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

Roman KOCH1, Esmail MOUSSAVIAN2, Bojan OGORELEC3, Dragomir SKABERNE3 & Ioan I. BUCUR4

1 Institut für Paläontologie, Loewenichstr. 28, D-91054 Erlangen; e-mail: rkoch@g40.pal.uni-erlangen.de;
2 Institut für Paläontologie u. hist. Geologie der Universität München, Richard-Wagner-Straße 10, D-8000 München;
3 Geolo{ki zavod Slovenije, Dimi~eva 14, SLO-1000 Ljubljana, e-mail: bojan.ogorelec@geo-zs.si, dragomir.skaberne@geo-zs.si,
4 Babes-Bolyai University, Department of Geology-Paleontology, M. Kogalniceanu str. 1, RO-3400 Cluj-Napoca, Romania, ibucur@biogeo.ubbcluj.ro

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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 sequence 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 build-up investigated, beginning, with the incrustation of varying substrates and biogenic particles. Finally, a dense network of encrustation-sequences is formed interfering 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 limestone. 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.

*Knjiga vsebine*

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 jazalno enoto, sestavljeno iz nepopolno razvitrjih oolitov (supeficial ooliths). Prekrivajo ga sedimetni nastali v plitvim morjih in v medplimski vodol. Na razkrivajo krpa hkratotrajne periodične oknopine in zgodnje diagenetski dotok sladke vode (teksture plačljive oceša, vadozni meljer, haraceje). Nad temi sedimetni, znotraj *cones Salpingogorgiella dinarica*, so razvit tanko plastnat do plakasti laminirani bituminozni apnenci.

V osrednjem delu grebena se menjajo leče apnenci z algi *Lithocodium* in strukturo boundstone z do 4 m debelimi plasti z rudistnimi školjkami, ki jih ločujejo pasti debelo do srednjezrnatega, srednje do slab omejenega biokastnega apnencna. Ti faciesi se tudi lateralno prepletajo in se koncentrirani v osrednjem delu grebena. V tem delu je greben najdebelnejši. V njen prevladujo apnenci s strukturo packstone, grainsstones in boundstone. Obdajajoči lagunske sedimetni, ki jih sestavljajo apnenci s prevladujočimi krpastimi, mudstone in wackstone, smo raziskali v tako imenovan standardnem profilu Sabotin, ki je 300 m severno od obravnavanega grebena. Prek njen vertikalnih profilov smo tri vertikalne profil, ki zajemajo debelino 64 do 100 m (A = 90 m, B = 100 m, C = 64 m). Srednji profil B, ki obsega največjo debelino in najboljše prikazuje vertikalni časovni razvoj znotraj krpastega grebena, smo določili kot referenčni profil. Ta zajema razlicito razvilino od belonih apnencev s naj manj etulo iz osrednjega dela grebena, ki je 300 m severno od obravnavanega grebena. Pri korelaciji z uporabo različnih časovnih crti (vodiho poravnat), se pokaza velik vpliv in pomembnost, že zelo zgodnje diferencialne kompakcije ne cementiranih drobnozrnatih sedimeto v primerjavi s jedrom krpastega grebena. Večja debelina samega krpastega grebena, je posledica zgodnje diagenetskih fenomenov (syn. *Bacinella irregularis*), kar je povzročilo manjšo stopnjo kompakcije.

Nadalje smo lahko, glede na položaj krpastega grebena, določili smer raztezanja lagune v osrednjem delu krpastega grebena in 300 m severno od obravnavanega grebena. *Lithocodium aggregatum* in *Salpingoporrella dinarica*, je zavesno razvito v osrednem delu grebena, ki je 300 m severno od obravnavanega grebena. *Lithocodium aggregatum* in *Palorbitolina lenticularis* krpasti greben.

**Introdukcija**

*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***
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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, hippocrinitids) 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 rudist-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 Berriasian 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 specialized 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 profiles 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 overthrust (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 individual 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).
Biostratigraphy

The whole assemblage of microfossils (appendix) indicate an Early Aptian (Bedoulian) age (Schroeder 1975, Arnaud-Vanneau 1980, Arnaud-Vanneau & Chiocciini 1985, Luperto Sinni & Massa 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 being indicative for Aptian time interval (upper part of the Lower Aptian and lower part of the Upper Aptian (Farinacci & Radoićić 1994, Velić 1977, Sokač et al. 1978, Lj. Štriba 1979, Turnšek & Buser 1966, Koch et al., 1989, Koch et al. 1998, Jurkovšek et al.1996, L. Štriba 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 allochons, 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-
Development of a Lithocodium (syn. Bacinella irregularis)-reef-mound- 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 by 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 biogenic constituents 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

| Thickness (m) | Lithology | Name     | Texture | Litho | Dasy | Bio | Rudists | Echin | Foram | Appl. F. | Orbito | Mil | Cyano | Ostra |
|--------------|-----------|----------|---------|-------|------|-----|---------|-------|-------|----------|--------|-----|-------|-------|
| 0-21         | Unit-SO   | Central patch reef; Lithocodium-Bacinella-rudist boundstones  |
| 21-30        |           |          |         | S.m.  |      |     |         |       |       |          |        |     |       |       |
| 30-55        |           |          |         | S.d.  |      |     |         |       |       |          |        |     |       |       |
| 55-90        | Unit-LBR  |          |         |       |      |     |         |       |       |          |        |     |       |       |
| 90-120       |           |          |         |       |      |     |         |       |       |          |        |     |       |       |
| 120-150      |           |          |         |       |      |     |         |       |       |          |        |     |       |       |

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), foraminifera (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, organogenic 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 faunal 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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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, stromatoporoids 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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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 isopachous 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. Characteristic 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 freshwater influxes. Predominantly mudstones with small ostracods and charophytes (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 successive 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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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 bituminous 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.

**Characteristics of the Lithocodium reef-mound**

As mentioned above, the „reef“ was first noted due to its 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-

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**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 margensis* Luperto Sinni & Masse. 12-transverse-oblique section; 13-Longitudinal-oblique section. Sample C28-44270, x 50.
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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) probably 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 together 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 compaction. 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 revealing 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 Ban
er et al. 1990 which all seem to be synony-

mous. 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) interpreted it as a foraminifer.

Based on systematic and palaeoecological 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 a 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 μm size which are slightly recrystallized to micrite (< 4 μm). The skeleton of a juvenile 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 tissue. 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 organism 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 discussed 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 activity 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 intensively with sedimentary textures. Also important in this environment, but generally subordinate, other encrusters as microbial/cyanobacterial associations, agglutinating foraminifera and probably non-skeletal organisms occurred too.

The intensive encrustation took place periodically and diachronous, interrupted by short-term higher energy bioclastic environments. Thus a vertical alternation and lateral interfingeriing of bioclastic sediments and massive encrusted carbonate-sands with rudist-biostroms are formed which altogether 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 of about 40 m occurring within a complete positive structure of total thickness of about 100 m. The general shallow 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. Additionally early marine phreatic cements were formed in open pores of the packstones and grainstones. Lenses of small rudist-biostroms formed which are separated 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 additionally forced by differential compaction of the neighboured lagoonal sediments which are more micritic and therefore 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, Radoišič 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 whenever 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 reeval structures with high fluid rates of pore water commonly reveal a much more intensive early diageneric cementation than associated fine-grained sediments where even nearly no cementation can occur at the same time (Lighty 1983). 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 developed by accumulation of organisms, growth framework 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 comparison to the massive limestones in profile B (34 m). Therein intensive cementation additionally to early binding and probably 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 horizontal line 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 mechanical compaction.

Compaction went on after the deposition 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.
Verneulinia sp.

A4-44257
Palorbitolina lenticularis (Blumenbach)

A6-44272
Orbitolinidae
Everticyclammina sp.

A7-44263
Glosmosira sp.
Nezzazatiniellana sp.

A8-44295
Salpingoporella dinarica Radoičić
Verocorsella sp.
Nezzazatiniellana sp.

A13-44271
Debarina hahounerensis Fourcade, Raoul & Vila
Earlandia conradi Arnaud-Vanneau
Arenobulimina sp.
Dobrogelina sp.
Nezzazatiniellana sp.
Verocorsella sp.

A21-44293
Sabaudia minuta (Hofker)
Verocorsella laurentii (Sartoni & Crescenti)
Bolivinopsis sp.

A22-44262
Salpingoporella dinarica Radoičić
Dobrogelina sp.

A24-44301
Salpingoporella dinarica Radoičić

A26-44301
Bolivinopsis
Nezzazatiniellana sp.

A28-44233
Debarina hahounerensis Fourcade, Raoul & Vila
Earlandia conradi Arnaud-Vanneau
Arenobulimina sp.
Dobrogelina sp.
Nezzazatiniellana sp.
Verocorsella sp.

A29-44301
Salpingoporella dinarica Radoičić
Dobrogelina sp.

A39-44301
Bolivinopsis
Nezzazatiniellana sp.

A44-4287
(?) Salpingoporella dinarica Radoičić

A45-44301
Bolivinopsis

A48-44301
Salpingoporella dinarica Radoičić

A52-44301
(?) Charopytes

A55-44301
Halimedaceae

A56-44301
Sabaudia minuta (Hofker)
Glosmosira urgoniana Arnaud-Vanneau
Verocorsella laurientii (Sartoni & Crescenti)
Debarina sp.
Development of a Lithocodium (syn. Bacinella irregularis)-reef-mound-…

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

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

Profile B

B3-44280
Orbitolinidae – (?Palorbitolina
Earlandia? conradi Arnaud-Vanneau
Nezzazatinella sp.
Meandrospira sp.

B5-44289
Orbitolinidae
Glomospira sp.
Andersenolina sp.

B6-44287
Orbitolinidae – (?Palorbitolina
Verneuilina sp.

B17-44283
Glomospira urgoniana Arnaud-Vanneau
Vercorsella sp.
Nobalesia sp.
Belorussia sp.
Nezzazatinella sp.

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

B20-44276
Salpingoporella muehlbergii (Lorenz)
Vercorsella lauerentii (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 Cushen & Galzewski
Vercorsella lauperitii (Sartoni & Crescenti)
Andersenolina sp.

B32-44300
Vercorsella arenata Arnaud-Vanneau
Nezzazatinella sp.

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

B35-44286
Salpingoporella dinarica Radoičić

B37-44285
Salpingoporella dinarica Radoičić
Sporostrulina cretacea Reuss
Vercorsella sp.
Nezzazatinella sp.
Bolivinopora 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 breuninmanni 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
Nubecularia sp.
Nezzazatinella sp.

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

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

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

C40-44279
Salpingoporella dinarica Radoičić

General list

CALCAREOUS ALGAE
Cylindroporella ivanovici (Sokač)
Cylindroporella sp.
(?) Cylindroporella sp.
Salpingoporella maehilbergii (Lorenz)
Salpingoporella dinarica Radoičić
Halimedaeeae
Polystrata alba (Pfender)

Vermiporella sp.
(?) Cretaci cladus menervini Luperto Sinni
(?) Charophytes

FORAMINIFERA
Arenobulimina cf. corniculum Arnaud-Vanneau
Chara rentia cuvillieri Neumann
Debarina hahounerensis Fourcade, Raoult & Vila
Earlandia? conradi Arnaud-Vanneau
Girularella? prismatica Arnaud-Vanneau
Glomospira urgoniana Arnaud-Vanneau
Nautiloculina broennimannii Arnaud-Vanneau & Peybernes
Palorbitolina lenticularis (Blumenbach)
Praechrysalidina infracretacea Luperto Sinni
Pseudolituonella conica Luperto Sinni & Masse
Pseudolituonella galovenensis Foury
Sobaudia minuta (Holker)
Spiroloculina cretacea Reuss
Vercorsella arenata Arnaud-Vanneau
Vercorsella campasaurii Sartoni & Crescenti
Vercorsella laurentii (Sartoni & Crescenti)
Vercorsella cf. scarsellai (De Castro)
Verneuilina polonica Cushman & Galzewski
Voloshinoides murgensis Luperto Sinni & Masse
Andersenolina sp.
Arenobulimina sp.
Belorussiella sp.
Bolivinopsis sp.
Charentia sp.
Debarina sp.
Dobrogelina sp.
Earlandia? sp.
Everticyclammina sp.
Gaudryina sp.
Glomospira sp.
Involutina sp.
Meandrospira sp.
Noualesia sp.
Nezzazatinella sp.
Nubecularia sp.
(?) Pseudocyclammina sp.
Spiroloculina sp.
Vercorsella sp.
Verneuilina sp.