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# GEOLOGIE UND PALÄONTOLOGIE

## Hypoxic Events on a Middle Miocene Carbonate Platform of the Central Paratethys (Austria, Badenian, 14 Ma)

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(With 8 text-figures and 8 plates)

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### Abstract

During the Middle Miocene Badenian the Eisenstadt-Sopron Basin was structured by the Leitha and the Fertőrákos carbonate platforms, comprising different lithological types of the Leitha Limestone. In the quarry "Kummer" near St. Margarethen (Burgenland, Austria) three lithofacies of the Leitha Limestone can be observed. A short historical review, data on regional geology and sedimentology, along with detailed autecological and synecological analyses of the fauna are presented.

The section is characterised by the intercalation of bright yellow calcarenites (corallinean debris facies) and olive green marls (laminated marl facies). This fining and thinning upward sequence is interrupted by rudstones, chaotically sedimented in a broad channel. The mainly cross-bedded calcarenites bear corallinean debris, rhodolithes, oysters, pectinids and fragmented echinoids.

The most striking feature of the laminated marl facies is the extraordinary preservation of the fauna, which consists of a large number of various fishes, regular and irregular echinoids, bryozoan colonies (in situ), pectinids, and brachiopods. In addition, rich foraminiferal faunas and calcareous nannoplankton are investigated. In small lagoon-like structures with reduced water energy and turbulence, marl sedimentation took place. These 30 m to 60 m deep depressions were surrounded by carbonate sand build-ups. Storm events caused sedimentation of coarser-grained material via rip currents from the shoals into the subtidal level of the depressions. The channelised rudstones (*rudstone* facies) are deposits of multiple-phase, seismic events. Therefore the section represents tempestites with at least one observable deepening upward sequence.

The remarkable preservation of the fauna is interpreted to be caused by two different processes: In the case of the benthic animals, such as the bryozoans and the echinoids, this preservation is mainly related to the lack of agitation. In small populations of echinoids whose spines are still attached, on the other hand, occasional hypoxic events killed off the benthic fauna and created conditions that preserve even complete fishes, by precluding scavenging and deterioration. Hypoxic conditions are further indicated by the microfauna, the nannoplankton and by the occurrence of iron-sulfides (altered to iron-oxides) within the marl layers.

For the first time the bivalves "*Chlamys*" *rakosensis* CSEP.-MEZ. and *Flexopecten scissus* (FAVRE), the brachiopod *Discinisca* cf. *leopolitana* (FRIEDB.), the spiny lobster *Palinurus* sp. and the echinoid *Brochopleurus* sp. are documented from the Austrian Miocene. The first description of tubes of Pectinariidae for the Badenian of the Central Paratethys is presented. Similarly, the fish family Pristidae is recorded for the first time for the Paratethys based on dermal denticles of *Pristis* sp.

**Keywords:** Hypoxic events, paleoecology, paleoenvironment, Middle Miocene, Badenian, Leitha Limestone, Fertőrákos Platform, Leitha Platform, rip currents, debris flows, tempestites, Austria, Central Paratethys

### Zusammenfassung

Im Badenium wird das Eisenstadt-Sopron Becken durch die Leitha- und die Fertőrákos-Karbonatplattform gegliedert. Diese werden von unterschiedlichsten Lithofazies-Typen des Leithakalks aufgebaut. Der untersuchte Steinbruch "Kummer" (St. Margarethen, Burgenland) weist Leithakalksedimente dreier Faziesbereiche mit einer reichen und diversen Fauna auf. Die überregionale Bedeutung der Lokalität St. Margarethen lassen eine ausführlichere Darstellung sinnvoll erscheinen. Neben einem kurzen Überblick über die Erforschungsgeschichte des Eisenstadt Sopron Beckens werden Angaben zur regionalen Geologie und Sedimentologie ebenso gegeben wie eine Analyse der Autökologie und Synökologie der Fauna.

Das aufgenommene Profil wird durch eine Wechsellagerung von Kalkareniten und Mergel charakterisiert. Zumindest eine *fining and thinning upward* Sequenz ist zu erkennen. Die im Liegenden des Profils dominierenden kreuzschräggeschichteten Kalkarenite (Algenschutt-Fazies) führen eine allochthone Vergesellschaftung aus Rhodolithen, Austern, Pectiniden und fragmentierten Echiniden. Zusätzlich wurde eine reiche Foraminiferenfauna und kalkiges Nannoplankton nachgewiesen. Die eingeschalteten laminierten Mergel (laminierte Mergel-Fazies) kennzeichnet eine diverse und gut erhaltene Fischfauna, vollständige Bryozoenkolonien, Echinodermen, Pectiniden und Brachiopoden. Diese Sequenz wird durch *rudstones* (*rudstone*-Fazies), die in einer Rinnenstruktur abgelagert wurden, unterbrochen.

Als Environment werden ausgedehnte Karbonatsandplattformen interpretiert, an deren Rand sich kleinräumige 30-60 m tiefe Senken bildeten. Von den seicht sublitoralen Hochzonen wurden Kalkarenite durch



*rip-currents* in die tieferen Bereiche dieser niedrig energetischen Wannen transportiert, wo als autochthone Sedimentation Mergel abgelagert wurden. Das Profil schließt somit Tempestite auf, die zumindest eine *deepening upward* Sequenz erkennen lassen. Die eingeschalteten *rudstones* hingegen werden als *debris flow* Ablagerungen angesprochen, die durch Erdbeben ausgelöste Sedimentationsereignisse widerspiegeln.

Die ungewöhnlich gute Erhaltung der aus den laminierten Mergeln stammenden Fauna wird auf zwei verschiedene Prozesse zurückgeführt: bei benthischen Organismen wie Seeigeln und Bryozoen begünstigte die geringe Wasserbewegung die artikuliertete Erhaltung. Das gleichzeitige Absterben von Seeigelpopulationen wird auf gelegentlich auftretende Sauerstoffkrisen zurückgeführt. Sauerstoffarme Bodenbedingungen und das daraus ableitbare Fehlen von Räubern und Aasfressern erklären zugleich die zahlreichen weitgehend unzerstörten Fische. Ein weiteres Indiz für zeitweilige Sauerstoffarmut sind die in Laminare angereicherten Eisenoxide, die aus Eisensulfiden entstanden sind.

Im Rahmen dieser Arbeit konnten die Bivalven "*Chlamys*" *rakosensis* CSEP.-MEZ. und *Flexopecten scissus* (FAVRE), der Brachiopode *Disciniscia* cf. *leopolitana* (FRIEDB.), die Languste *Palinurus* sp. und der Seeigel *Brochopleurus* sp. erstmals aus dem Miozän Österreichs nachgewiesen werden. Röhren von Pectinariidae werden erstmals aus dem Badenium der Zentralen Paratethys erwähnt. Ebenso gelang der sichere Erstnachweis von Sägerochen durch Hautzähnnchen von *Pristis* sp. für die Paratethys.

**Schlüsselwörter:** Sauerstoffkrisen, Palökologie, Palaeoenvironment, Mittelmiozän, Badenium, Leithakalk, Fertörákos-Plattform, Leitha-Plattform, Brandungsrückströmungen, *debris flows*, Tempestite, Österreich, Zentrale Paratethys

## Introduction

The quarry "Kummer" is a well-known fossil-bearing locality within the Badenian sediments of the Neogene Eisenstadt-Sopron Basin. The basin is bordered by the Leithagebirge in the N, the Fertörákos-Ruster Hügelland in the E, the Sopron Hills in the S and the Rosaliengebirge in the W (Fig. 1). The quarry exposes strata along the Fertörákos-Ruster Hügelland and is situated at the main road about 2 km E of St. Margarethen village (47° 48' N, 16° 38' E; ÖK 1:50000, sheet 78, Rust), adjacent to the famous "Roman quarry" in Burgenland, Austria (Figs. 1, 2).

Two excavation campaigns of the Natural History Museum Vienna in 1987 and 2000 had the primary aim to save at least parts of the excellently preserved fish fauna from industrial exploitation, and to document the sedimentary environment and the ecology of the Leitha Limestone facies outcropping in the quarry. This was done by measuring a composite section (Figs. 2, 5), by documenting the sedimentary features within the quarry, by micropaleontologic investigations and by collecting the diverse invertebrate and fish fauna. Fossils from private collections and former excavation campaigns, accessible at the Museum of Natural History Vienna, completed our data.

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## Historical Review

Geological investigations in the Eisenstadt-Sopron Basin were first carried out by CZIZEK (1852), but it was ROTH v. TELEGD (1897; 1905) who mapped this area in detail at that time for the Hungarian Geological Survey. During the first part of the 20<sup>th</sup> century, work on stratigraphy (WINKLER 1926; KAPOUNEK 1935; 1939), morphological observations (e.g. ROTH-FUCHS 1926) and tectonic investigations (TAUBER 1951; WINKLER-

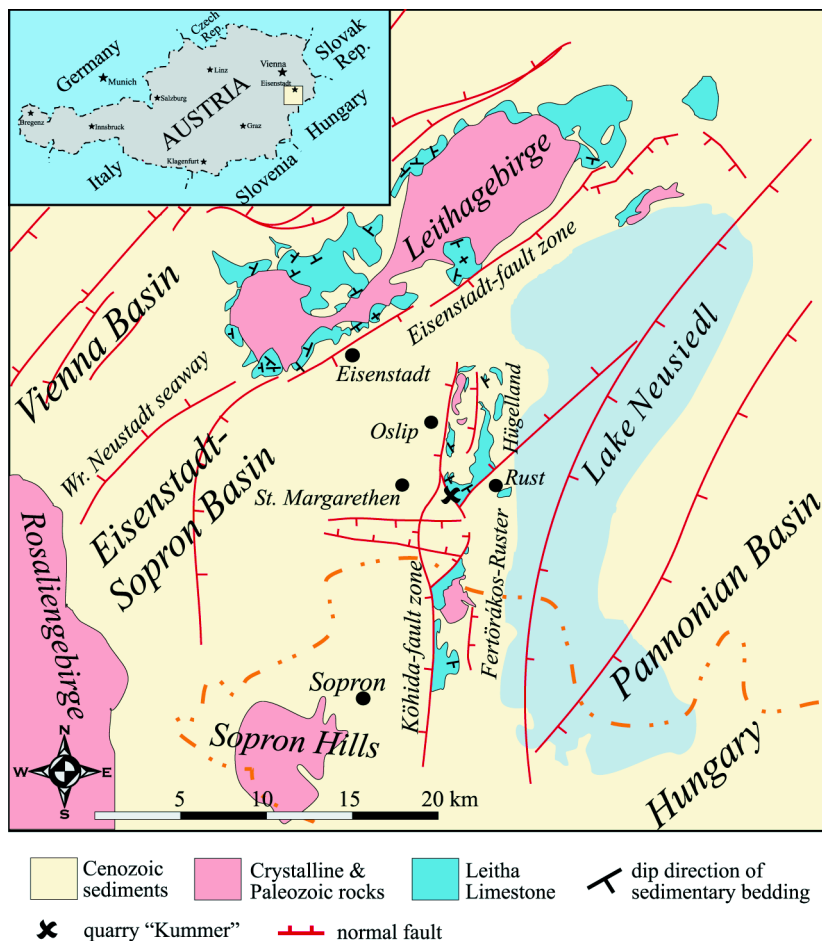


Fig. 1: The Eisenstadt-Sopron Basin, the SE part of the Vienna Basin and the westernmost parts of the Pannonian Basin with the most important tectonic lines and occurrences of the Leitha Limestone in the Leithagebirge and in the Fertörákos-Ruster Hügelland.

HERMADEN 1957; KÜPPER 1961) were made. TOLLMANN (1955) working at the SW margin and H. SCHMID (1968) working at the SE margin of the Leithagebirge used micro-paleontological methods for mapping and stressed the importance of "young" tectonics in this area. More recent sedimentological investigations were made by PASCHER (1988) and HAAS (1996) in the "Mattersburg Bay" and along the W margin of the Leithagebirge, respectively.

FUCHSS' (1965) study on the geology and stratigraphy of the Austrian part of the Fertörákos-Ruster Hügelland provides up-to-date basal knowledge about the area, which was quarried even in Roman times. Since then the weakly cemented and highly porous limestones in the vicinity of the villages of St. Margarethen and Osip (Fig. 1) served as building material. The "Roman quarry" (Fig. 2) was exploited mainly during the Baroque period. Therefore the Middle Miocene sediments became the focus of

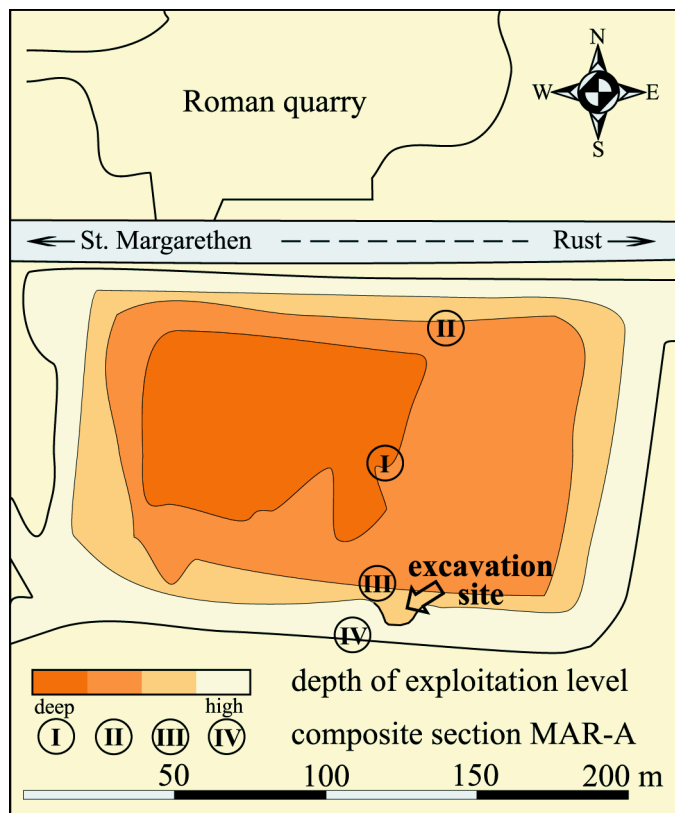


Fig. 2: Map view of the quarry "Kummer" (status: 28. 9. 2000) at the main road (B 52) 2 km east of St. Margarethen. The famous Roman quarry is situated directly to the N. Section MAR-A is a composite section taken from the lowermost to the uppermost exploitation level, which comprises a total thickness of about 35 m.

scientific interest early on and were termed "Leythakalk" by KEFERSTEIN (1828). Intense quarrying caused a rapid increase in paleontological data during the 19<sup>th</sup> century, partly reflected in monographs dealing with major invertebrate groups of the Vienna Basin (HÖRNES 1856; 1870; LAUBE 1871; DREGER 1889). Additionally, the extraordinary rich and well-preserved fish fauna of this area was recognised as new to science and found its way into the literature (HECKEL 1850; 1856; HECKEL & KNER 1861; KNER 1862).

In the following decades up to the 1990s the knowledge on the fauna in the St. Margarethen and Oslip outcrops was enlarged by numerous taxonomical studies, e.g. GORJANOVIC-KRAMBERGER (1902), SCHMIDT (1955), UDIN (1964), VAVRA (1979; 1980), BACHMAYER, F. (1980), BELLWOOD & SCHULTZ (1991), SCHULTZ (1993), CHANET & SCHULTZ (1994), MLIKOVSKÝ (1998).

Special interest was given to the fish fauna in the so-called laminated facies in the quarry "Kummer" (Fig. 2). These strata can be characterized as intercalations of a few mm to several cm thick layers of olive green marls and cm to dm thick layers of bright yellow limestones (Fig. 5). A first genetic interpretation of this facies was given by FUCHS (1965) based on the ostracod assemblage. He considered the marls to have formed in a protected bay cut off from the open sea. Similarly, DULLO (1983) concluded that the fine-laminated marls were deposited in restricted lagoonal basins, which formed

due to the regional uplift. Mud chips within intercalating algal debris limestone layers were interpreted by DULLO (1983) as indicators for repeated subaerial conditions. These interpretations were also accepted in the excursion guides of PILLER & KLEEMANN (1991) and PILLER & VAVRA (1991). Further data were given by RÖGL in BACHMAYER (1980), who suggested deposition in fully marine conditions of a calm nearshore habitat with seagrasses. Later, this interpretation was confirmed by BELLWOOD & SCHULTZ (1991) and SCHULTZ (1993). In contrast, PILLER & al. (1996) reinterpreted the facies based on sedimentological investigations and discussed a very shallow intertidal environment, with intercalations of biogene-bearing coarse sands, deposited by spring tides or during single storm events.

### Regional Geology

The north-vergent thrusting and shortening of the Calcareous Alps and the Penninic Nappes of the Eastern Alps ended in the Karpatian (KRÖLL & WESSELY 1967), about 17 Ma ago. Gravitational instability of the thickening crust resulted in an eastward lateral extrusion and orogen parallel extension (RATSCHBACHER & al. 1991) of crustal wedges into the Pannonian region during the Miocene (ROYDEN & al. 1983; ROYDEN 1988; EICHHÜBL 1993; DECKER & al. 1994). These processes terminated the Lower Miocene Molasse phase and transformed the Central Paratethys into a complex system of subbasins with quite different sedimentary histories (RÖGL & STEININGER 1983; PISERA 1996).

Lateral extrusion ended the piggyback basin stage of the Vienna Basin during the Ottnangian/Karpatian, and subsidence within a pull-apart basin (ROYDEN 1985) along NE-trending sinistral faults (PERESSON & DECKER 1997) occurred. Duplexing as the most important subsidence mechanism (PILLER & al. 1996) controls syntectonic sedimentation. Together with rapidly changing trans- and regression cycles, complex sedimentation patterns evolved (RÖGL & STEININGER 1983; RÖGL 1998). From Karpatian to Pannonian time (~ 17 Ma to ~ 8 Ma) the Vienna Basin subsided in its central part up to 5.5 km (KRÖLL & WESSELY 1993), whereas the Eisenstadt-Sopron Basin and the southern part of the Vienna Basin subsided no more than ~ 2 km. The onset of E-W compression in the Late Pannonian (~ 8 Ma) terminated the eastward lateral extrusion of the Eastern Alps (PERESSON & DECKER 1997) and thus subsidence in the Vienna Basin. Finally, Late Pannonian sediments document basin inversion. Significant surface uplift since the Pannonian is documented by Badenian, Sarmatian and Pannonian deposits in topographical elevations between 300 m and 400 m (PILLER & al. 1996).

Modern investigations on the tectonic evolution of the Eisenstadt-Sopron Basin are missing; nevertheless, it is possible to correlate the sedimentary development with that of the Vienna Basin (WESSELY 1993). The initiation of the basin started in the Karpatian. During this period the basin was part of a crystalline hilly area with a drainage pattern from S to N (TOLLMANN 1955). Fluvial systems eroding the crystalline basement deposited the gravels of the "Ruster Schotter" (TOLLMANN 1955; FUCHS 1965) and transported coarse material towards the marine northern part of the Vienna Basin. Limnic coal-bearing sediments are documented in the S of the basin. A first marine transgression via the "Wiener Neustädter Pforte" ("Wiener Neustadt seaway" see Fig. 1) is documented for the Badenian (Lower Lagenid Zone) by reworked Karpatian deposits outcropping along the NE margin of the Eisenstadt-Sopron Basin. In the following phase the

Leithagebirge and the Fertőrákos-Ruster Hügelland (Fig. 1) formed elevations (islands and shoals) where coralline limestones and small, poorly diversified reefs could grow (summarized by the term Leitha Limestones).

In the vicinity of St. Margarethen the so-called fish-bearing laminated marl facies of the Badenian Leitha Limestone crops out in the quarry "Kummer". These marls are dated to the Late Badenian (RÖGL in BACHMAYER 1980; BELLWOOD & SCHULTZ 1991), corresponding to the regional *Bulimina-Bolivina* Zone after PAPP & al. (1978). Equally, the new dating based on calcareous nannoplankton by CORIC (this paper) indicates zone NN5. The Paratethyan Late Badenian is correlated with the Early Serravallian stage of the Mediterranean standard scale (see RÖGL 1998). The formation of Leitha Limestone along the western shore of the Vienna Basin was limited due to the terrigenous input from a system of fluvial fans / fan deltas interfingering with the pelitic Baden Tegel. This lithofacies is characterized by marls and sandy marls with variable clay content and a rich macro- and microfauna. Relatively shallow paleo-water-depths between 50 m and 200 m (PAPP & STEININGER, in: PAPP & al. 1978) during rapid subsidence are due to high sediment supply into the basin (WESSELY 1988).

During the Sarmatian stage, about 12.5 Ma ago, reduced marine conditions prevailed. Deltas along the margins of the Vienna Basin had their maximum extension (SAUER & al. 1992). This situation can be assumed for the eastern part of the Eisenstadt-Sopron Basin, where mainly Gilbert type deltas, controlled by the Köhida-fault zone (Fig. 1), deposited sands and gravels into the basin (ROSTÁ 1993). Beside that, the so-called detritic Leitha Limestones (reworked Badenian coralline limestones) were sedimented.

After a regressive phase during the Latest Sarmatian and Earliest Pannonian (~ 12 Ma) a relative sea level rise with an ongoing decrease in salinity followed. Sediments of the basin rims (depositional environments of fluvial fans) and basinal deposits (limnic sediments) can be found as remains of the Pannonian Lake System, having its depositional center more eastwards. The retreat of the Pannonian Lake, as a reaction to the E-W compression (PERESSON & DECKER 1997), terminated the main sedimentary history of this area in the Late Pannonian. Finally, lignite sediments in the area of the Wiener Neustadt seaway (KLAUS 1950) document an already terrestrial environment in the late Pannonian.

### Local Tectonics

The western scarp of the Ruster-Fertőrákos Hügelland is defined by the Köhida-fault zone, generally orientated in N-S direction (Fig. 1). Conjugate fault sets in the northern wall of the quarry "Kummer" and in the adjacent "Roman quarry" document the fault zone in this area (Fig. 3). Here the fault zone rotates in a NNW-SSE direction (Figs. 1, 4a). The frequency of faults increases towards the W, that is towards the scarp. Normal faults dipping to the W are partly listric and more frequent than faults dipping towards the E (Fig 3). Synsedimentary faulting is documented by faults ending within strata. Lineations indicate major normal faulting towards the W. However observations of minor, younger strike slip movements along the fault zone indicate a more complex history of basin evolution. Microtectonic observations along the NE-SW trending and SE dipping Eisenstadt fault-zone document ESE-WNW orientated extension (FODOR 1991). It can be concluded that both fault zones document an ~E-W extension as one important stage in the subsidence history of the Eisenstadt Sopron Basin.

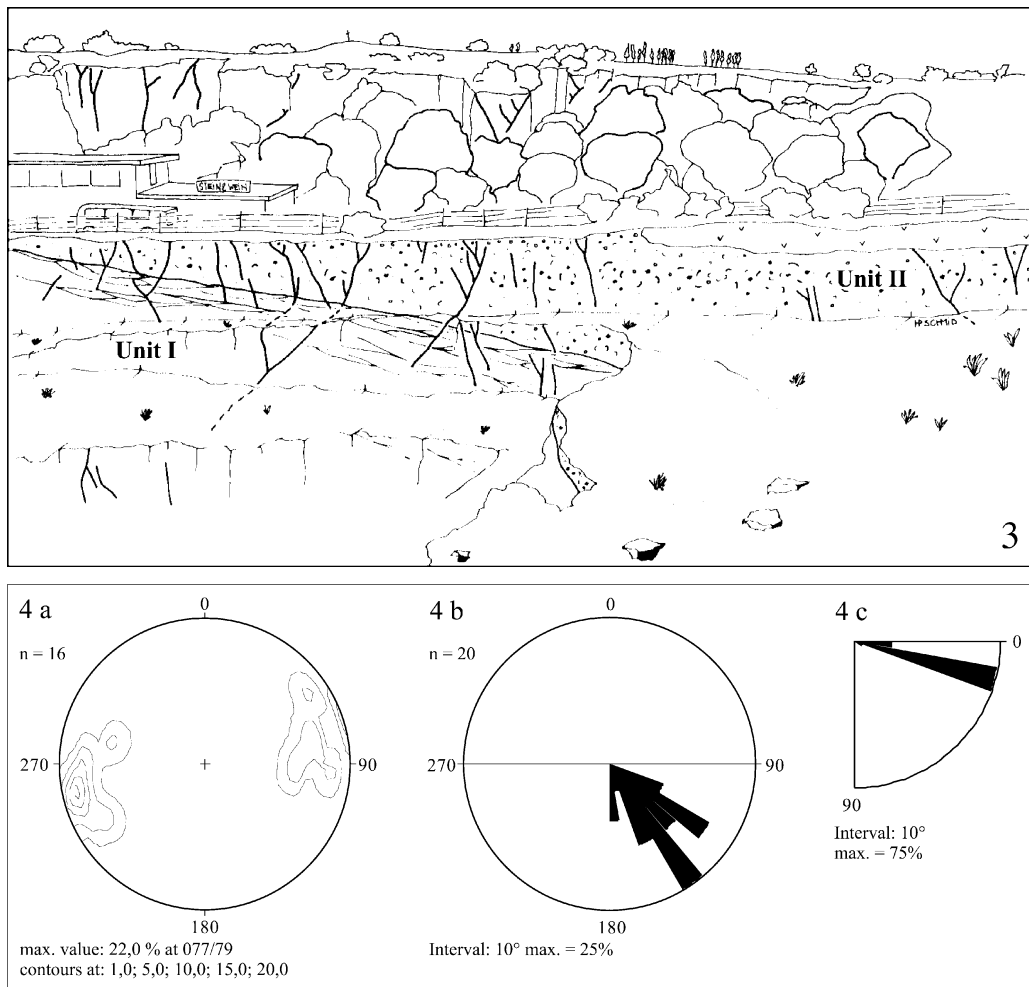
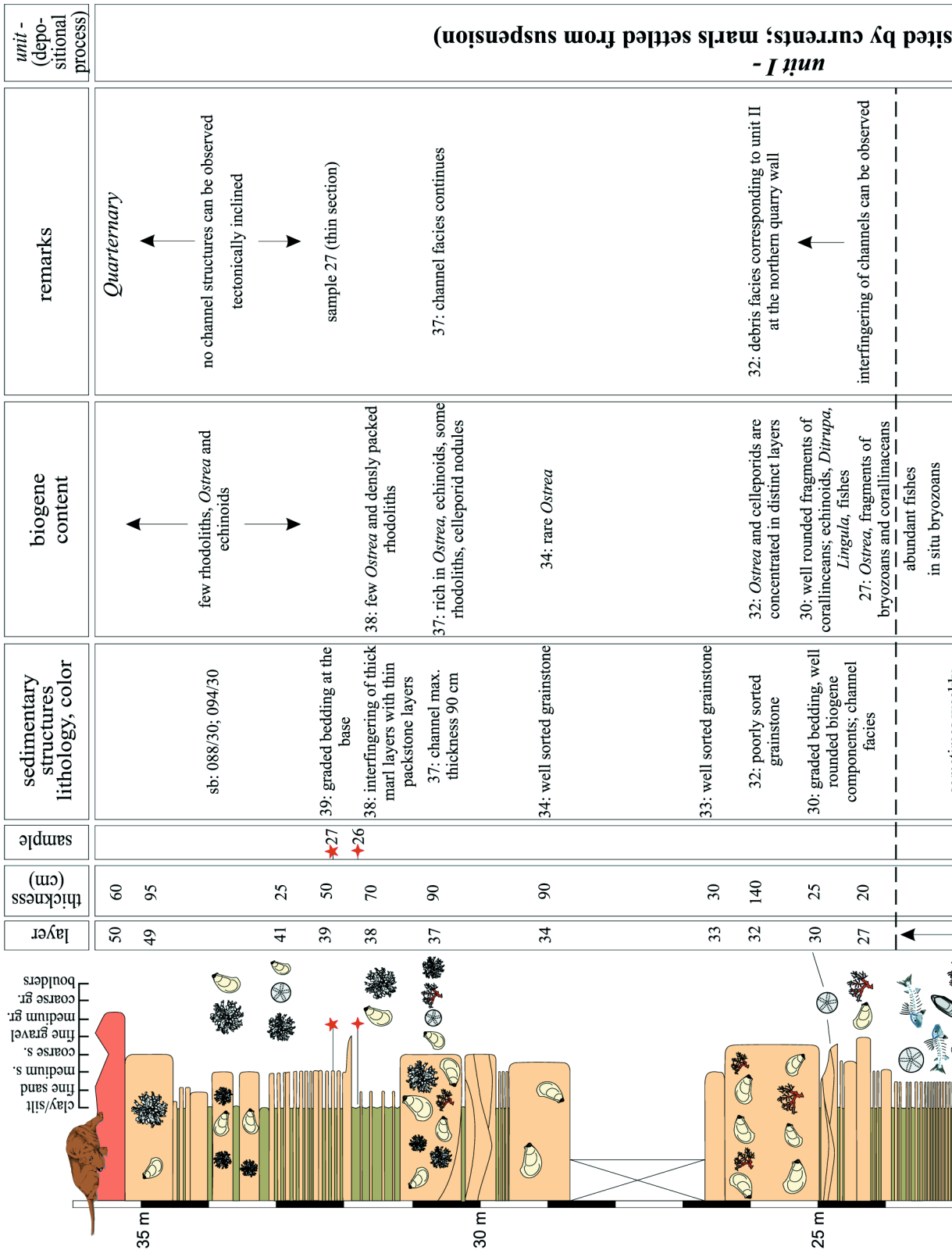


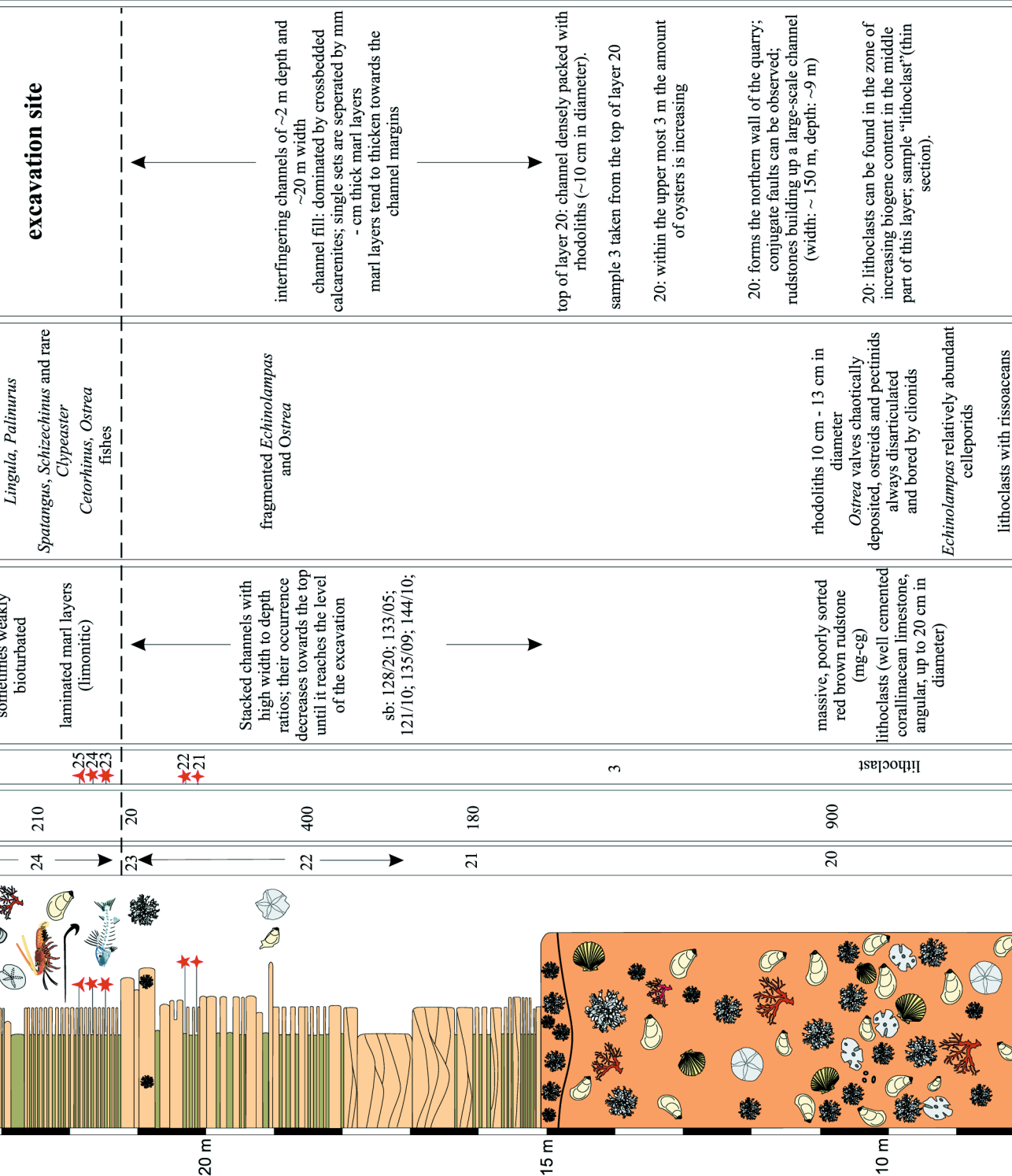
Fig. 3, 4: (3) Along the northern wall of the quarry "Kummer" in the front and in the "Roman quarry" (background) the Köhida fault-zone striking in NNW-SSE direction can be seen. The conjugate faults tilt sedimentary strata in both outcrops. In the front the channel shaped unit II eroding cross-bedded unit I can be seen. (4) Structural data from the quarry "Kummer". (4a) Contour map of fault plane poles indicating a conjugate fault system oriented NNW-SSE direction. (4b) Rose - diagram of sedimentary bedding planes showing dip towards the SE. (4c) 75% of the beds have an inclination between  $10^\circ$  and  $20^\circ$  (same data set as 4b).

Fig. 5 (next page): Section "MAR-A" within the quarry "Kummer" near St. Margarethen (status: 11. 9. 2000). The section can be characterized by the interbedding of:

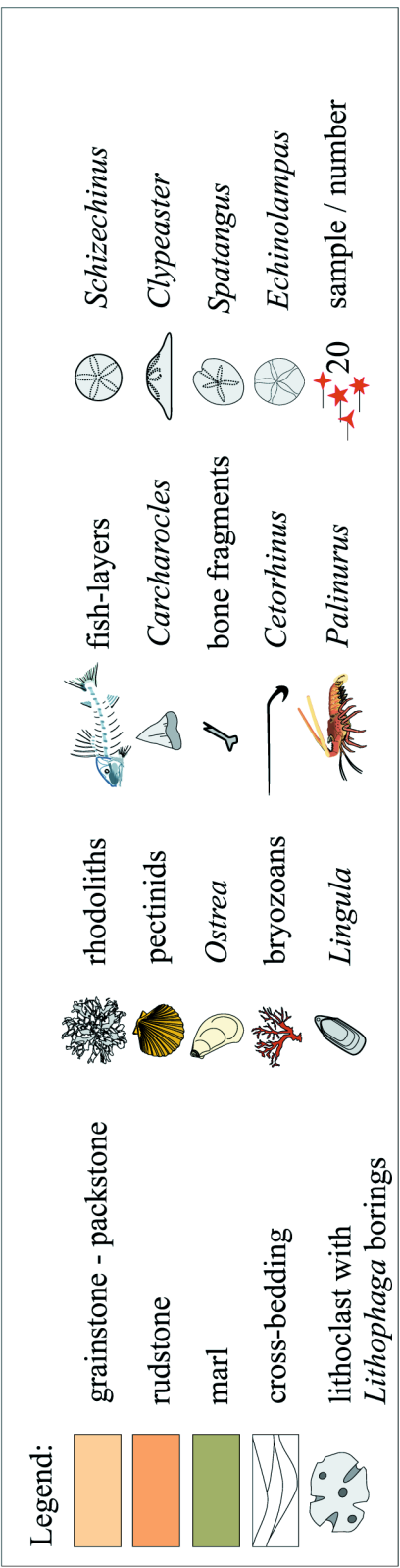
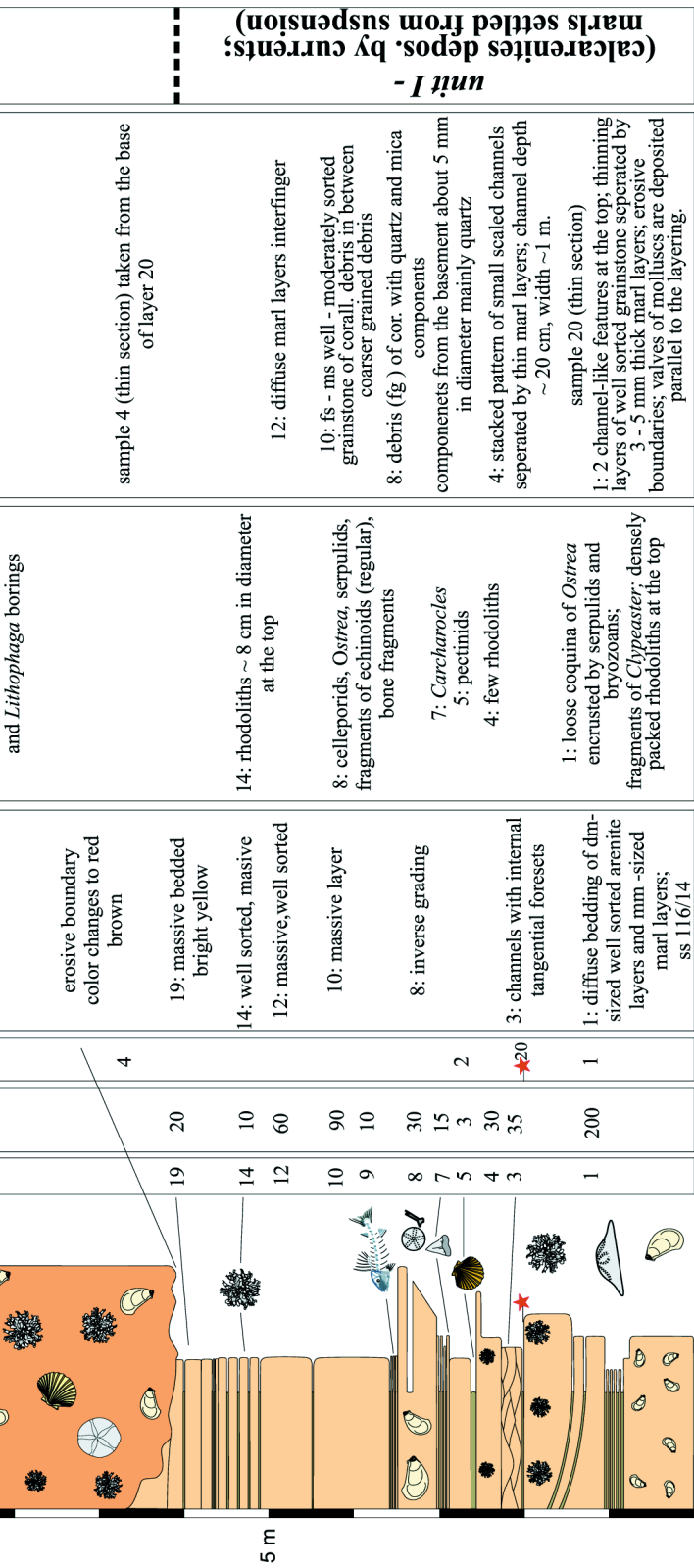
1. calcarenites (coralline debris): bright yellow, poorly cemented, highly porous, poorly - well sorted, bioclasts bearing, bed thickness 1 mm - 90 cm.
2. marls: olive green, bed thickness 1 mm - 10 cm.



unit I -  
settled by currents; marls settled from suspension)







## Section St. Margarethen (MAR-A), Quarry "Kummer"

### 1. Sedimentology

During excavation campaigns the focus was placed mainly on the fish-bearing part of the section. To document also the base and top of the excavation level the composite section "MAR-A" (= St. Margarethen section A) was taken in the quarry "Kummer". This section can be described as a sequence of interbedded bright yellow, poorly cemented, highly porous, moderately sorted, bioclast-bearing calcarenites with olive green laminated, partly fish-bearing marls. Within these deposits coarser-grained brown, highly porous, bioclast-rich sediments intercalate (Figs. 3, 5). Generally high dip angles of sedimentary bedding planes as well as the dip direction towards the SE are interpreted as a result of local tectonic tilting (Figs. 4 b, 4 c).

Sedimentological investigations and a diverse macro- and microfauna allow the definition of two units along the section (Fig. 5). Fieldwork observations were completed by thin sections, analysis of the microfauna, X-ray diffraction analysis, and total organic carbon analysis. The microfacies classification of DULLO (1983) was applied. The complex reorganisation of these sediments by diagenesis is only briefly outlined. Between two and four phases can be distinguished in the calcarenites of St. Margarethen (DULLO 1983).

1. >10 µm thin marine micritic cement around biogene components
2. vadose leaching; removal of all aragonitic shells resulting in high porosity; followed by compaction and brecciation
3. vadose sparitic cement (meniscus cements, dripstone cements and rim cements)
4. freshwater phreatic cements (seldom)

### Unit I

#### ("corallinacean debris facies" and "laminated marl facies")

Unit I starts with 6 m of bright yellow calcarenites (corallinacean debris facies) sometimes forming massive layers, which are mainly deposited in small-scaled stacked channels of about 20 cm depth and 1 m width. Channel fills partly show tangential foresets and normal grading. Channels are in some cases separated by thin marl laminae, and boundaries between the layers are erosive. In layer 8 fine-gravel-sized quartz and mica components occur; they could not be found macroscopically in the following succession. Between 6 m and 15 m of the section unit II is intercalated. Towards the excavation level, the marl content increases successively and develops its maximum thickness there (Fig. 5). Channels with a lateral extension of ~20 m and a maximum depth of ~2 m form a stacked pattern interfingering with the sediments of unit II. The lithology of unit I in this stratigraphic position is named "laminated marl facies". From base to the excavation level a thinning and fining upward sequence can be observed, followed by perhaps another thinning and fining upward sequence towards the top of the section (Fig. 5).

Within the excavation level it was possible to measure the orientations of mostly well-preserved fish individuals: the corpses were randomly orientated (Fig. 6). Above that, massive to cross-bedded, sometimes normal-graded calcarenites intercalating with marls of variable thickness crop out.

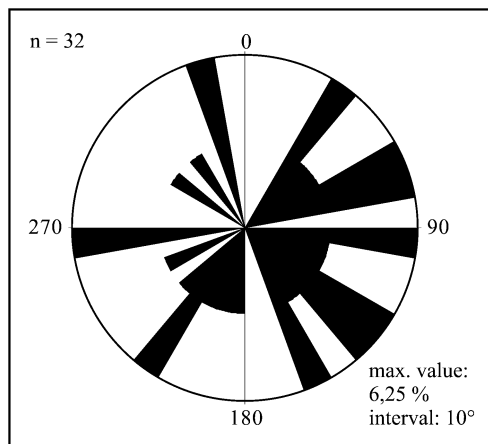


Fig. 6: Rose - diagram showing random fish orientations (heads measured in forward direction) within one layer in the excavation level.

In thin sections the calcarenites could be defined as grainstones (DUNHAM 1962). After DULLO's (1983) classification one type is assigned to the foraminiferal facies, the other one to the foraminiferal algal debris facies. Both sediments are well sorted, highly porous and show internal bedding. The major component is coralline debris, but beside this massive accumulations of foraminifera (in decreasing abundance: *Elphidium*, *Asterigerinata*, *Textularia*; minor amounts of: *Quinqueloculina*, *Sphaerogypsina*, *Triloculina*, rotaliids) occur. Fragments of bivalves, bryozoans, serpulids, ostracods and echinoid spines can be found.

In a thin section identified as foraminiferal facies, one marl layer (wackestone) displays an impoverished fauna. *Globigerina* sp., some small benthic foraminiferas (mainly *Asterigerinata*) and thin-valved molluscs were identified.

Semiquantitative X-ray diffraction analysis (modified method after SCHULTZ 1964) of a marl sample from the laminated marl facies showed ~45 % calcite, ~42 % clay minerals ~8 % quartz and small amounts of plagioclase and halite. The clay mineral spectrum is dominated by smectite, mica, chlorite and kaolinite. Total organic content analysis from a marl sample showed values in the range of 0.2 %.

## Unit II (rudstones)

Unit II is composed of massive, highly porous, poorly sorted, bioclast-bearing rudstones and forms a channel-shaped deposit well exposed at the northern wall of the quarry (Fig. 3). The channel starts with a prominent erosive boundary coinciding with a marked color change to red brown and can be traced laterally for 125 m with a max. thickness of ~9 m. The channel can also be observed at the 100 m distant southern wall of the quarry, where it crops out with a reduced thickness and smaller components. Although internal bedding or grading is missing, the channel fill can be separated by the occurrence of biogenic components and lithoclasts into 4 parts (Fig. 5). The lowermost 2.5 m with few oysters and pectinids, a middle part (~2 m thick) with rhodolithes, oysters, and lithoclasts, an upper part (~4 m thick) with again fewer biogenic components and a channel-shaped uppermost part with densely packed rhodolithes corresponding to the pavement

facies of DULLO (1983). The lithoclasts are Lower Badenian Leitha Limestones of white, angular-shaped wackestones with *Lithophaga* borings and abundant rissoid gastropods. The rudstones cannot be assigned to only one microfacies type in thin section, therefore they are defined as foraminiferal algal debris facies to pavement facies. Angular to sub-angular corallinacean debris and oyster shells predominate the component spectrum. The accessories are bryozoan, pectinid and gastropod fragments, echinoid spines, serpulids, and some monocrystalline quartz. The foraminiferal fauna is composed of *Elphidium*, *Asterigerinata*, *Quinqueloculina*, *Rosalina*, *Eponides*, *Amphistegina*, *Textularia*. The lithoclasts are defined as bioclastic algal debris facies. Corallinacean debris dominates in a micritic matrix; some shells of bivalves, few bryozoan remains and spines of echinoids occur. The foraminiferal fauna is impoverished, and individuals are broken. *Amphistegina*, miliolids (*Quinqueloculina*, *Sphaerogypsina*) and *Asterigerinata* occur.

## 2. Paleontology

### Unit I ("laminated marl facies") (Plates 1-8)

A diverse and very diagnostic macro- and microfauna was investigated within the marly facies. In the following the most important groups are described and autecological conclusions are summarized for each group. All the described and illustrated taxa derive from the excavation level. In addition to the fauna, the calcareous nannoplankton was studied by S. CORIC and its stratigraphical implications are briefly summarised.

### Porifera & Radiolaria

monaxone and triaxone spicules of sponges and rare tests of radiolarians are present in sieve samples.

### Polychaeta (pl. 1, fig. 1)

*Ditrupa cornea* (LINNÉ)

*Serpula* sp. (cf. *discohelix* SEGUENZA)

*Pomatoceros* sp.

*Polydora* sp.

Pectinariidae indet.

Serpulids are by far the most ubiquitous polychaetes in the investigated samples. Due to the prevailing soft bottom conditions they settle only secondary hardgrounds such as oysters and pectinids. They are more commonly found attached to echinoids, mainly on *Spatangus austriacus*, usually forming dense crusts associated with membraniporiform bryozoans or various celaporids. In contrast, the genus *Polydora* is only recorded by rare borings in *Ostrea digitalina* (DUB.).

Additionally, scattered specimens of *Ditrupa cornea* (L.) contribute to the fauna. According to CHENG (1974) *Ditrupa* lives on sandy to muddy bottoms in the shallow and moderately deep sublittoral. The free-living animals are mainly epifaunal suspension feeders (JORDANA & al. 2000) but are even regarded as microcarnivorous detritus feeders by some authors (FÜRSICH 1984). *Ditrupa* may settle relatively high-energy environments with shifting substrates due to its capability to escape sedimentation.

The most interesting polychaete is an approximately 11 cm long slightly conical tube consisting of agglutinated foraminifera. Due to sediment compaction the tube is flat, attaining 13 mm maximum diameter and 7 mm minimum diameter at the termination. The generic identification of such tubes is very difficult and problematical. Amongst the modern Pectinariidae the genus *Pectinaria* forms similar but usually smaller tubes. These marine animals live as suspension feeders on sand and mud. However, a relationship to polychaetes of the family Terebellidae (e.g. *Lanice*) cannot be excluded.

### Mollusca (pl. 1, figs. 2, 3)

*Ostrea digitalina* (DUBOIS)

"*Chlamys*" *rakosensis* CSEPREGHY-MEZNERICS

*Flexopecten scissus* (FAVRE)

*Crassadoma multistriata* (POLI)

*Aequipecten scabrellus* (LAMARCK)

*Flabellipecten besseri* (ANDRZEJOWSKY)

*Flabellipecten leythajanus* (PARTSCH)

*Oppenheimopecten aduncus* (EICHWALD)

*Periglypta* cf. *miocaenica* (MICHELOTTI)

Lucinidae indet.

*Conus* sp.

Molluscs are rather rare in the laminated marl facies. A bias in the fauna is due to selective preservation which overemphasises calcitic taxa such as oysters and pectinids, whilst aragonitic shells are mainly dissolved. Nonetheless, since even these forms are documented by casts and moulds, the scarceness of gastropods and infaunal bivalves seems to be primary. Hence, the mollusc fauna is strongly dominated by epifaunal suspension feeders. *Ostrea digitalina* is common, but never attains the size of the populations in the adjacent foraminiferal algal debris and pavement facies as exposed in the Roman quarry. Apart from the usually smaller size, the shells are distinctly thinner and are often more weakly ornamented. In contrast to this, in the same section, the species is thick and heavily ornamented in coarse corallinean debris.

The otherwise rare "*Chlamys*" *rakosensis* is one of the most abundant pectinids within the fish-bearing marly layers and thus seems to be a facies-index species. Its autochthonous occurrence is proved by a pair of disarticulated but very closely adjoining right and left valves. *Flexopecten scissus* is less abundant and is documented from the marls by few juvenile valves. Similarly, *Flabellipecten besseri* is mainly recorded by subadult specimens. Additionally, only *Aequipecten scabrellus* is a rather common element in the marls, whilst all other pectinids occur very scattered. Especially the large valves of *Flabellipecten leythajanus* and *Oppenheimopecten aduncus* are very rare and are found usually directly at the top of the algae debris layers. The interpretation of an at least partly allochthonous occurrence of these shells is also supported by the fact that these two species are very characteristic and widespread elements of the adjacent corallinean and rhodolite facies.

The dominating pectinid taxa comprise semisessile byssate and vagile species which all indicate shallow sublittoral conditions. For example *Crassadoma multistriata* is a semisessile, byssate species which lives attached to plants, tunicates or rocks in all water depths down to 40 m (MANDIC & HARZHAUSER 1999). In contrast, species laying on the sediment such as *Oppenheimopecten aduncus* are rare.

The occurrence at the quarry Kummer in St. Margarethen is the first Austrian evidence for "*Chlamys*" *rakosensis* CSEP.-MEZ. which is only reported from the Leitha Limestone

in Hungary (CSEPREGHY-MEZNERICS 1960). Correspondingly, *Flexopecten scissus* (FAVRE) was unknown from the Austrian Miocene until now.

### Echinodermata (pl. 1, fig. 4, pl. 2, pl. 3, fig. 1)

*Brochopleurus* sp.

*Schizechinus dux* (LAUBE)

*Clypeaster scillae* (MICHELIN)

*Brissopsis* sp.

*Spatangus austriacus* (LAUBE)

Ophiuroida indet.

The otherwise rare species *Schizechinus dux* LAUBE is the most frequent echinoid in the laminated marls. It has no living representatives, but the closely related species *Schizechinus duciei* (WRIGHT) from the Late Miocene of the Maltese Islands occurs exclusively within a coralline algal bioherm together with *Psammechinus tortonicus* (GREG.), diverse brissids, *Clypeaster altus* (LESKE), *Schizaster* sp., *Echinolampas hemisphaericus* (LAM.) and *Echioneus* cf. *cyclostomus* LESKE (CHALLIS 1980), for which a depositional depth of more than 25 m was inferred (PEDLEY 1978). Within this bioherm, coralline algal patch reefs are interspersed with seagrass beds (PEDLEY 1978). Since *S. duciei* is often found as - though crushed - whole specimens with the apical system, lantern and teeth still in place, CHALLIS (1980) suggested a low-energy microenvironment within the bioherm as their preferred habitat.

A morphologically similar, extant echinoid is *Lytechinus variegatus* (LAM.), which occurs as a dominant echinoid species together with *Tripneustes ventricosus* (LAM.) and *Clypeaster rosaceus* (L.) in turtlegrass areas on sand bottoms off the coast of Key Largo, Florida (KIER & GRANT 1965). Furthermore it was reported from rocky areas near the shore and rarely on sand; its maximum depth range seems to be connected to that of the turtlegrass (KIER & GRANT 1965). Another similar extant species is *Sphaerechinus granularis* LAM., which lives in the Mediterranean Sea below 8 to 10 m on pebbly rock bottoms and more commonly on medium to coarse sandy sediments with seagrass patches (A. KROH, pers. observation; RIEDL 1983).

The second very common echinoid species is *Spatangus austriacus* LAUBE. The presence of relatively small partitioned isopores in the shallow frontal ambulacrum of *S. austriacus* indicates that this form ploughed the sediment surface or was shallow burrowing (compare SMITH 1980b). Recent species of *Spatangus* (e.g. *S. raschi* LOVÉN) do not completely bury themselves in fine sediments, but plough (SMITH 1980a). A depth range of 9 to 55 m for species living in coarse sands and shell grounds, but 183 to 274 m for species living in fine sand and sandy mud was listed by CHALLIS (1980). The extant form *Spatangus purpureus* LESKE, which reaches a similar size as *S. austriacus*, is known to live shallow burrowing (up to 20 mm below the sediment surface) in muddy sand habitats below 10 m in the Mediterranean Sea (RIEDL 1970). Likewise, *S. austriacus* is here interpreted to have been shallow burrowing or ploughing in the medium to coarse sandy environment present at the studied locality.

*Brochopleurus* sp. is documented by few specimens only. Although this genus has no living representatives, it will most probably have occupied a similar habitat as most extant small sized Echinacea. These forms, like *Psammechinus*, often live in shallow, but protected habitats. *Psammechinus microtuberculatus* (BLAINV.), for example, in-

habits shallow habitats on secondary hardgrounds, under stones or within seagrass or macroalgal patches (RIEDL 1983; GÖTHEL 1992).

*Clypeaster scillae* (DESM.), which is common in the corallinacean debris but only very rare in the laminated marls, is morphologically similar to the extant *C. rosaceus*. It shares its tumid ambitus, deep infundibulum and has a moderately high test profile. KIER & GRANT (1965) recognised two different morphotypes within the genus *Clypeaster* within their study area: forms with a low test profile, a relatively thin margin and a flat ventral surface, represented by *Clypeaster subdepressus* (GARY), and forms with a high test profile, a deep infundibulum and a thick, tumid margin, represented by *Clypeaster rosaceus* (L.). The shape of these forms seems to be highly related to their mode of living. *C. subdepressus* is a shallow-burrowing species, whereas *C. rosaceus* lives epibenthically and rarely is found ploughing the sediment, buried up to its ambitus only. *C. rosaceus* was reported to occur most commonly on sandy sediments with seagrass patches and is known to feed on *Thalassia* (KIER & GRANT 1965; KIER 1975; HENDLER & al. 1995). Thus *Clypeaster scillae* is interpreted as an epibenthic or ploughing form living in sandy habitats with seagrass patches.

Finally a single fragment of *Brissopsis* sp. was found. Extant species of this genus live as shallow burrowers in muddy sediments such as silt, sandy silt and clayey silt (e. g. *Brissopsis lyrifera* (FORBES), KIER 1975).

The occurrence of larger regular echinoids as whole tests, although crushed by sediment compaction, with their apical system, lantern and spines still in place in some specimens of *Schizechinus dux*, hints to very low water energy condition without turbulence and proves negligible post-mortem transport. Even the few fragments that were found are relatively large segments of *Schizechinus* consisting of at least 2 complete ambulacra and interambulacra. In more agitated settings these echinoids would readily disarticulate and occur only as single plates and small test fragments of a few plates. There is even one slab with 4 specimens of *Schizechinus dux* in live position, indicating a sudden death of this echinoid association. However, a preservation as an obruption deposit caused by a catastrophic event can be ruled out since many echinoids are commonly encrusted by sessile organisms such as bryozoans and serpulids. Comparable multi-species clumps are described from the Northern Adriatic Sea, where such aggregates document an encrusting phase of up to 20 months (NEBELSICK & al. 1997).

### Crustacea (pl. 5)

*Palinurus* sp.  
Portunidae indet.

Decapods are rarely found in the section. Nonetheless, it was possible to collect a complete specimen of a large, adult spiny lobster. The Recent representatives of the genus *Palinurus* live in deeper coastal waters, preferring rocky habitats. *Palinurus vulgaris* is reported by RIEDL (1970) to have its maximum between 40 and 70 m depth. The very good preservation of the specimen suggests little transportation and documents the absence of scavengers.

Ostracods are also common in sieve samples but are not investigated within the frame of this paper.

**Bryozoa** (pl. 3, figs. 2, 3; pl. 4, figs. 1-4)

<i>Membranipora nobilis</i> (REUSS)	⊙	<i>Smittina cervicornis</i> (PALLAS)	
<i>Ramphonotus appendiculata</i> (REUSS)	⊙	<i>Reteporella</i> sp.	
<i>Callopora fenestrata</i> (REUSS)	⊙	<i>Escharina</i> cf. <i>otophora</i> (REUSS)	⊙
<i>Micropora parvicella</i> CANU & LECOINTRE	⊙	<i>Arthropoma</i> sp.	⊙
<i>Calpensia gracilis</i> (MÜNSTER)	⊙	<i>Umbonula macrocheila</i> (REUSS)	⊙
<i>Hippoporina rarepunctata</i> (REUSS)	⊙	<i>Myriapora truncata</i> (PALLAS)	
<i>Echaroides coccinea</i> (ABILDGAARD)	⊙	Celleporidae indet.	⊙
<i>Schizoporella dunkeri</i> (REUSS)	⊙	<i>Crisia</i> sp.	
<i>Microporella inamoena</i> (REUSS)	⊙	<i>Hornera striata</i> MILNE-EDWARDS	
<i>Calloporina decorata</i> (REUSS)	⊙		
<i>Cellaria</i> cf. <i>salicornioides</i> LAMOUROUX		⊙ encrusting secondary hardgrounds	

Bryozoans are ubiquitous fossils in the marl layers of St. Margarethen. However, the most striking feature of the bryozoan occurrences at the locality "Kummer" is their autochthonous, articulated preservation. *Hornera striata*, *Myriapora truncata*, *Reteporella* sp, and *Smittina cervicornis* are found more or less in situ, forming scattered colonies up to 7 cm diameter. An extraordinary colony of *Membranipora nobilis* encrusting algae thalli attains even 17 cm diameter. Besides the Membraniporidae many colonies of Celleporidae display a subcentral, hollow, tube-like cavity which can be attributed to marine plants. Plaster casts of these structures revealed undulating, irregular outlines with slightly compressed cross-section.

The articulated preservation of large colonies clearly furnishes evidence for low to nearly absent water agitation. According to data compiled in SCHMID (1989), *Cellaria salicornioides*, *Calloporina decorata*, *Calpensia gracilis*, *Umbonula macrocheila*, *Smittina cervicornis* (syn. *Porella cervicornis*) and *Retepora* sp. (syn. *Sertella* sp.) indicate very low sedimentation rates. Fully marine conditions are clearly documented by the presented bryozoan assemblage.

*Smittina cervicornis* is described from the modern Adriatic Sea by RIEDL (1970) from coralline bottoms below 25 m water depth. SCHMID (1989) states for the same species occurrences in water depths from 40 to 60 m, with decreasing abundance down to 120 m and a distribution down to 60 m for *Calloporina decorata*. Similarly, she gives a preferred depth range from 30 to 80 m and a maximum depth of 100 m for *Echaroides coccinea*. For *Cellaria salicornioides* she cites preferred water depths from 50 to 80 m and maximum distributions down to 100 m. In contrast, the related *Cellaria fistulosa* is also common from 20 to 100 m, settling secondary hardgrounds and muddy sand (RIEDL 1970). *Myriapora truncata* is recorded by RIEDL (1970) from shady, sheltered habitats of rocky shores and from secondary hardgrounds in approximately 20 m depth. Similarly, he mentions *Retepora beaniana* from coralline bottoms below 25 m, but also from very shady rocky habitats and secondary hardgrounds in shallower waters. The Recent *Hornera frondiculata*, a close relative of the Miocene *Hornera striata*, is reported from 20 to more than 50 m water depth (RIEDL 1970).

Altogether the bryozoan fauna hints at poorly agitated marine environments between 30 to 60 m depth with very low sedimentation.



**Brachiopoda** (pl. 1, fig. 4)*Lingula dregeri* ANDRAE*Discinisca* cf. *leopolitana* (FRIEDBERG)

The brachiopod fauna of St. Margarethen is the first *Lingula-Discinisca* assemblage to be described from the Miocene of the Vienna Basin. Both genera are extremely rare in Austrian Miocene deposits. Amongst the discinids only the strongly sculptured *Discinisca scutellum* has hitherto been reported from the Austrian Lower Badenian (Middle Miocene) by DREGER (1882). Therefore *Discinisca* cf. *leopolitana* is the first record of this species for Austria and the second documented *Discinisca* species in the Vienna Basin. *Lingula*, however, was already described from the Leitha Limestone by DREGER (1882). Note that *Lingula dregeri* ANDRAE was originally described by DREGER (1889) as *Lingula suessi* DREGER, which is a homonym of a Triassic species (for details see RADWANSKA & RADWANSKI 1984). All collected lingulids were found with articulated valves but have never been observed to occur in life position. In contrast, *Discinisca* cf. *leopolitana* is represented only by disarticulated dorsal valves.

*Lingula* is adapted to a wide salinity range, dwelling even in brackish habitats. The Recent *Lingula anatina* is known from laboratory experiments to survive even very heavy fluctuations of salinity ranging from 16 to 50 ‰ (HAMMOND 1983). Typically it lives on sandy substrate in the intertidal to shallow sublittoral. Due to its rather low escape abilities, *Lingula anatina* avoids high sedimentation and prefers low energy environments (SAVAZZI 1991). Although Recent representatives of the genus *Lingula* are predominantly reported from intertidal habitats - which seems to be to some extent an artificial sampling effect - there is also good evidence for sublittoral populations of the animals from 16 to about 74 m water depth (see PLAZIAT & al. 1978; PAINE 1970 and references therein). This coincides well with the statement of DREGER (1882), who interpreted his specimens to derive from shallow water environments.

An interesting observation of PAINE (1970) was that, as opposed to the sand-dwelling intertidal species, "non-intertidal" lingulids prefer finer sediment such as silt and clay, which fits well to the population of *Lingula dregeri* in St. Margarethen. A comparable occurrence of lingulids (consisting mainly of the related *Lingula dumortieri*) is reported by RADWANSKA & RADWANSKI (1984) and BARCZYK & POPIEL-BARCZYK (1977) from the Badenian Korytnica Basin in Poland. There, close to Chomentow, the lingulids are also found in marly sands which interfinger with coralline limestone. According to GUTOWSKI (1984) the marly sands containing this lingulid assemblage reflect shallow marine conditions below the tidal zone.

The taphonomy of lingulids was investigated by EMIG (1980), who concludes that flat-lying shells (in contrast to life-position preservation) occur due to long-lasting salinity reduction, storm deposits or simply in case of natural death.

The ecological requirements of *Discinisca* are summarised by RADWANSKA & RADWANSKI (1984; 1986). Following these authors, the Recent representatives favour intertidal to shallow sublittoral environments down to 45 m depth. Tendencies to form clusters or to settle sheltered habitats are documented. The animals are attached to any primary or secondary hardground such as rocks, pebbles, or shells. The same holds true for the specimens from St. Margarethen. At least 14 shells are concentrated on a small slab of marl

measuring about 7x5 cm. Within this slab, the specimens are restricted to a bryozoan-serpulid aggregate, which obviously gave shelter and habitat to the *Discinisca* colony. This remarkable in situ preservation again points to negligible water turbidity during the sedimentation of the marls.

## Aves

### *Gavia schultzi* MLIKOVSKÝ

Loons are diving birds which prey on fishes or insects, being common in marine and freshwater habitats (MILKOVSKÝ 1998).

## Calcareous nannoplankton of the laminated marl facies of St. Margarethen

Contribution by S. CORIC (fig. 7)

*Braarudosphaera bigelowii* (GRAN & BRAARUD) DEFLANDRE  
*Calcidiscus leptoporus* (MURRAY & BACKMAN) LOEBLICH & TAPPAN  
*Calcidiscus tropicus* KAMPTNER  
*Calcosolenia murrayi* GRAN  
*Coccolithus miopelagicus* BUKRY  
*Coccolithus pelagicus* (WALICH) SCHILLER  
*Coronocyclus nitescens* (KAMPTNER) BRAMLETTE & WILCOXON  
*Cyclicargolithus floridanus* (ROTH & HAY in HAY et al.) BUKRY  
*Discoaster deflandrei* BRAMLETTE & RIEDEL  
*Discoaster multiradiatus* BRAMLETTE & RIEDEL  
*Geminolithella rotula* (KAMPTNER) BACKMAN

*Helicosphaera carteri* (WALLICH) KAMPTNER  
*Helicosphaera euphratis* HAQ  
*Helicosphaera mediterranea* MÜLLER  
*Helicosphaera recta* HAQ  
*Helicosphaera walbersdorfensis* MÜLLER  
*Helicosphaera waltrans* THEODORIDIS  
*Micrantholithus flos* DEFLANDRE  
*Micrantholithus vesper* DEFLANDRE  
*Pemma papillatum* MARTINI  
*Reticulofenestra bisecta* (HAY et al.) ROTH  
*Reticulofenestra haqii* BACKMAN  
*Reticulofenestra minuta* ROTH  
*Reticulofenestra pseudumbilicus* GARTNER  
*Thoracosphaera saxeae* STRADNER  
*Umbilicosphaera jafari* MÜLLER  
*Zygrhablithus bijugatus* DEFLANDRE

## Material and methods

Preparation of smear slides for light microscope study was performed following the standard preparation techniques. Smear slides were studied using a Leitz light-microscope at 1000 x magnification. The quantitative analyses were performed by counting about 200 specimens in each sample.

## Results

The samples from the section MAR-A (excavation level) yield generally well-preserved and rich associations. Rare reworked species include Cretaceous and early Cenozoic taxa (e.g. *Arkangelskiella* sp., *Micrantholithus* sp., *Discoaster* sp.). Nannofossil abundance varies according to lithology; in calcarenites approximately 1 to 5 specimens per field/view were identified, whereas in the marly layers 5 to 15 specimens per field/view were counted.

The dating of the sediments as Badenian is confirmed based on the presence of rare specimens of *Helicosphaera waltrans* and *H. walbersdorfensis*.

Section St. Margarethen Sample MAR-A-25	<div> <div>marl</div> <div>marl, limonitic</div> <div>marl with arenite laminae</div> <div>calcarenite</div> <div>marl with arenite laminae</div> <div>calcarenite</div> <div>marl with arenite laminae</div> <div>calcarenite</div> <div>marl with arenite laminae</div> <div>calcarenite</div> </div>									
	1	2	3	4	5	6	7	8	9	10
Laminae nos.	1	2	3	4	5	6	7	8	9	10
Thickness in mm	3	2	3	3/5	10	6	3	2	3/4	7
<i>Braarudosphaera bigelowii</i>	1		1		1	4				2
<i>Calcidiscus leptoporus</i>				2		6	14	19	10	8
<i>Calcidiscus tropicus</i>						11	15	6	21	4
<i>Calciosolenia murrayi</i>	2	2			1					
<i>Coccolithus miopelagicus</i>	5	3	5	5	2		5	2	3	2
<i>Coccolithus pelagicus</i>	147	147	141	158	151	140	109	121	145	116
<i>Coronocyclus nitescens</i>	2	9	3	3	1	8	3	1		
<i>Cyclicargolithus floridanus</i>	1	1	3	1	1			2	1	6
<i>Discoaster deflandrei</i>							1			
<i>Discoaster multiradiatus</i>	1									
<i>Geminolithella rotula</i>	3	3	1			4	5			6
<i>Helicosphaera carteri</i>	2	1	6		6		1	1	1	4
<i>Helicosphaera euphratis</i>										
<i>Helicosphaera mediterranea</i>	2									
<i>Helicosphaera walbersdorfensis</i>							1	2		
<i>Helicosphaera waltrans</i>	2				1					
<i>Micrantholithus flos</i>		1		1	1	3				
<i>Micrantholithus vesper</i>								1	1	2
<i>Pemma papillatum</i>			3	1						
<i>Reticulofenestra bisecta</i>	5	2	6	8		1	5	7	1	
<i>Reticulofenestra haqii</i>	4	7	5	2	5		9	10	7	18
<i>Reticulofenestra minuta</i>	2	1					1	1		16
<i>Reticulofenestra pseudoumbilicus</i>	21	22	26	23	20	19	31	25	9	8
<i>Thoracosphaera saxeaa</i>	3		1							
<i>Umbilicosphaera jafari</i>						1				
<i>Zygrhablithus bijugatus</i>	1									

Fig. 7: Quantitative distribution of calcareous nannoplankton within a 45 mm thick laminated section of marls and calcarenites.

The assemblages are dominated by *Coccolithus pelagicus* (50 - 80 %) and reticulofenestrids (10 - 20 %). The accompanying assemblages contain *Calcidiscus leptoporus*, *C. tropicus*, *Coronocyclus nitescens*, *Geminolithella rotula* and *Cyclicargolithus floridanus*. *Discoaster* spp. and *Sphenolithus* spp. are absent or very rare. Based on these assemblages the zonation of FORNACIARI & al. (1996), proposed for the Mediterranean Sea, was applied to the St. Margarethen Section. In particular, the studied interval can be correlated with the MNN5a/b boundary, which falls into zone NN5 of the standard zonation of MARTINI (1971).

In modern oceans *C. pelagicus* is typical in the subpolar belt where temperature averages between 7 and 14 °C and is, therefore, considered as an indicator of cool waters (MCINTYRE & BE 1967). In contrast, the species has wide distributions in warm-temperate Pliocene sediments. (BAUMANN & al. 2000). In Badenian sediments from the Romanian basin, *Coccolithus pelagicus* occurs in low abundances associated with typically warm water species such as discoasterids and sphenoliths (CHIRA & MARUNTEANU 1999). Especially in the Vienna Basin, this species is very abundant in Badenian sediments, where it can represent 50 - 90 % of the entire nannofossil assemblage (STRADNER & FUCHS 1977).

The nearly monospecific mass-occurrences of coccoliths is generally connected to distinct changes in ecological parameters. Typically, such r-strategists indicate nutrient-rich or fluctuating conditions (HALLOCK & al. 1991). Correspondingly, for the *C. pelagicus* bloom in the study-area an explanation might be increased nutrient input and/or freshwater overflow linked to the adjacent river systems (cf. SAUER & al. 1992, fig. 13).

## Foraminiferida of the laminated marl facies of St. Margarethen

Contribution by F. RÖGL (fig. 8)

### Textulariina:

*Spirorutilus scaliger* (LUCZKOWSKA)  
*Textularia laevigata* (d'ORBIGNY)

### Spirillina:

*Patellina corrugata* WILLIAMSON  
*Spirillina vivipara* EHRENBERG

### Rotaliina:

*Ammonia tepida* (CUSHMAN)  
*Ammonia pseudobeccarii* (PUTRJA)  
*Angulogerina angulosa* (WILLIAMSON)  
*Asterigerinata planorbis* (d'ORBIGNY)  
*Asterigerinata mamilla* (WILLIAMSON)  
*Astrononion stelligerum* (d'ORBIGNY)  
*Bolivina* spp.  
*Buliminella elegantissima* (d'ORBIGNY)  
*Cancri auriculus* (FICHTEL & MOLL)  
*Caucasina gutsulica* (LIVENTAL)  
*Caucasina subulata* (CUSHMAN & PARKER)  
*Cibicidoides* spp.  
*Discorbinoides* sp.  
*Elphidiella* spp.  
*Elphidium fichtelianum* (d'ORBIGNY)  
*Elphidium flexuosum* (d'ORBIGNY)

*Elphidium macellum* (FICHTEL & MOLL)  
*Elphidium* cf. *reginum* (d'ORBIGNY)  
*Elphidium rugosum* (d'ORBIGNY)  
*Eoepionidella* sp.  
*Eponides umbonatus* (FICHTEL & MOLL)  
*Fissurina laevigata* REUSS  
*Fursenkoina acuta* (d'ORBIGNY)  
*Gavelinopsis* sp.  
*Glabratella effusa* (KRASHENINNIKOV)  
*Globocassidulina subglobosa* (BRADY)  
*Globulina gibba* d'ORBIGNY  
*Guttulina communis* (d'ORBIGNY)  
*Hansenisca* cf. *soldanii* (d'ORBIGNY)  
*Heterolepa* cf. *dutemplei* (d'ORBIGNY)  
*Lobatula lobatula* (WALKER & JACOB)  
*Melonis* sp.  
*Neoconorbina terquemi* (RZEHA)  
*Paliolotella orbignyana* (SEGUENZA)  
*Planorbulina mediterraneensis* (d'ORBIGNY)  
*Porosononion* sp.  
*Pseudofissurina quadricostulata* (REUSS)  
*Reussella laevigata* CUSHMAN  
*Reussella spinulosa* (REUSS)  
*Rosalina obtusa* d'ORBIGNY

Section St. Margarethen											
Sample MAR-A-25		marl	marl, limonitic	marl with arenite laminae	calcarenite	marl with arenite laminae	calcarenite	marl with arenite laminae	calcarenite	marl with arenite laminae	calcarenite
Laminae nos.		1	2	3	4	5	6	7	8	9	10
Thickness in mm		3	2	3	3/5	10	6	3	2	3/4	7
<i>Elphidium</i> spp.											
<i>Elphidiella</i> spp.			o					o	o		o
<i>Asterigerinata planorbis/mamilla</i>											
<i>Lobatula lobatula</i>					o				o		
<i>Cibicidoides</i> spp.			o		o	o	o		o	o	o
<i>Bolivina/Rugobolivinella</i>					o			o	o	o	o
<i>Glabratella/Discorbinoides</i>					o		o	o			o
<i>Neoconorbina terquemi</i>		o	o	o	o		o				
<i>Rosalina</i> spp.		o	o	o	o	o		o	o	o	o
<i>Ammonia tepida/pseudobeccarii</i>		o	o			o			o	o	o
<i>Hansenisca</i> sp.		o									
<i>Stomatorbina concentrica</i>		o	o						o		
<i>Cancris auriculus</i>		o		o	o	o	o		o	o	o
<i>Gavelinopsis</i> sp.		o	o	o		o	o		o	o	
<i>Planorbulina mediterraneensis</i>		o								o	
<i>Spirillina vivipara</i>		o	o	o	o	o	o	o		o	
<i>Patellina corrugata</i>		o		o	o	o			o	o	o
<i>Angulogerina angulosa</i>			o	o			o				o
<i>Caucasina gutschulica/subulata</i>				o	o			o	o		o
<i>Reussella laevigata</i>		o	o	o	o		o	o		o	
<i>Virgulinella pertusa</i>		o				o	o			o	
<i>Fissurina/Pseudofissurina/Paliolatella</i>		o	o	o	o	o	o	o	o	o	o
<i>Globocassidulina subglobosa</i>			o	o		o			o		o
<i>Porosononion</i> sp.			o	o	o	o	o	o	o	o	o
<i>Reussella spinulosa</i>				o	o	o		o			
<i>Globulina/Guttulina</i>				o	o	o	o	o		o	o
<i>Fursenkoina acuta</i>					o				o		
<i>Spirorutilus scaliger</i>					o	o					
<i>Textularia laevigata</i>						o	o		o	o	o
<i>Astrononion stelligerum</i>						o		o			
<i>Eponides umbonatus</i>						o					
<i>Eoeponidella</i> sp.						o	o			o	
<i>Buliminella elegantissima</i>						o	o	o	o	o	o
<i>Rotorbinella</i> sp.								o	o	o	o

Fig. 8: Semi-quantitative distribution of benthic foraminifera within a 45 mm thick laminated section of marls and calcarenites.

*Rotorbinella* sp.*Rugobolivinella* sp.*Stomatorbina concentrica* (PARKER & JONES)*Virgulinella pertusa* (REUSS)**Globigerinina:***Globigerina praebulloides* BLOW*Globigerina subcretacea* LOMNICKI*Globigerinita uvula* (EHRENBERG)*Globoquadrina* sp.*Globorotalia bykovae* (AISENSTAT)*Turborotalita quinqueloba* (NATLAND)

To investigate the environmental conditions of the laminated and banded marls and calcarenites a 45 mm thick section was studied in detail, in single laminae (fig. 8). The washed residue of the marly lower part of this section (laminae nos. 1-3) consists of predominantly benthic foraminifera and of only some calcarenite with cemented biogenic detritus and foraminifera. The assemblage of layer no. 2 with limonitic marl shows no differences. The marly layers up-section have thin, 0.3-0.5 mm laminae of calcarenite. The intercalated, thicker, 3-10 mm layers of calcarenite are divided themselves by very thin laminae of grey marl. The assemblages in marls and calcarenites are similar, with minor differences such as the more common presence of *Bolivina* in the marls. Only in the thicker layer of calcarenite on the top, frequent *Lobatula* indicate some seagrass. Planktic foraminifera are generally absent, with only few specimens being found in the marls.

Ecologically, the foraminiferal fauna is dominated by epifaunal forms, free living on sand and vegetation (*Elphidium*, *Asterigerinata*). Others cling to hard substrates (*Glauertella*, *Neoconorbina*, *Patellina*, *Spirillina*) or to seagrass (*Lobatula*). Only *Bolivina*, occurring in greater numbers in the lower marly part, prefers an infaunal habitat. All faunal components inhabit the inner shelf in well-oxygenated temperate to warm waters (MURRAY 1991). The small size and thin wall of the elphidiids point to a deeper environment, comparable to 30-50 m in the Adriatic Sea. In contrast the sample studied from the fish beds of former excavations (RÖGL in BACHMAYER 1980) showed a frequent occurrence of *Lobatula*, *Discorbis*, and heavily shelled elphidiids, indicating a shallow environment with seagrass meadows.

In the studied samples textulariids are very scarce, lagenids are absent, and indicators of reduced oxygen content are only present in very low numbers (*Caucasina*, *Virgulinella*). The absence of miliolids may be caused by the washing procedure, which also destroyed the relics of calcareous algae. The interpretation of the environmental conditions was supported by thin-sectioning of a marly layer. This middle part of this layer shows a thin horizon with dispersely distributed, thin-walled benthic foraminifera of a similar assemblage as the accompanying calcarenites, but no fauna below and above. This may be explained as an anoxic event during deposition of marls, with a short interruption of well-oxygenated waters, enabling autochthonous foraminiferal growth in the marls. Most of the fauna in the calcarenites seems to be transported from the surroundings.

### **Pisces of the laminated marl facies of St. Margarethen**

Contribution by O. SCHULTZ (pl. 6 – 8)

*Carcharias acutissimus* (AGASSIZ)*Cetorhinus parvus* LERICHE*Carcharhinus priscus* (AGASSIZ)*Pristis* sp.

Dasyatoidea or Mylobatoidea

*Aetobatus arcuatus* AGASSIZ

Anquilliformes indet.

"Clupea" *haidingeri* HECKEL

*Palimphemus anceps* KNER*Lophius* sp.*"Capros"* sp.*Aeoliscus* sp.*Nerophis zapfei* BACHMAYER*Scorpaena prior* HECKEL in HECKEL & KNER*Jemelkia jemelka* (HECKEL)*"Trigla" infausta* HECKEL in HECKEL & KNER*"Caranx" boeckhi* GORJANOVIC-KRAMBERGER*Dentex* sp.*"Pagrus" priscus* HECKEL*Sparus umbonatus* (MÜNSTER)*Julis agassizi* (MÜNSTER)*Julis sigismundi* HECKEL*"Labrus" parvulus* HECKEL*Calotomus preisli* BELLWOOD & SCHULTZ*Miobothus weissi* CHANET & SCHULTZ

Only a small part of the fish fauna of the laminated marl facies in St. Margarethen is published. Moreover, some of the above-listed taxa should be revised. Nevertheless, some general paleocological conclusions can be deduced from recently studied species. One part of the documented fish fauna represents inhabitants of seagrass and/or muddy bottom biota in shallow coastal waters. These are mainly taxa such as *Pristis* sp., *Aetobatus arcuatus*, *Lophius* sp., *Nerophis zapfei*, *"Trigla" infausta*, *Calotomus preisli* and *Miobothus weissi*. Extant relatives of the second group mainly inhabit coral reefs or rocky substrates. This group is represented by *Julis agassizi* and *Julis sigismundi*. However, *Sparus umbonatus*, the frequent Scorpaenidae and the unidentified Anguilliformes may inhabit both habitats.

Representatives of shallow waters are *Dentex* sp. and the sharks *Carcharias acutissimus* and *Carcharhinus priscus*. Additionally, rare pelagic species such as *Cetorhinus parvus* occur. A speciality is the occurrence of *Aeoliscus* sp. These fishes swim vertically, in head-down position, and hide among spines of sea urchins.

In conclusion, the documented fish fauna indicates water depth shallower than 60-70 m. The living relatives of many of these fishes are distributed in tropical waters.

## Unit II (rudstones)

The composition of the fauna of the coralline debris facies as represented in unit II is quite different from that of the laminated marls. In the following only a brief summary is given. The most striking difference can be seen in the molluscan fauna. Whilst small-sized and thin-shelled species predominate in the marls, large-sized and robust forms appear in the coralline sand. Two typical species are *Ostrea digitalina* and *Flabellipecten leythajanus*, which occur both in form of loose coquinas. Additionally, *Macrochlamis nodosiformis* and *Oppenheimopecten aduncus* contribute to the fauna. Corals, sometimes with associated cirripeds, are rather rare; they are always transported and never form in situ colonies within the section MAR-A at the quarry "Kummer". In contrast to the marls of unit I, where the echinoids generally occurred in the form of whole test, here fragments prevail. Additionally the taxonomic composition of the echinoderm fauna is different. *Echinolampas hemisphaeicus* (LAM.), which usually lives in coarse sands, as do extant species of this genus (e. g. *E. crassa* (BELL), THUM & ALLEN 1975), is the most common echinoid. *Clypeaster scillae* (MICH.) also occurs occasionally, and very rarely denuded or even fragmented specimens of *Schizechinus dux* (LAUBE) can be found. Whereas rhodolithes are very rare allochthonous elements in the marls of unit I, here they are very common.

Another very striking difference between the fauna of the marls and that of unit II is the composition of the fish fauna. Vertebrates are recorded only based on isolated teeth or bones; isolated jaw fragments of fishes are rare; complete fish-skeletons are absent. Despite the clear bias due to the different preservation of the fishes in the two environments, the fossil record demonstrates, that the shark and ray fauna was different originally. Whilst the marls bear only few and scattered remains, the corallinacean sand displays several species of sharks and rays. Additionally, ribs of sirenians and various remains of dolphins are common in unit II.

Thus the fauna of unit II is here interpreted to indicate a well-aerated sublittoral environment of mobile coarse carbonate sands with seagrass patches.

### **Anthozoa**

*Tarbellastraea reussiana* (MILNE-EDWARDS & HAIME)

*Acanthastraea horrida* (REUSS)

### **Echinodermata**

*Metopaster muelleri* (HELLER)

*Echinolampas hemisphaericus* (LAMARCK)

*Clypeaster scillae* (MICHELIN)

### **Crustacea**

*Pyrgoma multicostatum* SEGUENZA

### **Brachiopoda**

*Discinisca* cf. *leopolitana* (FRIEDBERG)

### **Mollusca**

"*Chlamys*" *rakosensis* (CSEPREGHY-MEZNERICS)

*Flexopecten scissus* (FAVRE)

*Crassadoma multistriata* (POLY)

*Aequipecten scabrellus* (LAMARCK)

*Aequipecten elegans* (ANDRZEJOWSKI)

*Flabellipecten besseri* (ANDRZEJOWSKY)

*Flabellipecten leythajanus* (PARTSCH)

*Oppenheimiopecten aduncus* (EICHWALD)

*Macrochlamis nodosiformis* (SERRES)

*Spondylus crassicosta* LAMARCK

*Ostrea digitalina* (DUBOIS)

*Periglypta miocaenica* (MICHELOTTI)

*Lithophaga laevigata* (QUOY & GAIMARD)

*Astraea* (*Bolma*) sp.

*Conus* sp.

### **Pisces** (contributed by O. SCHULTZ)

*Carcharias cuspidatus* (AGASSIZ)

*Carcharocles megalodon* (AGASSIZ)

*Cetorhinus parvus* LERICHE

*Galeocерdo aduncus* AGASSIZ

Dasyatoidea or Mylobatoidea

*Aetobatus arcuatus* AGASSIZ

*Sparus umbonatus* (MÜNSTER)

*Sphyræna substriata* (MÜNSTER)

### **Mammalia**

*Thalattosiren* sp.

*Acrodelphis* sp.

## **I n t e r p r e t a t i o n**

A variety of different litho-facies types of the Leitha Limestone are documented in the quarry "Kummer". They reflect the interaction of different depositional processes, resulting in a lateral facies changes within section "MAR-A". At least one fining and thinning upward sequence spanning from the base of the section up to the excavation level is defined. A second fining and thinning upward sequence probably exists towards the top (Fig. 5).

For the marls and the calcarenites of unit I we suggest different depositional processes and two sources. Delta fans along the basin rims supplied their siliciclastic load into the Eisenstadt-Sopron Basin and the Vienna Basin. Hypopycnal flow transported the clays as a buoyantly supported surface plume (READING 1996) into the basin. In the working



area small, low-energy depressions permitted the clastics to settle from suspension at low sedimentation rates (background sedimentation). The high clay mineral content (~45%) rules out explaining the marls as suspension load of the calcarenites. Furthermore the dominating smectite points to the erosion of volcanic deposits in the hinterland. For the calcarenites we interpret storm events as the driving force for sedimentation. They triggered loose accumulations of carbonate sands at the rims of corallinean debris build-ups, like those cropping out in the "Roman quarry", and transported them to deeper levels. These seaward, unidirectional flows (rip currents) transported their load in shallow storm surge channels below the storm weather wave base (AIGNER 1984). Consequently, unit I can be interpreted as a subtidal succession of tempestite deposits, where marly background sedimentation was episodically interrupted by calcarenite deposition of storm-induced flows. The lack of macroscopic occurrences of crystalline components from layer 8 on may point to a stage in the evolution of the carbonate sand build-ups where the crystalline basement of the Ruster-Fertörákos Hügel-land was almost totally buried by calcarenites.

We interpret a deepening upward sequence from the base of the section to the excavation level, based on the fining and thinning upward trend. Within this succession the deposits of unit II are intercalated. Sedimentological observations like the distinct erosional lower boundary, lack of bedding, angular lithoclasts and no autochthonous fossils suggest debris flows as the responsible depositional mode. These flows formed a channel-shaped deposit consisting of three amalgamated sedimentation events and an uppermost current-winnowed clast supported part (pavement facies). Again, the components must have been made available along the margins of the corallinean build-ups, but the pebble sized, angular lithoclasts point to a slightly different hinterland than that mentioned above. These components may have been accessible to erosion during a minor regressive phase where Lower Badenian Leitha Limestones already existed. Synsedimentary faults in unit I below unit II document seismic activity, which was likely during the main phase of subsidence of the Vienna and Eisenstadt-Sopron Basins. Earthquakes or tsunamis probably remobilized meta-stable non-cohesive sediments with high in situ water contents, transforming them into high density and viscous fluids, generating disorganized sediments (EINSELE 1991). The lower erosive boundary is due to scouring. The documented grain size and thickness gradation of the channel from the northern towards the southern wall of the quarry is a frequent observation along the down slope directions of debrites (EINSELE 1991).

A much more detailed picture of the paleoenvironment and a reliable estimation of the waterdepth of the mentioned small, low-energy depressions is given by the investigated faunal assemblage. The bryozoan assemblage suggests water depth below 20 or 30 m, while the fish fauna indicates depths shallower than 70 m. Thus the depositional depth is interpreted to range between 30 and 60 m. Additionally, only very low to absent turbulence can be stated for the marly layers of the quarry "Kummer". The in situ occurrence of *Discinisca* cf. *leopolitana* within a bryozoan-serpulid hardground, the in situ preservation of the apical system and the Aristotle's lantern in *Schizechinus dux* and the attached spines on some specimens of this echinoid, as well as the extraordinary preservation of the bryozoan colonies indicate very calm and sheltered conditions. These in situ findings clearly furnish evidence for an autochthonous thanatocoenosis. Hence, only negligible or even absent post-mortem transport of the fauna is suggested for most of the fish-bearing layers. The random orientation of fishes measured within one single

layer supports this interpretation (Fig. 6). Current-driven transportation or movement by springtides can thus be excluded.

After death the shells of bivalves and especially the coronas of *Spatangus* and *Schizechinus* often acted as secondary hardground for encrusting organisms. Based on the size of the attached polychaetes this encrusting phase lasted at least for several months; obruption can thus be definitely excluded. However, the sudden death of several individuals, as documented for the echinoid *Schizechinus dux*, hints at a distinct lethal event (pl. 2).

Such events could potentially be related to occasional fluctuations of salinity. E. g. the lingulids are known to survive osmotic stress in hypo- or hypermarine environments, but non-marine salinity conditions can be ruled out due to the overwhelming normal marine character of the fauna. All the documented molluscs and bryozoans are stenohaline. Accordingly, the absence of miliolid foraminifera also points to stabile, fully marine salinity, without remarkable fluctuations. Thus, even short-termed shifts in salinity are excluded since these would probably be reflected in the foraminiferal assemblages.

A second possible explanation for the sudden death of numerous individuals is repeated hypoxic events. A semi-enclosed and stratified water body, shallow depth, and soft bottom conditions are prerequisites allowing the development of hypoxid or anoxid conditions (STACHOWITSCH 1991). In the modern northern Adriatic Sea the development of near-bottom hypoxia is usually associated with the decay of organic matter accumulated during previous phytoplankton blooms (JUSTIC 1991). These blooms are related to periodic changes in freshwater and nutrient supply and annual changes of the current system.

A similar scenario is forwarded here as an interpretation for the fossil hypoxia at St. Margarethen. The phytoplankton blooms - mainly composed of *Coccolithus pelagicus* and some reticulifenestrids - might have been triggered by periodic increased input of nutrients deriving from the various deltas in the SW of the Vienna Basin (cf. SAUER & al. 1992, fig. 13). Periodic variations in river discharges might have been caused by seasonality in precipitation as assumed for the Badenian terrestrial environments.

The mass-accumulations of fishes as well as the autochthonous thanatocoenosis of echinoderms, bryozoans and brachiopods thus might have been triggered by severe oxygen minima which affected the stagnant bottom waters of the depressions. Unfavourable oxygen conditions close to the bottom surface may also explain the absence of scavengers or carnivores which is indicated by the large number of complete or hardly disarticulated fishes and echinoids. Whilst the sessile fauna and the echinoids might be victims of such local catastrophes, most of the fish-remains cannot be explained by such events. The specimens represent mainly adult individuals; no conspicuous portion of juveniles can be observed. Thus these findings are interpreted to represent the "normal fallout" which was preserved due to occasional phases of dysaerobic bottom water layers.

A comparable hypoxid phenomenon was documented by STACHOWITSCH (1984) and NEBELSICK & al. (1997) from the northern Adriatic Sea, where the burrowing echinoid *Schizaster canaliferus* was observed to emerge from the sediment under oxygen deficiency conditions. The tests are prevented from being destroyed by the coinciding mortality of benthic predators and scavengers. After the mortality phase the coronas are soon settled by epibionts such as serpulids, resulting in multi-species clumps which are well comparable to those described herein from the laminated marl facies of St. Margarethen.

A thin-sectioned marly layer with a drastically impoverished autochthonous foraminiferal fauna also indicates anoxic bottom conditions without infaunal and epifaunal life. Nevertheless, most of the time the oxygen level of the basin was high enough to enable the settlement by a diverse benthic fauna. The muddy bottom was mainly ploughed by large echinoids; deep-burrowing organisms are almost missing, probably due to the small-scale intercalations of coralline debris and clay. In similar recent settings, such intercalations are known to occlude deep burrowing due to mechanical problems and the high amount of energy needed to burrow in such sediments. Secondary hardgrounds, such as coronas of echinoids, shells of bivalves or algae thalli were encrusted by bryozoans and polychaetes and settled by small regular echinoids. The presence of scattered patches of seagrass is indicated by foraminifera as well as by some of the fishes and supported by the echinoid fauna. Additionally, some fishes, such as *Julis agassizi*, derive from the adjacent rocky bottom environments. A weak influence from the open sea is documented by planktic foraminifera, radiolarians and the giant shark *Cetorhinus parvus*.

The reconstruction of the paleoenvironments in the section MAR-A indicates the presence of low-energy depressions dominated by fine-grained sedimentation. These small low-energy depressions were surrounded by carbonate sand build-ups. Storm events and seismic activity caused (re-) sedimentation of coarser-grained material from the shoals into the subtidal level of the depressions by gravity flows.

Based on the sedimentological and paleontological investigations, the dipping of Leitha Limestones away from the crystalline basements and the documented subsequent reefal structures on the Leithagebirge and the Fertörákos-Ruster Hügelland (DULLO 1983; PILLER & VAVRA 1991) we propose two separated, small-scaled carbonate platforms. They are named Leitha Platform and Fertörákos Platform. The assumed separated nature of these platforms at the northern end of the Fertörákos Ruster Hügelland is based on observations of PILLER & KLEEMANN (1991) suggesting currents along the southern tip of the Leithagebirge, which can be explained by a seaway in this position.

## Conclusions

The development of Badenian carbonate platforms at the westernmost margin of the Central Paratethys was limited due to their position near the basin rims and their location outside the tropical zone. Only minor, poorly diversified reefs but extensive carbonate sand shoals evolved in semi-enclosed basins. Nonetheless, two small carbonate platforms can be postulated based on the relict Leitha Limestones surrounding the topographic highs of the Fertörákos-Ruster Hügelland and the Leithagebirge during the Badenian. For the larger one, which extended at least 30 km in SW-NE direction and attained about 10 km width, the term Leitha Platform is proposed herein. The smaller one in the south, reaching about 20 km from the north to the south, the term Fertörákos Platform is introduced. A connection between these carbonate shoals via the northern extension of the Fertörákos Platform cannot be excluded but seems to be unlikely based on the dip directions (Fig. 1). The position of the described section was on the western side of the Fertörákos Platform. It documents a paleoenvironment with carbonate sand shoals surrounding small depressions. Fine clastic background sedimentation (lamina-

ted marls) was interrupted by sedimentation events triggered by storms (corallinacean debris deposits) and more seldom seismic activity (rudstones). Bottom waters depleted of oxygen repeatedly caused mass mortalities of the benthic fauna and enabled an excellent preservation of the vertebrates. Rare, extraordinarily severe crises are documented by scattered layers with mass occurrences of fishes, whilst most of the fish fauna seems to represent long-termed accumulations from the oxygenated water column. During phases of normal oxygenation the stagnant basin was settled by large populations of echinoids and bryozoans.

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## **Plates**

### Plate 1

**Fig. 1: Pectinariidae indet.** The first record of a pectinariid tube from the Badenian of the Paratethys. The tube consists nearly exclusively of foraminifera, such as *Asterigerinata* and *Elphidium*; rarely, spine fragments of echinoids are also agglutinated.

St. Margarethen, Austria, Upper Badenian, Inv. NHMW2000z0133/0002 – natural size.

**Fig. 2: "*Chlamys*" *rakosensis* (CSPREGHY-MEZNERICS)**

This species is documented only from the Fertőrákos Platform.

St. Margarethen, Austria, Upper Badenian, Inv. NHMW2000z0133/0003 – natural size.

**Fig. 3: *Flexopecten scissus* (FAVRE)** with encrusting serpulids.

A very common species in the eastern part of the Central Paratethys, which is recorded herein for the first time from the Austrian Miocene.

St. Margarethen, Austria, Upper Badenian, Inv. NHMW1986/138/96-97 – natural size.

**Fig. 4: *Lingula dregeri* ANDREAE**

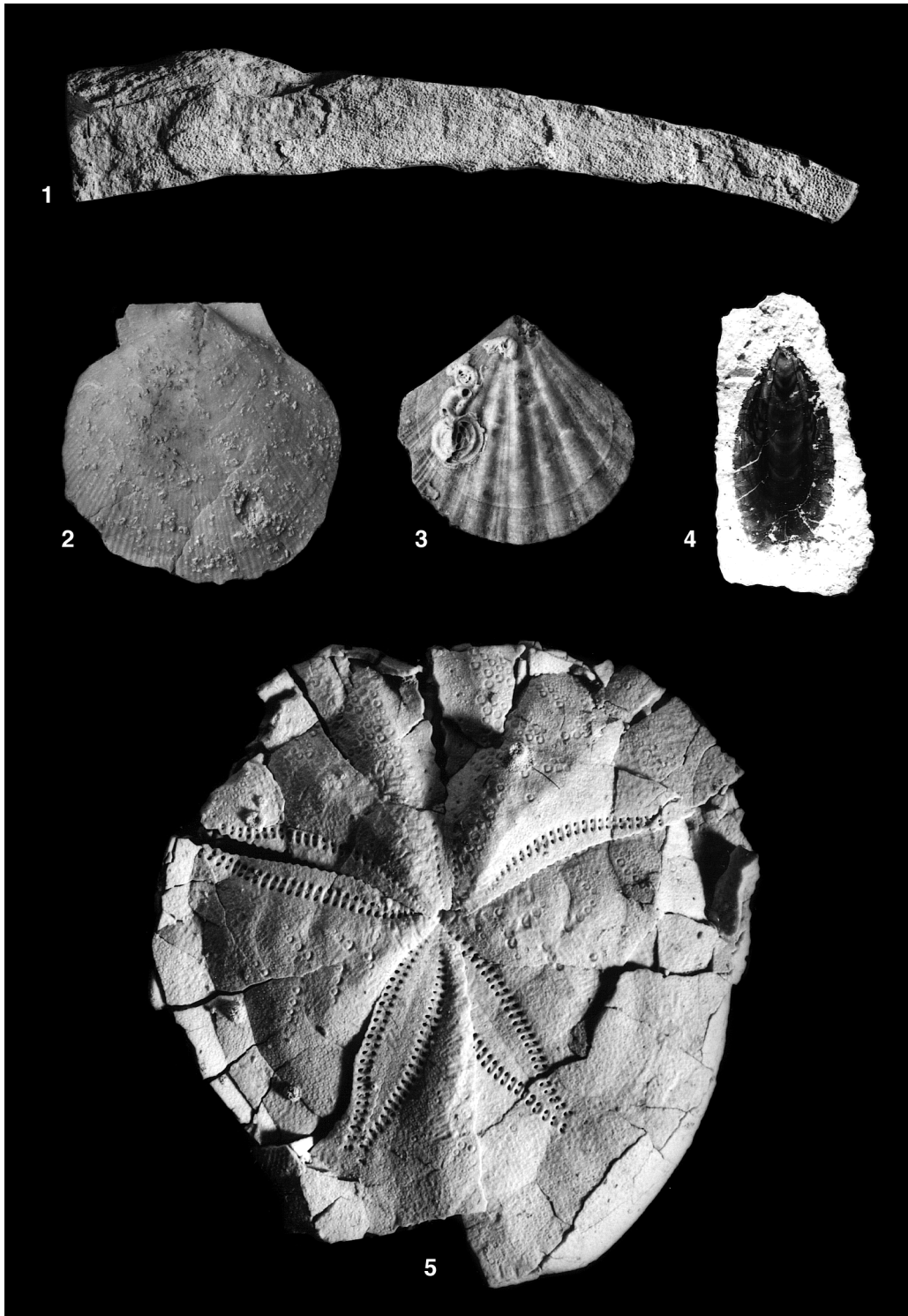
Due to their rather fragile shell, lingulid brachiopods are usually destroyed in shallow marine settings. These brachiopods are suspension feeders and live infaunally in muddy sediments.

St. Margarethen, Austria, Upper Badenian, Inv. NHMW2000z0133/0012 – natural size.

**Fig. 5: *Spatangus austriacus* (LAUBE)**

This shallow-burrowing echinoid often attains a remarkable size. Burrowing echinoids are known to come to the sediment surface before their death; in this habitat they are subsequently settled by a variety of encrusting organisms and act as secondary hardgrounds.

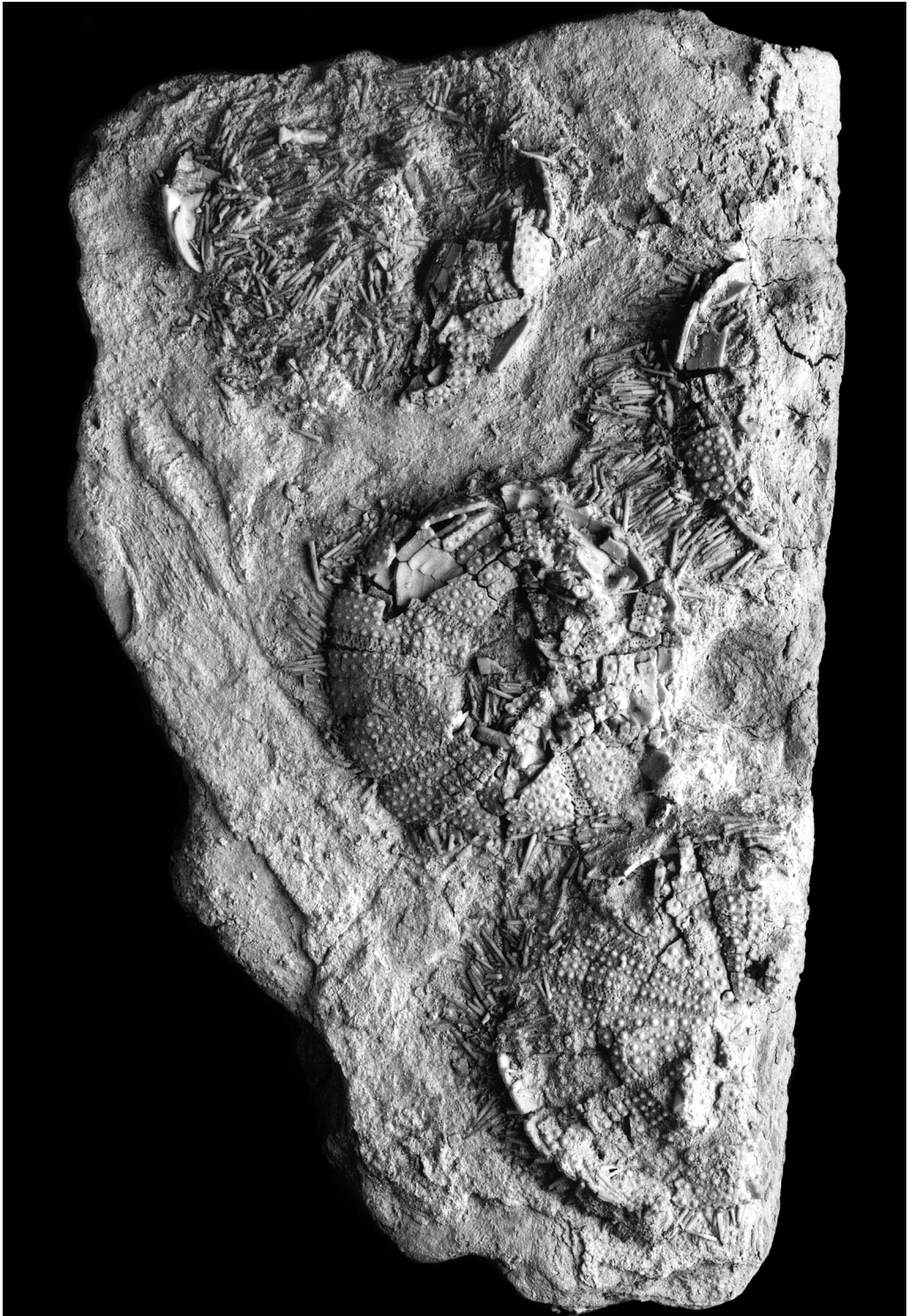
St. Margarethen, Austria, Upper Badenian, Inv. NHMW1986/138/130 – natural size.



**Plate 2**

Slab with a group of 4 specimens of *Schizechinus dux* (LAUBE). Their remarkable preservation, especially the presence of the spines and parts of the Aristotle's lantern (jaws), can only be explained by a lethal event that caused the death of this small population.

St. Margarethen, Austria, Upper Badenian, collection G. WANZENBÖCK/Gainfarn – natural size.



**Plate 3**

**Fig. 1:** Ventral view of *Schizechinus dux* (LAUBE); through the peristome (mouth) the plates of the apical system are visible. The preservation of the apical disc in regular echinoids is rather uncommon in shallow marine habitats and is here related to the lack of turbulence.

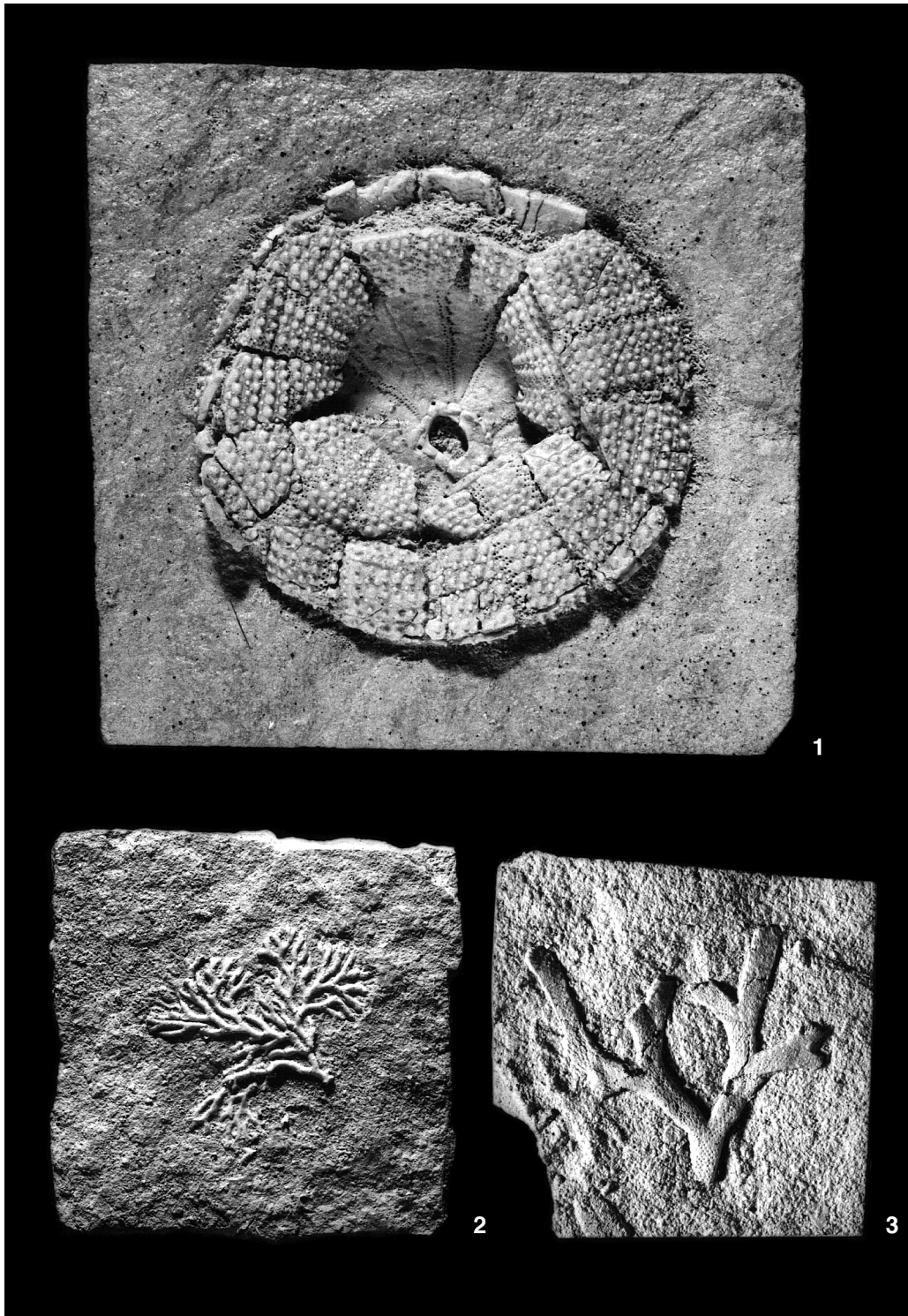
St. Margarethen, Austria, Upper Badenian, Inv. NHMW 1986/118/1 – natural size.

**Fig. 2:** *Smittina cervicornis* (PALLAS)

St. Margarethen, Austria, Upper Badenian, Inv. NHMW 1976/1844/38 – natural size.

**Fig. 3:** *Reteporella* sp.

St. Margarethen, Austria, Upper Badenian, Inv. NHMW 1986/138/124 – natural size.





#### Plate 4

Four stereoscan photographs of different cheilostomate bryozoan colonies encrusting a dead specimen of *Spatangus austriacus* (LAUBE) on the inside of the corona as well as on the outside. Living relatives or representatives of the five species shown here prefer low sedimentation rates and full marine conditions.

**Fig. 1: *Echaroides coccinea* (ABILDGAARD)**

St. Margarethen, Austria, Upper Badenian, Inv. NHMW2000z0180/0000(a)

**Fig. 2: *Calpensia gracilis* (MÜNSTER)**

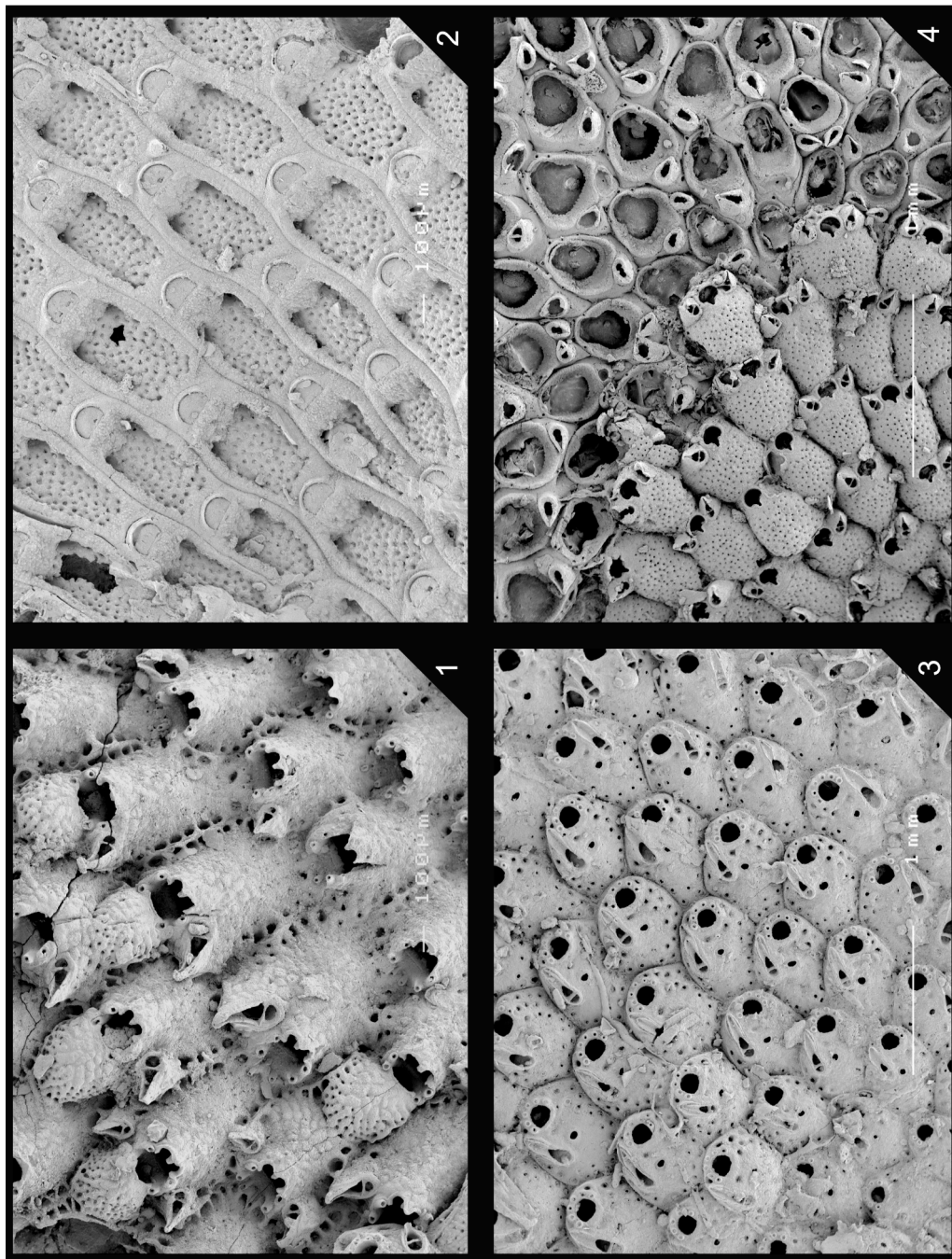
St. Margarethen, Austria, Upper Badenian, Inv. NHMW2000z0180/0000(b)

**Fig. 3: *Calloporina decorata* (REUSS)**

St. Margarethen, Austria, Upper Badenian, Inv. NHMW2000z0180/0000(c)

**Fig. 4: *Schizoporella dunkeri* (REUSS) overgrowing a dead colony of *Ramphonotus appendiculata* (REUSS)**

St. Margarethen, Austria, Upper Badenian, Inv. NHMW2000z0180/0000(d)



**Plate 5**

***Palinurus* sp.** – ventral view of a spiny lobster

St. Margarethen, Austria, Upper Badenian, Inv. NHMW1988/140/108 – 0.4 x natural size.



**Plate 6**

***Pristis* sp.**, portion of dermal denticles of saw, so closely adjoining as to conceal the skin entirely.

The representatives of *Pristis* are bottom-dwelling fishes.

St. Margarethen, Austria, Upper Badenian, Inv. NHMW 2000/0134/0003 – fig. 1: 3.4 x; fig. 2: 10.7 x.





**Plate 7**

**Fig. 1:** *Cetorhinus parvus* LERICHE, gillraker

Basking sharks are large plankton feeders

St. Margarethen, Austria, Upper Badenian, Inv. NHMW1988/0140/0145 – natural size.

**Fig. 2:** Undescribed anguilliform fish.

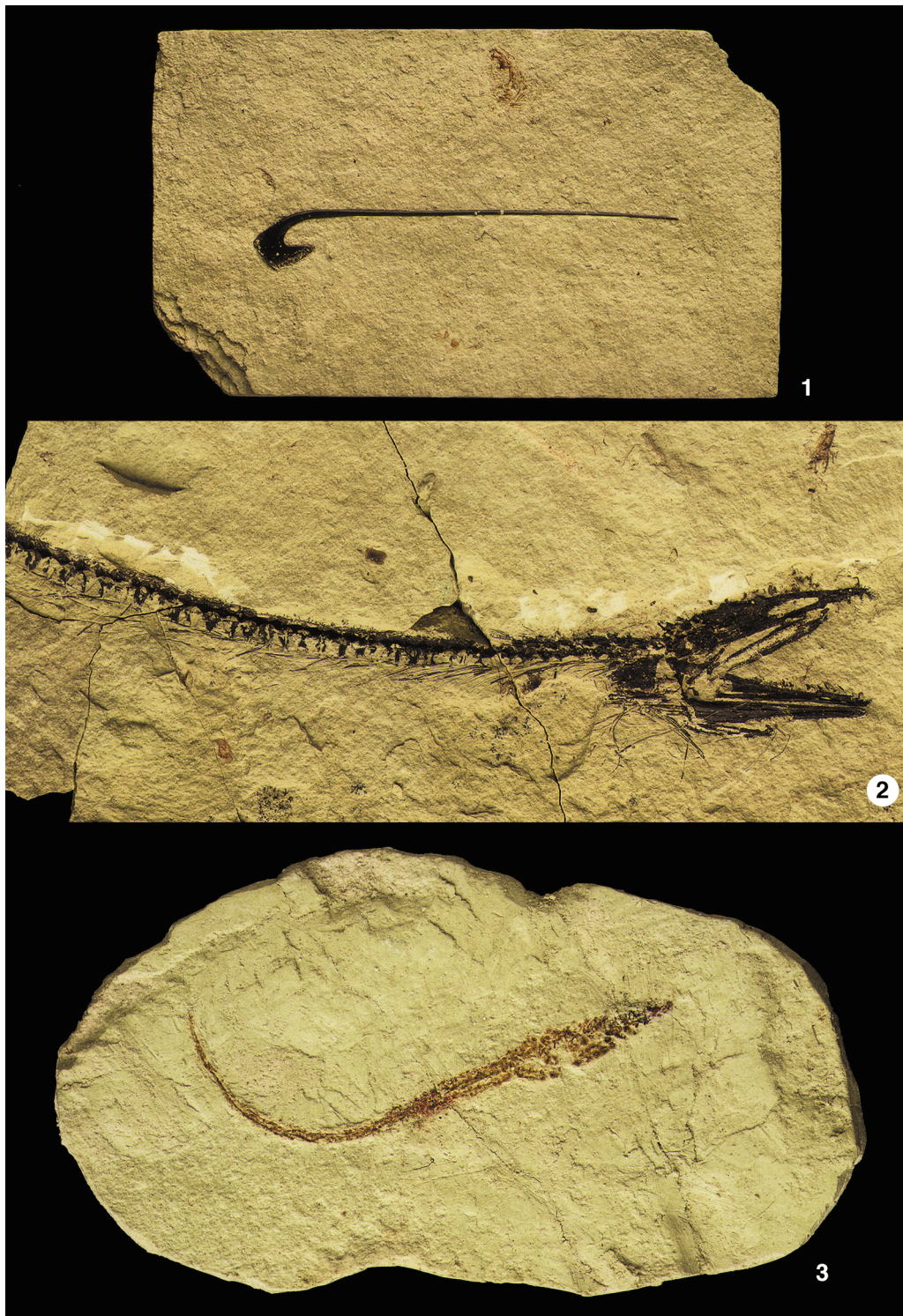
St. Margarethen, Austria, Upper Badenian, collection of G. WANZENBÖCK, Gainfarn – 0.9 x natural size.

**Fig. 3:** *Nerophis zapfei* BACHMAYER

Today *Nerophis* is a typical inhabitant of nearshore *Posidonia* meadows in less than 50 m depth.

St. Margarethen, Austria, Upper Badenian, collection of K. WEISS, Wien – 1.2 x natural size.







**Plate 8**

**Fig. 1: *Sparus umbonatus* (MÜNSTER), lower jaw**

St. Margarethen, Austria, Upper Badenian, collection G. WANZENBÖCK, Gainfarn – 2 x natural size.

**Fig. 2: *Aeoliscus* sp.**

Shrimpfishes swim vertically, in a head-down position, and are today typical for tropical marine waters.

St. Margarethen, Austria, Upper Badenian, Inv. NHMW1974/1650/8 – natural size.

**Fig. 3: *Calotomus preisli* BELLWOOD & SCHULTZ; upper pharyngeal bones.**

The dentition of upper and lower jaw and other plesiomorphic characters determine the representatives of this genus as an old phylogenetic stage in Scaridae. The recent distribution of *Calotomus* is restricted to tropical marine waters.

St. Margarethen, Austria, Upper Badenian, Inv. NHMW1989/0090b – 3 x natural size.

**Fig. 4: Mass-accumulation of small undetermined fish.**

St. Margarethen, Austria, Upper Badenian, collection of G. WANZENBÖCK, Gainfarn – 1.2 x natural size.

