation of buildups within these environments.

Differential Compaction

The correlation of the three profiles A, B, and C allows to reveal the history of differential compaction of the associated lagoonal sediments in comparison to the more massive patch reef limestones.

Differential compaction will occur wherever a compactible unit changes laterally in thickness or compactibility (Labute & Gretener 1969). It is generally accepted that finer-grained sediments (micrite, clay) have a higher water content than coarser-grained sediments. This effect triggers the compactional behaviour of fine-grained sediments (Bayer & Wetzel 1989). Consequently the geometry of pores will be altered by early compaction (Wetzel 1984). Therefore the pore water in micritic sediments shows only very minor flow rates due to decrease of permeability with decreasing grains size, decreasing pore-throat diameters with increasing time of overburden. Thus coarse grained sediments and also reefal strcutures with high fluid rates of pore water commonly reveal a much more intensive eraly diagenetic cementation than associated finer-grained sediments where even nearly no cementation can occur at the same time (Lighty 1985). Shinn & Robbin (1983) documented in experiments different the mode and degree of compaction can be in recent sediments. Similar experiments were carried out by Fruth et al. (1966), documenting the varying degrees of compactibility of wackestones, packstones and oolitic grainstones.

These help to establish the following genetic model of differential compaction of the lateral deposited sediments in comparison to the more massive Sabotin patch reef limestone in different.

The top of the basal unit-SO, which is characterized by a marked bed surface, is taken as horizontal time line upon which the patch reef dveloped by accumulation of organisms, growth franmework and cementation.

The key for this model is documented best by the decreasing dip of correlation lines between profile B and A from bottom to top. It is obvious that the sediments of the unit-LBR have been most intensively compacted in profile A (25 m; more micritic) in comparision to the massive limestones in profile B (34 m). Therein intensive cementation additionally to early binding and probabaly also in-situ carbonate production caused a more rigid structure.

The overlying unit-ST reveals reversal compaction in comparison of 20 m in profile A to 15 m in profile B due to deposition of more granular sediments in the area profile A. The same can be concluded for the overlying unit-IT. It can be assumed that the base of the unit-BS has been a nearly horizontalline immediately after deposition of the micritic, fine-layered sediments.

Consequently it becomes obvious that the main compaction must have occurred within the time span of about 50 m sediment-deposition overlying the patch reef. Furthermore a decrease in the degree of compaction from unit-LBR to unit-BS can be assumed which was caused by relief-egalisation due to sedimentation and early machanical compaction.

Compaction went on after the depostion of sediments overlying the limestones studied. This resulted in a further deformation process also of micritic fine-bedded sediments which were primary sedimented horizontal.

Thus differential compaction resulted in differences in thickness of about 10 m from the patch reef (profile B) to the more lagoonal influenced sediments (profile A) within a lateral distance of about 50 m.

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APPENDIX

List of microfossils:

Profile A

A2-44259
Palorbitolina lenticularis (Blumenbach)
Arenobulimina sp.
Verneuilina sp.

A4-44257
Palorbitolina lenticularis (Blumenbach)

A6-44272
Orbitolinidae
Everticyclammina sp.

A7-44263
Glomospira sp.
Nezzazatinella sp.

A8-44295
Salpingoporella dinarica Radoičić
Vercorsella sp.
Nezzazatinella sp.

A13-44271
Debarina hahounerensis Fourcade, Raoult & Vila
Earlandia conradi Arnaud-Vanneau
Arenobulimina sp.
Dobrogelina sp.
Nezzazatinella sp.
Vercorsella sp.

A16-44291
Sabaudia minuta (Hofker)
Vercorsella laurentii (Sartoni & Crescenti)
Bolivinopsis sp.

A18-44277
Salpingoporella dinarica Radoičić
Dobrogelina sp.

A19-44282
Praechrysalidina infracretacea Luperto Sinni
Vercorsella cf. scarsellai (De Castro)
Novalesia sp.
Dobrogelina sp.

A21-44293
(?) *Salpingoporella dinarica* Radoičić

A22-44262
Salpingoporella dinarica Radoičić
Glomospira urgoniana Arnaud-Vanneau
Nezzazatinella sp.

A24-44301
Salpingoporella dinarica Radoičić

A26-44287
(?) Charopytes

A28-44233
Halimedaceae
Orbitolinidae
Sabaudia minuta (Hofker)
Glomospira urgoniana Arnaud-Vanneau
Vercorsella laurentii (Sartoni & Crescenti)
Debarina sp.

A29-44258
Sabaudia minuta (Hofker)
Nezzazatinella sp.
Glomospira sp.

A30-44265
Cylindoporella ivanovici (Sokač)
Giraliarella? prismatica Arnaud-Vanneau
Earlandia? conradi Arnaud-Vanneau
Sabaudia minuta (Hofker)
Nezzazatinella sp.
Vercorsella sp.
(?)*Pseudocyclammina* sp.

Profile B

B3-4428(?)
Orbitolinidae – (?)*Palorbitolina*
Earlandia? conradi Arnaud-Vanneau
Nezzazatinella sp.
Meandrospira sp.

B5-44289
Orbitolinidae
Glomospira sp.
Andersenolina sp.

B6-44267
Orbitolinidae – (?)*Palorbitolina*
Verneuilina sp.

B17-44283
Glomospira urgoniana Arnaud-Vanneau
Vercorsella sp.
Novalesia sp.
Belorusiella sp.
Nezzazatinella sp.

B18/19 (?)
Salpingoporella muehlbergii (Lorenz)
(?) *Cylindroporella* sp.
Vercorsella camposaurii Sartoni & Crescenti
Pseudolituonella gavonensis Foury
Sabaudia minuta (Hofker)
Verneuilina sp.
Nezzazatinella sp.
Arenobulimina sp.
Andersenolina sp.

B20-44276
Salpingoporella muehlbergii (Lorenz)
Vercorsella laurentii (Sartoni & Crescenti)
Nezzazatinella sp.

B21-44255
Salpingoporella muehlbergii (Lorenz)
Pseudolituonella gavonensis Foury
Nezzazatinella sp.

B24-44298
Orbitolinidae
Spiroloculina cretacea Reuss

B25-44278
Polystrata alba (Pfender)
Orbitolinidae

B30-44260
Verneuilina polonica Cushman & Galzewki
Vercorsella laurentii (Sartoni & Crescenti)
Andersenolina sp.

B32-44300
Vercorsella arenata Arnaud-Vanneau
Nezzazatinella sp.

B33-44275
Salpingoporella dinarica Radoičić
Praechrysalidina infracretacea Luperto Sinni
Sabaudia minuta (Hofker)
Nezzazatinella sp.
Vercorsella sp.

B35-44286
Salpingoporella dinarica Radoičić

B37-44285
Salpingoporella dinarica Radoičić
Spiroloculina cretacea Reuss
Vercorsella sp.
Nezzazatinella sp.
Bolivinopsis sp.
Debarina sp.
Earlandia? sp.

Profile C

C2-44299
Palorbitolina lenticularis (Blumenbach)

C5-44290
Polystrata alba (Pfender)
Palorbitolina lenticularis (Blumenbach)

C8-44266
Earlandia? sp.
Gaudryina sp.

C10-44297
Vermiporella sp.
Palorbitolina lenticularis (Blumenbach)

C12-44402
Salpingoporella muehlbergii (Lorenz)
Cylindroporella sp.
Nautiloculina broennimanni Arnaud-Vanneau & Peybernes
Sabaudia minuta (Hofker)
Involutina sp.
Vercorsella sp.
Dobrogelina sp.

C15-44294
Earlandia? sp.
Vercorsella sp.

C17-44296
Polystrata alba (Pfender)
Vercorsella sp.

C19-44296
Polystrata alba (Pfender)
Orbitolinidae
Charentia sp.
Gaudryina sp.

C20-44284
Orbitolinidae
Sabaudia minuta (Hofker)
Charentia cuvillieri Neumann
Pseudolituonella conica Luperto Sinni & Masse
Earlandia? conradi Arnaud-Vanneau

C22-44254
Salpingoporella dinarica Radoičić
Pseudochrysalidina infracretacea Luperto Sinni
Vercorsella sp.
Nubecularia sp.
Spiroloculina sp.
Nezzazatinella sp.

C28-44270
Salpingoporella dinarica Radoičić
Praechrysalidina infracretacea Luperto Sinni
Voloshinoides murgensis Luperto Sinni & Masse
Arenobulimina sp.
Dobrogelina sp.

C35-44269
Praechysalidina infracretacea Luperto Sinni
Arenobulimina cf. *corniculum* Arnaud-Vanneau

C38-44288
Salpingoporella dinarica Radoičić
(?) Cretacicladus menervini Luperto Sinni
Praechrysalidina infracretacea Luperto Sinni
Glomospira urgoniana Arnaud-Vanneau
Dobrogelina sp.
Arenobulimina sp.

C40-44279
Salpingoporella dinarica Radoičić

General list

CALCAREOUS ALGAE

Cylindoporella ivanovici (Sokač)
Cylindroporella sp.
(?) *Cylindroporella* sp.
Salpingoporella muehlbergii (Lorenz)
Salpingoporella dinarica Radoičić
Halimedaceae
Polystrata alba (Pfender)
Vermiporella sp.
(?) Cretacicladus menervini Luperto Sinni
(?) Charophytes

FORAMINIFERA

Arenobulimina cf. *corniculum* Arnaud-Vanneau
Charentia cuvillieri Neumann
Debarina hahounerensis Fourcade, Raoult & Vila
Earlandia? conradi Arnaud-Vanneau
Giraliarella? prismatica Arnaud-Vanneau
Glomospira urgoniana Arnaud-Vanneau
Nautiloculina broennimanni Arnaud-Vanneau & Peybernes
Palorbitolina lenticularis (Blumenbach)
Praechrysalidina infracretacea Luperto Sinni
Pseudolituonella conica Luperto Sinni & Masse
Pseudolituonella gavonensis Foury
Sabaudia minuta (Hofker)
Spiroloculina cretacea Reuss
Vercorsella arenata Arnaud-Vanneau
Vercorsella camposaurii Sartoni & Crescenti
Vercorsella laurentii (Sartoni & Crescenti)
Vercorsella cf. scarsellai (De Castro)
Verneuilina polonica Cushman & Galzewki
Voloshinoides murgensis Luperto Sinni & Masse
Andersenolina sp.
Arenobulimina sp.
Belorusiella sp.
Bolivinopsis sp.
Charentia sp.
Debarina sp.
Dobrogelina sp.
Earlandia? sp.
Everticyclammina sp.
Gaudryina sp.
Glomospira sp.
Involutina sp.
Meandrospira sp.
Novalesia sp.
Nezzazatinella sp.
Nubecularia sp.
(?)*Pseudocyclammina* sp.
Spiroloculina sp.
Vercorsella sp.
Verneuilina sp.