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Coralline Red Algal Limestones of the Late Eocene Alpine Foreland Basin in Upper Austria: Component Analysis, Facies and Paleecology

Michael W. **Rasser**, Vienna

KEYWORDS: MICROFACIES ANALYSIS – COMPONENT ANALYSIS – FACIES – PALECOLOGY – RED ALGAL LIMESTONES – CORALLINE ALGAE – PEYSSONNELIACEAN ALGAE – RHODOLITHS – LARGER FORAMINIFERA – BRYOZOA – ALPINE FORELAND BASIN – UPPER AUSTRIA – LATE EOCENE – PALEOGENE

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SUMMARY

Late Eocene sediments of the Upper Austrian Alpine Foreland Basin discordantly overlie Mesozoic and crystalline rocks, which are deeply eroded and form a distinct pre-Eocene relief. Late Eocene deposits contain red algal limestones with a remarkable lateral extent and a high diversity of sedimentary facies. Towards the south the algal limestones change into more clastic sediments, which are characterized by larger foraminifera and bryozoans. Main components are coralline algal branches and detritus, coralline crusts, rhodoliths, peyssonneliacean aggregates and crusts, nummulitid and orthophragminid

foraminifera, corals, bryozoans, as well as terrigenous components.

Rank correlation and factor analysis were calculated in order to obtain informations about relations between components. Hierarchical cluster analysis allowed the designation of 17 facies, most of them are dominated by coralline algae. Actualistic comparisons and correlations obtained from statistical analyses allowed the reconstruction of the depositional environments.

Main features of the northern area are huge accumulations of unattached coralline algae (branches, rhodoliths, detritus), which are comparable to the present-day "Maerl"-facies. They formed loose frameworks cut by sand channels. The frequency of coralline detritus decreases upsection. Peyssonneliacean algae in higher parts of the profiles show growth-forms that are comparable to peyssonneliaceans of the Mediterranean circalittoral soft bottoms. This succession can be interpreted by an increasing relative sea level. Besides, crustose coralline algal frameworks were growing on morphological highs which are partially comparable to the present-day "Coralligène de Plateau" of the Mediterranean Sea.

In contrast to the northern area, sedimentation rate of the southern area is too low to keep up with rising sea level. The typical succession from nummulitid- to orthophragminid- and bryozoan-dominated facies can be interpreted by an increasing water depth from shallowest subtidal to the deeper photic zone and finally to the aphotic zone.

1 INTRODUCTION

Most Late Eocene shallow water carbonates of the Eastern Alps and the Alpine Foreland Basin are small-scaled and tectonically isolated (e. g., PAPP, 1958; JANOSCHEK, 1964; OBERHAUSER, 1995). In contrast, the autochthonous Late Eocene of the Alpine-Carpathian Foreland Basin is part of a

Address: Dr. M. W. Rasser, Institute of Paleontology, University of Vienna, Geozentrum, Althanstrasse 14, A-1090 Vienna. E-mail: Michael.Rasser@univie.ac.at. Correspondence address: Institute of Geology and Paleontology, Karl-Franzens-University of Graz, Heinrichstrasse 26, A-8010 Graz

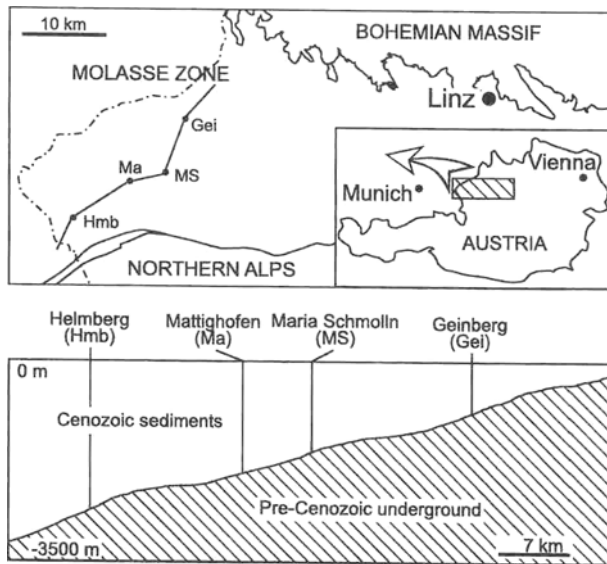


Fig. 1. Sketch of study area showing the geological units, studied deep wells, as well as position of NE - SW directed section (lower part). Section shows the present-day dipping of the European plate (hatched; not to scale) and position of deep wells; note that section cuts two E - W striking swells: one between Helmburg and Mattighofen (corresponding to the "Central Swell Zone" after WAGNER, 1998), the other at Maria Schmolln. Deep wells: Gei = Geinberg, MS = Maria Schmolln, Ma = Mattighofen, Hmb = Helmburg.

laterally extensive belt of platform carbonates. They are reported from France (SINCLAIR et al., 1998), Switzerland (BURKHARD and SOMMARUGA, 1998), Bavaria (BUCHHOLZ, 1984; 1989), and Upper Austria (WAGNER, 1996; 1998). Although only known from deep wells, the sediments in question provide the unique possibility to study undisturbed vertical and lateral successions of high diverse algal limestone facies which are partially comparable to present-day occurrences.

ABERER (1958) gave a first overview of the studied sediments. He defined lithostratigraphic units and discussed the Nummulite biostratigraphy of PAPP (1958).

JANOSCHEK & GÖTZINGER (1969), KOLLMANN (1977), KRÖLL et al. (1981), and BRIX & SCHULTZ (1993) published overviews of the Molasse Zone in Upper and Lower Austria. Lithology of Late Eocene sediments was described by KOLLMANN (1966) and WAGNER (1980). WAGNER et al. (1986), NACHTMANN & WAGNER (1987), and WAGNER (1996; 1998) summarized the geodynamic evolution of the study area. The current paper is part of a series of studies (most of them are still in press) dealing with biostratigraphy, taxonomy of calcareous algae (RASSER and PILLER, 1999), as well as underground morphology and sediment distribution (RASSER, 1999) of the autochthonous Late Eocene sediments of the Alpine Foreland Basin in Upper Austria.

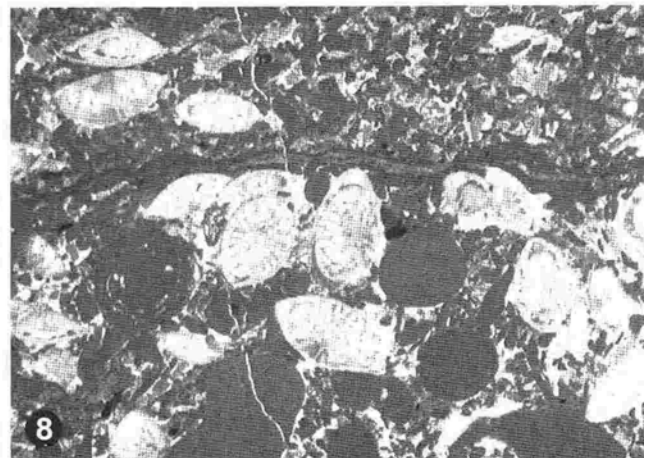
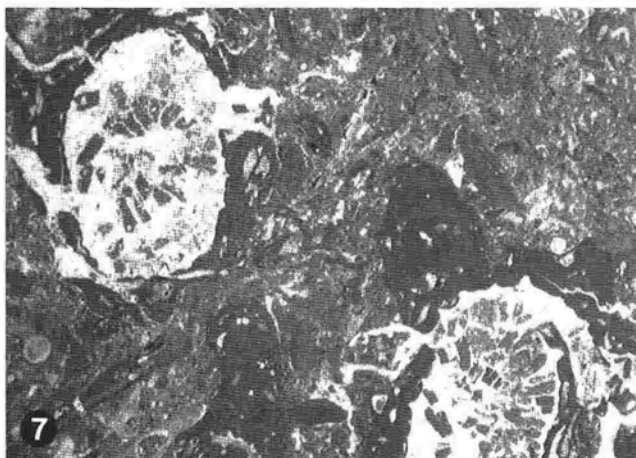
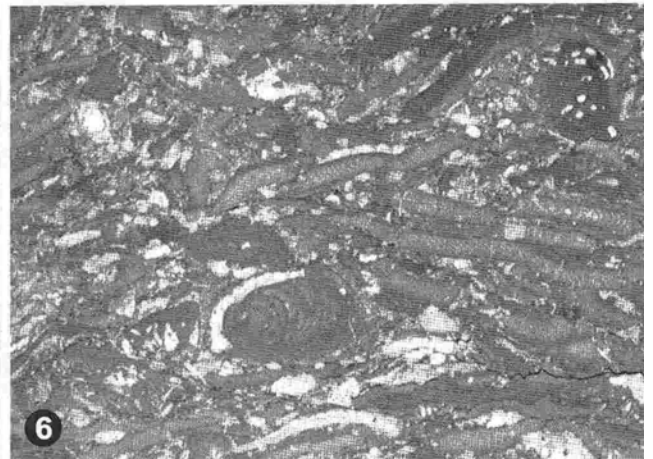
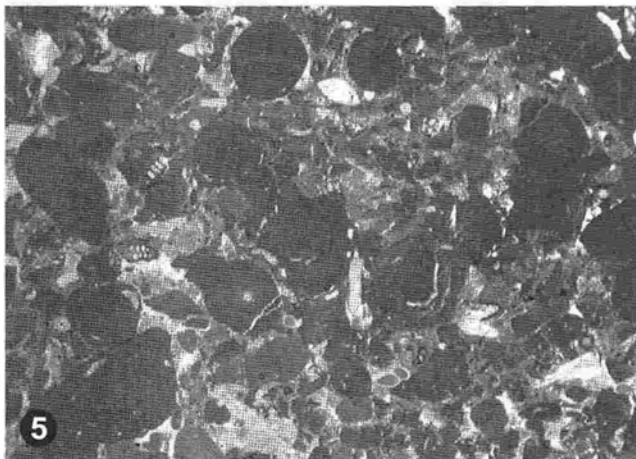
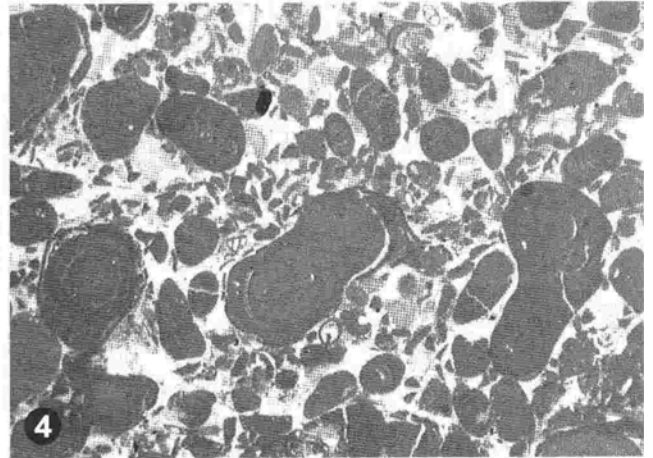
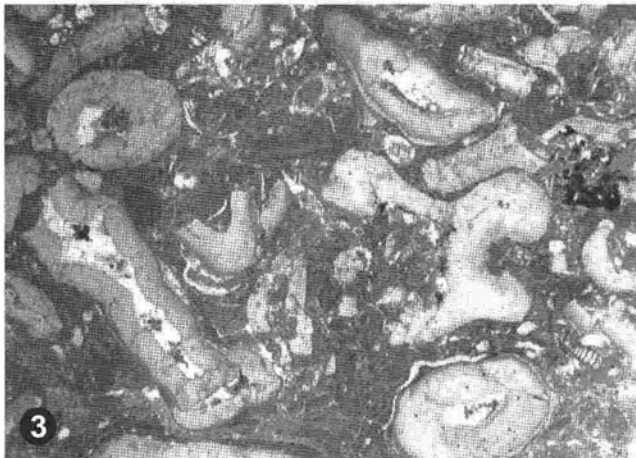
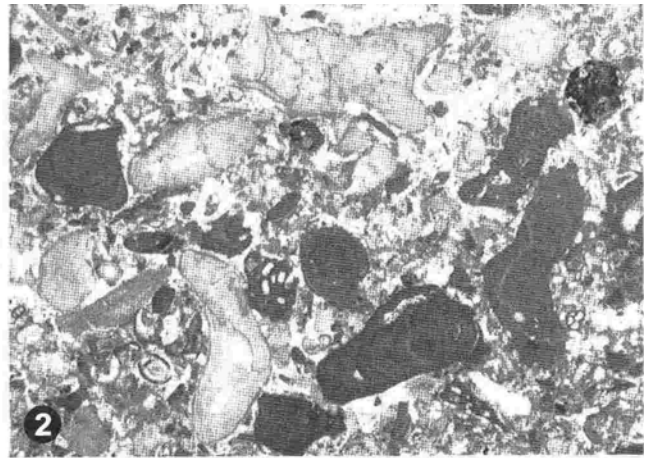
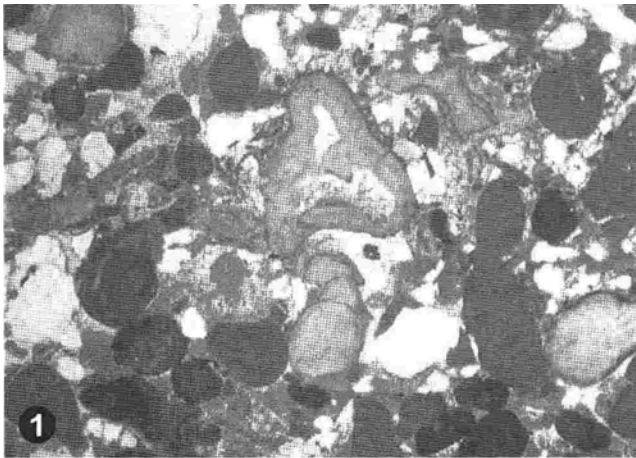
The components are described and analysed using Spearman rank correlation, hierarchical cluster analysis, and factor analysis. Relations between components are interpreted. Facies designation revealed from cluster analysis was tested with factor analysis and a transition probability matrix (Markov-chain) was calculated. The facies are described qualitatively and quantitatively. Actualistic comparison was conducted in order to reconstruct the paleoecology and facies development.

2 STUDY AREA

The Molasse Zone of Upper Austria and Salzburg is part of the Alpine-Carpathian foreland basin (STEININGER et al., 1986; WAGNER, 1996). The Cenozoic basin of the study area has the form of a south-dipping, 30-55 km wide asymmetrical trough. Its northern margin is formed by the outcropping basement of the Bohemian Massif, while its southern margin corresponds to the Alpine thrust front (Fig. 1). In this basin the thickness of the Cenozoic sequence ranges from a few meters along its northern margin to over 3000 m along the Alpine deformation front. Today the crust of the European foreland extends as a monoclinial ramp at least some 50 km southward from the Alpine deformation front under the Alpine-Carpathian nappe complexes (WESSELY, 1987). The pre-Cenozoic underground and the studied Late Eocene algal limestones are only

Plate 12 Late Eocene of the Alpine Foreland Basin in Upper Austria - Facies characteristics. Width of pictures 12.6 mm.

- Fig. 1. (A) Terrigenous Coralline Detritus - Peyssonneliacean Facies, showing coralline algae (dark) and peyssonneliacean aggregates (grey). Sample Gei-309.
- Fig. 2. (B) Coralline Detritus - Peyssonneliacean Facies. Sample MS-287.
- Fig. 3. (C) Peyssonneliacean Facies; note the high amount of micrite compared to Figs. 1 and 2. Sample MS-300.
- Fig. 4. (D) Branched Coralline Facies with grainstone matrix; coralline branches are unfragmented, fine-grained coralline detritus is well rounded. Sample Ma-215.
- Fig. 5. (D) Branched Coralline Facies with packstone matrix. Sample MS271.
- Fig. 6. (E) Crustose Coralline Detritus Facies. Crusts do not form bindstones, but seem to be in-situ. Sample Ma-250.
- Fig. 7. (F) Coralline Detritus - Coral Facies; coral skeletons are usually not preserved; note encrustations by coralline algae. Sample MS-297.
- Fig. 8. (G) Coralline Detritus Facies, showing one of the rare nummulitid-accumulations; note that horizontal coralline crust overgrows larger foraminifera. Sample MS-272.



known from deep wells drilled by the Rohöl AG Vienna. Approximately 200 deep wells are known in Upper Austria and Salzburg.

3 GEOLOGY AND LITHOSTRATIGRAPHY

Late Eocene sediments of the eastern Alpine Foreland Basin (Austria and Bavaria) were part of the northern Tethys shelf. The Late Eocene transgression was caused by subduction of the European Plate under the Adriatic Plate during the Alpine orogeny (WESSELY, 1987; ZIEGLER, 1987; WAGNER, 1998). In terms of subsidence patterns in Foreland Basins, the Late Eocene Alpine Foreland Basin represents the initial stage of asymmetrical flexural loading (ZWEIGELT et al., 1998); this caused the formation of a carbonate ramp. Late Eocene sediments transgressed on a tectonically dissected and deeply eroded underground composed of Mesozoic sediments (WAGNER, 1980; 1998). The reconstruction of tectonical throws shows several basin-parallel troughs and swells, which influenced the distribution of Late Eocene sediments (Fig. 1; RASSER, 1999). The latter are overlain by deeper water Lower Oligocene sediments ("Latdorf-Fischschiefer") reflecting the increasing subsidence during Alpine orogeny (WAGNER, 1998).

Earlier studies on sedimentology and lithostratigraphy were conducted by WAGNER (1980; 1996; 1998). He summarized the studied sediments to the Perwang-Group. Basal siliciclastic sediments, which were not studied in the current paper, are represented by limnic sands and clays (Voitsdorf-Formation), intertidal sands and clays (Cerithium-Beds), and beach sands (Ampling-Sandstone). He described "nummulitic sandstone", orthofragminid-dominated sediments (Perwang-Formation) and "*Globigerina*-limestones" (Nußdorf-Formation) from the southern part and algae-dominated sediments ("Lithothamnium-limestone") from the northern part of the study area. Comparable facies are documented from the adjacent Late Eocene

Foreland Basin of Bavaria (FÜCHTBAUER, 1964; BLIND, 1965; BUCHHOLZ, 1984; 1989). Towards the south, the studied deposits pass into the "Stockletten"-facies of the Helvetic Zone (DARGA, 1992).

4 METHODS

4.1 Sampling and Quantification

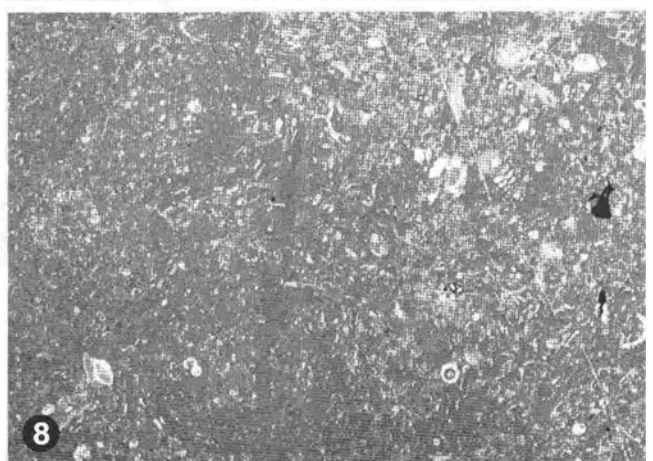
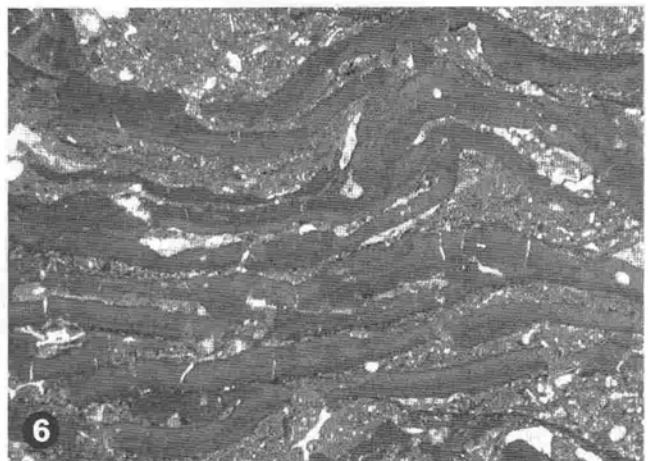
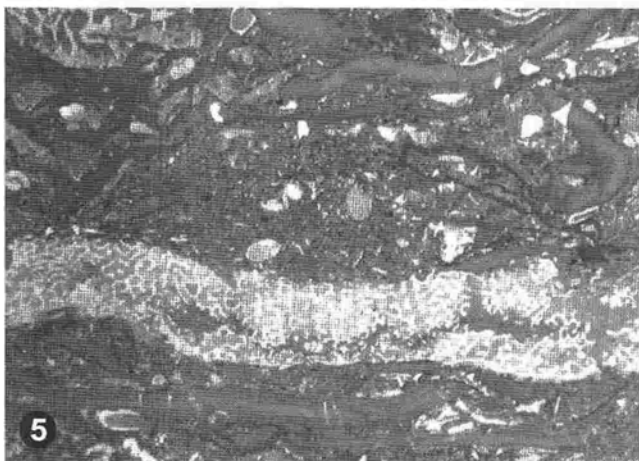
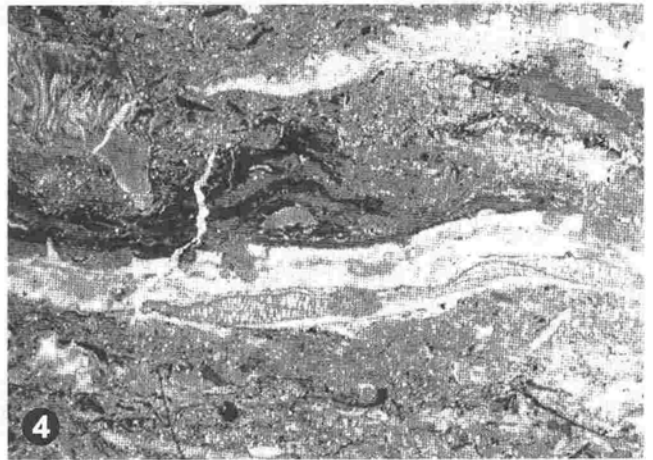
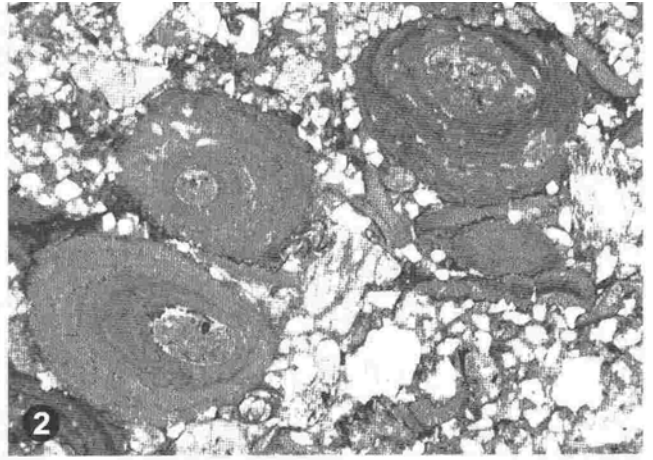
The sampled cores reveal a diameter of approx. 7 cm. Samples were not taken in distinct verticals interval but whenever the facies changed. When one facies reached a thickness of more than one meter samples were taken at least in a one-meter interval. Paleontological thin sections with sizes of 5 x 5 and 12 x 6 cm, several polished slabs, as well as several SEM-samples were prepared. 120 thin sections of the deep wells Geinberg, Mattighofen, Maria Schmolln, and Helmberg (Fig. 1) were quantified. Modal composition of thin sections was analysed by point counting using "Prior" point counter, model G. This instrument allowed to count an area of 30 x 30 mm. Each sample was counted up to 600 points. Grain solid method after DUNHAM (1962) was used. Because of their large size, rhodoliths cannot be counted in thin sections. Their abundance was estimated directly from the cores using the estimation charts of BACCALLE and BOSELLINI (1965). Quantified components and modal composition of samples are listed in Appendix 1. The studied material is stored at the Institute of Paleontology, University of Vienna, Austria.

4.2 Statistical Analyses

Statistical analyses were calculated using the SPSS for Windows (versions 5 and 7) software package (BÜHL and ZÖFEL, 1996). Spearman's Correlation Coefficient was calculated using 2-tailed significance, as data are not normally distributed (tested with Kolmogorov-Smirnov). Correlation Coefficients reveal whether the variables (i. e.,

Plate 13 Late Eocene of the Alpine Foreland Basin in Upper Austria - Facies characteristics

- Fig. 1. (I) Coralline Quartz Sandstone Facies with fragmented ostreid bivalve (upper left) and dark coralline algae. Sample MS-265. Width of picture 12.6 mm.
- Fig. 2. (J) Foraminiferal Quartz Sandstone Facies, showing *Acervulina linearis*; note rounded growth-form and sediment-filled inner cavities. Sample Hmb-317. Width of picture 13.2 mm.
- Fig. 3. (J) Foraminiferal Quartz Sandstone Facies, dominated by nummulitids. Sample Hmb-323. Width of picture 14 mm.
- Figs. 4 - 6. Development of a crustose framework (K; Crustose Coralline - Coral Facies) in deep well Mattighofen.
- Fig. 4. Base of coralline framework: Bivalve in a fine-grained matrix (mesh-like structure in the middle part), encrusted by an unpreserved coral colony; the latter is encrusted by dark coralline algal crusts. Sample Ma-203. Width of picture 12.6 mm.
- Fig. 5. (K) Crustose Coralline - Coral Facies; middle part of crustose framework, represented by a coralline - coral bindstone. Sample Ma-206. Width of picture 12.6 mm.
- Fig. 6. (K) Crustose Coralline - Coral Facies; upper part of crustose framework, dominated by coralline crusts. Sample Ma-207. Width of picture 12.6 mm.
- Fig. 7. (L) Discocylinid Facies. Sample Hmb-329. Width of picture 12.6 mm.
- Fig. 8. (M) Bioclastic Packstone Facies. Sample Hmb-342. Width of picture 12.6 mm.



components) of different objects (i. e., geological samples) are linked in an underlying causative process (SWAN and SANDILAND, 1995). Variables are significantly correlated if the significance (p) is < 0.05 . Correlation coefficient (R_s) shows the degree of correlation and if it is positive or negative (DAVIS, 1973). A correlation between ± 0.2 and ± 0.5 is low, between ± 0.5 and $0.7 \pm$ it is medium, between $0.7 \pm$ and ± 0.9 it is high (BÜHL and ZÖFEL, 1996).

However, variables can show dummy correlations caused by the influence of any other interfering variable. Therefore, partial correlation was calculated using 2-tailed significance. This method reveals whether two variables, which were correlated by the Spearman rank correlation, are still correlated after the exclusion of selected variables (BÜHL and ZÖFEL, 1996).

Hierarchical cluster analysis was used to find correlations between geological samples ("objects" in statistical terminology) and to separate distinctive facies. This was necessary owing to the high amount of samples and components. First the "Nearest Neighbour" method was calculated to eliminate outliers. Final cluster analysis was calculated using the "Ward Method" with "Euclidian distance" interval. Relative values of quantified components were transformed using the arc sinus function using the program MS Excel for Windows; formula: $\text{asin}(\sqrt{\#})$, where # means the respective value.

Factor analysis reduces the overall complexity of data by extracting factors which account for the variance observed in the data. It calculates a hypothetical value (= factor) and a correlation coefficient which shows the degree of correlation between each variable and the factor in a factor matrix. This method was used to confirm the formation of clusters obtained from cluster analysis - and thus to test the reliability of facies designation. Geological samples were analysed and factor loadings plotted on a scatterplot. Vertical distances between samples of one cluster reveal their similarities. Factor analysis was additionally used for analysis of variables. The latter are correlated to different factors, which can be interpreted as

paleocological parameters. Varimax rotation was conducted in order to enhance the important loadings.

Markov chain analysis (MIALL, 1973; SWAN and SANDILANDS, 1995) was conducted in order to obtain general trends of facies development. A transition probability matrix was calculated based on a transition frequency matrix. Transitions are defined where the facies changes. The matrix reveals the probability that one facies follows above the other. As the number of observed transitions was not sufficient for reliable conclusions (at least five transitions per entry), the results have to be interpreted with caution.

4.3 Carbonate Nomenclature

Carbonate nomenclature is used after DUNHAM (1962) and EMBRY and KLOVAN (1972). EMBRY and KLOVAN defined floatstones as the conglomeratic analogues of wackestones; rudstones are the conglomeratic analogues of both pack- and grainstones. This nomenclature is expected to reflect the hydrodynamic energy of the depositional environment. Therefore, EMBRY and KLOVAN use it only for allochthonous limestones in which the particle size is caused by erosion and redeposition. Nevertheless, terms like "rhodolith rudstone" (as a ruditic analogue for grain- and packstone dominated by rhodoliths) are used in the current study, as they sufficiently describe particle sizes and matrix content. Additionally, the term "diagenetic packstone" is used for packstones which are obviously caused by pressure solution of the groundmass (FLÜGEL, 1982).

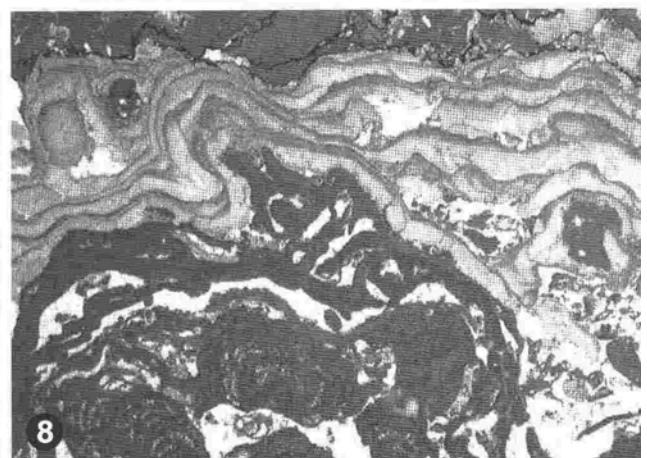
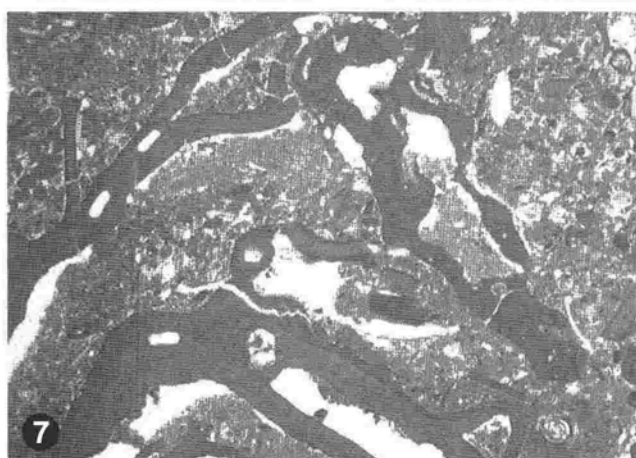
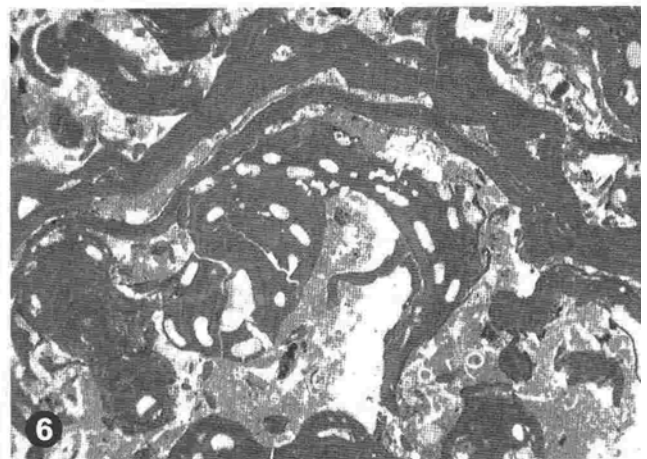
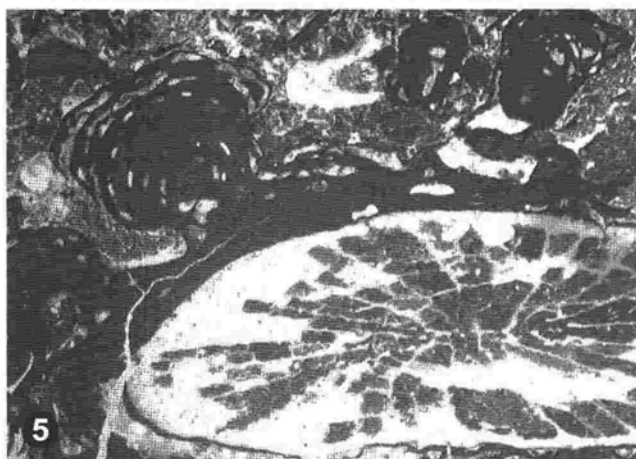
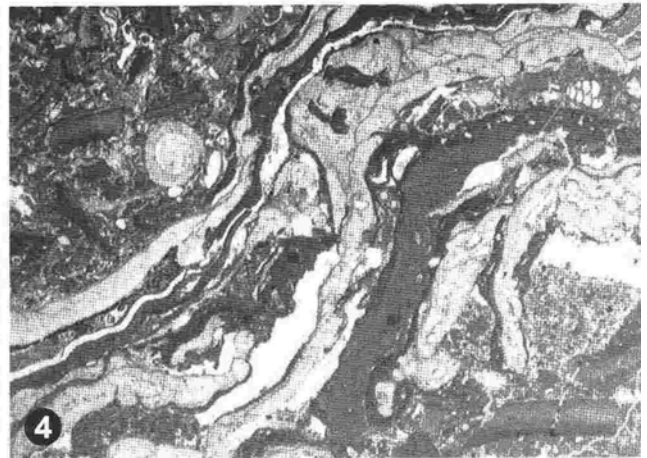
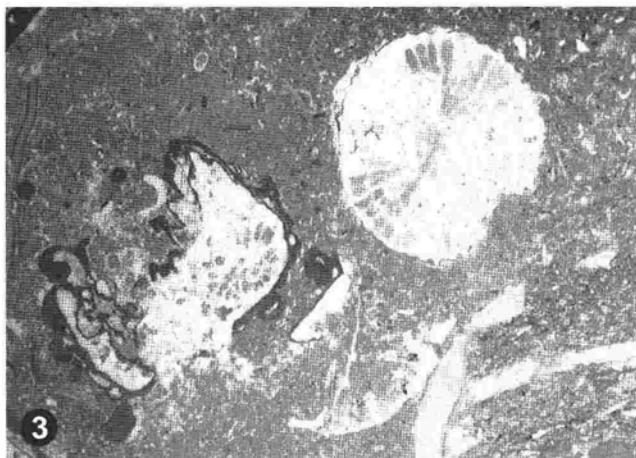
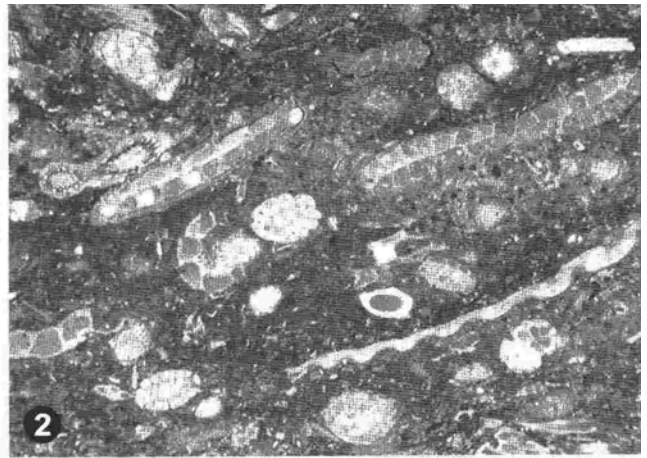
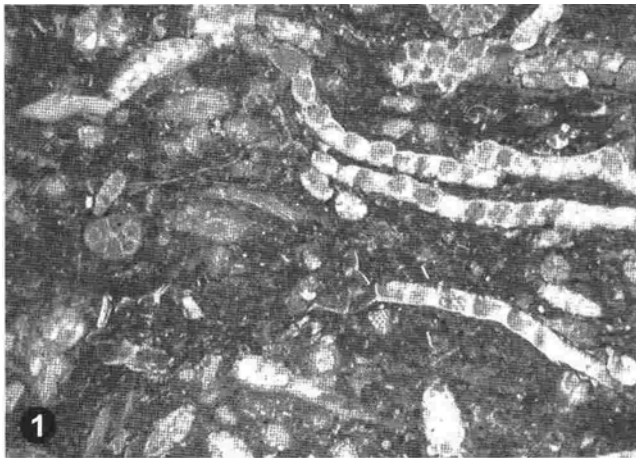
5 RESULTS

5.1 Components

The carbonate components are almost only dominated by skeletal components. Non-skeletal components, like ooids and grapestones, do not occur. No activity of cyanobacteria was observed. Micrite envelopes are lacking, peloids are extremely rare. Extra- and intraclasts were

Plate 14 Late Eocene of the Alpine Foreland Basin in Upper Austria - Facies characteristics

- Fig. 1. (N) Bryozoa Facies, with unilaminar erect growth-forms. Sample Hmb-334. Width of picture 12.6 mm.
 Fig. 2. (N) Bryozoa Facies, with erect (bilaminar) massive and erect fragile growth-forms. Sample Hmb-334. Width of picture 12.6 mm.
 Fig. 3. (O) Coral Rudstone Facies. Sample Ma-209. Width of picture 12.6 mm.
 Fig. 4. (P) Peyssonneliacean (grey) Bindstone showing inter-growth of coralline crusts (dark). Sample MS-286. Width of picture 12 mm.
 Fig. 5. (H) Rhodolith Facies showing columnar to branched rhodolith with coral-nucleus. Sample Ma-214. Width of picture 13.2 mm.
 Fig. 6. (H) Rhodolith Facies showing succession from columnar to laminar rhodolith growth-form; note open-spaced structure. Sample Ma-217. Width of picture 13.2 mm.
 Fig. 7. (H) Rhodolith Facies showing laminar - boxwork rhodolith; note open-spaced structure. Sample Ma-221. Width of picture 13.2 mm.
 Fig. 8. (H) Rhodolith Facies showing rhodolith with a succession from columnar to laminar coralline algae (dark) and to laminar Peyssonneliacean algae (grey). Sample Ma-224. Width of picture 13.2 mm.



not found. This chapter gives an overview of the allochems and defines the categories used for point-counting (compare Appendix 1).

5.1.1 Terrigenous components

Terrigenous components are mostly sand-sized quartz grains (Pl. 13/1, 2), which originate from the Bohemian Massif. They were not further differentiated in point counting.

5.1.2 Coralline Algae

Coralline algae (Corallinaceae, Rhodophyta) are the most important biota in limestones of the northern area (deep wells Mattighofen, Maria Schmolln, Geinberg). They contribute up to 90% of the components. The coralline diversity of the studied material is low; six genera were found, which are represented by eight species: *Lithoporella melobesioides* (FOSLIE) FOSLIE, *Neogoniolithon* sp., *Spongites* sp. 1 and sp. 2, *Phymatolithon* sp., *Melobesioidea* indet., and *Sporolithon* sp. 1 and sp. 2 (RASSER and PILLER, 1999). This chapter defines the main growth-form types observed in the studied material.

Rhodoliths (Pl. 14/5-8) are unattached nodules with a size of >2 cm (ADEY, 1986) which predominantly (>50%) consist of nongeniculate encrusting coralline red algae (BOSELLINI & GINSBURG, 1971; BOSENCE, 1983a; ADEY, 1986). They are additionally defined by the occurrence of different growth directions in order to separate them from coralline branches. Other encrusting organisms contributing to the rhodoliths (peyssonneliacean algae, foraminifera, serpulids, bryozoa) were not counted separately. Nuclei are rarely visible and mostly consist of corals (Pl. 14/5) or coralline fragments. Non-nucleated rhodoliths are supposed to be formed by overturned coralline crusts. Size and shape of rhodoliths is difficult to recognize owing to the effects of oblique sections and the small core diameter of deep wells. Most rhodoliths are ellipsoidal or discoidal (growth-form terminology after BOSENCE, 1983a) and laminar-concentric with a remarkable amount of sediment or cement between crusts (Pl. 14/6); their maximum diameter observed is 6 cm; columnar rhodoliths are less frequent.

Successions from columnar to laminar, or vice versa, can be observed (Pl. 14/6, 8). Distinct trends do not occur.

The term **coralline branches** includes two types of growth-forms: (1) branched, isolated, unfragmented algal thalli (Pl. 12/2, 4) and (2) small, unfragmented multi-layered aggregates predominantly consisting of coralline algae. Coralline branches are separated from rhodoliths by a size of <2 cm (for multi-layered aggregates) and by only one or two growth directions (for branched growth-forms).

Coralline crusts (Pl. 12/6; Pl. 13/4-6) are herein defined as unfragmented, dorsoventrally organised layers of encrusting coralline algae. Three types of crusts occur: (1) crusts growing consecutively over each other to form a bindstone (Pl. 13/6); (2) single-layered crusts, which are directly growing on fine-grained soft bottom; (3) crusts which are not in-situ, but lack fragmentation. Coralline crusts can be associated with encrusting peyssonneliaceans, serpulids, encrusting foraminifera, bryozoans, or encrusting corals. Corals can be abundant and form bindstones together with coralline crusts (Pl. 13/5). In contrast to other growth-forms of coralline algae, coralline crusts are never affected by microboring.

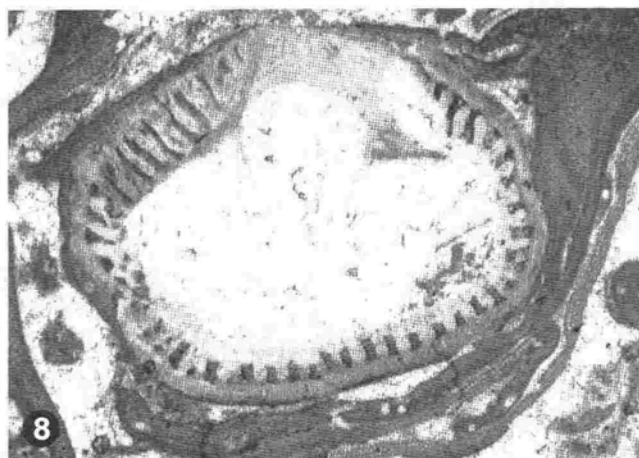
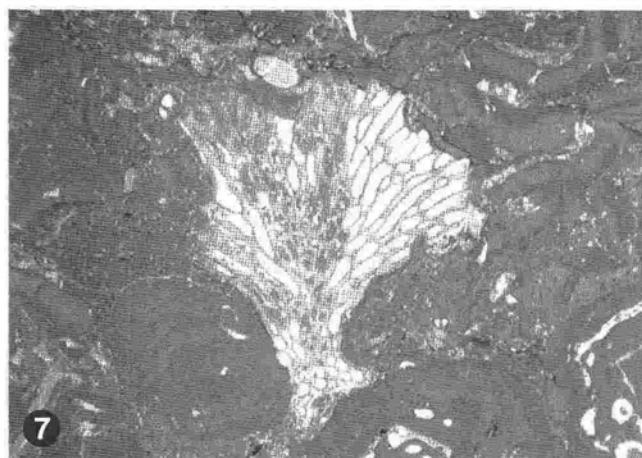
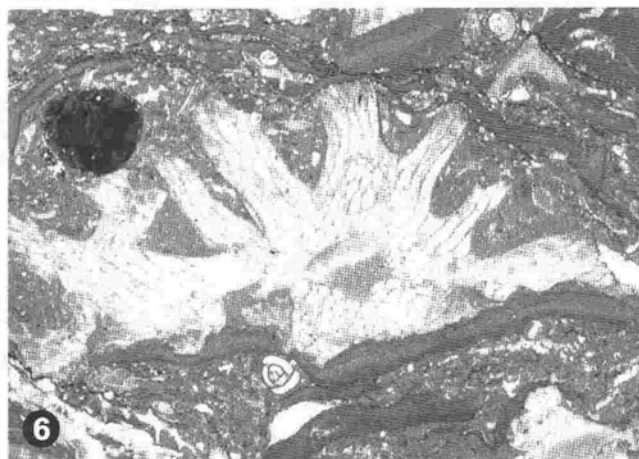
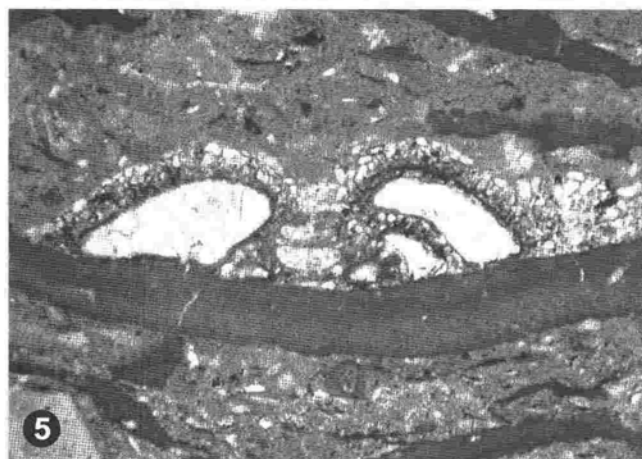
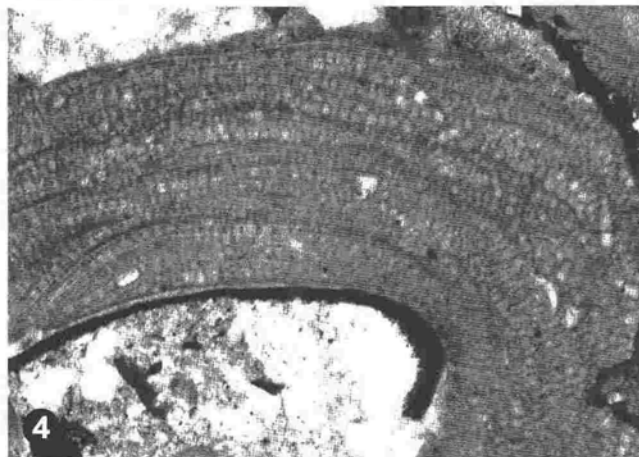
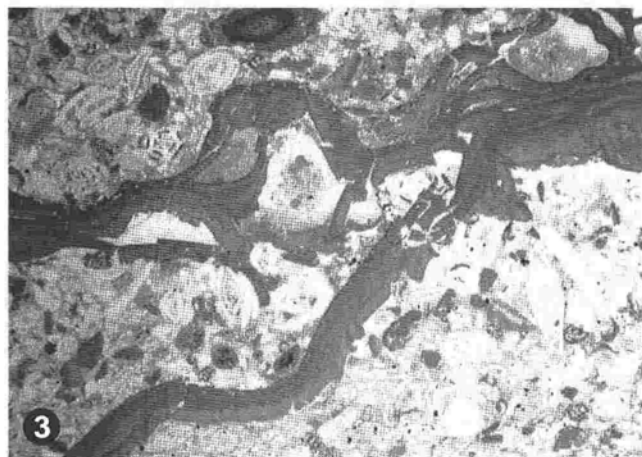
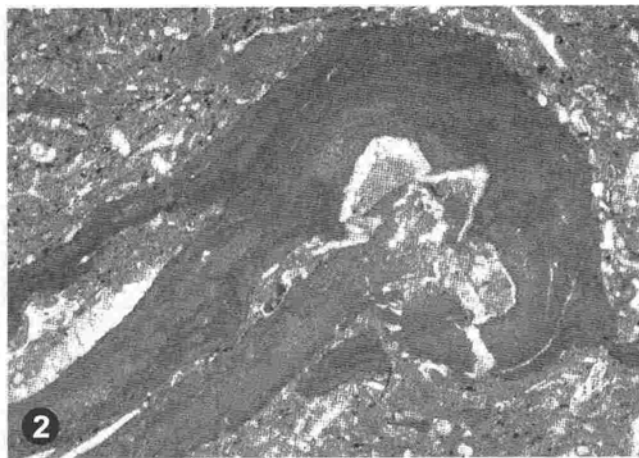
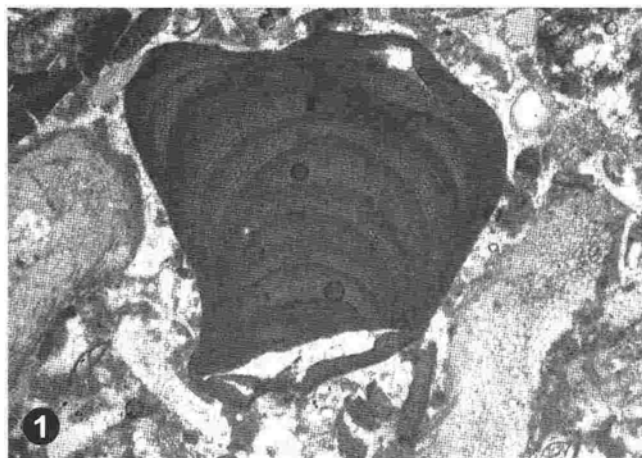
Coralline detritus is defined by fragmented coralline algal thalli. Ruditic detritus is usually not rounded, arenitic detritus is well-rounded (Pl. 12/4). Thalli which are obviously secondarily broken by sediment pressure (i. e., when parts of broken thalli were lying in contact to each other) were not counted in this category.

5.1.3 Peyssonneliacean Algae

Peyssonneliacean algae (Peyssonneliaceae, Rhodophyta; formerly: Squamariaceae) are represented by *Polystrata alba* (PFENDER) DENIZOT (Pl. 12/1-3). Peyssonneliacean aggregates, detritus, and crusts can be differentiated. Peyssonneliacean detritus is usually not rounded and always accompanied by unfragmented specimens. Peyssonneliacean aggregates are herein defined as unfragmented, rounded to irregular aggregates. They are characterized by an inner cavity which is filled by sparite or sediment (Pl. 12/1-3). Peyssonneliacean crusts are less abundant than coralline crusts. Peyssonneliacean crusts form a monospecific bindstone in only one sample (Pl. 14/4), but they do

Plate 15 Late Eocene of the Alpine Foreland Basin in Upper Austria - Selected components

- Fig. 1. Coralline branch, showing thin thallus portions continuously overgrowing a fracture zone in the lower part. Sample MS-287. Width of picture 3.5 mm.
- Fig. 2. Coralline crust showing overgrowth of unattached part of the crust. Sample Ma-234. Width of picture 2 mm.
- Fig. 3. Coralline crust overgrowing nummulitid accumulation. Sample Ma-205. Width of picture 12 mm.
- Fig. 4. Detail of *Acervulina linearis*. Note the thin brightish layers characterising this species. Sample Hmb-317. Width of picture 1.5 mm.
- Fig. 5. *Haddonina heissigi* overgrowing coralline crust. Sample Ma-204. Width of picture 3.5 mm.
- Fig. 6. Bryozoa growing on a coralline crust. Sample Ma-206. Width of picture 8.4 mm.
- Fig. 7. Bryozoa attached on a coralline branch, pointing to a stable substrate. Sample MS-293. Width of picture 10.2 mm.
- Fig. 8. Brachiopod encrusted by coralline algae. Sample MS-291. Width of picture 3.5 mm.



never contribute to coralline algal bindstones. Peyssonneliaceans sometimes occur in rhodoliths (Pl. 14/8) and rarely form monospecific nodules. In contrast to coralline algae, peyssonneliaceans are never bored.

5.1.4 Foraminifera

Orthophragminid (Pl. 13/7) and nummulitid foraminifera (Pl. 12/8, Pl. 13/3) are the most frequent taxa. Most important species are *Discocyclina augustae augustae* VAN DER WEIJDEN, *Nummulites chavannesi* DE LA HARPE, and *N. stellatus* ROVEDA. Species identification follows LESS (1987). A publication dealing with taxonomy and biostratigraphy of larger foraminifera is in press. Nummulitids are mostly thick-walled and sub-globular, orthophragminids are very thin and flat.

Globigerinid planktonic foraminifera are restricted to the hanging-wall parts of the southern area (deep well Helmberg). Smaller miliolid foraminifera can be abundant in coralline algae-dominated facies, mostly associated with smaller textulariids. The dominant sessile foraminifer associated with coralline algae is *Haddonina heissigi* HAGN (Pl. 15/5). Additionally, a few specimens of *Planorbulina* were found. The encrusting *Acervulina linearis* HANZAWA (Pl. 13/2; Pl. 15/4) is restricted to one sample. It forms half tubes or tubes with sediment- or sparite-filled inner parts. Several rotaliid larger foraminifera occur which could not be identified.

5.1.5 Corals

Corals are represented by encrusting (Pl. 13/5) and branched (Pl. 12/7) growth-forms. Encrusting corals are usually restricted to coralline algal bindstones (Pl. 13/5). Branched corals, which are most probably non-hermatypic, are abundant in some samples. They probably formed biostromes. The micrite content of the sediment is usually high (Pl. 12/7; Pl. 14/3). Both encrusting and branched corals are frequently associated with coralline crusts, and in places with brachiopods. Most branched corals are either encrusted by thin coralline algal crusts, or serve as rhodolith-nuclei.

5.1.6 Molluscs

Gastropods are rare. Most of them were found above the peyssonneliacean-bindstone. Only fragments of ostreids (Pl. 13/1, 4) can be identified among the bivalves. They predominantly occur in quartz-sandstones associated with coralline algae, or in algae-dominated sediments. The low abundance of molluscs may be caused by the low fossilization potential of aragonitic gastropods and bivalves. Many of the bioclasts may represent mollusc fragments.

5.1.7 Bryozoa

Bryozoans (Pl. 14/1, 2; Pl. 15/6, 7) occur in rock-forming quantities in the southern area; they are associated with orthophragminids and glauconite. Growth-forms are

mostly erect: delicate branching cyclostomes and cheilostomes and bilaminar robust branching cheilostomes (compare SMITH, 1994). The same growth-forms occur in algal-dominated sediments, together with unilaminar encrusting forms. The latter encrust corals or coralline algae.

5.1.8 Brachiopoda

Only one type of a punctate brachiopod was found (Pl. 15/8). It is restricted to algal-dominated sediment without terrigenous influence, often together with branched corals. Brachiopods are frequently encrusted by coralline algae and can act as nuclei of rhodoliths.

5.1.9 Echinodermata

Echinodermata are represented by (mostly rounded) fragments or spines. They could not be further identified.

5.1.10 Serpulids

Calcified serpulid worm tubes can be recognized by concentric layers in transverse sections (HOROWITZ & POTTER, 1971). They are rare and do not show any regular distribution. Occasionally they grow on coralline crusts and rhodoliths.

5.1.11 Bioclasts

Bioclasts are - in contrast to biomorpha - fragmented, partially rounded skeletal particles of silt- and sand-size (FLÜGEL, 1982). This category was only counted when the particle could not be designated to any of the above carbonate components.

5.2 Spearman Rank Correlation

Appendix 1 shows the frequency of components revealed from point counting. Some of the components were combined for statistical analysis owing to their low frequency: corals and encrusted corals were combined to "corals"; gastropods and bivalves were combined to "molluscs"; brachiopods and encrusted brachiopods were combined to "brachiopods". For the same reason, "unknown components", serpulids, and ostracodes were not considered. Finally, the following variables were used for statistical analyses:

1. Coralline branches
2. Coralline crusts
3. Coralline detritus
4. Peyssonneliacean aggregates
5. Peyssonneliacean crusts
6. Peyssonneliacean detritus
7. Foraminifera
8. Corals
9. Molluscs
10. Bryozoa
11. Brachiopoda
12. Echinodermata

Corals	R_s	.4162																	
	p	p .000																	
Brachiopoda	R_s	-.1252	.1312																
	p	p .188	p .168																
Bryozoa	R_s	.2110	.0675	.0606															
	p	p .026	p .491	p .526															
Coralline branches	R_s	-.0542	-.1032	.0889	-.2675														
	p	p .583	p .279	p .351	p .004														
Coralline detritus	R_s	.0431	-.0545	.3180	.0693	.4562													
	p	p .665	p .568	p .001	p .468	p .000													
Echinodermata	R_s	.0003	.1414	-.0239	.0351	.1572	.3005												
	p	p .998	p .137	p .802	p .713	p .098	p .001												
Foraminifera	R_s	-.2820	-.2355	-.3225	-.0323	-.3392	-.3414	.0231											
	p	p .003	p .012	p .001	p .735	p .000	p .000	p .809											
Molluscs	R_s	.0184	-.0136	-.0254	-.1290	-.0970	-.2034	-.0223	.1161										
	p	p .847	p .887	p .791	p .175	p .309	p .031	p .031	p .816										
Peys. crusts	R_s	.1138	-.1952	-.065	.0455	.0170	-.0925	-.2172	-.0776	-.0029									
	p	p .232	p .039	p .496	p .634	p .859	p .332	p .021	p .416	p .976									
Peys. detritus	R_s	-.1606	-.1115	-.0378	-.1539	-.0295	.1852	-.0492	-.1342	-.0035	.0135								
	p	p .091	p .242	p .692	p .105	p .758	p .051	p .606	p .158	p .971	p .888								
Peys. unfragm.	R_s	-.2229	-.1036	-.0639	-.2928	.0387	-.0223	-.1772	-.1295	-.0884	.1187	.6774							
	p	p .018	p .227	p .503	p .002	p .686	p .816	p .062	p .173	p .354	p .213	p .000							
Rhodoliths	R_s	.0959	.0409	-.0333	-.0821	-.0182	-.0599	-.0562	-.2523	-.0986	.2325	-.0542	.0441						
	p	p .533	p .668	p .728	p .390	p .849	p .530	p .556	p .007	p .301	p .014	p .571	p .644						
Terrigenous	R_s	-.1516	-.0702	-.2251	-.1603	-.2645	-.4890	-.2060	.2743	.1781	.0877	-.1169	-.1055	-.1761					
	p	p .111	p .462	p .017	p .390	p .005	p .000	p .029	p .003	p .060	p .358	p .219	p .268	p .063					
		Coralline crusts	Corals	Brach.	Bryozoa	Coralline branches	Coralline detritus	Echino.	Foramin.	Molluscs	Peys. crusts	Peys. detritus	Peys. unfragm.	Rhodol.					

Tab. 1. Matrix of Spearman rank correlation, using the complete data set, showing Coefficient (R_s) and Significance (p) ($N = 112$). Bold type and thick framed coefficients are those which remained significant after partial correlation.

13. Terrigenous components

14. Bioclasts

5.2.1 Rank Correlation of all Geological Samples

The Spearman rank correlation between all 14 variables revealed 24 significant correlations (Tab. 1). Partial correlations of all significant correlations were calculated to exclude false correlations. The results revealed, that only 10 significant correlations remained:

(a) Positive correlations after partial correlation, sorted by correlation coefficient (R_s):

1. Peyssonneliacean aggregates + peyssonneliacean detritus (0.677)
2. Coralline detritus + coralline branches (0.456)
3. Corals + coralline crusts (0.416)
4. Coralline detritus + Brachiopoda (0.318)
5. Coralline detritus + Echinodermata (0.301)

(b) Negative correlations after partial correlation, sorted by correlation coefficient (R_s):

6. Terrigenous components + coralline detritus (-0.489)
7. Foraminifera + coralline detritus (-0.341)
8. Foraminifera + coralline branches (-0.339)
9. Coralline branches + Bryozoa (-0.268)
10. Foraminifera + corals (-0.236)

Interpretation:

Correlations 1 and 2: the more unfragmented algae occur, the more fragmented are present (and vice versa). This can be interpreted by a very short transport after fragmentation and thus by a parautochthonous occurrence of algal detritus. In fact, coralline detritus is almost always accompanied by a remarkable amount of coralline branches.

This corresponds to the observation that both coralline and peyssonneliacean detritus is mostly unrounded.

Correlation 3: The occurrence of encrusting corals is related to the occurrence of coralline bindstones. This can be caused by the equal ecological requirements of both binders. They can be frequently observed in the same samples.

Correlation 6 can be related to the lack of terrigenous components in most of the coralline detritus – dominated samples.

Correlations 7 and 8: The negative correlation of foraminifera with both coralline branches and coralline detritus can be explained by the observation that foraminifera are most abundant in samples with very low abundance of coralline algae.

Correlation 9: Comparable to the above-mentioned correlations, negative correlation of coralline branches and Bryozoa can be explained by the observation that bryozoans are most frequent in Bryozoa-marls. The latter usually lack coralline branches.

5.2.2 Rank Correlation of Algae-Dominated Samples

The analysis of the entire data set contains both algae-dominated sediments of the northern area and foraminifera/bryozoan-dominated sediments of the southern area. This mixture can cause some of the above negative correlations. Therefore, another rank correlation was calculated without consideration of samples from Helmborg.

Spearman rank correlation revealed 21 significant correlations (Tab. 2). Ten correlations remained significant after a partial correlation:

(a) Positive correlations after partial correlation, sorted by correlation coefficient (R_s):

Corals	R _s	.1292																	
	p	.217																	
Brachiopoda	R _s	-.0582	-.2280																
	p	.579	.028																
Bryozoa	R _s	.0832	.2875	-.2271															
	p	.428	.005	.029															
Coralline branches	R _s	.2629	.1468	.2303	-.1143														
	p	.011	.160	.026	.275														
Coralline detritus	R _s	.1082	.0917	-.2290	.3849	-.1504													
	p	.302	.382	.027	.000	.150													
Echinodermata	R _s	-.620	-.1054	.0392	-.0794	.1414	.0978												
	p	.555	.315	.709	.450	.176	.351												
Foraminifera	R _s	-.2810	-.0682	-.1029	-.1923	-.1064	-.1888	.1907											
	p	.006	.516	.326	.065	.310	.070	.067											
Molluscs	R _s	-.0017	-.0687	.0416	.0661	-.1232	-.0175	.0663	.0647										
	p	.987	.513	.692	.529	.239	.867	.528	.538										
Peys. crusts	R _s	-.672	.0120	-.0617	.1748	-.1235	.2662	-.2131	-.1695	.0603									
	p	.522	.909	.557	.094	.238	.010	.040	.104	.566									
Peys. detritus	R _s	-.0800	-.1110	-.3294	-.2564	.0012	-.1766	-.1449	.0281	.0378	.0420								
	p	.446	.289	.001	.013	.991	.090	.166	.789	.719	.689								
Peys. unfragm.	R _s	-.0876	-.3251	-.1927	-.2902	-.1943	-.1498	-.2471	-.0204	-.0450	.6993								
	p	.404	.001	.064	.005	.062	.152	.017	.846	.669	.000								
Rhodoliths	R _s	-.0252	-.0474	-.2190	.0007	-.2359	-.0034	-.0967	-.1753	-.0936	.2937	-.0856	.0207						
	p	.811	.652	.035	.994	.023	.974	.356	.093	.372	.004	.415	.844						
Terrigenous	R _s	-.2224	.0350	-.1388	-.0505	-.3731	.0137	.0192	.1188	.0604	.0314	-.0414	-.0813	-.1527					
	p	.032	.739	.191	.631	.000	.896	.855	.257	.565	.765	.694	.439	.144					
		Coralline crusts	Corals	Brach.	Bryozoa	Coralline branches	Coralline detritus	Echino.	Foramin.	Molluscs	Peys. crusts	Peys. detritus	Peys. unfragm.	Rhodol.					

Tab. 2. Matrix of Spearman rank correlation, using the complete data set except samples from Helmborg, showing Coefficient (Rs) and Significance (p) (N = 112). Bold type and thick framed coefficients are those which remained significant after partial correlation.

1. Peyssoneliacean detritus + peyssoneliacean aggregates (0.699)
 2. Corals + coralline crusts (0.385)
- (b) Negative correlations after partial correlation, sorted by correlation coefficient (R_s):
3. Coralline detritus + terrigenous components (-0.373)
 4. Coralline branches + Peyssoneliacean detritus (-0.329)
 5. Peyssoneliacean aggregates + Bryozoa (-0.325)
 6. Peyssoneliacean aggregates + Echinodermata (-0.247)
 7. Coralline detritus + rhodoliths (-0.235)
 8. Coralline branches + Bryozoa (-0.228)
 9. Coralline branches + coralline crusts (-0.227)
 10. Coralline branches + rhodoliths (-0.219)

Interpretation:

Only two positive correlations of the former calculation are confirmed. As expected above, the negative correlations between foraminifera and coralline detritus, coralline branches, and corals of the former rank correlation were probably caused by the influence of samples from deep well Helmborg, only. Two negative correlations are, however, still evident: Coralline detritus + terrigenous components and coralline branches + Bryozoa. The other negative correlations did not occur in the previous rank correlation.

Correlation 9 reflects the low abundance of coralline branches in samples dominated by coralline crusts. In opposition to branches, coralline detritus is more abundant. This can point to a high hydrodynamic energy.

5.3 Hierarchical Cluster Analysis

5.3.1 Entire Data Set.

Components as in chapter 5.2; for clusters see Fig. 2. For mean abundance of components see Fig. 3. Two main

clusters were obtained: A – H is dominated by coralline algae (branches or detritus and rhodoliths); only cluster C is dominated by peyssoneliaceans. The second main cluster (I – N) combines samples with higher amounts of terrigenous components and a low amount of both coralline branches and detritus.

Clusters A - C are characterized by the occurrence of peyssoneliaceans + coralline algae and belong to a superior cluster; the latter characteristically lacks corals and rhodoliths. **Cluster A** is characterized by a nearly equal abundance of coralline algae (branches and detritus) and peyssoneliaceans (aggregates and detritus), combined with a remarkable amount of terrigenous components. **Cluster B** is comparable to cluster A, but it reveals a lack of terrigenous components and a higher amount of coralline detritus. **Cluster C** combines samples which are dominated by peyssoneliacean aggregates. Coralline detritus, coralline branches, as well as very rare foraminifera occur.

Clusters D - G form another superior cluster which combines samples dominated by coralline branches (D) and those dominated by coralline detritus (E - G). **Cluster D** is characterized by samples with the highest abundance of coralline branches. Coralline crusts occur in four of 17 samples, but are extremely rare. Peyssoneliacean algae are rare. **Cluster E** is characterized by a high abundance of coralline detritus, combined with a moderate abundance of coralline branches and coralline crusts. It lacks corals. **Cluster F** shows a dominance of coralline detritus and a remarkable abundance of corals. **Cluster G** summarizes most of the samples (n = 24) and reveals the highest abundance of coralline detritus. Most samples additionally show high amounts of coralline branches. Rhodoliths, peyssoneliaceans, coralline crusts, and corals are extremely rare.

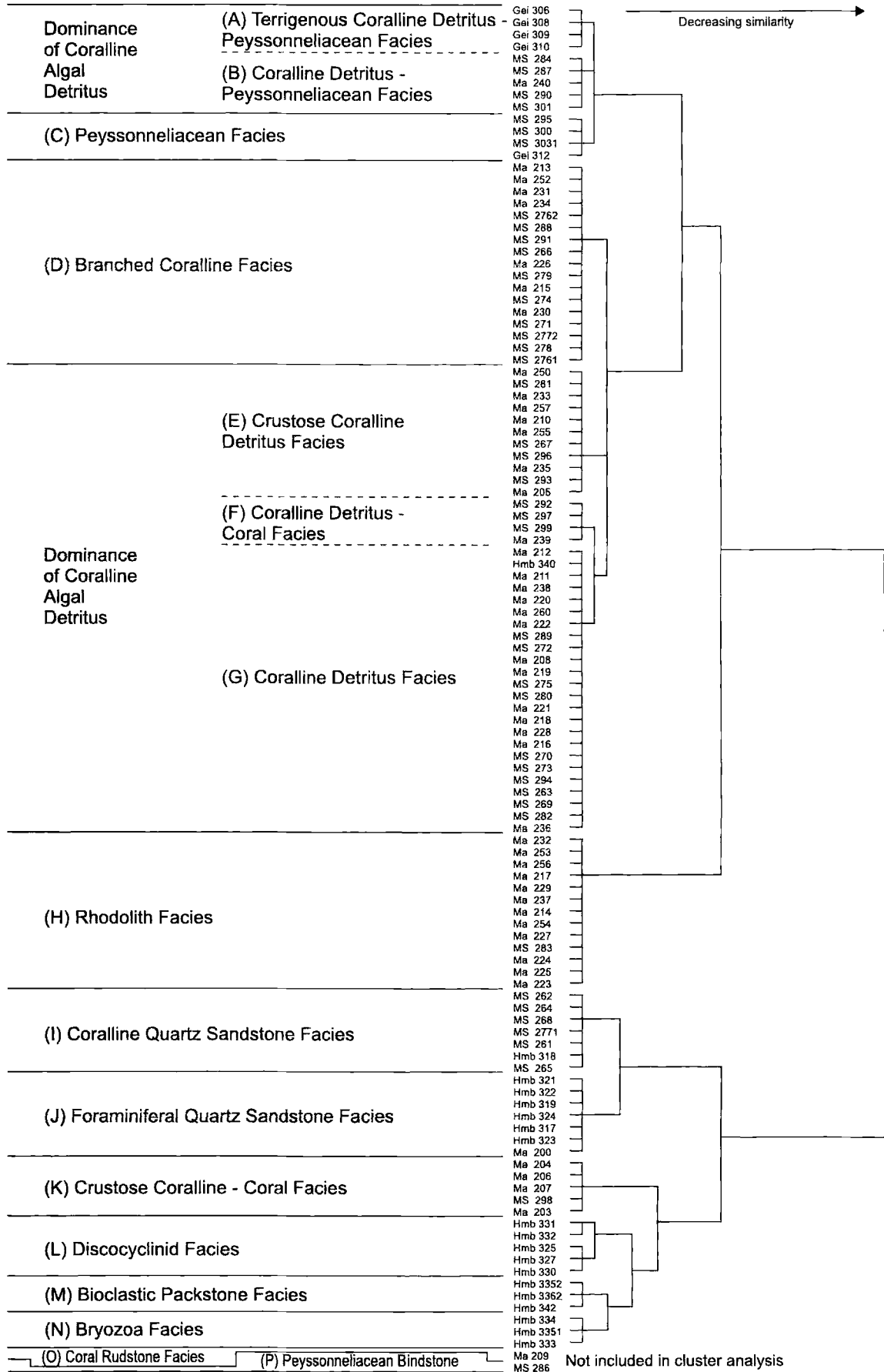


Fig. 2. Hierarchical cluster analysis including sample numbers and facies (A to P). For composition of facies and samples see Fig. 3 and Appendix 1.

Cluster H unites all samples with more than 24 % of rhodoliths. It is in the same main cluster as the samples characterized by coralline branches, detritus, and peyssonneliaceans. It is, however, an isolated cluster separated from A - G.

Clusters I to N are summarized to the second main cluster. It contains two superior clusters: I - J are characterized by high amounts of terrigenous components; K - N by the occurrence of Bryozoa, which are partially very abundant, and rare coralline branches and detritus. **Cluster I** combines samples which are dominated by terrigenous components and remarkable amounts of coralline detritus and branches. Foraminifera can occur. **Cluster J** combines very high amounts of terrigenous components with remarkable amounts of foraminifera (mostly nummulitids). Few amounts of molluscs occur in three (of seven) samples, rare Bryozoa and Echinodermata occur in one sample. **Cluster K** combines samples with high amounts of coralline crusts and (mostly encrusting) corals. Remarkable amounts of coralline detritus and a few bryozoa occur in cluster K, coralline branches are rare. **Cluster L** summarizes two smaller clusters. It combines samples with high abundance of foraminifera (mostly orthophragminids). Three (of five) samples are additionally characterized by huge amounts of terrigenous components (forming a cluster), three by Bryozoa. Note that nummulitids (cluster J) and orthophragminids (cluster L) are summarized in different clusters although they were not counted separately. **Cluster M** contains samples which are predominantly composed of arenitic bioclasts. The combination of Bryozoa and coralline detritus is characteristic. **Cluster N** combines samples with a very high abundance of bryozoans. Either foraminifera or terrigenous components occur subordinately.

Additionally to the cluster analysis regarding the entire data set, two analyses with different combinations were calculated to obtain informations about the significance of algal fragmentation and the occurrence of rhodoliths:

5.3.2 Fragmented and unfragmented combined

Unfragmented and fragmented corallines were combined to one variable; the same was done with the peyssonneliaceans; all other components were used as listed above (i.e., 12 component categories). One big coralline algae cluster consisting of all but one of the samples of the former cluster G and all but two of the former cluster D was formed (not figured). The former clusters E and F again formed two separate clusters. One cluster which is comparable to the former superior cluster A - C was obtained; it is characterized by the occurrence of peyssonneliaceans. The former cluster C was formed again. All other clusters of the former cluster analysis were formed again.

5.3.3 Rhodoliths excluded

This cluster analysis (13 component categories) was conducted in order to get informations about the formation

of rhodolith-cluster H. Was it only formed by the dominance of rhodoliths, or do the samples show additional similarities? The result (not figured) revealed that the samples of the former cluster H were grouped into other clusters. Former cluster C remained. However, samples of the clusters A and B are now combined to one cluster. The former cluster D, characterized by coralline branches, was formed again. One (231) of three samples, which contain corals, are now added to another coral-bearing cluster (see below). Four samples (226, 230, 234, and 279) were added to a new cluster characterized by coralline detritus. The two samples with the highest content of coralline branches of the former rhodolith-cluster H are now added to the new coralline branches-cluster. Also the former cluster G, characterized by coralline detritus, was formed again. Only two samples (212 and 340) with low amounts of coralline crusts and higher amounts of Bryozoa were put into another cluster, which is characterized by coralline detritus and coralline crusts. Five samples of the former rhodolith-cluster H, which are characterized by a higher abundance of coralline detritus and a lack of corals, are added to this new cluster (217, 223, 224, 229, 254). All other clusters were formed as before.

5.3.4 Summary of cluster analysis

Highest correlations occur between:

1. Terrigenous components + foraminifera (and partially molluscs)
2. Terrigenous components + peyssonneliacean algae + coralline algae (when equal abundance)
3. Coralline crusts + coralline detritus (when corals are absent)
4. Coralline detritus + coralline branches
5. Coralline detritus + Bryozoa (when coralline branches are absent)
6. Peyssonneliacean algae + coralline algae (when rhodoliths and/or corals are absent)
7. Corals + coralline crusts
8. Corals + coralline detritus (when the latter is dominant and rhodoliths are absent)
9. Brachiopoda + coralline detritus + corals
10. Brachiopoda + coralline detritus + coralline crusts (when rhodoliths are absent)
11. Samples with > 25% rhodoliths

Only three correlations correspond to Spearman rank correlation: (4) Coralline detritus + coralline branches, (7) corals + coralline crusts, and (9, 10) brachiopods + coralline detritus.

The second cluster analysis (12 component categories) revealed that samples dominated by coralline detritus are similar to those dominated by coralline branches. The third cluster analysis (13 component categories) revealed that the rhodolith-cluster H of the original dendrogram was only formed by the abundance of rhodoliths. There are no further similarities between samples characterized by abundant rhodoliths.

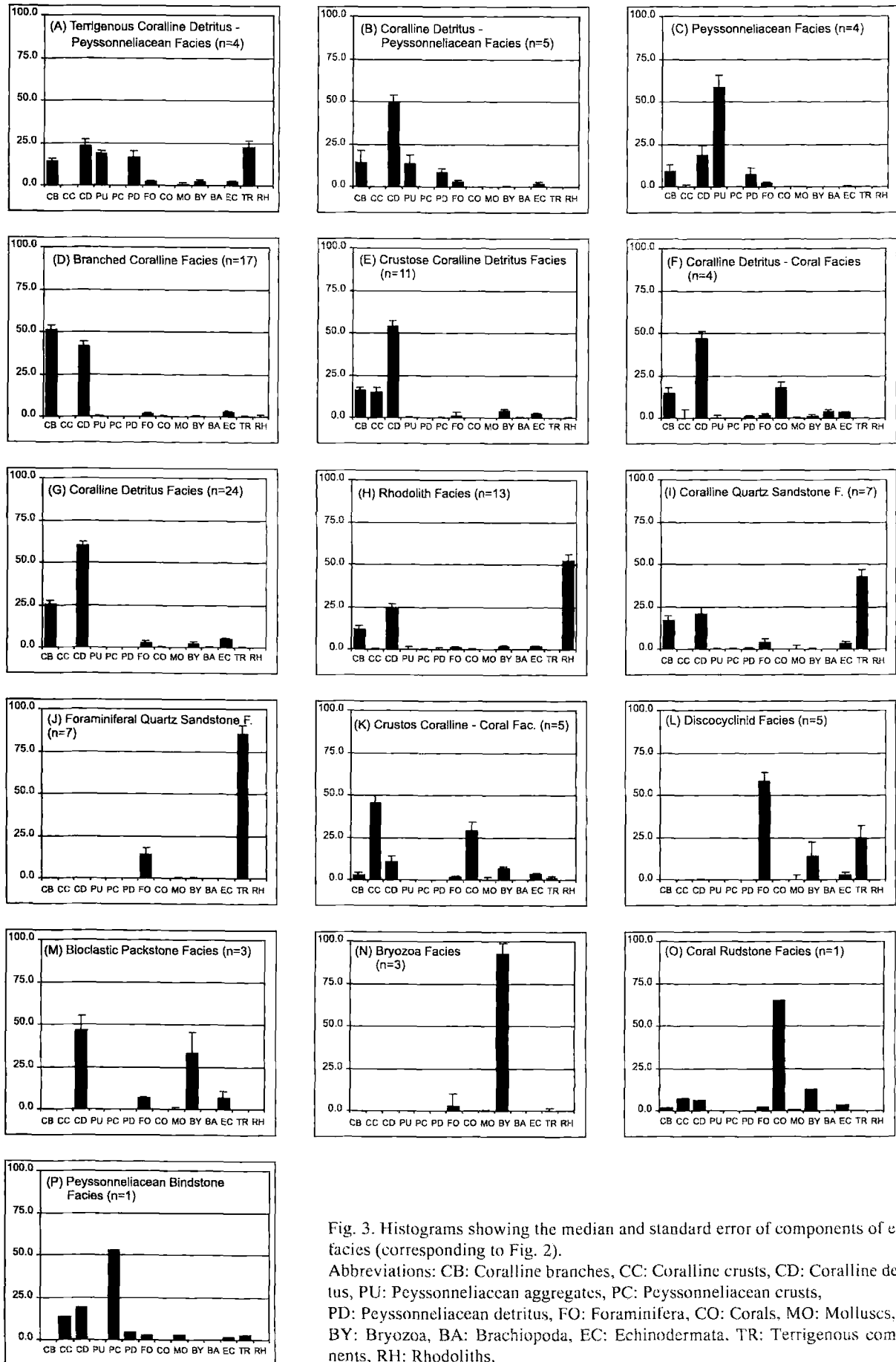


Fig. 3. Histograms showing the median and standard error of components of each facies (corresponding to Fig. 2). Abbreviations: CB: Coralline branches, CC: Coralline crusts, CD: Coralline detritus, PU: Peyssonneliacean aggregates, PC: Peyssonneliacean crusts, PD: Peyssonneliacean detritus, FO: Foraminifera, CO: Corals, MO: Molluscs, BY: Bryozoa, BA: Brachiopoda, EC: Echinodermata, TR: Terrigenous components, RH: Rhodoliths.

5.4 Factor Analysis

5.4.1 Testing Cluster Formation

Clusters formed by hierarchical cluster analysis allowed the designation of facies (Fig. 2). The second cluster analysis, which did not differentiate between coralline detritus and coralline branches, as well as the positive correlation between these variables suggests, however, not to differentiate between cluster D, E, F, and G – but to combine them to one facies. Therefore, factor analysis was conducted. The factor loading of each sample was plotted on a scatterplot diagram (Fig. 4), which revealed that most clusters are distinctively separated.

5.4.2 Component Analysis of Entire Data Set

The same samples and components (= variables) used for cluster analysis were used for factor analysis. Varimax rotated factor analysis reveals 5 factors (Tab. 3), accounting for 66.3 % of the variance. Owing to the high number of samples, a loading (i. e., correlation) of more than +/- 0.19 is significant. The results of factor analysis are compared with Spearman rank correlation and with hierarchical cluster analysis.

Factor 1: Terrigenous components, which are significant only with this factor, are highly correlated together with foraminifera and molluscs. Correlation of coralline detritus is highly negative; also coralline branches, Echinodermata, and Brachiopoda are negative.

Comparison with cluster analysis: The high correlation of terrigenous components and foraminifera corresponds to cluster J (Foraminiferal Quartz Sandstone), in which both components are abundant. Also cluster L (Discocylinid Facies), which is predominantly composed of ortho-phragminid foraminifera, shows a remarkable content of terrigenous components. Both of the clusters contain molluscs. Coralline algae are, however, very rare; Brachiopoda do not occur.

Interpretation: The co-occurrence of foraminifera, molluscs and quartz sand is supported by one paleocological factor, which is unfavorable for Brachiopoda, coralline branches, coralline detritus, and Echinodermata. The negative correlation of coralline algae can be caused by a **high sedimentation rate**: while foraminifera and molluscs are vagile organisms, algae are buried by sediment.

Factor 2: The correlation between peyssonneliacean aggregates and detritus is very high; this is the only factor with which both of them are significantly loaded. Coralline branches and Echinodermata are negatively loaded. Other significant correlations do not occur.

Comparison with rank correlation: Peyssonneliacean aggregates and detritus show the highest positive correlation coefficient.

Comparison with cluster analysis: Clusters A – C, which are characterized by the occurrence of peyssonneliacean algae, usually show low abundance of coralline branches.

Interpretation: Peyssonneliaceans can live under lower

light conditions than coralline algae. Therefore, **light availability** as a limiting factor for algae can be the influencing factor. Moreover, peyssonneliaceans are able to form crusts on muddy soft substrate (BASSO, 1990), which is not known from corallines. Therefore, this factor can be also interpreted by **substrate stability**.

Factor 3: Coralline crusts and corals are very high correlated; corals are only significantly correlated with this factor. Additionally, correlation of brachiopods is high. Only coralline branches are negative.

Comparison with rank correlation: Corals + coralline crusts are positively correlated.

Comparisons with cluster analysis: This combination corresponds to cluster K (Crustose Coralline - Coral Facies), which combines samples with a high quantity of corals and coralline crusts, but low quantity of coralline branches. In contrast to this, the correlation of Brachiopoda corresponds with cluster F (Coralline Detritus-Coral Facies), which shows Brachiopoda (however, with a low abundance) together with corals.

Remarks: The very high significance of coralline crusts and corals with the same factor agrees with the observation from thin sections, that only encrusting corals contribute to coralline bindstones. The correlation of brachiopods can be explained by the fact that they were mostly observed together with branching (but not with encrusting) corals.

Interpretation: **Substrate stability** is one of the basal requirements for the settlement of coralline algal crusts, corals, and Brachiopoda. High **hydrodynamic energy** probably reduce the occurrence of branches, as they become fragmented or cannot accumulate.

Factor 4: Bryozoa are highly significant, foraminifera show a lower positive correlation. Coralline branches, coralline detritus, and Brachiopoda are significantly negatively correlated.

Comparison with rank correlation: This combination corresponds to the negative correlation between foraminifera and coralline branches, on the one hand, and detritus, on the other. Moreover, coralline branches and Bryozoa are negatively correlated.

Comparison with cluster analysis: Clusters N (Bryozoa Facies) and M (Bioclastic Packstone Facies) show the highest amounts of Bryozoa. These clusters lack coralline branches. The positive correlation of foraminifera can be related to cluster L (Discocylinid Facies) which shows a relatively high abundance of Bryozoa.

Interpretation: In opposition to coralline algae, bryozoans do not depend on light. Therefore, this factor probably reflects the **light availability** of depositional environment. This interpretation does, however, not fit with the positive correlation of light-dependent larger foraminifera.

Factor 5 reveals positive correlations of rhodoliths and peyssonneliacean crusts, as well as negative correlations of Echinodermata and coralline detritus.

Comparison to cluster analysis: Most samples containing peyssonneliacean crusts occur in the rhodolith-cluster H. This factor cannot be interpreted.

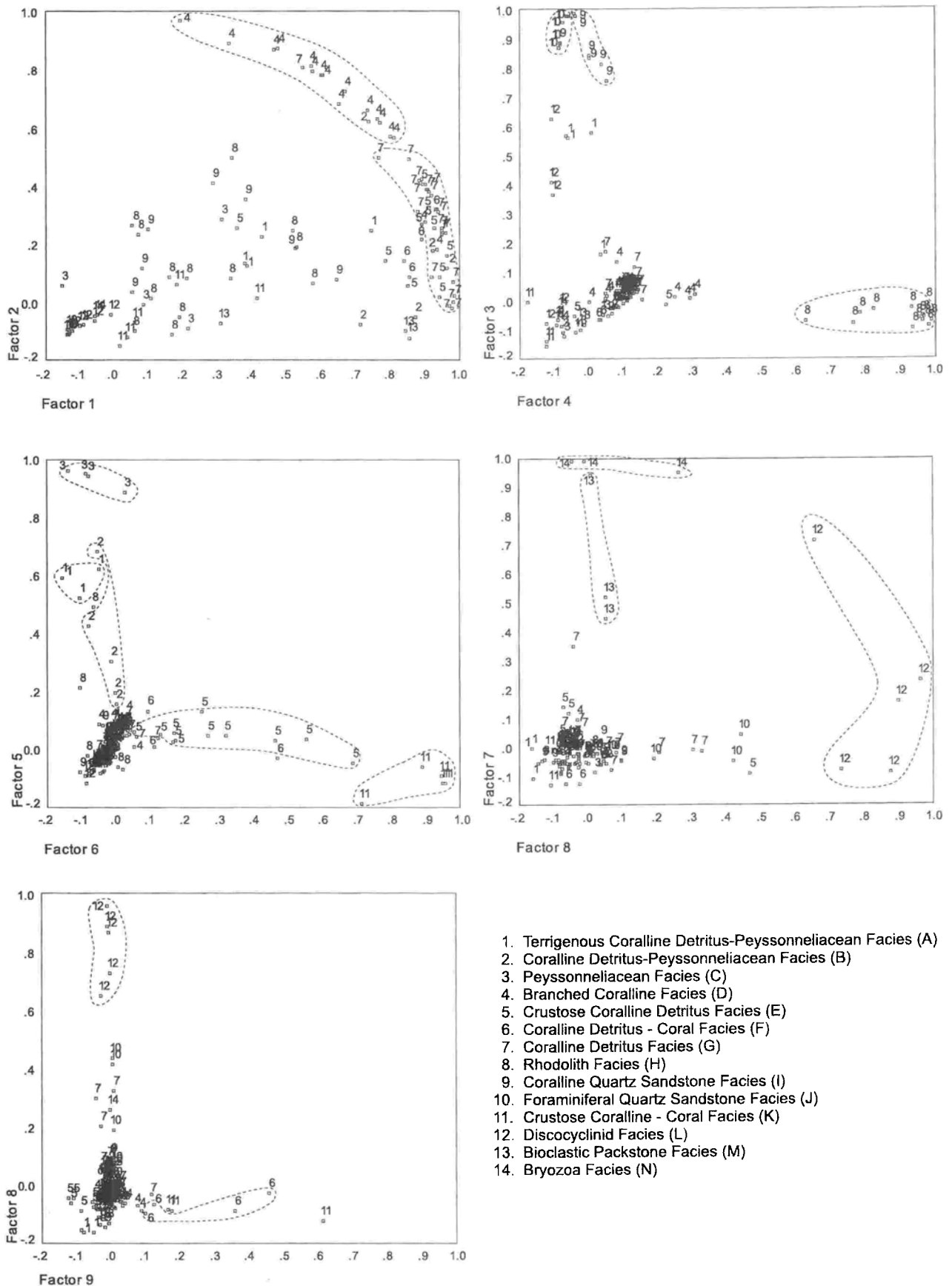


Fig. 4. Factor analysis testing the composition of clusters revealed from cluster analysis (Fig. 2) and thus the reliability of facies designation. Numbers 1 - 14 mark geological samples belonging to a specific cluster.

Factor	1	2	3	4	5
% of variance	18.1	13.5	11.5	9.5	8.7
Brachiopoda	-.16124	-.10117	.30080	-.30343	-.15940
Bryozoa	-.13718	-.14186	-.04723	.83343	-.08582
Coralline Branches	-.29812	-.19841	-.29684	-.63587	-.05272
Coralline Crusts	-.04888	-.06815	.81963	.03914	-.01975
Coralline Detritus	-.68316	-.13291	-.13954	-.44538	-.26123
Corals	.01351	-.04105	.83653	.04500	-.00470
Echinodermata	-.37079	-.24285	-.08211	.10901	-.44819
Foraminifera	.61390	-.17801	-.17743	.37802	-.16128
Molluscs	.61703	-.07977	.02625	-.06316	-.18656
Peys. Crusts	-.02825	-.00876	-.00925	-.02514	.64048
Peys. Detritus	-.07494	.88223	-.09599	.00340	-.01111
Peys. Aggregates	-.02329	.90326	-.05619	.01584	-.01768
Rhodoliths	-.16125	-.09768	-.09915	.08189	.76207
Terrigenous	.82222	-.01059	-.11739	-.02168	.04090

Factor	1	2	3	4	5	6
% of variance	15.8	15.3	12.2	9.9	8.2	7.1
Brachiopoda	-.17056	-.08348	-.38239	.28452	-.03145	-.01972
Bryozoa	.48700	-.21087	-.16354	.43936	-.22296	.37535
Coralline Branches	-.60879	-.38554	-.31105	.10719	.40927	-.08184
Coralline Crusts	.83335	-.10862	-.08623	.02449	.07755	-.03887
Coralline Detritus	-.29145	-.26469	-.34504	.60390	-.48272	-.06434
Corals	.80889	-.08298	-.20859	-.01987	.25769	-.06242
Echinodermata	.01353	-.22201	.15039	-.00387	-.36521	-.68689
Foraminifera	-.01722	-.12431	.77206	.04203	-.03824	-.13725
Molluscs	.10862	-.04614	.17447	.07583	.62255	.00050
Peys. Crusts	-.02936	-.04852	-.00298	-.18242	-.15207	.68127
Peys. Detritus	-.06923	.87560	.04082	.03097	-.09032	.08952
Peys. Aggregates	-.07090	.89992	-.06446	-.06562	.08211	-.02800
Rhodoliths	-.00491	-.10524	-.04469	-.83827	-.26893	.25139
Terrigenous	-.03230	.06881	.76066	.02945	-.36310	.03776

Tab. 3. Varimax rotated factor matrix using the entire data set (above) and varimax rotated factor matrix using the entire population, except Helmberg (below).

5.4.3 Component Analysis of Algae-Dominated Samples

As discussed in Spearman rank correlation, factor analysis can be influenced by the mixture of samples from the northern and southern area. Therefore, another factor analysis was calculated excluding samples from the southern area. Factor analysis reveals six factors (Tab. 3), accounting for 68.5 % of the variance. Owing to the number of samples (86), a loading (i. e., correlation) of more than +/- 0.217 is significant. The results of this factor analysis are compared with the Spearman rank correlation that excluded samples from the southern area, as well as with the hierarchical cluster analysis.

Factor 1: High positive correlations between coralline crusts and corals, as well as Bryozoa. Both coralline branches and detritus are negatively correlated. This factor is partially comparable to factor 3 of the factor analysis regarding the entire data set.

Comparison with rank correlation: Corals and coralline crusts are positively correlated, coralline branches and coralline crusts are negative.

Comparison with cluster analysis: The correlations correspond to cluster K, which is characterized by coralline bindstones with abundant encrusting corals. Bryozoa occur in most samples, coralline branches and detritus are usually subordinate.

Interpretation: **Substrate stability** is a basal requirement for the settlement of coralline crusts, corals, and Bryozoa. **Hydrodynamic energy** can prevent the accumulation of coralline branches and coralline detritus.

Factor 2: High positive correlations of peyssonneliacean aggregates and detritus, combined with a negative correlation of coralline detritus, coralline branches, Bryozoa, and Echinodermata.

Remarks: this factor can be compared with factor 2 of the factor analysis regarding the entire data set. It confirms the negative correlation between corallines (both branches and detritus) and peyssonneliaceans (both aggregates and detritus). It confirms the interpretation that peyssonneliacean and coralline algae have different ecological requirements.

Factor 3: Terrigenous components and foraminifera are highly positive correlated; coralline detritus, coralline branches, and Brachiopoda are negatively correlated.

Remarks: This factor can be compared to factor 1 of the analysis using the entire data set. It shows that foraminifera and terrigenous components are still highly correlated, although the Foraminiferal Quartz Sandstone and the Discocyclina Facies are not considered here.

Factor 4: Positive correlations between coralline detritus, Bryozoa, and Brachiopoda; negative correlation of rhodoliths.

Comparison to rank correlation: Coralline detritus is positively correlated with brachiopods, but negatively correlated with rhodoliths.

Comparison to cluster analysis: Coralline detritus is not abundant in the rhodolith-dominated cluster; coralline detritus-dominated clusters nearly lack rhodoliths.

Interpretation: Most rhodoliths are composed of thin delicate crusts, pointing to low **hydrodynamic energy**. The formation of coralline detritus can, in contrast, be interpreted by a high energetic environment.

Factor 5: Positive correlations to coralline branches, corals, molluscs, and terrigenous components; negative correlations to Bryozoa, coralline detritus, Echinodermata, and rhodoliths.

Remarks: The correlations cannot be compared to any former analysis or to the distributions of components. It is not interpretable.

Factor 6: Positive correlations of Bryozoa, peyssonneliacean crusts, and rhodoliths; negative correlation of Echinodermata.

Remarks: This factor can be compared with factor 5 of the factor analysis regarding the entire data set.

5.5 Facies Descriptions

Owing to highly diverse combinations of components, conduction of a cluster analysis was necessary to designate facies. This is most evident in samples dominated by coralline branches and coralline detritus (facies A, B, D - G), which partially seem to be similar and can hardly be designated without statistical methods. Figure 3 summarizes the quantitative composition of each facies. Table 5 summarizes the facies characteristics. Vertical distribution of facies in the profiles, as well as the composition, are given in Fig. 5 (deep well Geinberg), Fig. 6 (Mattighofen), Fig. 7 (Maria Schmolln), and Fig. 8 (Helmberg). Letters A - N in facies descriptions below refer to the clusters (Fig. 2).

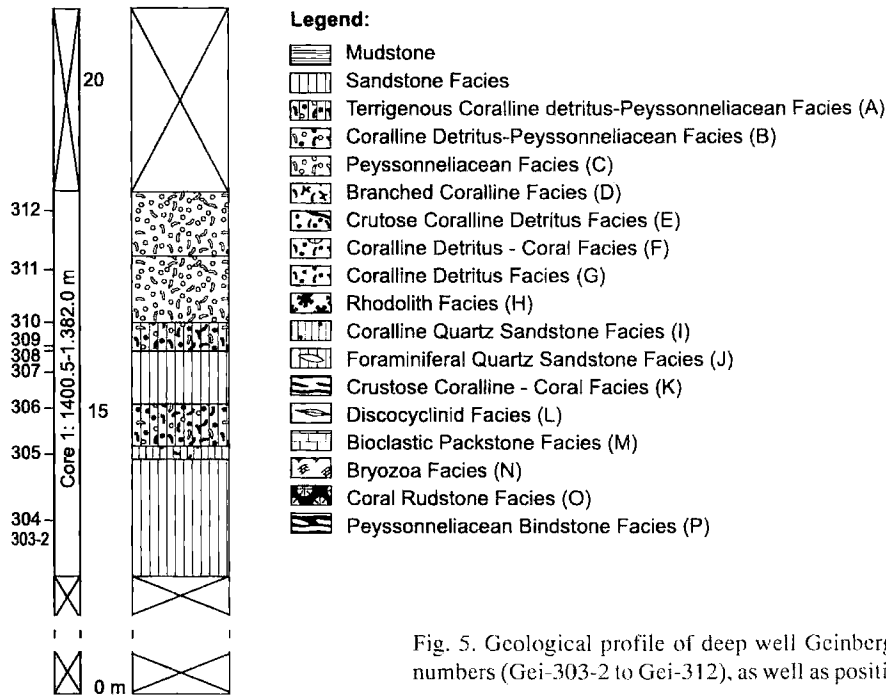


Fig. 5. Geological profile of deep well Geinberg (Gei) showing profile meters, sample numbers (Gei-303-2 to Gei-312), as well as position and absolute depth of deep well core.

5.5.1 Sandstone Facies

Sandstones are part of the terrigenous basal sequence (see WAGNER, 1980 for details). They are not studied in detail. WAGNER (1998) differentiates between Voitsdorf-Formation (limnic), Cerithien Beds (paralic), and Ampfing-Fm. (marine). They correspond to the "Klastische Transgressionsserie" of Bavaria (BUCHHOLZ, 1989).

5.5.2 (A) Terrigenous Coralline Detritus - Peyssonneliacean Facies (Pl. 12/1)

Classification: Terrigenous coralline detritus - peyssonneliacean rudstone with diagenetic bioclastic packstone (Gei-306 and Gei-308) or bioclastic pack- to grainstone (Gei-309 and 310) matrix.

Facies characteristics: This facies, in which peyssonneliacean algae and terrigenous components occur together, is characterized by a high diversity of components. It is the only facies in which no component category reaches an abundance of more than 25%. The most important difference to other coralline detritus - dominated facies is the abundance of both peyssonneliacean algae and terrigenous grains. Peyssonneliacean detritus is more abundant than in any other facies. This facies is restricted to Geinberg (Fig. 5).

Components: Coralline detritus, which dominates this facies, is mostly arenitic and well rounded. Peyssonneliacean detritus is more abundant than in any other facies. "Textularia-type" foraminifera are most abundant among the foraminifera, smaller miliolid foraminifera occur. Bryozoa are rare: cheilostome fragments, unilaminar encrusting and rigid erect branched cyclostomes occur. Echinoderms are mostly represented by spines. In contrast to foraminifera, the abundance of echinoderms increases with decreasing

abundance of terrigenous grains. Terrigenous components are arenitic and usually poorly rounded. They are remarkably more abundant near the profile base.

5.5.3 (B) Coralline Detritus - Peyssonneliacean Facies (Pl. 12/2)

Classification: Coralline detritus - peyssonneliacean rudstone (Ma-240, MS-284, MS-301) or rud- to floatstone (MS-287, MS-290). The matrix is formed by a grain- to packstone with a high amount of sparite (Ma-240, MS-284, MS-287, MS-290).

Facies characteristics: A high amount of coralline detritus (46-67%) and a moderate amount of peyssonneliaceans, together with a lack of quartz grains, characterize this facies. The difference to the Terrigenous Coralline Detritus - Peyssonneliacean Facies is the lack of quartz grains. This facies occurs in the hanging wall parts of the deep wells Maria Schmolln and Mattighofen.

Components: Coralline algal detritus is most prominent. In the samples Ma-240 and MS-284 most of the coralline algae, both fragmented and unfragmented, are heavily bored by microborers. Coralline detritus is poorly rounded to subrounded in all samples, independent from grain size. Peyssonneliaceans are predominantly unfragmented. They form globular and open laminar growth-forms; they are rarely overgrown by coralline algae. Foraminifera are high diverse. Textulariid and smaller miliolid foraminifera are dominant. Several types of rotaliid larger foraminifera can occur, but no nummulitids or orthophragminids. *Sphaerogypsina* occurs in one sample (MS-287). Bryozoa are mostly represented by cyclostomes: both massive uni- or multilaminar encrusting and delicate branching growth-forms occur. Echinodermata are mostly represented by rounded fragments and a few echinoid spines.

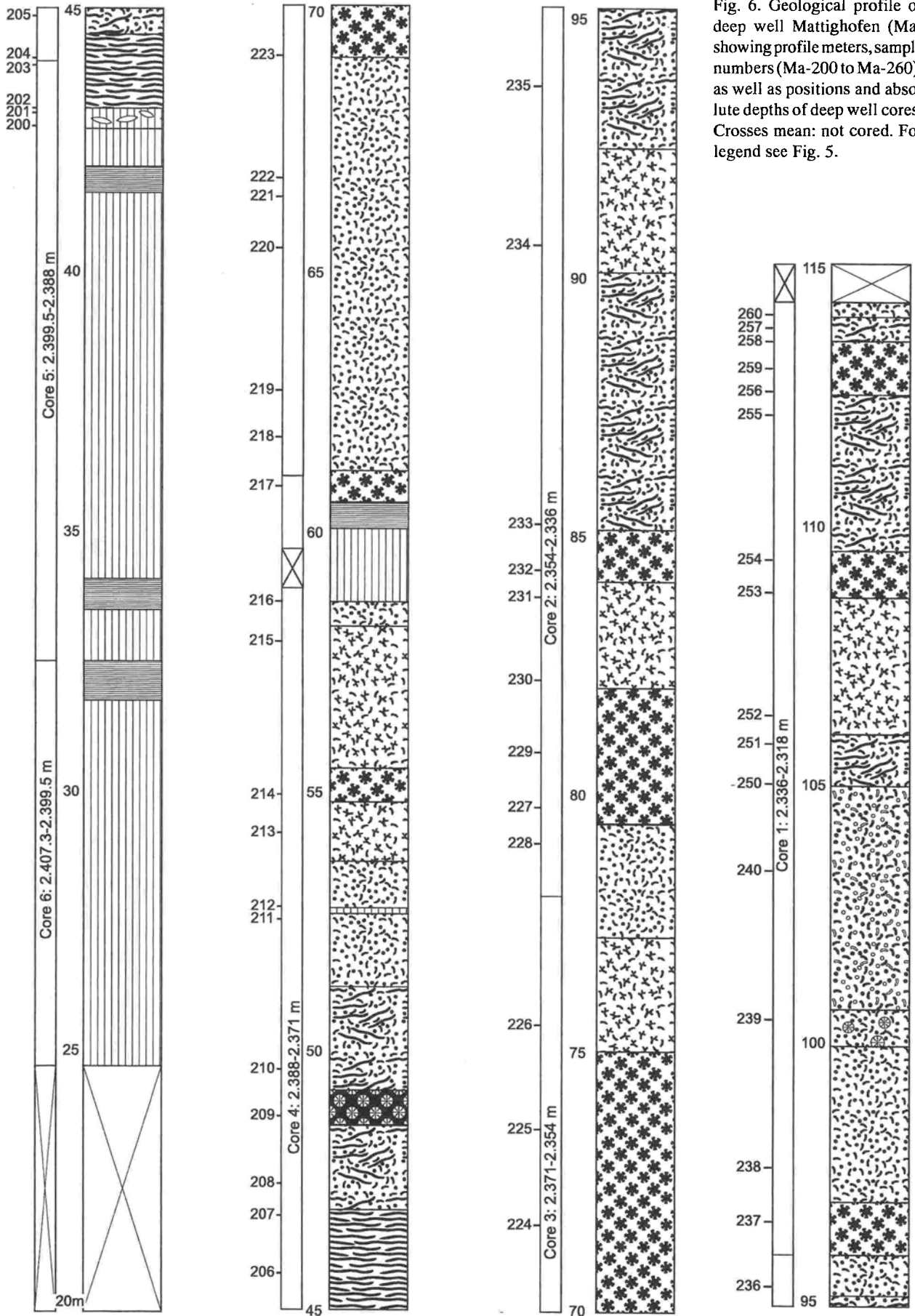


Fig. 6. Geological profile of deep well Mattighofen (Ma) showing profile meters, sample numbers (Ma-200 to Ma-260), as well as positions and absolute depths of deep well cores. Crosses mean: not cored. For legend see Fig. 5.

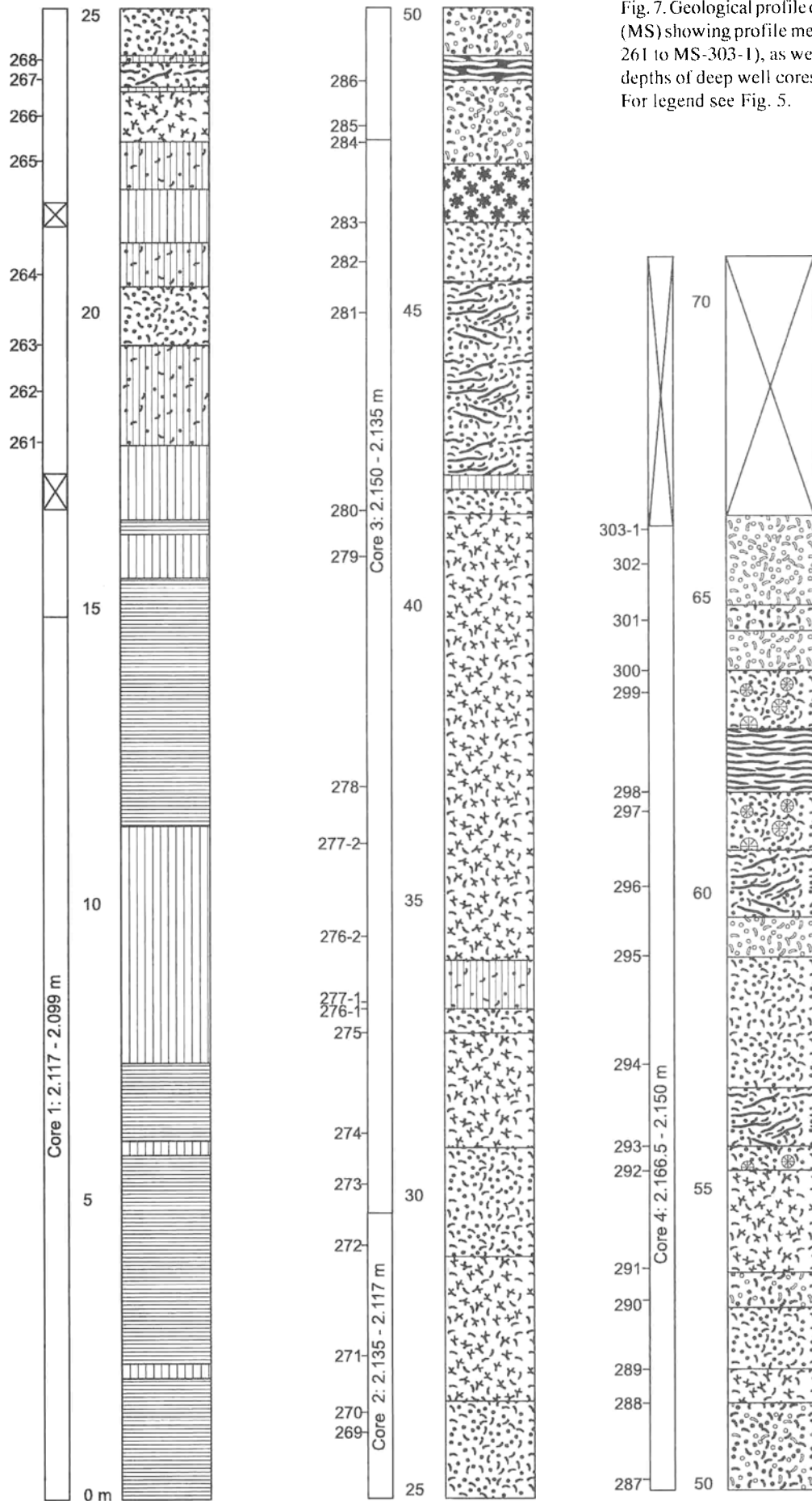


Fig. 7. Geological profile of deep well Maria Schmoln (MS) showing profile meters, sample numbers (MS-261 to MS-303-1), as well as positions and absolute depths of deep well cores. Crosses mean: not cored. For legend see Fig. 5.

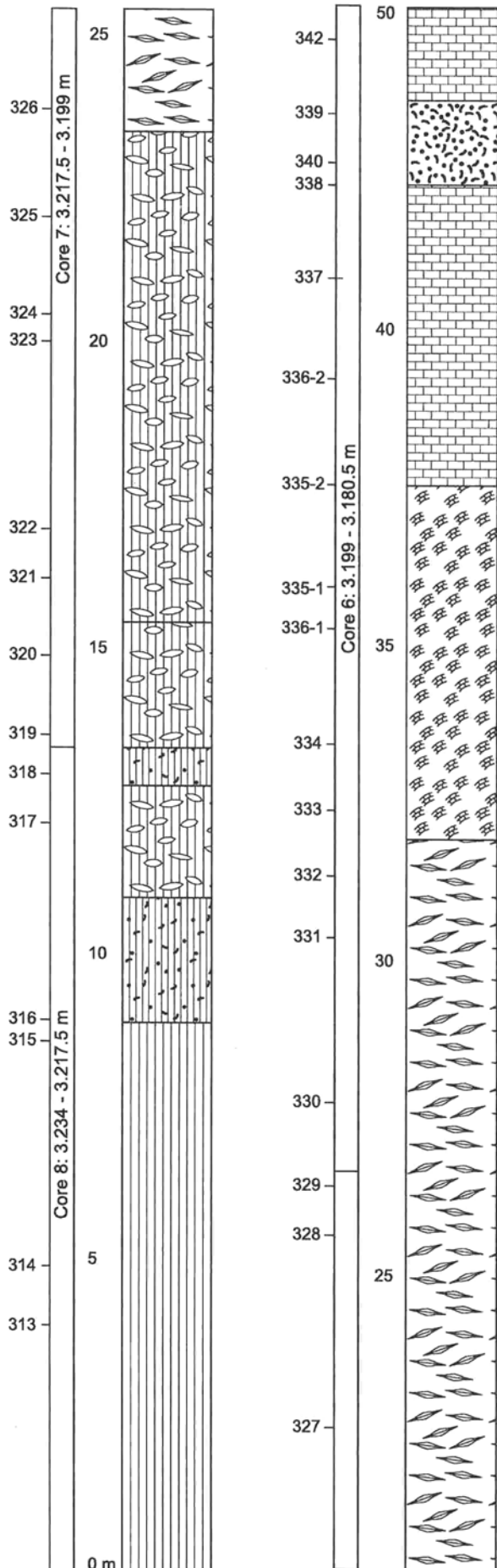


Fig. 8. Geological profile of deep well Helmburg (Hmb) showing profile meters, sample numbers (Hmb-313 to Hmb-342), as well as positions and absolute depths of deep well cores. For legend see Fig. 5.

5.5.4 (C) Peyssonneliacean Facies (Pl. 12/3)

Classification: Peyssonneliacean rudstone, mostly with packstone matrix. The matrix of Gei-312 is formed by a diagenetic packstone.

Facies characteristics: This facies is characterized by a dominance of unfragmented peyssonneliaceans (42-79%). Coralline algae always occur, coralline detritus can reach 25%. All other components are very rare; bryozoans and terrigenous components are lacking. The matrix is dominated by micrite. This facies is restricted to the topmost parts of profile Geinberg (Fig. 5) and Maria Schmolln (Fig. 7).

Components: Coralline algae are always present in this facies; they are usually poorly sorted and often encrust peyssonneliaceans. Coralline algae are best sorted in sample Gei-312, where mostly coarse arenitic corallines occur. Unfragmented coralline branches are mostly >2 mm. In contrast to arenitic coralline detritus, ruditic detritus is not rounded. Peyssonneliaceans are most abundant in this facies. They are mostly tube-shaped to globular and unfragmented. Peyssonneliacean detritus is mostly ruditic, moderate sorting dominates. Smaller miliolid and textulariid foraminifera are dominant among the foraminifera; they are not fragmented. Larger foraminifera are partially fragmented; several rotaliid taxa occur. Both rounded echinoderm fragments and spines occur.

5.5.5 (D) Branched Coralline Facies (Pl. 12/4-5)

Classification: Coralline algal rudstone; matrix either pack- to grainstone or grainstone.

Facies characteristics: The Branched Coralline Facies is characterized by the dominance of unfragmented coralline algal branches. The separation from the Coralline Detritus Facies is sometimes gradually. It is the only facies, besides the Rhodolith Facies, in which rhodoliths can be abundant. Foraminifera are not important. This facies is abundant in deep wells Mattighofen (Fig. 6) and Maria Schmolln (Fig. 7).

Components: Rhodoliths are columnar or laminar, sometimes successions from columnar to laminar can be observed. If nuclei are visible, they are formed by fragments of branching corals. In one case it is represented by a brachiopod which forms the nucleus of the only laminar-boxwork rhodolith of this facies. Coralline branches are always ruditic. Coralline detritus can be either ruditic and unrounded, or arenitic and subrounded to well rounded; sometimes sorting seems to be bimodal. Foraminifera, which are never abundant, are sometimes dominated by nummulitids. Moreover, miliolid and/or textulariid smaller foraminifera occur. Corals are mostly branching and rarely fragmented; they can serve as nuclei for rhodoliths. Brachio-

poda are mostly unfragmented. If terrigenous components occur, they are not rounded and coarse-arenitic.

5.5.6 (E) Crustose Coralline Detritus Facies (Pl. 12/6)

Classification: Coralline algal rudstone or bindstone, mostly with packstone matrix.

Facies characteristics: The facies is characterized by the dominance of coralline detritus and relative high abundance of coralline crusts. This facies occurs in deep wells Mattighofen (Fig. 6) and Maria Schmolln (Fig. 7).

Components: Two types of rhodoliths occur: (1) non-nucleated, flat, laminar-concentric rhodoliths in association with bindstones; rhodoliths are obviously formed by reworked crusts; and (2) ellipsoidal to spheroidal, columnar or (mostly) laminar rhodoliths. Coralline crusts are mostly not in-situ, but unfragmented. Some crusts are upside-down with continuous growth on the upper side, and thus may represent initial rhodoliths. In one case (Ma-205), nummulitids form thick accumulations within a bindstone; coralline crusts continue growing on the small nummulitid "mounds". Foraminifera are, however, rare or absent in most of the other samples. Smaller miliolid and textulariid foraminifera can occur, the latter are subordinate. Ostreids occur in some samples. Bryozoa are represented in some samples by branched and massive cyclostomes; they rarely form crusts in the bindstones.

5.5.7 (F) Coralline Detritus - Coral Facies (Pl. 12/7)

Classification: Coral-bearing coralline algal rudstone with pack- to grainstone matrix.

Facies characteristics: Coralline detritus and corals are abundant; terrigenous components and rhodoliths do not occur, coralline crusts are subordinate. This facies is restricted to higher parts of the profiles Mattighofen (Fig. 6) and Maria Schmolln (Fig. 7).

Components: Fragmented coralline crusts frequently form coralline detritus. Corals are mostly represented by branching growth-forms; most of them are encrusted by coralline algae. Foraminifera are rare: smaller miliolid foraminifera and some fragmented rotaliids.

5.5.8 (G) Coralline Detritus Facies (Pl. 12/8)

Classification: Coralline algal rudstone with grainstone or packstone matrix.

Facies characteristics: Dominance of coralline algal detritus; coralline branches are also abundant, other components occur subordinately. The grainstone matrix is much more abundant than in other algal-dominated facies. Sample Hmb-340 from the southern area remarkably differs by a high content of bryozoans. This facies occurs in all deep wells, except Geinberg.

Components: Coralline algae are bimodally sorted in facies with grainstone matrix. In that case, coralline branches and unrounded coralline detritus are mostly ruditic; rounded coralline detritus is arenitic. Fragmented coralline crusts can occur in samples with higher amount of micrite. In one

sample with grainstone matrix (MS-272) a coralline crust grows over a nummulitid accumulation. Rhodoliths are columnar or open-laminar concentric and mostly occur in samples with higher micrite content. Foraminifera are represented by nummulitids, other fragmented rotaliids, as well as smaller miliolid and textulariid foraminifera. Miliolids can be abundant in some samples, textulariids in others. Nummulitids are most abundant in samples with grainstone matrix. Terrigenous components are coarse-arenitic and poorly rounded.

5.5.9 (H) Rhodolith Facies (Pl. 14/5-8)

Classification: Rhodolith rudstone, mostly with grainstone- to packstone matrix.

Facies characteristics: The facies, which is restricted to deep well Mattighofen (Fig. 6), is characterized by the dominance of rhodoliths (>24%).

Components: Rhodoliths are composed of coralline and/or peyssoneliacean algae. They are columnar, columnar to laminar, or laminar. Laminar rhodoliths are mostly concentric, rarely boxwork. They are rarely affected by borings. Nuclei are visible in a few cases. They mostly consist of corals, rarely of rhodolith fragments. There are no distinct successions with respect to growth-form and/or taxonomic content - neither within the rhodoliths, nor in the vertical successions. Foraminifera are represented by nummulitids or smaller textulariids.

5.5.10 (I) Coralline Quartz Sandstone Facies (Pl. 13/1)

Classification: Nummulitid-bearing coralline algae- and quartz sandstones.

Facies characteristics: Owing to strong pressure solution and the resistant quartz grains it is mostly difficult to decide whether coralline algae are fragmented or only affected by pressure solution. The facies shows more similarities with the Foraminiferal Quartz Sandstone Facies than with the Discoeyclinid Facies. This facies occurs in deep wells Maria Schmolln (Fig. 7) and Helmberg (Fig. 8).

Components: Terrigenous components are predominantly poorly rounded and poorly to very poorly sorted. Coralline algae are mostly ruditic, the detritus is not rounded. Foraminifera are mostly represented by unfragmented nummulitids. In MS-264, smaller miliolid foraminifera occur. Molluscs are represented by fragmented ostreids. *Acervulina linearis* occurs in Hmb-318.

5.5.11 (J) Foraminiferal Quartz Sandstone Facies (Pl. 13/2, 3)

Classification: Larger foraminifera - bearing sandstone with carbonate cementation.

Facies characteristics: Quartz sandstone with nummulitids, sometimes accompanied by orthophragminids. Terrigenous components are either very poorly (coarse sand) or well (fine sand to silt) sorted. This facies is separated from the Discoeyclinid Facies by the high con-

tent of terrigenous components, and in places by the occurrence of nummulitids.

This facies occurs in deep wells Mattighofen (Fig. 6) and Helmburg (Fig. 8). In Mattighofen it is a coarse-grained, poorly sorted nummulitid-quartz sandstone. Helmburg shows a basal quartz sandstone, characterized by *Acervulina linearis* (Foraminiferal Quartz Sandstone), which is overlain by Coralline Quartz Sandstone. The latter is again overlain by Foraminiferal Quartz Sandstone, characterized by very poor sorted terrigenous components and nummulitids. Terrigenous components are fining upsection and orthophragminids occur in higher parts where they mark the transition into the Discocyclinid Facies.

Components: Besides quartz grains, nummulitids are dominant in all but one sample. They are partially fragmented. Smaller miliolid foraminifera are very rare. Orthophragminids are rare. One sample is dominated by the encrusting foraminifer *Acervulina linearis*. It forms tubes or half tubes with a cement- or sediment-filled inner part.

5.5.12 (K) Crustose Coralline - Coral Facies (Pl. 13/4-6)

Classification: Coralline algal - coral bindstone or coralline crusts - coral rudstone, with wacke- to packstone matrix.

Facies characteristics: Bindstone-forming crusts of coralline algae and corals characterize this facies in Mattighofen. In Maria Schmolln this facies is comparable to the Coralline Detritus - Coral Facies. A four meters thick bindstone is formed in Mattighofen. It develops from Foraminiferal Quartz Sandstone by a decrease of foraminifera and a fining-upward trend. It starts with horizontally upside-down oriented ostreid bivalves in a fine-grained matrix. They are encrusted by corals, followed by a thin coralline crust. After a thin sediment layer of a few millimetres (mostly wacke- to packstones), this "cycle" starts again. Generally, the abundance of corals decreases and coralline crusts increase upward. Crusts are never bored, pores between crusts are filled with fine sediment and detritus or sparite.

Components: Coralline detritus is usually not rounded and mainly consists of fragmented crusts. Coralline crusts in Mattighofen are thin and uni-layered at the base. Crusts are fragile to massive. They are bifurcated, partially fused, and upturned. Foraminifera are dominated by smaller miliolids, textulariids are very rare. *Haddonella heissigi* encrusts coralline algae, *Planorbulina* and some other rotaliids occur. Corals, mostly encrusting forms, contribute to the bindstone; only one sample contains branching forms. Encrusting corals are most abundant in the basal bindstone of Mattighofen (Fig. 6). Molluscs are only represented by ostreid bivalves which are restricted to the basal parts and form the initial substrate for bindstone-formation. Bryozoa are mostly represented by fragments of cyclostome branches; a few unilaminar crusts occur; one radiate cyclostome was found. Serpulids encrust coralline algae or corals and also occur as fragmented tubes.

Terrigenous components are fine-arenitic and poorly rounded.

5.5.13 (L) Discocyclinid Facies (Pl. 13/7)

Classification: Larger foraminifera rudstone with wacke- to packstone matrix.

Facies characteristics: This facies, which is restricted to Helmburg (Fig. 8), is characterized by larger foraminifera in a fine-grained matrix. Foraminifera are mostly horizontally oriented. The facies is separated from the Foraminiferal Quartz Sandstone by the low content of terrigenous components and by the dominance of discocyclinids. Nummulitids dominate one sample, reflecting the continuous development of this facies from the underlying Foraminiferal Quartz Sandstone. Owing to the low amount of terrigenous components it was, however, clustered together (see chapter 5.3) with samples dominated by discocyclinids. Bryozoa occur in varying quantities.

Components: Foraminifera of this facies are studied in detail by the author (publication in press). Sample 325 is dominated by nummulitids with subordinate orthophragminids. The latter dominate all other samples. They are predominantly unfragmented but layers dominated by orthophragminid fragments occur. Additionally, other fragmented rotaliids occur in some samples. Bryozoa are mostly represented by delicately branched cyclostomes; robust branched bilaminar cheilostomes occur. Terrigenous components are mostly fine-arenitic and poorly rounded.

5.5.14 (M) Bioclastic Packstone Facies (Pl. 13/8)

Classification: Bioclastic packstone, partially grain- to packstone.

Facies characteristics: The facies, which is restricted to Helmburg (Fig. 8), is dominated by fragmented bioclasts. It additionally differs from other facies types by its (very low) content of glauconite. Accumulations of mud and bryozoans can be related to fillings of burrows.

Components: Fine-arenitic and well rounded coralline detritus is abundant in some samples. Foraminifera are represented by rare textulariids, some small nummulitids and other, mostly fragmented, rotaliids. Planktonic foraminifera are restricted to the topmost sample. Some samples are dominated by fragmented Bryozoa.

5.5.15 (N) Bryozoa Facies (Pl. 14/1-2)

Classification: Bryozoa rudstone with wacke- to packstone matrix

Facies characteristics: The absolute dominance of bryozoans and the high amount of fine-grained matrix is characteristic for this facies. The higher abundance of foraminifera in sample Hmb-333 demonstrates that this facies develops more gradually from the Discocyclinid Facies.

Components: Foraminifera are represented by a few orthophragminids. Bryozoa are diverse and dominated by erect forms. Delicate branching cyclostomes are domi-

to:														Total
from:	B	C	D	E	F	G	H	I	J	K	O	P	Sd	
B		1	2	1									1	5
C	1			1										2
D				1	1	6	3						1	12
E			2	1	1	5	1	1		1	1			12
F	1	1												3
G	1	1	3		1		4	2						12
H	1		3	3		2								9
I			2			2							1	5
J										1				1
K				2	1									3
O				1										1
P	1													1
Sd				2		1	1	2	1				2	7
	5	3	12	11	4	16	9	5	1	3	1	1	2	73

to:														Total
from:	B	C	D	E	F	G	H	I	J	K	O	P	Sd	
B		0.20	0.40	0.20									0.20	
C	0.50			0.50										
D				0.08	0.08	0.50	0.25							0.08
E			0.17		0.08	0.42	0.08	0.08		0.08	0.08			
F	0.33	0.33								0.33				
G	0.08	0.08	0.25		0.08		0.33	0.17						
H	0.11		0.33	0.33		0.22								
I			0.40			0.40								0.20
J										1.00				
K				0.67	0.33									
O				1.00										
P	1.00													
Sd				0.29		0.14	0.14	0.29	0.14					

Tab. 4. Markov Chain Analysis: Transition frequency matrix. Counted transitions from facies of column to facies of uppermost row (above) and transition probability matrix (below).

nant, cheilostomes of the same growth-form are also abundant; bilaminar robust branching forms and several different fragments occur. Low fragmentation of fragile growth-forms point to a (par)autochthonous occurrence. Some glauconite grains occur. This facies is restricted to Helmberg (Fig. 8).

5.5.16 (O) Coral Rudstone Facies (Pl. 14/3)

Classification: Coral rud- to floatstone with wacke- to packstone matrix.

Facies characteristics: Most prominent components are corals in a micritic matrix. In contrast to other coral-bearing facies, both branching and encrusting corals occur; coralline algae are subordinate. Dolomitization occurs along pressure solution surfaces. This facies is restricted to one occurrence in Mattighofen (Fig. 6).

Components: Foraminifera are represented by a few miliolid smaller foraminifera. Two branching corals occur in growth-position, which are encrusted by unilaminar bryozoans and coralline algae. The substrate on which corals were growing cannot be recognized. Bryozoa are represented by unilaminar cheilostomes encrusting branching corals, delicately branched cheilostomes, and erect cyclostomes.

5.5.17 (P) Peyssonneliacean Bindstone Facies (Pl. 14/4)

Classification: Peyssonneliacean bindstone with wacke- to packstone or grainstone matrix.

Facies characteristics: This bindstone was only found in one sample. The approximately 20 cm thick succession of peyssonneliacean crusts is subordinately intergrown by coralline crusts. The matrix between crusts is mostly

micritic, but also shows sparitic areas. It differs from the Crustose Coralline - Coral Facies by the peyssonneliacean crusts and the occurrence of gastropods. This bindstone is restricted to Maria Schmolln (Fig. 7).

Components: Peyssonneliaceae and Corallinaceae form in-situ crusts. Coralline detritus and textulariid foraminifera occur between crusts. Unfragmented gastropods are relatively abundant in the sediment which directly overlies the bindstone.

5.5.18 Remarks

According to the lithostratigraphy of WAGNER (1998) facies A, B, C, D, E, F, G, H, I, K, O, J, and P are part of the "Lithothamnium Limestone"; J corresponds to the "Nummulitic Sandstone"; L is part of the Perwang-Fm.; M and N were not described. Most facies cannot be compared to those described from the Bavarian foreland basin (BUCHHOLZ, 1989): Facies A, B, C, D, E, G, M, N, and J were not described; facies F can be compared with the "Korallen-Wackestone"; H can be compared with both "Rhodolith-Wackestone", "Rhodolith-Floatstone", and "Rhodolith-Rudstone"; I and J are probably part of the "Klastische Transgressionssedimente"; K corresponds to the "Bindstone"; L corresponds to the "Discocyclinenmergel"; O can be compared with the "Korallen-Wackestone".

5.6 Markov Chain Analysis

Markov chain analysis was conducted in order to extract general trends of facies transitions. Only samples from deep wells Mattighofen and Maria Schmolln were analysed, as Geinberg and Helmberg are characterized by facies which are restricted to the respective deep wells. 73 transitions were observed - most of them, however, only once. Therefore, only a few statements are possible which have to be treated with caution.

Most transitions and highest transition probabilities (Tab. 4) occur from both Branched Coralline Facies (D – 6 transitions, probability = 0.50) and Crustose Coralline Detritus Facies (E – 5 trans., prob. = 0.42) to Coralline Detritus Facies (G). The latter (4 trans., prob. = 0.33) predominantly changes to Rhodolith Facies (H), which again changes to Branched Coralline Facies (D) and Crustose Coralline Detritus Facies (E) (both of them: 3 trans., prob. = 0.33).

These results reveal a cyclic sedimentation: Rhodolith Facies → Branched Coralline Facies / Crustose Coralline Detritus Facies → Coralline Detritus Facies → Rhodolith Facies.

These cycles can be interpreted by an increasing hydrodynamic energy from Rhodolith- to Coralline Detritus Facies, and indicate a shallowing upward. According to WALTHER'S law it can additionally be stated that these facies were laterally adjacent to each other during deposition.

6 DISCUSSION

6.1 Coralline Crusts

Four types of **Recent** crustose coralline algal frameworks are known: (1) algal ridges, (2) algal cup reefs, (3) trottoir, (4) coralligène. They can be differentiated by climate: tropical (1, 2) or temperate (3, 4); by the underlying substrate: rock bottom (1 - 4) or soft bottom (4); and by water depth: intertidal to shallowest subtidal (1 - 3), or shallower subtidal down to 160 m (4).

Algal ridges "represent a late successional stage of coral reef development forming a constructional cap over corals as the reef approaches sea level" (ADEY & BURKE, 1976; ADEY, 1978; BOSENCE, 1984; STENECK et al., 1997). **Algal cup reefs**, also called boilers or breakers, are intertidal cup-shaped algal bioherms arising from Pleistocene rocks (GINSBURG and SCHRÖDER, 1973). They are formed by intergrowing coralline algae and invertebrates; corals occur sporadic (GINSBURG and SCHRÖDER, 1973; DEAN and EGGLESTON, 1975; BOSENCE, 1983d). **Trottoirs** are known from the Mediterranean and Northern Atlantic (e. g., ADEY, 1986). They are intertidal frameworks, usually growing on steep rock shores, but can also form algal "micro-ridges" (THORNTON et al., 1978). Trottoirs are restricted to rock bottoms.

The only known type of present-day coralline algal frameworks comparable to the studied material is the Mediterranean **coralligène de plateau** (although it lacks corals), which can develop on soft bottoms. It occurs in deeper shelf waters (20 to 160 m) and passes laterally into carbonate sands and gravels or terrigenous sands and muds (BOSENCE, 1985a). Shelly gravel and rhodolith accumulations usually form the substrate for a crustose coralline construction. Caverns are abundant and many are filled with sediment. Coralline crust margins are commonly upturned and free (BOSENCE, 1985a).

According to BOSENCE (1985b), the hydrodynamic energy of coralline bioherms is reflected by the type of bioerosion: High-energy bioherms are robust and subject of widespread cementation, resulting in pervasive boring; low-energy bioherms are delicate and do not receive extraskelatal cements. Borers do not subject them to such an extent, but burrowing organisms break down the framework and form gravel sized sediment.

Fossil: The only fossil analogue to the studied coralline frameworks is described from the Miocene of Malta, which was compared with the present-day Mediterranean coralligène (BOSENCE and PEDLEY, 1982; BOSENCE, 1983c): Branched, unattached coralline algae colonize offshore sand ridges, sheltered seafloor areas are colonised by algal boxworks. Afterwards, a crustose framework with a low relief is formed. Rhodolith channels cut this crustose pavement and crustose detritus becomes spread over wide areas.

SINCLAIR et al. (1998) ascribe coralline bindstones from the Late Eocene Alpine Foreland Basin of France to an inner ramp environment (i. e., influenced by wave action), where they constructed a distinct relief.

Interpretation: The coralline bindstones and related

facies of the current study can be compared to the present-day Mediterranean coralligène and the Miocene of Malta: Crustose facies develop from rhodolith- or ostreid accumulations, but not from hard substrate. The main difference to the coralligène is that hermatypic corals contribute to the studied bindstones.

The occurrence of hermatypic corals suggests that studied crustose frameworks were growing in the upper photic zone. The high amount of fine-grained sediment filling the open spaces between crusts suggests the occurrence of hydrodynamic energy, which prevented the corallines from being buried. The dominance of delicate crusts, as well as substrate stability necessary for settlement of coralline frameworks indicate, however, that this energy was not too high. Factor analysis indicate that corals and coralline crusts have completely different ecological requirements in comparison with coralline detritus and branches. Higher water energy, causing an unstable substrate by shifting maerl ripples (see chapter 6.3), probably hindered the formation of crustose frameworks. With respect to its Recent analogue, the studied crustose algal frameworks are supposed to have formed a relief above the surrounding surface.

6.2 Rhodoliths

Rhodoliths are frequently used for paleocological interpretations (see below). Several restrictions are necessary for the current study: (1) Limestones are heavily cemented and rhodoliths can only be studied in thin sections and polished slabs; therefore, the type of shape and branching often remains uncertain. (2) For the same reason it can be difficult to differentiate between rhodoliths and encrustations. (3) Owing to the low diameter of deep well cores the lateral distribution remains questionable. (4) The number of samples is restricted and quantification is therefore difficult.

Recent: Living rhodoliths are found from intratidal pools (e. g., WEHRMANN et al., 1995) down to more than 200 m (ADEY & MACINTYRE, 1973; LITTLER et al., 1991). The typical lower limit in the tropics is about 80 m, in colder climates and higher latitudes 20 - 40 m (ADEY, 1986). Water energy is expected to be an important ecological factor for rhodolith distribution. It can influence the occurrence of herbivorous animals (STENECK, 1985) and controls growth-form and taxonomic successions (BOSELLINI & GINSBURG, 1971; BOSENCE & PEDLEY, 1982; BOSENCE, 1984; BRAGA & MARTIN, 1988; BOSENCE, 1991). Growth-form and shape of rhodoliths are expected to be controlled predominantly by the frequency of turning (BRAGA & MARTIN, 1988; BOSENCE, 1991). This is confirmed by the observation of BOSELLINI & GINSBURG (1971) that an increasing frequency of rhodolith turning causes a flattening of the branches, which then join together laterally (see also BOSENCE, 1991). Taxonomic successions are, however, not primarily controlled by hydrodynamic energy. They may be the result of a change in rhodolith size (the larger the size, the higher their stability) rather than of environmen-

Dominant component	Facies	Nomenclature	Other important components
Coralline branches	(D) Branched Coralline Facies	Coralline algal rudstone with pack- to grainstone matrix or grainstone matrix	Coralline detritus
Coralline detritus	(A) Terrigenous Coralline Detritus - Peyssonneliacean F.	Terrigenous coralline detritus - peyssonneliacean rudstone with bioclastic pack- to grainstone matrix	Detritic and unfragmented Peyssonneliacean, terrigenous, coralline branches
	(B) Coralline Detritus - Peyssonneliacean F.	Coralline detritus - peyssonneliacean rudstone or rud- to floatstone with grain- to packstone matrix	Detritic and unfragmented Peyssonneliacean, coralline branches
	(E) Crustose Coralline Detritus F.	Coralline algal rudstone or bindstone mostly with packstone matrix	Coralline crusts, coralline branches
	(F) Coralline Detritus - Coral F.	Coral-bearing coralline algal rudstone with pack- to grainstone matrix	Corals, coralline branches
	(G) Coralline Detritus F.	Coralline algal rudstone with grainstone matrix or with packstone matrix	Coralline branches
	(M) Bioclastic Packstone F.	Bioclastic packstone, partially grain- to packstone	Bryozoa, Foraminifera, Echinodermata
Coralline crusts	(K) Crustose Coralline - Coral F.	Coralline algal - coral bindstone or coralline crust - coral rudstone with wacke- to packstone matrix	Corals, coralline detritus
Rhodoliths	(H) Rhodolith F.	Rhodolith rudstone mostly with grainstone- to packstone matrix	Coralline detritus, coralline branches
Peyssonneliacean aggregates	(C) Peyssonneliacean F.	Peyssonneliacean rudstone with pack- to grainstone (mostly packstone) matrix	Coralline detritus, coralline branches, peyssonneliacean aggregates
Peyssonneliacean crusts	(P) Peyssonneliacean Bindstone F.	Peyssonneliacean bindstone with wacke- to packstone or grainstone matrix	Coralline detritus, coralline crusts
Foraminifers	(L) Discocyclinid F.	Foraminifera rudstone with wacke- to packstone matrix	Terrigenous components, bryozoans
Corals	(O) Coral Rudstone F.	Coral rud- to floatstone with wacke- to packstone matrix	Bryozoa, coralline crusts, coralline detritus
Bryozoa	(N) Bryozoa Facies	Bryozoa rudstone with wacke- to packstone matrix	Foraminifers
Terrigenous	(I) Coralline Quartz Sandst. F.	Coralline algae- and nummulitids-bearing quartz sandstones	Coralline detritus, coralline branches
	(J) Foram. Quartz Sandst. F.	Larger foraminifera - bearing sandstone	Foraminifers

Tab. 5. Summary of facies characteristics, nomenclature, and typical components. Sorted by dominant components.

tal change (ADEY and MACINTYRE, 1973). This is supported by the observation of BOSENCE (1983b), that smaller rhodoliths generally have a different encrusting flora than larger ones. In addition coralline algal growth-forms do not only depend on ecological factors: different taxa can show different growth-forms.

SCOFFIN et al. (1985) showed that complete envelopes of living tissue can be maintained on rhodoliths that remain static for periods of several months, but which rest on shifting sands. Therefore, REID & MACINTYRE (1988) assumed that shape and growth-form of nodules have little predictive value as indicators of ecological conditions.

Fossil: BOSENCE & PEDLEY (1982) described rhodoliths from the Miocene of Malta, which are partially comparable to the studied material: laminar rhodoliths are mostly discoidal in shape, with nuclei formed by leafy crusts. They are most common in both low-energy marls and high-energy crustose facies. Some of the rhodoliths in Upper Austria consist of both coralline and peyssonneliacean algae; the latter form monospecific rhodoliths, too. BUCHBINDER and HALLEY (1985) described comparable Eocene rhodoliths from a shallow platform. Like in the current study, rhodoliths composed of peyssonneliaceans or composed of coralline algae occur together without distinct vertical or lateral rhodolith distribution.

Most reliable paleoecological interpretations are based on taxonomic successions within rhodoliths. RASSER (1994) reconstructed a deepening upward sequence using the

succession from coralline to peyssonneliacean algae and acervulinid foraminifers.

Interpretation: The discussion about present-day occurrences of rhodoliths shows that paleoecological interpretations using rhodoliths bear several problems. Paleoecological indications are rare, as the occurrence of coralline and peyssonneliacean algae in the studied rhodoliths do not show any distinct trend. The rarely observed successions from columnar to laminar coralline algae are caused by a taxonomic change. This change can, however, be caused by the changing rhodolith size, causing a higher stabilisation, rather than by changing environmental conditions. Two interpretations are possible: (1) predominantly open laminar and boxwork growth-forms point to a rather low hydrodynamic energy, and (2) the lack of bioerosion points to a rapid sediment covering.

Cluster analysis revealed that the Rhodolith Facies is characterized by the dominance of rhodoliths, but not by the frequency of other components. It is therefore presumed that rhodolith accumulations can be formed in most coralline-dominated sediments.

6.3 Coralline Branches and Detritus

Recent: Sediments which are predominantly composed of unattached coralline algal branches, rhodoliths, and their detritus are called maerl (ADEY, 1986; FREIWALD et al., 1991; FREIWALD, 1994). Today, they are restricted to

the Mediterranean Sea and the Northern Atlantic (ADEY, 1986). In deeper water, peyssonneliaceans contribute to the maerl formation. In the turbid, high-energy waters of western Europe, most maerl occurs in protected bays at depth of 1 - 10 m. In rather low-energy and clear waters of the Mediterranean Sea maerl is more characteristic in depths down to 40 m. It is even reported from 180 m (ADEY, 1986). While maerl sediments in protected areas are characterized by large, fragile, and branched rhodoliths (ADEY, 1986: Fig. 17), those of higher energetic (tidal currents) areas are composed of interlocking coralline branches forming megaripples (SCOFFIN, 1988: Fig. 4).

In the northeastern Atlantic, loose frameworks of interlocking branched coralline algae form 10 to 30 cm high maerl banks which cover areas up to 0.5 km². Where currents are low, a mud and sand matrix is deposited between the algal branches. In the northeastern Atlantic this framework grows in sheltered parts of bays at depths of 1 - 8 m, in the Mediterranean at depths of 30 - 40 m (BOSENCE, 1983b).

Fossil: Temperate algal limestones from the Late Eocene of New Zealand reveal comparable features. Coralline algal gravels and algal-bearing quartz sandstones are comparable to facies D, G, H, and I of the current study, although the micrite content is remarkably higher in facies I. The sediments of New Zealand lack, however, corals, nummulitids, and orthofragminids. MACGREGOR (1983) interpreted the environment as a cold- and clear-water, near-shore algal facies swept by weak tidal currents, in 0-12 m depth.

Interpretation: Coralline branches and detritus probably formed banks or megaripples composed of interlocking branches, like those described from present-day maerl sediments. They were influenced by currents or/and wave agitation, reflected by the irregular distribution of pack- and grainstone-matrix. Hydrodynamic energy influenced the ratio of branches/detritus. Intercalations of siliciclastic sediments are caused by sand channels cutting through maerl frameworks.

Component analyses revealed positive correlations between coralline branches and detritus. This suggests, that fragmented branches were not transported over long distances. Statistical analyses indicate negative correlations between terrigenous components and coralline algae. In fact, terrigenous components are not abundant in coralline sediments, indicating that higher terrigenous input is unfavourable for coralline algal growth.

6.4 Peyssonneliacean Algae

Recent: Present-day peyssonneliaceans occur in depths of 8 - 120 m. They are best studied in the Mediterranean (review in BASSI, 1997) where they form crusts and unattached nodules. The unusual rounded and irregular growth-forms of the studied specimens are comparable to those of *Peyssonnelia rosa-marina* from the Mediterranean (BASSO, 1990). This species forms discoidal crusts on fine-grained soft bottoms between 40 and 70 meters water depth. The occasional overturning causes tube-shaped, ellipsoidal

and nodular growth-forms leaving large inner cavities filled by sediment. This occasionally leads to the formation of up to 8 cm large rhodoliths. BASSO (1990) points out that the distribution of this species is mainly controlled by the light availability. No comparable facies has been described from fossil material.

Interpretation: Growth-forms of the studied *Polystrata alba* correspond to those of *Peyssonnelia rosa-marina* from the Mediterranean. The high amount of micrite in peyssonneliacean-dominated facies, as well as the life habit of *Peyssonnelia rosa-marina*, indicate that they were growing on soft bottoms in relatively deeper water. Occasional turning of thalli, by currents or animal activities, leads to the formation of the described growth-forms. Undisturbed thalli are able to form bindstones. As peyssonneliacean algae are most abundant in upper parts of the studied sections this may point to lower-light conditions caused by greater depth or suspension compared to the coralline algae-dominated sediments. The different paleoecological requirements of peyssonneliacean and coralline algae are reflected by negative correlations in factor analysis.

6.5 Encrusting Foraminifera

Acervulina linearis with its special growth-form is restricted to one sample. DARGA (1993) described comparable tubular and half-tubular growth-forms from *Acervulina linearis* from the Late Eocene of the Helvetic Zone of Bavaria. *A. linearis* encrusted wooden remains of terrestrial plants which are partially preserved. This foraminifer was found both in lagoon-, ramp-, and basin-settings, comprising distinct growth-forms in the different environments. UNGARO (1996) described half-tubes formed by *Acervulina multiformis* which lived attached to seagrass or fleshy macro algae.

Interpretation: This growth-form of *A. linearis* is only known from the Late Eocene of the Alpine Foreland Basin (DARGA, 1993). Dominance of *A. linearis* in the studied material is restricted to one sample, which lacks coralline algae, but is over- and underlain by Coralline Quartz Sandstone. Why did the foraminifer "replace" the coralline algae? This could be caused by substances produced by rotting of the wood - as suggested by DARGA (1993). If *A. linearis* was epiphytic, the lack of corallines could be explained by the influence of non-calcified plants (e. g., space competition of sea grass or fleshy macro algae).

6.6 Orthofragminids and Nummulitids

Recent: Present-day larger foraminifera contain symbionts and are therefore restricted to the photic zone (HOHENEGGER et al., 1999). Main factors influencing their distribution are temperature, light intensity, water movement, substrate, and food (HOHENEGGER et al., 1999).

Foraminiferal tests can express environmental parameters (for review see: HOTTINGER, 1983; HOHENEGGER, 1994; 1995): Present-day lenticular, thick-walled nummulitids are most abundant below fair-weather wave base. They

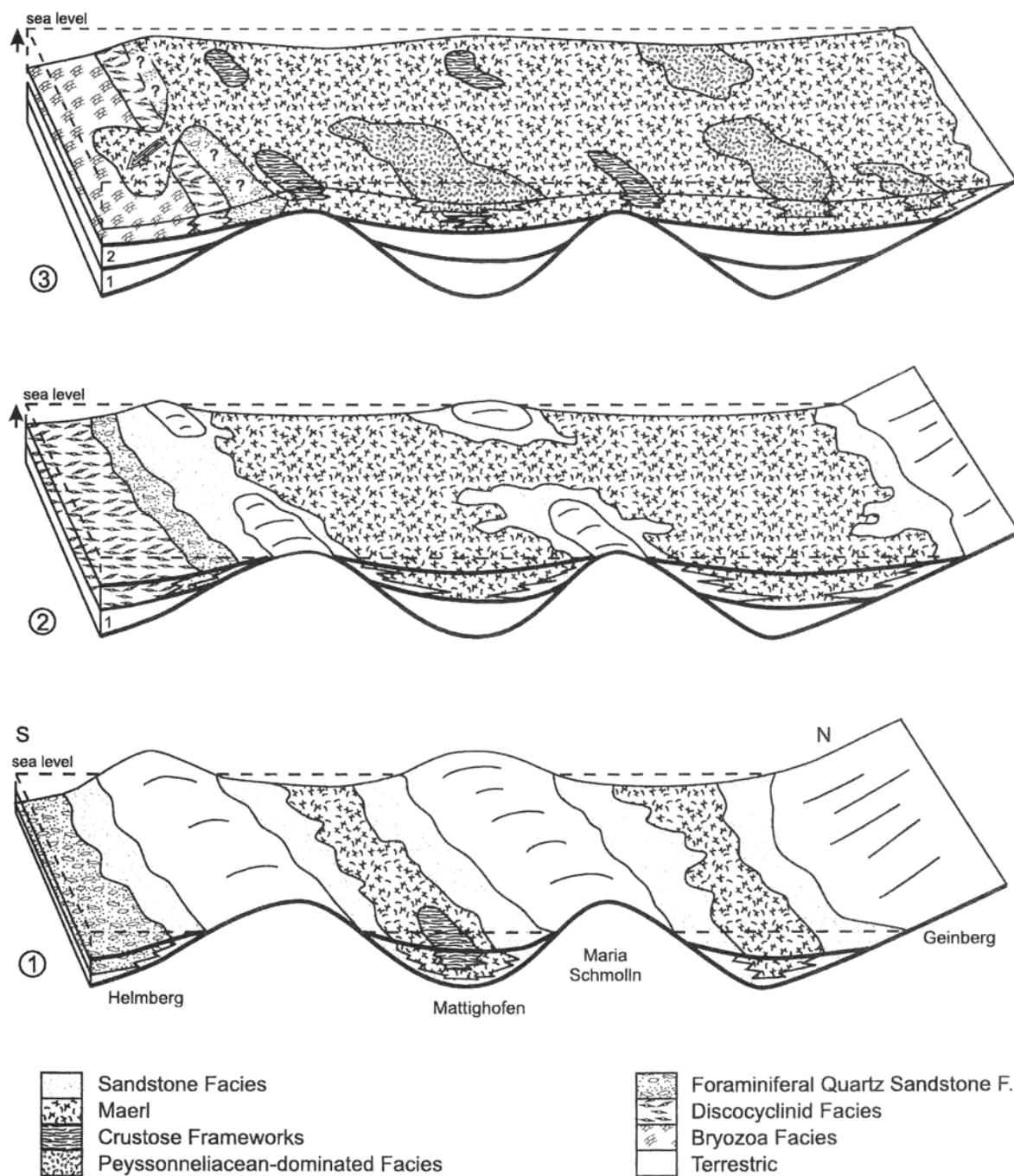


Fig. 9. Schematic reconstruction of Late Eocene facies development; not to scale. Approximate positions of deep wells is shown.

prefer coarse sandy substrates. No present-day analogues of orthofragminids occur. Comparable big, flat larger foraminifera like *Cycloclypeus* occur in deeper environments, down to the base of the photic zone (HOTTINGER, 1983; HOHENEGGER, 1994), mostly on fine-grained soft bottom (KOBA, 1978). Generally, the lower limit of larger foraminifera occurrence is at about 130-140 m water depth (HOTTINGER, 1983; MURRAY, 1987).

Fossil: COSOVIC & DROBNE (1998) ascribed orthofragminids of comparable morphologies to the lower most photic zone from the Middle Eocene of Istria. BASSI (1998) described discocyclusid packstones from the Late Eocene

of Northern Italy, which he interprets as inner ramp deposits. They are not comparable to the current study, as they are associated with coralline algae and show imbrications.

Interpretation: Statistical analyses revealed, that foraminifers and corallines are negatively correlated. Which paleological factors caused the absence of coralline algae in foraminifera-dominated facies of the southern area? Corallines occur from the tropics to the polar region, in depths down to more than 200 m (at least in the tropics), and in almost any hydrodynamic regime (although a certain water agitation is necessary for transport of nutrients). The most probable ecological factor excluding the occur-

rence of corallines in the mentioned facies therefore seems to be the substrate (expressed by abundance and grain size of terrigenous components) or/and sedimentation rate. The negative correlations between terrigenous components and coralline detritus support this interpretation.

The Foraminiferal Quartz Sandstone Facies, which is characterized by coarse quartz sand and lenticular nummulitids, lacks coralline algae because of the high hydrodynamic energy and/or the high sedimentation rate. The absence of coralline algae in the Discocyclinid Facies, which is characterized by fine-grained terrigenous material and large, flat orthophragminids, may be caused by the soft substrate. Here free living corallines and tests of dead foraminifera (which could provide substrate for coralline encrustations) are buried or sink into the soft sediments, vagile orthophragminids are able to free themselves.

Large, flat foraminifera, such as fossil orthophragminids and the Recent *Cycloclpeus*, cannot live in agitated waters, as they would shift away. This is in opposition to rounded nummulitids like those of the studied material. As the facies characteristics of the Discocyclinid Facies (grain size; flat, large orthophragminids; low fragmentation; occurrence of complete coccosphaeres) point to a low energy environment, the succession from the Foraminiferal Quartz Sandstone Facies to the Discocyclinid Facies indicate deepening upward.

6.7 Bryozoa

Recent: BONE and JAMES (1993) describe bryozoan sands and marls from temperate waters of southern Australia. Erect bryozoans are anchored to the soft-bottoms and lived in water depths down to more than 400 m.

Fossil: ZÁGORSEK (1996) conducted a study on Late Eocene Alpine-Carpathian Bryozoa marls. The stratigraphic column of Hybica (Slovakia) shows a vertical development which is comparable to the current study: Coralline algal limestones are overlain by *Discocyclina* marls and finally by bryozoan marls, which interfinger with *Globigerina* claystones. This succession is interpreted by a depositional environment on the shelf margin and the influence of cold upwelling water favouring the bryozoan growth.

Interpretations: Bryozoans of the Bryozoa Facies may have lived in deeper (aphotic) or/and colder environments than light-dependent organisms like larger foraminifera or calcareous algae. This suggests an ongoing deepening upward from Foraminiferal Quartz Sandstone Facies to Discocyclinid Facies and finally to the Bryozoa Facies. Although it is not abundant in the current study, the occurrence of glauconite is characteristic for cooler water (READING, 1986) or areas with low sedimentation rate (PURNACHANDRA RAO et al., 1993). An upwelling in the southern area may have occurred (WAGNER, 1998), but cannot be proved. If the formation of Bryozoa Facies was only caused by a cooling but not by a greater water depth, coralline algae could have thrived. The succession from Discocyclinid Facies to Bryozoa Facies therefore indicates an ongoing relative rise of sea level, reflecting the ongoing

subsidence of the Alpine Foreland Basin. Since bryozoans are suspension feeders (e. g., SMITH, 1994) a eutrophication of the environment, followed by low-light conditions, can be another explanation for the lack of phototrophic organisms.

7 DEPOSITIONAL MODEL

Three steps indicate the environmental development (Fig. 9).

1. Erosion on morphological high zones and deposition in depressions start to fill up of the underground relief with quartz sand. In the northern area, these coastal quartz sands grade laterally into Coralline Quartz Sandstone Facies and the latter into Branched Coralline Facies or Coralline Detritus Facies. Maerl sediments cover wide areas, probably cut by quartz sand channels. The formation of a crustose coralline-coral framework at Mattighofen is favoured by its protected position in a trough. In the southern area, Coralline Quartz Sandstone Facies develops over quartz sandstones. The high terrigenous input hinders the formation of maerl sediments, instead, nummulitid - dominated Foraminiferal Quartz Sandstones are formed below wave base.

2. Extensive maerl-fields develop in the northern area, which continue to fill up the relief. Terrigenous influence decreases owing to the rising sea-level. Frequency of coralline detritus reflects high hydrodynamic energy. Rhodolith accumulations and coral biostromes occur in low-energy areas. Thin sandstone intercalations in Maria Schmolln show that erosion of high zones is subordinate compared to stage one. The nummulitid - dominated facies of the southern area grades upsection into the Discocyclinid Facies. The soft substrate prevents coralline algae growth.

3. The rising sea level, caused by a subsidence of the foreland, reaches the northern-most part of the basin (Geinberg). Terrigenous input only occurs along the coast, high zones are completely flooded. The rate of carbonate sedimentation can keep up with rising sea level in the northern area. Fragmentation in the "Maerl"-facies is low. Crustose frameworks grow on morphological highs. The peyssonneliacean - dominated facies reflects the occurrence of muddy areas deeper than in (1) and (2). In contrast to the algal limestones of the northern area, sedimentation rate of the southern area is too low to keep up with the rising sea level. Some glauconite is formed. The Bryozoa Facies suggests an environment below the photic zone. Bioclastic packstones and coralline detritus originate from the northern area and can be interpreted as grain flows which reworked bryozoans and glauconite.

Alternatively, the dominance of bryozoans can be interpreted by eutrophication, too. The eutrophication of the environment caused a high water turbidity and did not allow the occurrence of light-dependent organisms. If the dominance of bryozoans was not caused by a greater water depth but by water turbidity, the overlying algal-dominated facies may represent a progradation of (par)autochthonous algal sediments.

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SAMPLE	Spart	Matrix	Coralline branches	Coralline crusts	Coralline detritus	Peys. aggregates	Peys. crusts	Peys. detritus	Foraminifera	Corals	Corals encrusted	Bivalves	Gastropods	Bryozoa	Brachiopods	Brachiopods encrusted	Echinodermen	Bioclasts	Others	Terrigenous	Sepulids	Ostracods	Rhodoliths
Ma 200		18.9							28.3					4.7			0.9			47.2			
Ma 202A	7.2	62.2		8.7	2.2				1.9			0.4		2.3			1.2	3.5		9.8		0.3	
Ma 203	5.8	48.3		9.8	3.4				0.7	15.7		3.0		3.0			1.2	5.9		3.3			
Ma 204	5.8	35.2	1.3	20.5	4.8				0.7	13.2		0.1		3.0			1.0	2.8	1.3	0.4	9.9		
Ma 205	10.1	15.8	10.1	21.5	12.5				15.0			0.2		0.9			2.5	10.8	0.5	0.2			
Ma 206	3.8	33.8		27.7	5.7				0.9	13.9	3.6			2.6			1.9	5.4	0.6			0.1	
Ma 207	7.1	51.3	3.7	18.5	5.9				1.2	3.9				2.8			2.6	1.6		1.2			
Ma 208	30.1	30.1	18.1		12.0				6.0				1.2	1.2			1.2						
Ma 209	11.6	53.0	0.5	2.1	1.7				0.7	18.9		0.2		3.8			1.0	6.1	0.3				
Ma 210	5.7	34.3	13.2	5.9	29.4									2.9			4.9	3.3		0.3			
Ma 211	11.6	4.5	6.7		54.4			2.7	1.7					3.2			11.9	3.2				0.2	
Ma 212	7.0	43.7	2.3	2.0	28.2			0.3	1.1		3.9			3.4			2.3	5.9					
Ma 213	3.8	25.8	38.3	1.0	16.5				0.2					0.2			1.6	2.4			0.2		10.0
Ma 214B	7.4	19.2	20.5	1.3	17.6				0.9			0.2		0.7			4.7	2.5	0.2				25.0
Ma 215	21.3	1.1	29.8		39.1	1.3			1.6					0.9			3.3	1.6					
Ma 216	11.0	3.9	21.0	1.6	50.9				2.1					1.0			5.8	2.1	0.5				
Ma 217	23.5	2.4	0.5		18.8				3.3					1.9			2.4			2.4			45.0
Ma 218	18.3	3.4	22.6		46.3			1.2	1.8			0.3		1.2			2.4	1.8	0.6				
Ma 219	36.7	9.2	13.8		18.3				9.2					1.8			6.4			3.7		0.9	
Ma 220	17.8	16.9	7.6		51.7			1.3	1.3					0.4			1.3	1.7					
Ma 221	18.0	11.0	16.0		47.0				1.0					3.0		1.0		3.0					
Ma 222	14.3	16.1	22.2		34.4			0.4	6.1			0.4		1.4			2.2	2.5					
Ma 223	10.9	4.9	15.8		14.2				4.4					1.6				3.3					45.0
Ma 224	5.4	5.0	10.4		23.3									3.0			1.5	1.5					50.0
Ma 225	14.0	2.0	6.5	3.0	17.5				0.5					2.0	1.0		1.0	2.5					50.0
Ma 226	40.4	10.1	21.2		22.2									1.0		1.0	1.0	3.0					
Ma 227	26.7	3.3	7.8	0.7	22.1						1.3							2.6		0.7			35.0
Ma 228	9.6	24.5	19.7		37.8				1.6				0.8				2.8	2.8	0.4				
Ma 229	11.7	5.9	3.5		19.5				4.7								7.4	2.3					45.0
Ma 230	17.8	10.3	27.7		32.0				2.0					5.9			3.2	1.2					
Ma 231	29.5	3.8	11.4		40.9	2.9				1.0	1.9						2.9	1.0					5.0
Ma 232	7.1	20.5	7.8		13.8	7.8		6.7	1.1			0.4		0.4			1.1	3.2	0.4				30.0
Ma 233	14.0	7.0	16.0	12.0	40.0			1.0	1.0			1.0					3.0	5.0					
Ma 234	9.3	5.6	14.9		37.2				0.9								8.4	16.7					7.0
Ma 235	10.0	18.0	6.0	17.0	32.0									2.0	3.0			12.0					
Ma 236	21.0	12.0	12.0		34.0										3.0	2.0	4.0	11.0		1.0			
Ma 237	17.1	8.0	1.2		12.2	1.8		3.7	1.8					1.2	0.6		3.7	8.6					40.0
Ma 238	5.9	2.9	3.9		40.2			1.0	4.9					2.0			10.8	25.5		1.0			2.0
Ma 239	10.3	18.1	5.9	11.3	24.5				1.5		8.3	1.0			2.9		2.5	13.7					
Ma 240	25.0	1.0	11.0		38.0	9.0		4.0	5.0								1.0	6.0					
Ma 250	8.9	5.9	10.9	24.8	36.6				3.0					2.0			1.0	5.9		1.0			
Ma 252	15.8	18.6	25.1		24.2	1.9			0.9								0.9	5.6					7.0
Ma 253		2.4	13.7		25.9	17.8		1.6	0.8					0.8			2.4	14.5					20.0
Ma 254	12.8	8.1	12.5		28.9	1.1		1.7	1.1					1.7			0.8	1.4					30.0
Ma 255	7.9	10.9	14.9	6.9	41.6									7.9			1.0	8.9					
Ma 256	12.5	20.4	6.3	1.6	22.0	0.8	6.3	3.1			1.6			1.6				3.9					20.0
Ma 257	1.0	2.0	9.0	12.0	44.0	3.0		4.0	2.0					4.0			2.0	17.0					
Ma 260	5.0	20.7	4.3		52.9	1.4		0.4	1.4					4.3	0.4	0.4	0.7	8.2					
MS 261	2.0	1.0	25.0		19.0	2.0		2.0									4.0	6.0		39.0			
MS 262	22.8	7.1	6.6		7.6				8.6								2.5	4.1		40.6			
MS 263	22.0	11.1	18.1		32.7	1.0		1.5	4.0								4.0	5.0		0.5			
MS 264	25.0	15.0	8.0		7.0				7.0								2.0	4.0		32.0			
MS 265	12.6	17.3	12.6		7.9			1.6	1.0			11.5		1.6			1.6	3.7		28.8			
MS 266	28.3	4.0	35.4		25.3				2.0								1.0			4.0			
MS 267	2.8	12.8	12.4	6.4	48.6			0.5	0.5			0.5		3.2		2.8	2.3	6.9		0.5			
MS 268	10.8	4.5	9.0		30.0			0.9	3.1					2.2			2.7	5.8		29.6			
MS 269	10.4	5.4	19.8		46.8				3.6		1.8						7.2	4.5		0.5			
MS 270	12.2	6.3	22.2		43.9				3.6					1.4			5.9	4.5					
MS 271	11.0	5.0	33.0	1.0	43.0				6.0									1.0					
MS 272	13.0	4.0	18.0		42.0				18.0								1.0	2.0					
MS 273A	13.5	1.2	17.1		51.6				1.6			0.4		2.8			7.9	4.0					
MS 274	20.0		30.0		34.0				3.0								3.0	10.0					
MS 275	13.0		27.0		51.0				1.0					1.0				3.0		4.0			
MS 276-1	8.2	52.9	21.2		4.7	2.4			1.2			1.2					2.4	5.9					
MS 276-2	13.3	25.0	34.0	0.5	23.4				1.6								1.6	0.5					
MS 277-1	3.2	5.1	14.3		27.6			0.5	1.4								6.0	6.9		35.0			
MS 277-2	11.0	19.0	35.0		19.0				1.0			3.0		1.0			3.0	8.0					
MS 278	17.0	15.0	37.0	1.0	20.0						6.0			1.0			2.0				1.0		
MS 279	27.0	12.0	28.0		25.0									2.0				6.0					

Appendix 1. Modal composition (%) of all components quantified by point counting.

SAMPLE	Spart	Matrix	Coralline branches	Coralline crusts	Coralline detritus	Peys. aggregates	Peys. crusts	Peys. detritus	Foraminifera	Corals	Corals encrusted	Blivalves	Gastropods	Bryozoa	Brachiopods	Brachiopods encrusted	Echinodermen	Bioclasts	Others	Terrigenous	Serpulids	Ostracods	Rhodoliths
MS 280	25.5	7.1	21.4		39.8									4.1						2.0			
MS 281	30.3	9.1	9.1	8.1	23.2				1.0					2.0			1.0	15.2		1.0			
MS 282	26.0	16.3	10.1		29.1			0.4	4.4			3.1					7.0	3.1	0.4				
MS 283	6.6	5.0	17.6	2.8	13.8		1.1		0.6		3.3		0.6	0.6				2.8		0.6			45.0
MS 284	12.7	13.8	2.2		33.2	25.4		6.7	1.9					0.4			1.9	1.9					
MS 286	9.0	12.0		9.0	13.0		36.0	3.0	2.0			2.0					1.0	8.0		2.0	3.0		
MS 287	21.0	10.0	3.0		29.0	11.0		9.0	1.0								5.0	10.0					
MS 288	9.1	32.4	31.1		23.3							0.5					1.4	2.3					
MS 289	7.0	23.0	18.0		36.0			1.0	6.0				1.0	2.0			1.0	5.0					
MS 290	15.0	9.0	10.0		47.0	3.0		6.0	2.0					2.0				6.0					
MS 291	10.3	28.3	30.9		23.3	2.2			0.9			0.4				1.3	1.3	0.9					
MS 292	5.7	40.1	8.6		25.8				0.4	0.4	10.0			1.1		1.4	1.4	5.0					
MS 293	1.9	16.2	5.7	7.6	42.8				1.0			1.9	7.6	2.9			1.0	6.7					5.0
MS 294	10.9	35.3	14.5		30.3				0.5					0.9	0.9	0.5	3.6	2.7					
MS 295	7.7	26.8	1.0		13.9	35.4		4.3	0.5			0.5					1.0	8.6			0.5		
MS 296	11.0	15.0	19.0	2.0	36.0			1.0						2.0		2.0	1.0	11.0					
MS 297	17.0	22.0	12.0		28.0			1.0		1.0	2.0			2.0		1.0	2.0	12.0					
MS 298	18.0	35.0	3.0	18.0	11.0						7.0						2.0	6.0					
MS 299	10.0	36.0	5.0		17.0	3.0		1.0	2.0	1.0	8.0				3.0		1.0	13.0					
MS 300	26.0	18.0	4.0		8.0	29.0		12.0	1.0									2.0					
MS 301	4.0	5.0	32.0		36.0	6.0		3.0										14.0					
MS 303-1	12.0	21.0	11.0	3.0	13.0	24.0		3.0	3.0									10.0					
Gei 306	3.0	35.0	6.0		10.0	9.0		9.0	1.0				2.0				1.0	13.0		11.0			
Gei 308	3.0	35.0	6.0		10.0	9.0		9.0	1.0				2.0				1.0	13.0		11.0			
Gei 309	23.0	13.0	10.0		16.0	16.0		1.0	2.0			1.0						2.0		16.0			
Gei 310	18.0	10.0	12.0		25.0	13.0		10.0				2.0					2.0	2.0		6.0			
Gei 312		6.0	10.0		1.0	71.0		6.0	2.0									4.0					
Hmb 316	10.0		3.0																	87.0			
Hmb 317	1.8	4.4	0.9					29.8				2.6						7.9		52.6			
Hmb 318	1.9	10.6	15.4		16.3	2.9	2.9		5.8					2.9				12.5		26.0	2.9		
Hmb 319	10.0		1.0						12.0											77.0			
Hmb 321									14.0											86.0			
Hmb 322									10.0											90.0			
Hmb 323									22.0			4.0								74.0			
Hmb 324									10.0			4.0								86.0			
Hmb 325	2.4	36.5							28.2			5.9						14.1		12.9			
Hmb 327		57.1							10.2			2.0						22.4		8.2			
Hmb 329		23.0							56.0									21.0					
Hmb 330		57.0							17.0					4.0			1.0	14.0		7.0			
Hmb 331	1.0	47.5			1.0				27.3					8.1			1.0	14.1					
Hmb 332		56.0							9.0					10.0			2.0	23.0					
Hmb 333		63.4							4.0					12.9				19.8					
Hmb 334		36.0										1.0		38.0				23.0		2.0			
Hmb 335-1		46.5							1.0					34.3				18.2					
Hmb 335-2	19.0	29.0			14.0				2.0			1.0		8.0			5.0	22.0					
Hmb 336-2	4.1	23.7			16.5				2.1					10.3			2.1	41.2					
Hmb 337	3.0	27.0			1.0				2.0					4.0			9.0	49.0		5.0			
Hmb 340		12.0	8.0	2.0	43.0				1.0					17.0			1.0	16.0					
Hmb 342	1.8	40.9			5.5				0.9					14.5			0.9	35.5					

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