

FACIES	39	139-178	Pl. 29-31	16 Figs.	1 Tab.	ERLANGEN 1998
---------------	-----------	----------------	------------------	-----------------	---------------	----------------------

Tectonically Controlled Late Cretaceous Terrestrial to Neritic Deposition (Northern Calcareous Alps, Tyrol, Austria)

Diethard Sanders, Innsbruck

KEYWORDS: FACIES – TECTONISM – NORTHERN CALCAREOUS ALPS – LATE CRETACEOUS (GOSAU GROUP)

CONTENTS

Summary

- 1 Introduction
- 2 Geological frame
- 3 Methods, definitions
- 4 Facies types
 - 4.1 Karstic deposits
 - 4.2 Lithic carbonate rudites
 - 4.3 Siliciclastic conglomerates
 - 4.4 Shallow-water carbonates
 - 4.5 Coal seams
 - 4.6 Marls
 - 4.7 Arenites
- 5 Facies associations
 - 5.1 Facies association 1
 - 5.2 Facies association 2
 - 5.3 Facies association 3
 - 5.4 Facies association 4
 - 5.5 Facies association 5
 - 5.6 Facies association 6
 - 5.7 Facies association 7
- 6 The Late Cretaceous shelf
 - 6.1 Substrate morphology, tectonism
 - 6.2 Facies distribution and dynamics
- 7 Conclusions
- References

SUMMARY

The Turonian to Santonian terrestrial to neritic succession (Lower Gosau Subgroup) in the Northern Calcareous Alps of the eastern part of the Tyrol, Austria, provides an example for deposition on a compartmentalized, narrow, microtidal to low-mesotidal, wave-dominated, mixed siliciclastic-carbonate shelf. The shelf was situated in front of a mainland with a relatively high, articulated relief, and underwent distinct changes in facies architecture mainly as a result of tectonism.

The investigated succession was deposited above a deeply incised, articulated truncation surface that formed when the Eo-Alpine orogen, including the area of the future Northern Calcareous Alps, was uplifted and subaerially eroded. Distinct facies associations were deposited from (1) alluvial fans and fan deltas, (2) rivers,

(3) siliciclastic lagoonal to freshwater marsh environments, (4) areally/temporally limited carbonate lagoons, (5) transgressive shores, (6) siliciclastic shelf environments, and (7) an aggrading carbonate shelf. During the Turonian to Coniacian, the combination of high rates of both subsidence and sediment accumulation, and a narrow shelf that was compartmentalized with respect to (a) morphology of the substratum, (b) fluvial input of siliciclastics and contemporaneous input of carbonate clasts from fan deltas, (c) deposition of shallow-water carbonates, and (d) water energy and -depth gave rise to an exceptionally wide spectrum of facies as a distinguishing feature of the succession. With the exception of facies association 7, which formed only once, depositional sequences in the Turonian to Coniacian interval contain all of the facies associations 1 to 6. During Turonian to Coniacian times, the shelf was microtidal to low-mesotidal, and was dominated by waves, storm waves and storm-induced currents. In vegetated marshes, schizohaline to freshwater marl lakes existed. Transgressions occurred onto fan deltas and in association with estuaries, or in association with gravelly to rocky shores. The transgressive successions, including successions deposited from transgressive rocky carbonate shores, are overlain by regressive successions of shelf carbonates or shelf siliciclastics. Deposition of shallow-water carbonates generally occurred within lagoons and over short intervals of time. A „catch-up“ succession of shelf carbonates about 100 m thick accumulated only in an area protected from siliciclastic input.

In its preserved parts, the Turonian to Coniacian succession does not record deposition adjacent to major active faults. Lateral changes in thickness result mainly from onlap onto the articulated basal truncation surface. Subsidence most probably was controlled by major detachment faults outside the outcrop area, and/or was distributed over a wide area in association with secondary faults above the major detachments.

During Coniacian to Early Santonian times, both the older substratum and the overlying Turonian-Coniacian succession were subaerially exposed, faulted and deeply eroded. The following Early Santonian transgression ensued

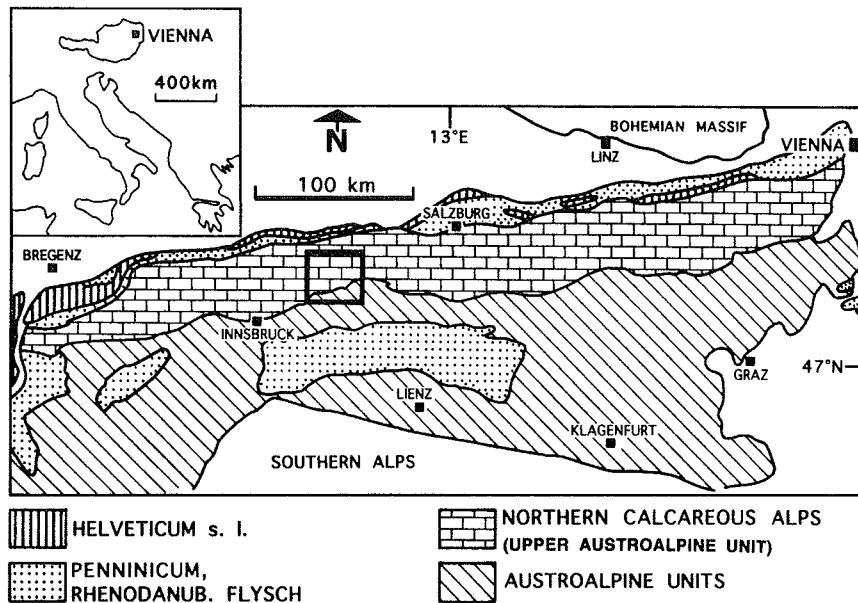


Fig. 1. Position of working area (heavy black quadrangle) in the Eastern Alps.

with rocky carbonate shores ahead of a sandy, narrow shoreface-inner shelf environment and a deeper shelf with intermittently dysaerobic mud. The transgression was associated with the influx of cooler and/or nutrient-rich waters, and heralds an overall deepening. Still during the Early Santonian, the deepening was interrupted by another phase of subaerial exposure. Subsequently, a short phase of shelf deposition was terminated by deepening into bathyal depths.

1 INTRODUCTION

A prime feature of the Upper Cretaceous terrestrial to neritic succession of the Northern Calcareous Alps (Lower Gosau Subgroup) is the wide spectrum of facies and facies associations, and facies heteropy over short lateral distances (FAUPL et al., 1987; WAGREICH & FAUPL, 1994; SANDERS et al., 1997). The deposition of the Lower Gosau Subgroup was influenced by (a) oblique convergence and unroofing of the Eo-Alpine orogen, with consequent extensional faulting and strike-slip faulting both in the basement and the sedimentary cover, (b) a deeply truncated substratum with an articulated erosional morphology, (c) contemporaneous input of carbonate rock fragments from fan deltas, rivers and shorelines, and siliciclastic input from rivers that drained the more internal parts of the orogen, (d) mixed siliciclastic/biogenic carbonate deposition, (e) high subsidence rates and high rates of relative sea-level rise, and (f) environmental changes related to nutrient input and paleoceanographic conditions (cf. PLATT, 1986; RATSCHBACHER et al., 1989; WAGREICH & FAUPL, 1994; NEUBAUER et al., 1995; SANDERS et al., 1997). These factors gave rise to a very wide spectrum of facies and facies associations which, combined with heteroaxial tectonic deformations of the Northern Alps (e. g. DECKER et al. 1993; EISBACHER & BRANDNER, 1996), are locally arranged in a complex fashion. For the reconstruction of facies distribution and -dynamics, a synoptic integration of de-

tailed mapping and densely spaced correlation of sections, biostratigraphy and sedimentologic data thus is crucial.

The changes in biotic assemblages within a sequence stratigraphic framework have been described by SANDERS et al. (1997). In this paper, an overview is given of the facies and facies associations of the Lower Gosau Subgroup in the western part of the Northern Calcareous Alps. Reconstructions of both facies architecture and facies dynamics are given within the frame of transgressive and regressive shelf development, respectively. The long-term development of the Late Cretaceous terrestrial to shelf environments of the investigated area cannot be cast into a single model, but shows major changes over time, mainly as a result of tectonism (cf. WAGREICH & FAUPL, 1994).

2 GEOLOGICAL FRAME

The Northern Calcareous Alps are part of the Upper Austroalpine tectonic unit (fig. 1). Since the Liassic, the area of the Northern Calcareous Alps was part of the Austroalpine microplate that was situated along the northern, passive continental margin of the larger Adriatic plate (CHANNELL et al., 1990; WAGREICH & FAUPL, 1994). From latest Jurassic to Early Cretaceous times, the Austroalpine microplate was situated in a convergent plate tectonic setting, with the consequent formation of detached sedimentary cover nappes in the area of the Northern Alps (RATSCHBACHER, 1987; RATSCHBACHER et al., 1989; POLINO et al., 1990; FROITZHEIM et al., 1994). Subsequent to thrusting and nappe formation, large parts of the Eastern Alps became uplifted and eroded, accompanied by extensional exhumation (PLATT, 1986; RATSCHBACHER et al., 1989; POLINO et al., 1990). At least in the area of the Northern Calcareous Alps the erosion produced a deeply dissected, subaerial morphology along the truncation surface at the base of the Upper Cretaceous.

From Turonian to Santonian times, the exposed areas became re-submerged, and deposition of the Gosau Group

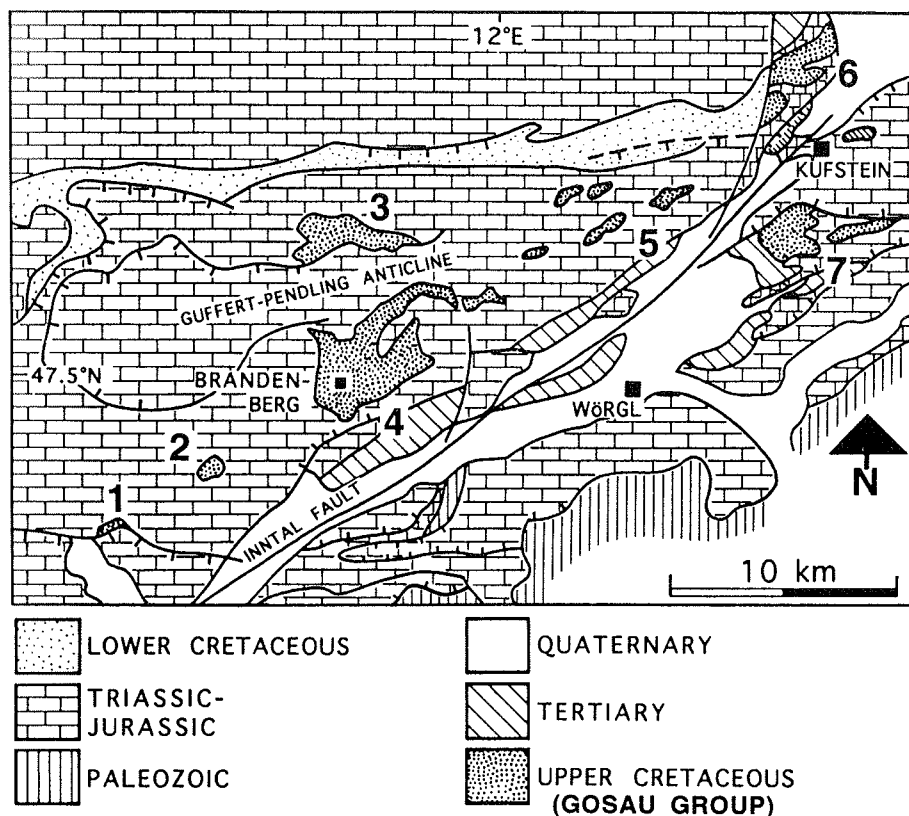


Fig. 2. Geological map of the investigated area (simplified from BRANDNER, 1985). The Triassic-Jurassic succession of the thrust nappes of the Northern Calcareous Alps is overlain along a deeply incised truncation surface by Upper Cretaceous deposits which, in turn, are unconformably overlain by Tertiary strata. The Northern Calcareous Alps are cut by a Neogene sinistral strike-slip fault (Inntal Fault). Outcrops of Upper Cretaceous deposits are labelled 1 to 7.

1=Maurach,
2=Pletzachalm,
3=Brandenberg (northern part),
4=Brandenberg (southern part),
5=Pendling area
6=Hechtsee area,
7=Eiberg.

started under overall high subsidence rates (WAGREICH, 1991). The Gosau Group is subdivided into the Lower Gosau Subgroup (Upper Turonian to Campanian) that consists of terrestrial to deep neritic deposits, and the Upper Gosau Subgroup (Santonian to Eocene), which is made up by bathyal to abyssal deposits (WAGREICH & FAUPL, 1994). During the Late Cretaceous, the area of the Northern Calcareous Alps was situated at about 30-35° north paleolatitude (MAURITSCH & BECKE, 1987; DERCOURT et al., 1993), within the Late Cretaceous monsoonal belt (PARRISH & CURTIS, 1982; PRICE et al., 1995).

In the investigated area the Lower Gosau Subgroup ranges in age from ?Middle/Late Turonian to Late Santonian, and unconformably overlies a substratum of Early Triassic to Jurassic carbonate rocks of both the Bajuvaric and Tirolic nappe stacks of the Upper Austroalpine tectonic unit (fig. 2) (TOLLMANN, 1976; BRANDNER, 1985); the Upper Santonian to Maastrichtian deep-water succession (Upper Gosau Subgroup) is not considered. In the Lower Gosau Subgroup, the combination of mapping, correlation of sections and biostratigraphic data allows for the recognition of allostratigraphic units that can be interpreted as parts of depositional sequences (fig. 3) (SANDERS et al., 1997; SANDERS, 1997 a). From north to south across the investigated area, the Late Cretaceous deposits that are in direct contact with the substratum become progressively younger (fig. 4), probably as a result of a „second-order“ landward shift of onlap during the Late Cretaceous tectonically controlled re-submergence of the accretionary wedge (SANDERS et al., 1997; SANDERS, 1997 b; cf. WAGREICH & FAUPL, 1994). This pattern, however, is somewhat complicated because of Late Cretaceous faulting and erosion as

recorded by Upper Cretaceous erosional remnants below a transgressive succession of Late Coniacian-Santonian age (figs. 3, 5, 15) (SANDERS, 1997 a, b).

3 METHODS, DEFINITIONS

The Upper Cretaceous succession of the outcrop areas of Brandenberg, Maurach, Pletzachalm and parts of the Upper Cretaceous near Kufstein (fig. 2) were mapped on a scale of 1/10.000 and, locally, 1/5.000 (SANDERS 1996 b; 1997 b). For the Upper Cretaceous succession at Eiberg and Kufstein, aside from field trips and sampling, the maps of WOLFF (1985, with explanatory notes), GRUBER (1995) and the description of sections by IBRAHIM (1976) provided important information. Mapping was supplemented by correlation of columnar sections and by biostratigraphic data (cf. FISCHER, 1964; IBRAHIM, 1976; HERM et al., 1979; IMMEL et al., 1982; RISCH, 1985; WAGREICH, 1992; TRÖGER & SUMMESBERGER, 1994; SUMMESBERGER & KENNEDY, 1996; SANDERS et al., 1997; SANDERS & BARON-SZABO, 1997, for biostratigraphic data). Facies subdivision was made according to lithological composition, sedimentary structures (lithofacies), and fossil content (biofacies). In the following, each facies is described and interpreted, followed by a description and interpretation of the facies associations. Where important for the interpretation of a facies, the vertical association with other facies is mentioned in the description. In addition, a few facies of subordinate abundance, thickness and of minor importance with respect to the interpretation of a depositional system are mentioned together with the description of the association. To avoid long descriptive names or meaning-

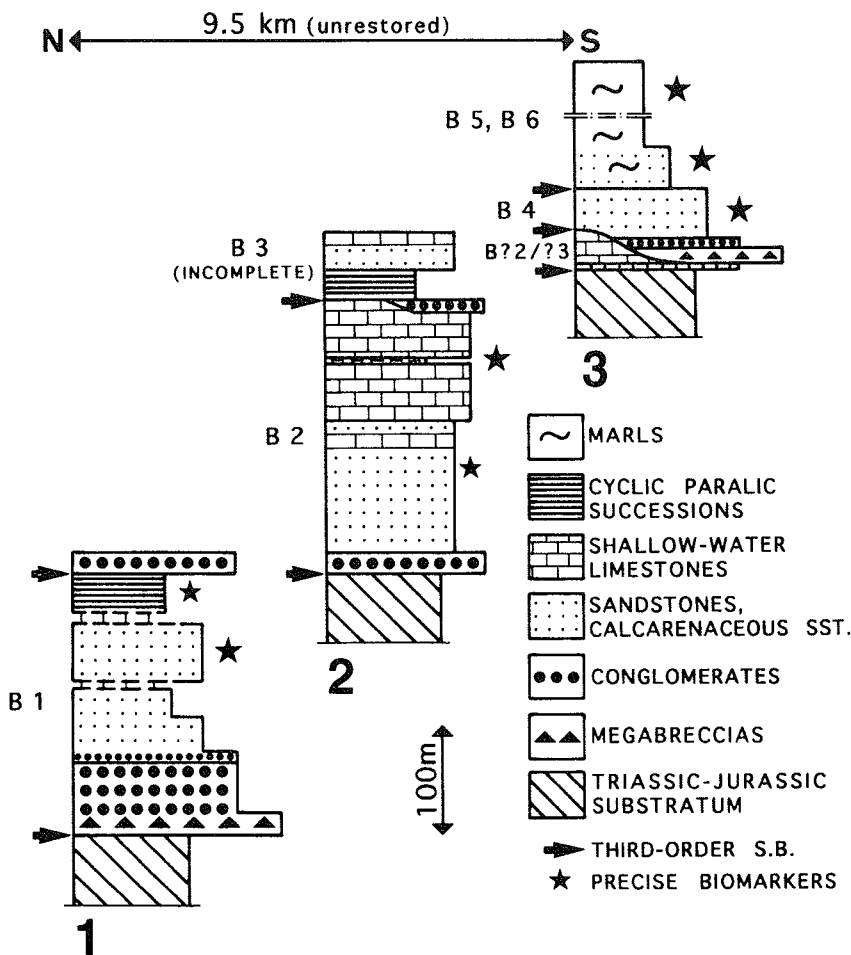


Fig. 3. Summary sections of the Upper Cretaceous of Brandenburg from north (section 1) to south (section 3). The labels B1 to B6 refer to allostratigraphic units as recognized in the area of Brandenburg (SANDERS et al., 1997; SANDERS, 1997 a). Over a distance of 9.5 km (unrestored for post-Cretaceous shortening), the deposits that directly overlie the older substratum become younger from ?Middle/Late Turonian in the north to Early Santonian in the south. In the southern part of the outcrop area, the pattern is complicated by local erosional remnants (labelled „B?2/?3“) mainly of Upper Cretaceous neritic limestones.

less numberings, each description is headed by the interpretive term.

In this paper, the term arenite is used for all lithologies that show a framework supported by sand-sized grains (cf. ZUFFA, 1985), and that contain more than 50% of siliciclastic sand and/or carbonate rock fragments. Since the bioclastic limestones commonly are devoid of or contain only a few percent of arenite grains as defined, this subdivision of arenites and limestones proved well-applicable both in field and thin section. In the following, arenites that consist of (a) subequal amounts of carbonate rock fragments, bioclastic material and siliciclastic sand are termed bioclastic hybrid arenites, (b) arenites of carbonate rock fragments and siliciclastic sand are designated as calcilithic hybrid arenites, (c) arenites that consist mainly of carbonate rock fragments are termed calcilithic arenites, whereas (d) sandstones consist mainly of siliciclastic grains.

4 FACIES TYPES

4.1 Karstic deposits

In the Triassic-Jurassic substratum, down to more than 100 m stratigraphically below the base of the Upper Cretaceous, features of karstification are common, and include karstic veins, caverns, dikes and sills. The caverns are typically filled by red- to green-weathering, finely laminated to „massive“, silty mudstone. The karstic dikes

are up to more than 20 m wide, and are filled by collapse breccias to -megabreccias with a matrix of red silty mudstone and/or green weathering, poorly lithified, silty mudstone. At the top of the substratum, the dikes are truncated and overlain by Upper Cretaceous transgressive successions (SANDERS, 1997 b). On top of the substratum, deposits up to several meters thick and at least several hundred meters in width of pisoidic bauxite are locally present (SCHULZ, 1960); pisoidic bauxite also was found in karstic dikes closely below the top of the substratum. In Upper Cretaceous shallow-water limestones, features of karstification include sandstone pipes, karstic veins and internal breccias, karstic calcirudites with a matrix of silty marl, and microkarstic cavities (SANDERS et al., 1997; SANDERS, 1997 b).

Interpretation: In the substratum, the areal extent and depth of karstification, and the large size of the karstic dikes record a mature paleokarst (cf. CHOQUETTE & JAMES, 1988). Mature paleokarst systems may develop within only some tens of thousands of years, given a humid climate and an active groundwater hydrologic regime with sufficient hydraulic head (CHOQUETTE & JAMES, 1988; HANDFORD & LOUCKS, 1993). Pisoidic bauxite typically forms in well-drained, topographically elevated karst areas (high-level karst) (BARDOSSY, 1982; MINDSZENTY, 1984). The karstification of the Cretaceous limestones suggests that the karst in the substratum represents a multi-phase

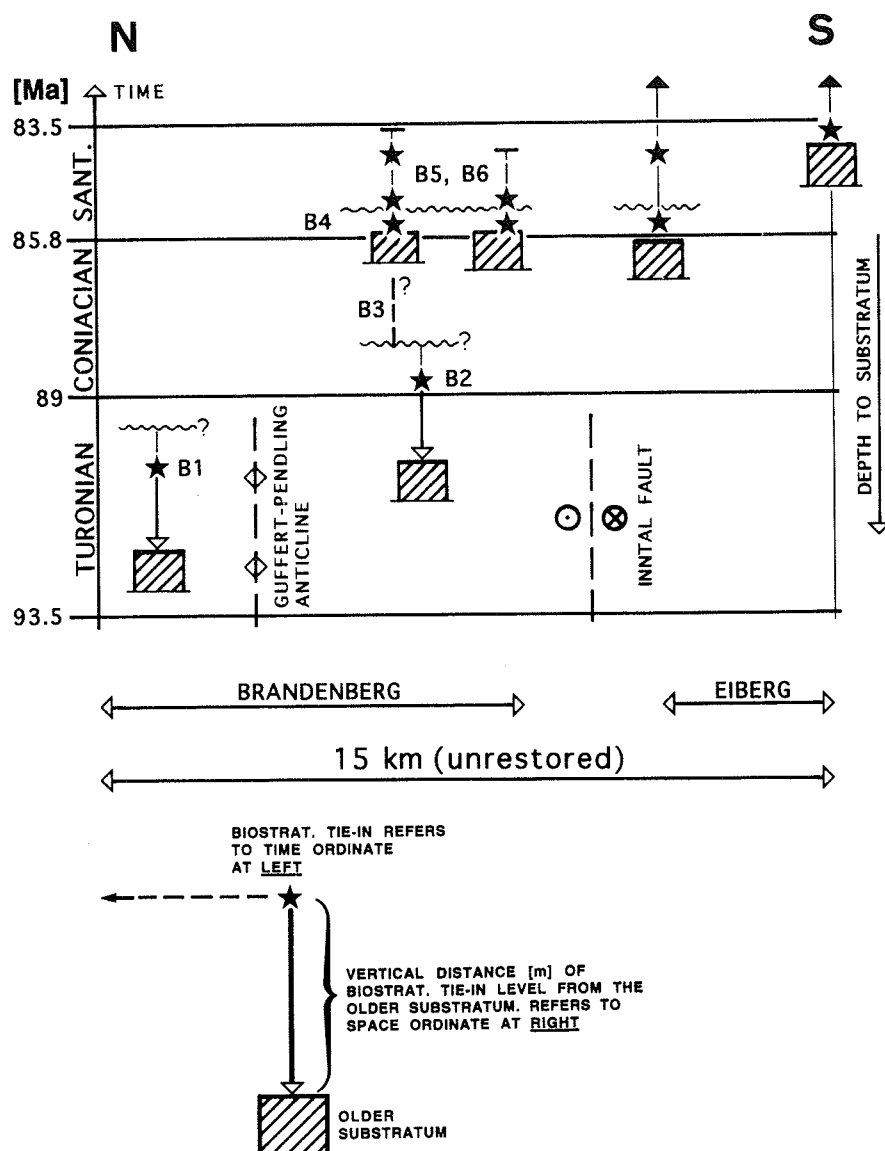


Fig. 4. Combined north-south chronostratigraphic and spatial relations of the Upper Cretaceous in the area of Brandenburg and Eiberg relative to the older substratum (cross-hatched). The estimated sinistral offset along the Inntal Fault has been restored. The northern outcrop in Brandenburg is separated from the southern margin of outcrop at Eiberg by a lateral distance of about 15 km (unrestored for Tertiary shortening). Numbers B 1 to B 6 refer to allostratigraphic units as recognized in the area of Brandenburg (see fig. 3). The asterisks indicate biostratigraphic datums at biozone level, and refer to the time scale of GRADSTEIN et al. (1994) on the left ordinate of the diagram. The vertical distance of each asterisk to the underlying substratum (cross-hatched) indicates the vertical spatial distance of the biostratigraphic datums from the local substratum, and refers to the ordinate „depth to substratum“ on the right margin of the diagram (from SANDERS, 1997b).

karst (SANDERS, 1997 a). The truncation of wide karstic dikes at the base of the Upper Cretaceous, however, indicates that at least the major phase of karstification preceded the onlap of Upper Cretaceous strata.

4.2 Lithic carbonate rudites

4.2.1 Mass flow breccias, gravel sheet breccias

Megabreccias up to about 10 meters in thickness and with clasts up to several meters in size are locally present at the base of the Upper Cretaceous (fig. 3) (SANDERS et al. 1997: pl. 2/4). The megabreccias are clast-supported, extremely poorly sorted, and appear unbedded or consist of beds several meters thick. The base of the beds is slightly erosive to nonerosive. Internally, the beds do not show an organization with respect to grain size or sedimentary structures; the matrix of the megabreccias is a red weathering silty mudstone. The megabreccias consist of angular fragments of carbonate rocks that are derived from the local substratum. The megabreccias are overlain by lithic calcirudites (breccias and/or conglomerates) that have been deposited from alluvial fans (see below). In

Brandenburg, an interval of breccia composed of angular to subrounded, gravel- to cobble-sized lithoclasts is both intercalated and appears to pinch out into paralic marls (see description below) (SANDERS et al., 1997). The breccia is clast- to matrix-supported, and consists of lithoclasts that are derived from the local substratum. The matrix is a grey paralic marl with coalified plant fragments.

Locally, at the base of the Upper Cretaceous, intervals of clast-supported, fine to coarse breccias ranging from thin veneers up to more than 10 m in thickness are present that consist of angular gravels from the immediately underlying Triassic-Jurassic substratum. Typically, these breccias are arranged in indistinct layers or more or less plane beds up to a few meters thick that consist of fine gravels to cobbles embedded in a brown to ocre matrix of dolosiltite. Locally, these breccias contain intercalated intervals of red silty mudstone, and show scoured bedding planes. Thicker intervals of breccias of this type are common on top of the Hauptdolomit Formation (Norian). At many locations, in vertical section, the Hauptdolomit gradually develops into these breccias, via a zone of increasingly widened, densely spaced joints (accompanied by an in-

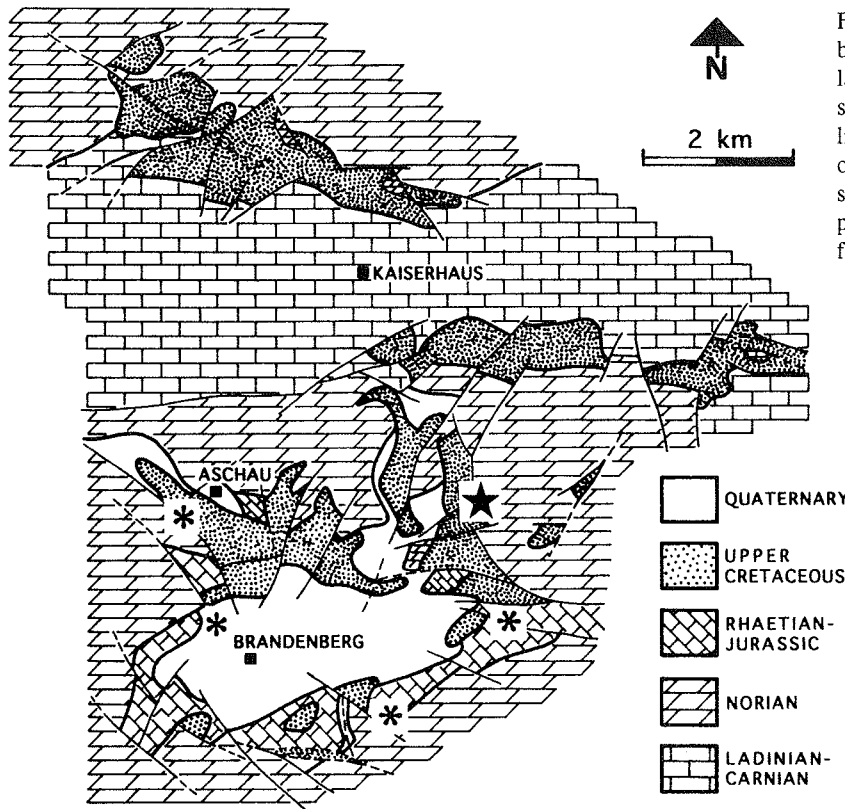


Fig. 5. Simplified geological map of Brandenburg area. The asterisks mark the location of larger erosional remnants of Upper Cretaceous shallow-neritic deposits (mainly shallow-water limestones) below a transgressive succession of Santonian age (see also fig. 3, fig. 14). The star marks the location of probable Late Cretaceous age (see fig. 11, fig. 14).

creasing amount of clast displacement) that are filled by dolosiltite and/or red, silty mudstone. These gradual vertical transitions are less than a metre to about 10 m in thickness.

Interpretation: The megabreccias were deposited from subaerial mass flows, as suggested by the lack of vertical organization within the beds according to clast size or matrix content, by the slightly erosive to nonerosive bedding surfaces, and by their matrix of red, silty mudstone or of paralic marls. For the described intervals of breccias, their clast-supported texture, poor to well sorting, the scarce dolosiltite matrix, and the lack of a clear-cut vertical organization with respect to grain size all suggest that these breccias may have been deposited, at least in part, from subaerial slope deposits on exposed carbonate rock terrains. Depending on the characteristics of the source area, such as density of rock jointing, vegetation cover, relief and climate, subaerial slope deposits commonly record processes like debris flows, sliding, dry grain flows and run-off, and may exhibit characteristics that are transitional to alluvial fan deposits (e. g. STATHAM, 1976; GARDNER, 1979; WILSON, 1990; BERTRAN et al., 1997). An interpretation in terms of rheolithic breccias is suggested in those cases where the boundary between the underlying Hauptdolomit and an overlying breccia of clearly sedimentary origin occurs via the described transition zones.

4.2.2 Alluvial fan conglomerates

At the base of the Upper Cretaceous, successions up to nearly 100 m thick that consist mainly of red weathering conglomerates are locally present. Most commonly, the

conglomerates are clast-supported, poorly to moderately well sorted and consist of subrounded to well-rounded

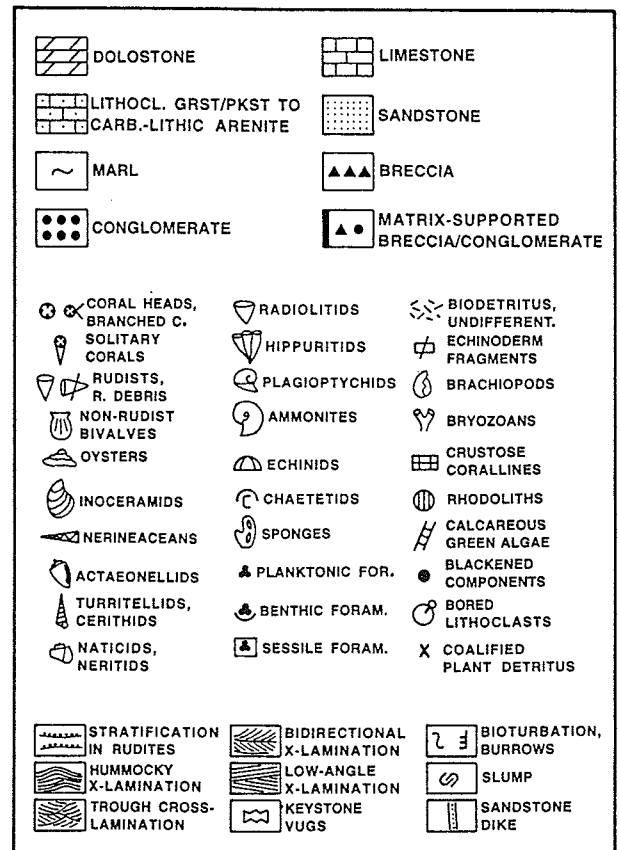


Fig. 6. Key to symbols.

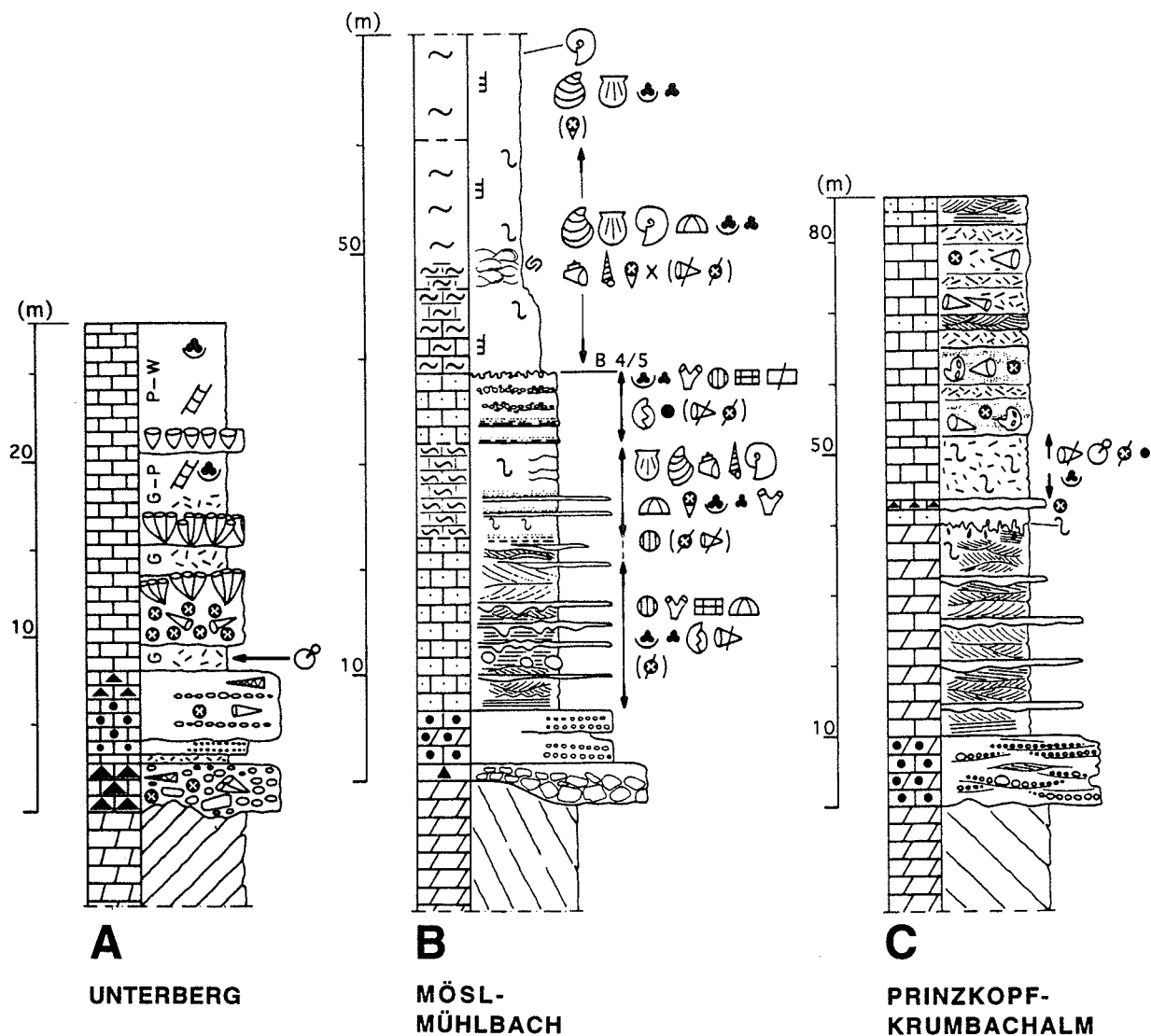


Fig. 7A. Section at Unterberg, Brandenburg. The substratum is overlain by a talus breccia composed of gravels to cobbles derived from the substratum, and with coral heads, nerineids and clusters of *Vaccinites*. The breccia is locally intercalated with thin bedsets of arenite of mixed calcilithic/shallow-water bioclastic composition. The breccia is overlain by a succession of shallow-water limestones that contains a coral-rudist construction, a hippuritid biostrome and a radiolitid biostrome, accompanied by a vertical change from bioclastic grainstones (G) to bioclastic packstones (P) to wackestones (W).

Fig. 7B. Summary section of the Lower Santonian in the area of Mösl-Mühlbach, Brandenburg. At the base, local megabreccias are overlain by breccias and conglomerates (Pl. 29/2). Commonly, the substratum is directly overlain by a succession that consists, in its lower part, of calcilithic arenites (Pl. 31/3) and bryozoan arenites (Pl. 31/4; see text for description), and intercalated intervals of conglomerate. Very well-rounded, spherical boulders locally float within the arenites. Up-section, the arenites grade into bioturbated marly arenites to sandy marls with inoceramids, gastropods, echinoids and ammonites. The marly arenites are sharply overlain by an interval some meters thick of well-lithified, mixed calcilithic-bioclastic arenite rich in blackened bioclasts; this interval is topped by a deeply corrugated surface that, in turn, is sharply overlain by sandy-silty marls (Pl. 31/5) with inoceramids, echinoids and ammonites.

7C. Section near Krumbachalm, Brandenburg. Triassic carbonates are unconformably overlain by an interval about 10 m thick of conglomerates composed of very well-rounded clasts derived from the local substratum. Higher up, a succession of cross-laminated calcilithic arenites with thin intervals of conglomerates with shallow-water fossils (corals, rudists) is present. This interval, in turn, is sharply overlain by a coral rudstone and by packstones to floatstones rich in micritized, bored, encrusted and blackened bioclasts and carbonate rock clasts that are penetrated by *Trypanites* (Pl. 29/7; arrowed interval in section). In the upper part, intervals of coral-sponge-rudist limestones (Pl. 30/4, 30/6) change vertically with intervals of bioclastic packstones to grainstones to rudstones, black pebble packstones, and cross-laminated calcilithic hybrid arenites.

clasts of fine gravel to cobble size. The matrix is a red silty mudstone to red weathering calcilithic arenite. Individual conglomerate beds are less than a metre to some meters thick, are „massive“ or stratified, and locally are amalgam-

ated with vertically adjacent beds. Within the beds, no or only an indistinct normal size-grading of the clasts is typical. The base of these beds is relatively plane, save local scours. Amalgamated beds of this type locally build

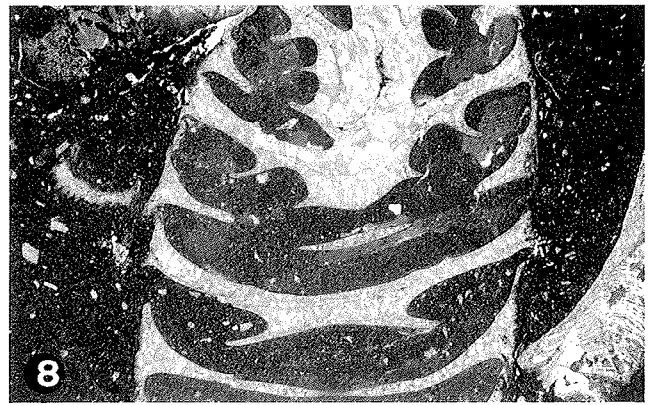
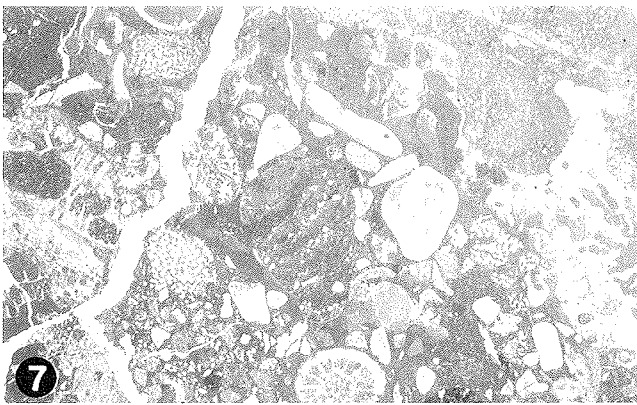
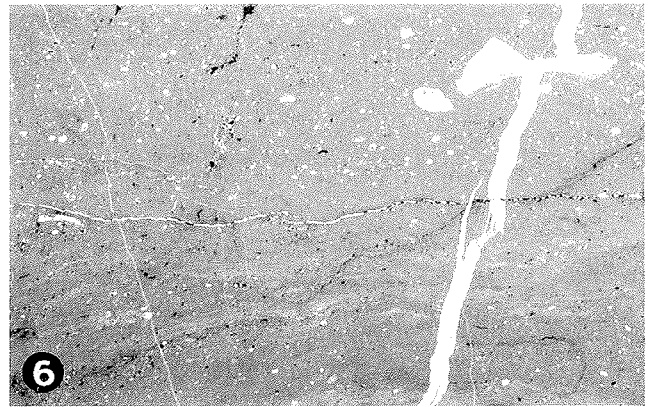
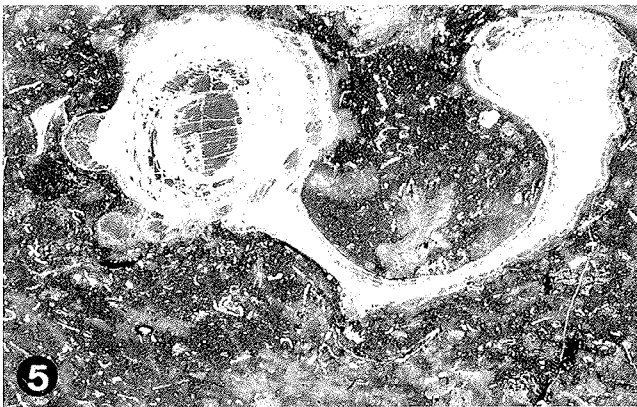
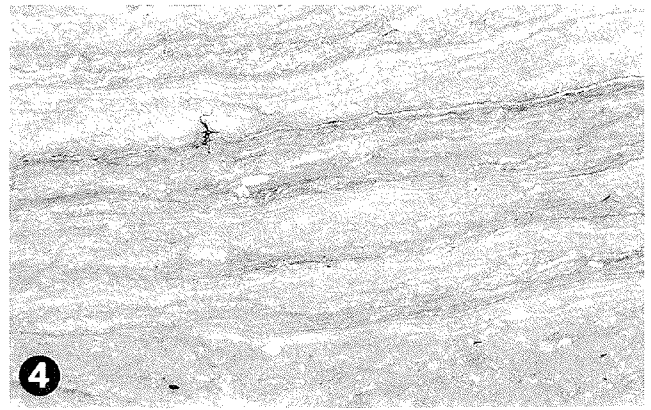
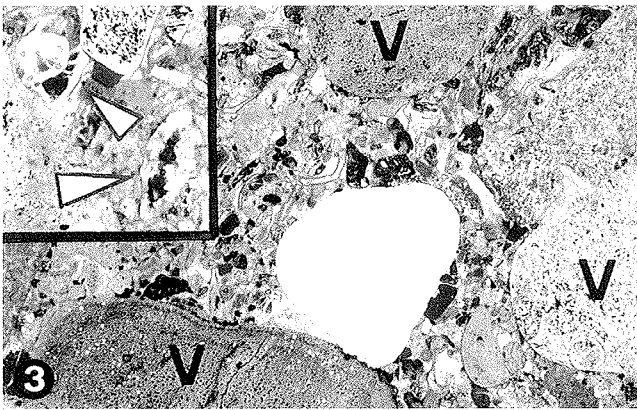
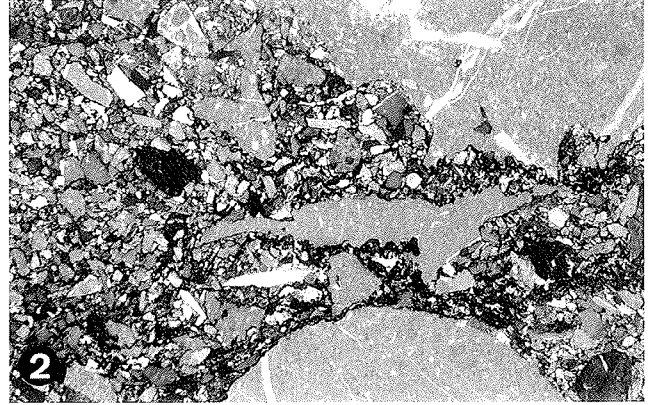
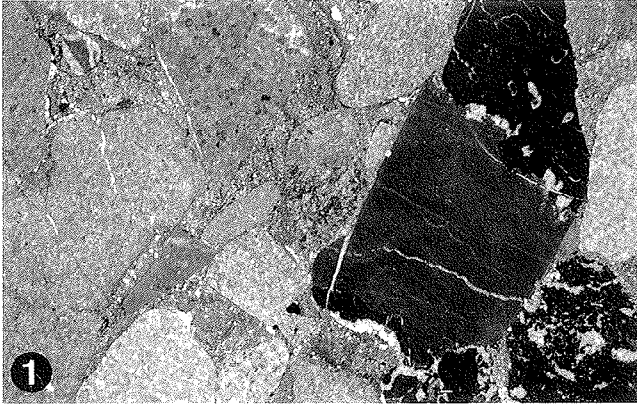
packages up to more than 10 meters thick. Both the amalgamated beds or individual beds of conglomerates are vertically intercalated with intervals less than a metre to a few meters thick of red silty mudstone or, rarely, with beds up to about one meter thick of red weathering calcilithic arenite. The intervals of red silty mudstone and/or of the calcilithic arenites locally pinch out because of erosional truncation at the base of an overlying conglomerate bed. Less commonly, intervals up to a few meters thick of well-lithified, moderately well- to well-sorted, fine to coarse conglomerates are present that consist of well-rounded clasts embedded in a scarce matrix of dolosiltstone to dolomudstone. These conglomerates may show horizontal stratification, low-angle cross-stratification, and downward-convex surfaces of erosion. Locally,

truncated lenses of pebbly dolostone are intercalated between individual beds of conglomerates. These conglomerates are intercalated, either by a gradual transition or with an erosive base, near the top of the successions of the red weathering conglomerates.

Interpretation: The described conglomerates were deposited from alluvial fans, as indicated by their coarse grain size, the overall poor to moderate sorting, the clast spectrum that is derived from the local substratum, the poorly lithified matrix of red silty mudstone, the poor internal organization of most beds, and the vertical association of lithoclastic conglomerates and beds of red silty mudstone (compare HOOKE, 1967; BULL, 1972; SALLER & DICKINSON, 1982; NEMEC & POSTMA, 1993). Within the alluvial fan conglomerates, several types can be distin-

Plate 29 Shore zone conglomerates and limestones from freshwater to shallow-marine subtidal environments, Upper Cretaceous of Brandenburg, Austria.

- Fig. 1. Conglomerate of carbonate rock clasts embedded in a scarce matrix of dolosiltite. The clast spectrum is dominated by coarsely crystalline dolostones. Other carbonate rocks, like e. g. ooid grainstones, fenestral peloidal grainstones, lime mudstones and bioclastic packstones to grainstones are minor in abundance. Note the well rounding of the lithoclasts, and the densely packed, locally fitted fabric resulting from intergranular pressure solution. Width of view: 17 mm. Sample 24.4.94/4. Trauersteg, Brandenburg.
- Fig. 2. Arenitic matrix and clasts of a conglomerate composed mainly of lithoclasts derived from erosion of Triassic-Jurassic carbonate rocks. The clasts commonly are well- to very well-rounded. A part of the surface of a single clast or entire clasts may show a pitted surface. The matrix of the conglomerate is an arenite composed of very angular to very well-rounded carbonate rock fragments and a few bioclasts. Width of view: 17 mm. Sample SS 2. Voldöppberg, Brandenburg.
- Fig. 3. Conglomerate composed of fine to medium gravel of volcanic rocks (v) and, subordinately, of silicified limestones (white clast), radiolarian chert, serpentinite, dolostones, and diverse types of Triassic-Jurassic limestones. The matrix is an arenite composed of sand-sized grains of dolostones and limestones and, subordinately, siliciclastics (quartz, serpentine, feldspar) and bioclasts including lagenid foraminifera, fragments from rudists and other molluscs, as well as from red algae, echinoderms and corals, and a few alcyonarian sclerites. Width of view: 17 mm. Sample ATZ 1. Haidach, Brandenburg. Inset: Detail of the same sample, showing two abraded tests of lagenids (arrowtips), and a serpentine grain above. Width of view: 2 mm.
- Fig. 4. Cryptmicrobially laminated lime mudstone composed of submillimetre-thick, alternating light and grey laminae, with a few thin-shelled ostracods and fine-grained detritus from characeans. Width of view: 17 mm. Sample 1.8.95/5. Haidach, Brandenburg.
- Fig. 5. *Pyrgulifera* (large bioclast in photo), embedded in a matrix of bioturbated wackestone that contains characean fragments, a few ostracods and coalified plant fragments. Width of view: 13 mm. Sample 29.11.94/16. Krumbachalm, Brandenburg.
- Fig. 6. In the lower part of the photo, a cryptmicrobially laminated lime mudstone with a few, very small tests of ostracods, miliolids and textulariaceans is present. The laminated mudstone is overlain by a bioturbated wackestone with ostracods, small rotaliaceans, textulariaceans, miliolids, a few small fragments from non-rudist bivalves and an accessory fraction of siliciclastic sand grains. Width of view: 17 mm. Sample 28.11.93/2. Haidach, Brandenburg.
- Fig. 7. Poorly sorted packstone composed mainly of fragments from corals and of carbonate lithoclasts of sand to fine gravel size. In addition, fragments from rudists, stromatoporoids, gastropods (incl. actaeonellids), and a few smaller benthic foraminifera are present. The carbonate rock clasts include dolostones and limestones that are closely identical to lithologies in the local substratum. Note the well rounding of the carbonate rock clasts; the bioclasts are very well-rounded to angular. Width of view: 17 mm. Sample 10.11.94/3. Krumbachalm, Brandenburg.
- Fig. 8. Rudstone composed of nerineids, and a few shells and large shell fragments of radiolitids (right margin of picture). The nereid shell is abraded at its margin. The matrix is a packstone to wackestone with small mollusc fragments, smaller benthic foraminifera, a few ostracod tests, and well-sorted bioclastic silt. Width of view: 17 mm. Sample 1.8.95/9. Haidach, Brandenburg.



guished that formed as a result of different processes of deposition including mass flows, stream floods and sheet floods (SANDERS, 1996 b; see also WAGREICH, 1988). The conglomerates devoid of red silty mudstone that are intercalated with beds of pebbly dolostone may have been deposited in association with more or less persistently flooded channels (cf. SMITH, 1974; BOOTHROYD & NUMMEDAL, 1978). At least a part of the well-stratified fine conglomerates may have originated from occasional wave reworking in the distal portion of the subaerial part of the fan delta.

4.2.3 Shallow-marine lithic calcirudites

(1) Conglomerates that consist of subparallel-horizontal to low-angle cross-stratified beds of very well-rounded, spherical to oblate gravels to small boulders that are derived from the local substratum (Pl. 29/1). These conglomerates build intervals up to 10 m thick, are devoid of fossils, and contain a matrix of calcilithic arenite to silt. Locally scarce, finely crystalline dolomite cement is present. Both stylolitic and non-stylolitic clast-clast pressure solu-

Plate 30 Limestones, rhizolithic marls, and arenites, Upper Cretaceous of Brandenburg, Austria.

- Fig. 1. Fine-grained rudstone composed of small nerineaceans up to 1 cm in length, cerithiaceans, and fragments thereof. The matrix is a dark grey wackestone rich in fragments from gastropods, and a few small fragments from both non-rudist bivalves and rudists. The shells of both the nerineaceans and the cerithiaceans locally are thinned, possibly because of abrasion and/or early diagenetic dissolution. Width of view: 17 mm. Sample 15.8.96/6. Atzlsäge, Brandenburg.
- Fig. 2. Radiolitid rudstone. The radiolitids are embedded subparallel to bedding, are about 0.5 cm in diameter, and are more or less coarsely fragmented and/or abraded. The matrix is a wackestone to packstone that is composed nearly exclusively of poorly sorted, angular fragments from radiolitids and an accessory content of ostracods, textulariaceans and miliolids. Width of view: 17 mm. Sample 28.10.95/5. Köglalm near Kufstein.
- Fig. 3. Radiolitid floatstone composed mainly of the fragments from the free valves of radiolitids (large bioclast in center of photo), of fragments derived from the radial funnel plates of radiolitid shells, and a few fragments from echinoderms and from the cellular radiolitid ostracum. The coarse bioclasts most commonly are angular and unmicritized. The matrix is a very poorly sorted packstone composed of angular radiolitid fragments and a few smaller benthic foraminifera (miliolids, textulariaceans, nezzatids). Width of view: 17 mm. Sample HM 3. Heumöseralm, Brandenburg.
- Fig. 4. Detail of boundstone composed of demosponges, hippuritids, radiolitids, corals, stromatoporoids and red algae. In this photo, a demosponge and a laterally adjacent hippuritid are shown. Note the morphological distortion of the hippuritid shell, and the serpulid tubes. The matrix is microbioclastic wackestone to mudstone with silt-sized, angular mollusc fragments. Width of view: 17 mm. Sample 17.9.95/24. Krumbachalm, Brandenburg.
- Fig. 5. Detail of boundstone composed of corals, rudists and sponges and corallines. The photo shows a coral skeleton interlayered with and overlain by crusts of *Archaeolithothamnium* and bryozoans. Both the coral head and the crusts are overgrown by a lychniskid sponge. The matrix is a poorly sorted bioclastic wackestone to mudstone with small fragments from rudists and corals. Width of view: 17 mm. Sample ATZ 6. Haidach, Brandenburg.
- Fig. 6. Detail of floatstone composed of corals, sponges and rudists. The photo shows a foliose coral bored by lithophagids that are preserved within their borings. Note the geopetal infill of micropeloidal grainstone in the lower lithophagid boring. The bioclast in the lower left of the photo is a strongly bored rudist fragment. The matrix is a lime mudstone with irregular, faint lamination. Width of view: 13 mm. Sample 10.11.94/8. Krumbachalm, Brandenburg.
- Fig. 7. Thin section of unfossiliferous marl to fine siltstone with very fine coalified plant fragments (tiny dark specks). The marl shows more or less disrupted layers some millimeters to 1.5 cm thick of slightly different shades. Locally, subcircular „tunnels“ of less than a millimeter to about 1 mm in width are present, and are filled by coalified plant material and/or pyrite (dark spot near right margin). Width of view: 17 mm. Sample 3.10.95/5. Nachbergalm, Brandenburg.
- Fig. 8. Moderately sorted arenite composed of carbonate rock fragments, siliciclastic grains and bioclasts. The coarse bioclastic fraction is dominated by juvenile nerineids and actaeonellids; echinoderm fragments, smaller benthic foraminifera and fragments from green algae are subordinate. The siliciclastic fraction is dominated by subangular to subrounded grains of polycrystalline quartz, monocrystalline quartz and serpentine grains; the sand-sized carbonate rock grains are subrounded to very well-rounded. The matrix of the arenite is a dark grey, marly lime mudstone. Width of view: 17 mm. Sample 3.12.96/16. Nachbergalm, Brandenburg.

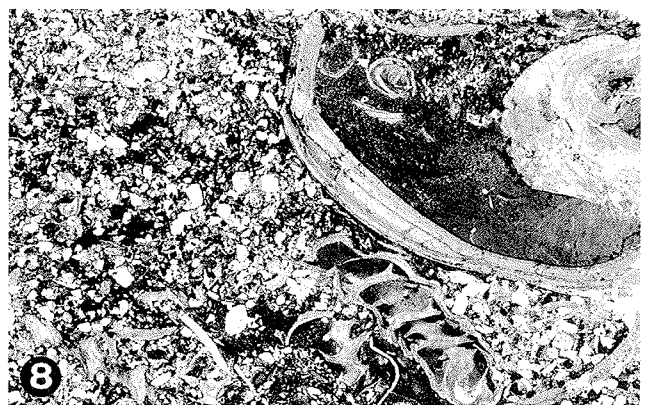
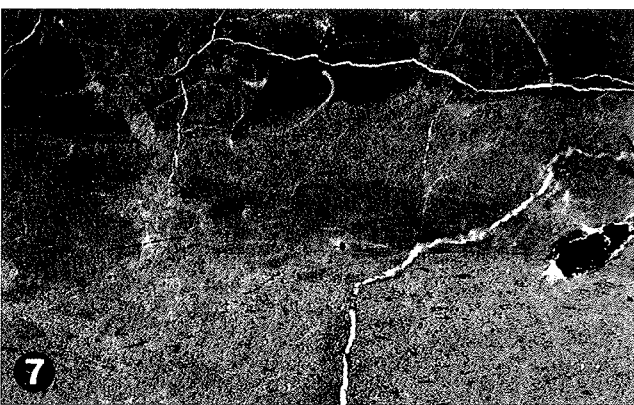
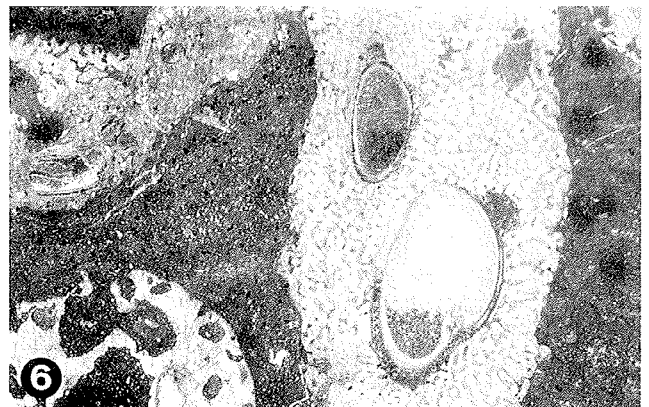
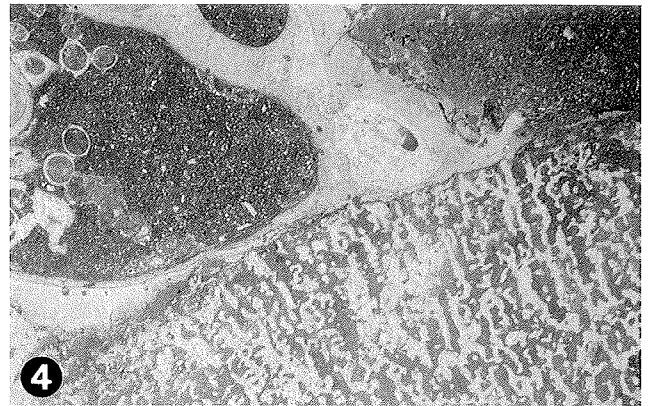
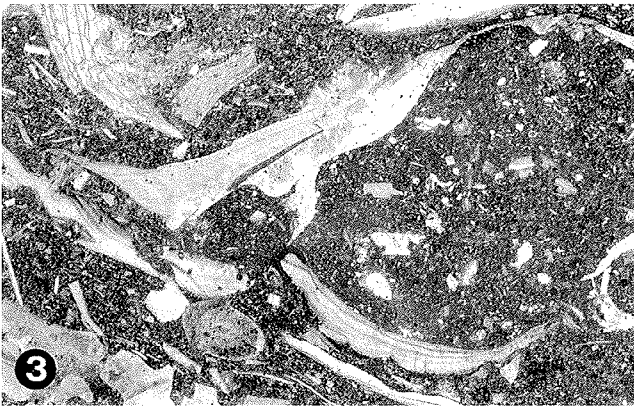
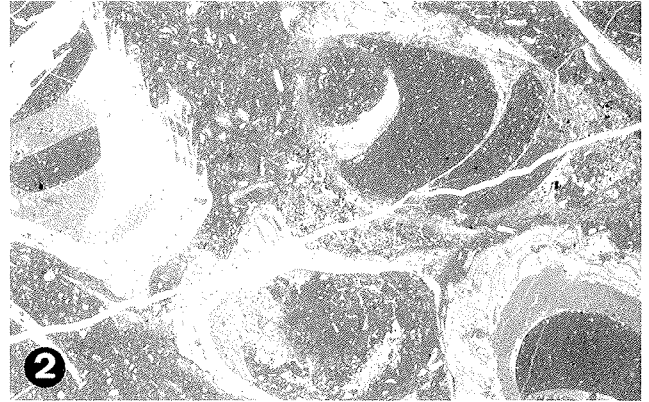
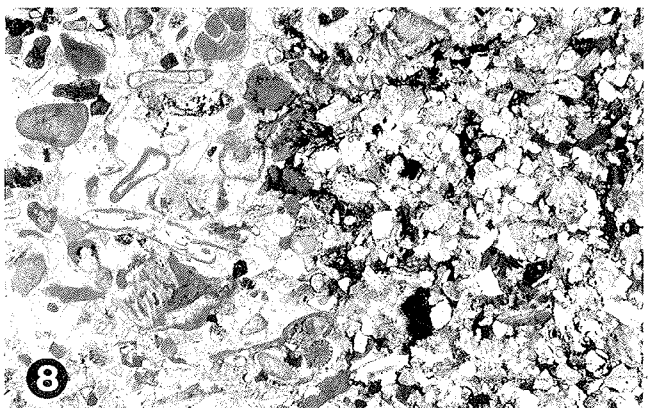
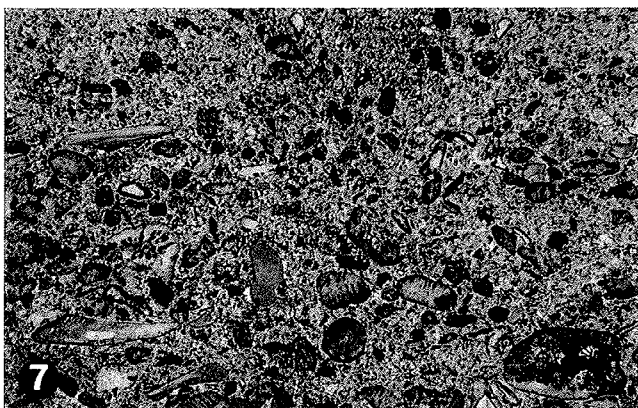
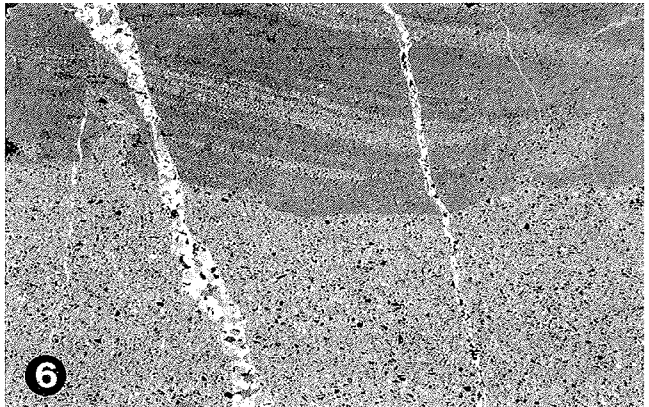
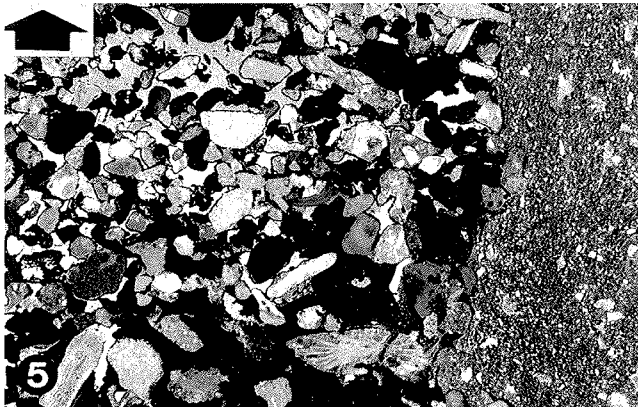
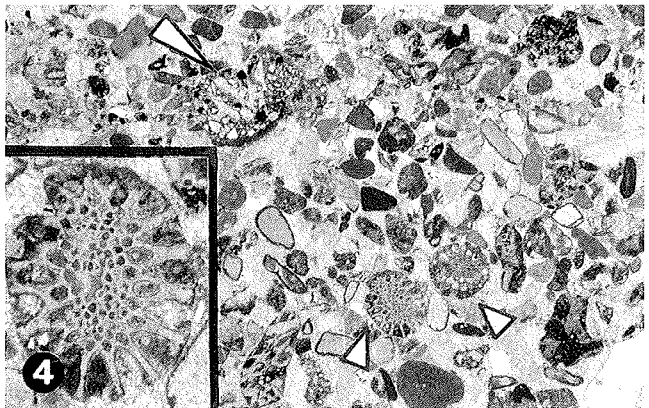
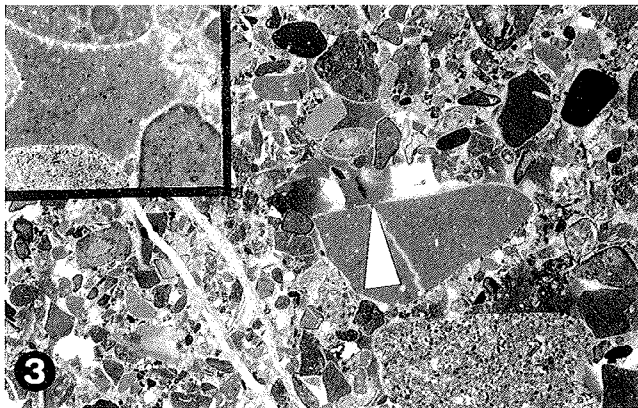
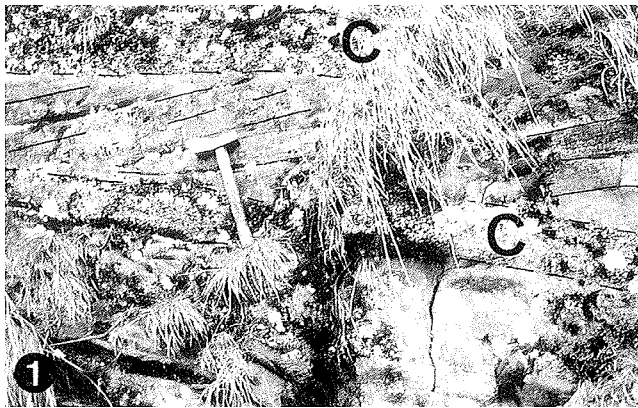


Plate 31 Arenites and marls from nearshore to shelf environments, Upper Cretaceous of Brandenburg, Austria.

- Fig. 1. Detail of an interval composed of cross-laminated arenite and sharply intercalated beds of fine to medium-grained siliciclastic conglomerate (c). The intervals of cross-laminated arenite are up to more than a metre thick, and consist of one or several stacked, elongate lenses some tens of meters in length of unidirectionally dipping tangential-oblique and/or sigmoidal laminasets. In outcrop intersection, the conglomerate intervals typically display a gentle lense-shaped to tabular geometry. Hammer for scale is 33 cm long. Kreuthalm, Brandenburg.
- Fig. 2. Thin section of moderately sorted fine- to medium-grained sandstone composed of angular to subangular grains of mono- and polycrystalline quartz, serpentine, feldspar and a few percent of subangular to well-rounded carbonate rock fragments. The sandstone is cemented by isopachous fringes of dolomite rhombohedra, overlain by blocky calcite spar. Width of view: 8 mm. Sample 24.11.94/11. Krumbachalm, Brandenburg.
- Fig. 3. Poorly sorted arenite composed of carbonate rock fragments (ooid grainstones, dolostones, boundstones, mudstones to wackestones) derived from the local Triassic to Upper Cretaceous substratum, a subordinate amount of bioclasts, and a few angular clasts of chert. Top to right. Some of the carbonate rock fragments contain biomarkers of the Triassic, Jurassic or the Late Cretaceous. The rock fragments typically are subrounded to well-rounded; some are blackened or stained red. Most of the bioclasts are penecontemporaneous, and typically include fragments from echinoderms and red algae. Note the isopachous fringes of dog tooth spar, overlain by geopetal infills of lime mudstone (arrowtip) which, in turn, is overlain by blocky calcite spar. Width of view: 17 mm. Sample I 79. Voldöppberg, Brandenburg. Inset: Isopachous fringes of dog tooth spar, and infill of lime mudstone. Width of view 1.5 mm.
- Fig. 4. Moderately well-sorted, coarse arenite composed of carbonate rock fragments and bioclasts. The bioclastic fraction is characterized by fragments from branched bryozoans (arrowtips), and from molluscs (in part from rudists), coralline algae and echinoderms; in addition, ataxophragmiine foraminifera (arrowtip) are present. Both the carbonate rock fragments and the bioclasts are well- to very well-rounded; the mollusc fragments are coated by micrite rims. Width of view: 11 mm. Sample 21.10.95/6. Atzlgraben, Brandenburg. Inset: Fragment of branched bryozoan. Width of view: 1.5 mm.
- Fig. 5. Vertical boundary between a mixed calcilithic-bioclastic arenite (left and center) and a poorly sorted, marly siltstone (right; black arrow points to sedimentologic top). The bioclastic fraction of the arenite is of overall identical composition and taphonomy as the bioclastic fraction as described for the arenite in Pl. 31/4. The arenite locally shows small aggregates of pendant scalenohedral calcite cement, but is mainly cemented by a first generation of thin fringes of dark brown, microcrystalline carbonate cement. The dark brown cement fringes are overlain by a dark brown, ferroan lime mudstone (black in photo) and, locally, by blocky calcite spar (light interstitial areas). Both the allochems and the cements are sharply truncated along the boundary to the laterally adjacent marly siltstone. The siltstone is mainly composed of silt-sized bioclastic material and siliciclastic grains; a few larger sand grains and bioclasts (planktic foraminifera, fragments from inoceramids and echinoderms) are admixed. The matrix is a marly mudstone. Width of view: 12 mm. Sample 6.6.96/5. Tiefenbach, Brandenburg.
- Fig. 6. The lower part of the photo shows a faintly parallel-laminated, well-sorted fine arenite composed of microsparitic carbonate rock fragments, mono- and polycrystalline quartz, serpentine, chert, feldspar, and a few opaques. The fine arenite is overlain by a foreset-laminated fine arenite to siltstone. Width of view: 17 mm. Sample 3.12.94/7. Nachbergalm, Brandenburg.
- Fig. 7. Part of normally graded bed of bioclastic grainstone. The medium to coarse sand fraction of the grainstone consists of subrounded to well-rounded fragments from rudists and other molluscs, corals, red algae, echinoderms, bryozoans and a few miliolids. Most of the bioclasts bear micrite rims. The fine sand to silt fraction consists of both bioclastic material and calcilithic rock fragments. The fine bioclastic fraction has been largely replaced by a finely crystalline, subhedral to anhedral dolomite. Width of view: 17 mm. Sample 3.8.95/10. Weissach, Brandenburg.
- Fig. 8. Vertical transition (top to right) from a bioclastic grainstone into an arenite composed of carbonate rock fragments, siliciclastic grains and bioclasts. The bioclastic grainstone consists of rounded, micrite-fringed fragments from molluscs, green algae, red algae, corals, rudists and echinoderms, smaller benthic foraminifera, and some percent of siliciclastic sand. The grainstone is cemented by isopachous fringes of dog tooth spar, overlain by blocky calcite spar. The boundary between the grainstone and the overlying arenite is sharpened by pressure solution. In the overlying arenite, lithification proceeded mainly by intergranular pressure solution, leading to a tightly packed texture. Width of view: 9 mm. Sample ATZ 9. Haidach, Brandenburg.



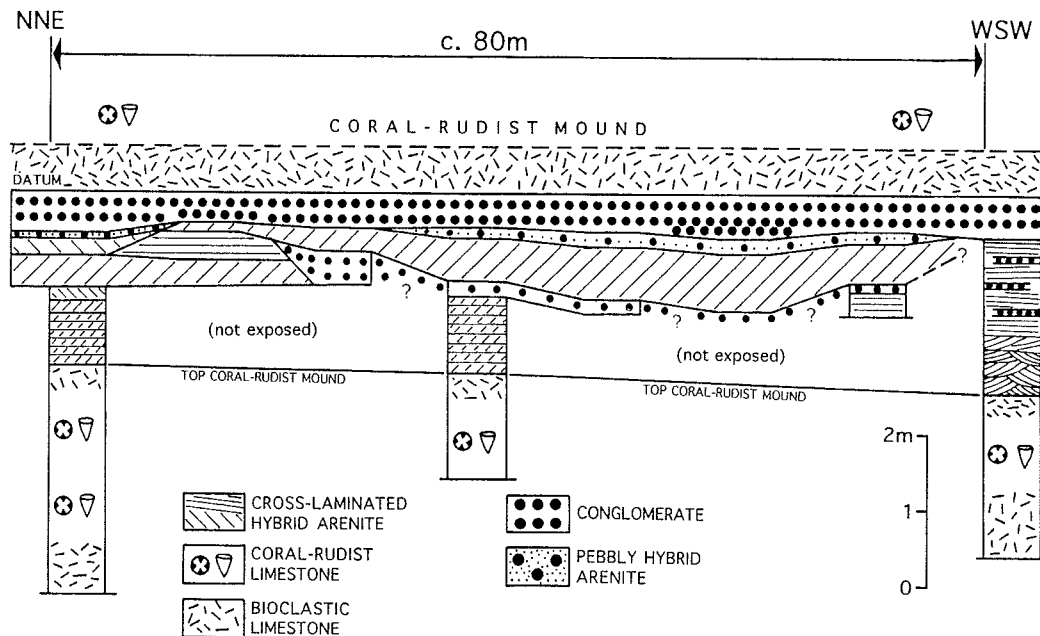


Fig. 8. Scheme of outcrop near Haidach, Brandenburg (vertically exaggerated; see fig. 12 for stratigraphic position). The lower part contains bioclastic limestones overlain by a mound of coral-rudist limestones (Pl. 30/5). These are overlain by an interval of calcilithic arenites (Pl. 31/8) that show trough cross-lamination and stacked unidirectionally inclined laminasets. The upper part of the arenite interval consists of pebbly hybrid arenites and of sets some tens of meters long and up to about 1 m thick of unidirectionally inclined oblique-tangential to sigmoidal laminasets (dip of laminae shown schematically) (Pl. 31/1). Less commonly, the arenites show subparallel lamination (section at right). The arenites are overlain by an interval of siliciclastic conglomerate with marine macrofossils, and with a matrix of bioclastic hybrid arenites with marine bioclasts (Pl. 29/3). The conglomerate is sharply overlain by an interval of packstone (hatched) with strongly micritized and abraded bioclasts (see SANDERS & BARON-SZABO, 1997) which, in turn, is overlain by marly coral-rudist limestones.

tion is common. Truncated lenses less than a metre thick of horizontally laminated calcilithic arenite are locally intercalated into the conglomerates. These conglomerates invariably are present at the base of marine transgressive successions. Intervals of these conglomerates can be correlated along strike over several kilometers, and show lateral variations with respect to thickness, mean grain size and internal organization (fig. 7C) (SANDERS, 1997 b).

(2) Conglomerates with a matrix of calcilithic arenite that consist of amalgamated beds of moderately well- to well-sorted fine gravels to cobbles of Triassic-Jurassic carbonate rocks, and a few clasts of volcanics, sandstones, and chert. These conglomerates occur in compound channel-fills up to several meters thick that interfinger with laterally adjacent, cross-laminated calcilithic arenites. Each truncation surface at the base of a compound channel-fill grades into a reactivation surface within laterally adjacent, cross-laminated arenites. Locally, conglomerates are present that consist of coarse gravels to cobbles in ungraded to indistinctly graded beds that range in thickness from one clast diameter to about 50 cm. The beds show both asymmetric and symmetric high-angle scours at their base, contain arenite rip-up clasts, and are intercalated into cross-laminated arenites with marine fossils. The top of these conglomerate beds is plane, save some projecting lithoclasts.

(3) At the base of the Turonian-Coniacian marine succession, intervals a few meters thick of extremely poorly sorted breccias are locally present. The breccias consist of angular to subrounded fine gravels to small

boulders of carbonate rocks penetrated by *Trypanites* (lithophagids, clionids) and, subordinately, of coral heads, nerineids and disoriented clusters of rudists, embedded in a calcarenite matrix of mixed calcilithic/shallow-water bioclastic composition. The breccias are overlain by carbonate rock conglomerates with corals and rudists and, higher up, by successions of biogenic shallow-water carbonates. At the base of the Santonian marine succession, breccias to conglomerates are common (fig. 7B) (SANDERS, 1997 b; IBRAHIM, 1976). Within short lateral distances, the thickness of the intervals of breccias to conglomerates varies from zero to more than 10 meters. Both the breccias and the conglomerates are extremely poorly to moderately sorted, clast- to matrix-supported, and consist of fine gravels to boulders of Triassic, Jurassic and Upper Cretaceous carbonate rocks that typically are penetrated by *Trypanites*, and contain a few megafossils (e. g. radiolitic fragments). The matrix of the breccias typically is a dark red, marly wackestone to calcilithic arenite with marine bioclasts, whereas the conglomerates typically bear a matrix of winnowed, calcilithic arenite with clasts from ramose bryozoans, echinoderms, coralline algae, brachiopods, lagenids, textulariaceans, ostreids, inoceramids, and, locally, a few globotruncanids (Pl. 29/2) (SANDERS, 1997 b; compare also FISCHER, 1964; IBRAHIM, 1976).

Interpretation: The first type of conglomerates represents beachface conglomerates, as indicated by their position at the base of transgressive successions, the subparallel to low-angle cross-stratified beds of very well-rounded, spherical to oblate gravels to small boulders, and the

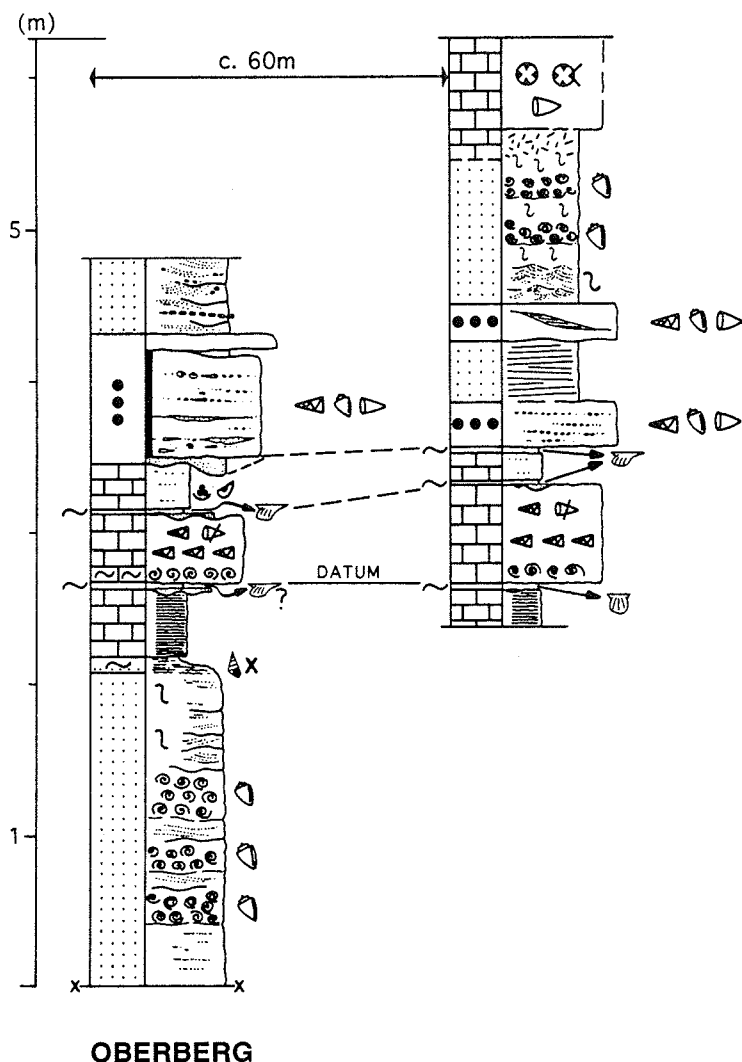


Fig. 9. Detail of section at Oberberg, Brandenburg. In the left column, marly sandstones rich in *Actaeonella* cf. *obtusa* are overlain by bituminous limestones and an interval of nerineid limestones. The bituminous limestones are sharply overlain, along an erosive boundary, by an interval of conglomerate and arenite with marine fossils. Higher up (right column), partly bioturbated arenites with inclined cross-lamination and „*Actaeonella* beds“ are overlain by bioclastic limestones and, at the exposed top, by marly coral-rudist limestones.

glomerates that overlie the breccias, by contrast, have been deposited in a beachface to upper shoreface environment (SANDERS, 1997 b) (cf. SEMENIUK & JOHNSON, 1985).

4.3 Siliciclastic conglomerates

4.3.1 Beachface conglomerates

These are composed of well- to very well-rounded clasts of volcanics, chert and, locally, serpentinite, metagabbro and opicalcite and a few abraded and fragmented fossils (actaeonellids, nerineids, rudists, corals, oysters) (Pl. 29/3). The matrix typically is a calcilithic arenite with a few bioclasts (lagenids, and fragments from corals, rudists, gastropods, bryozoans and echinoderms). These conglomerates build laterally extensive intervals up to more than 1 meter thick (fig. 8), and locally interfinger with intervals of low-angle cross-laminated arenites (fig. 9). The conglomerate intervals consist of horizontal- to low-angle cross-stratified bedsets and locally intercalated, truncated lenses of calcilithic arenite that show horizontal lamination or sigmoidal cross-lamination and tangential-oblique cross-lamination. The texture of individual conglomerate beds ranges from clast-supported to matrix-supported, to a pebbly arenite. Within the clast-supported layers, imbrication of disc-shaped clasts is fairly common and, locally, bidirectional imbrication in stacked, clast-supported layers is present.

Interpretation: From their overall characteristics, these siliciclastic conglomerates are identical to the above described carbonate beachface conglomerates. The clasts of volcanics serpentinites and metagabbros and, possibly, at least a part of the chert clasts are derived from source areas outside the Northern Calcareous Alps. The clasts are derived from river input, and were subsequently distributed by longshore drift. Probably as a result from the distance from source and, possibly, because of repeated reworking before final deposition, the siliciclastic beachface conglomerates are of more constant and smaller mean grain size than their carbonate counterparts, and are rich in oblate- to disc-shaped clasts. Such clast shapes are characteristic, but not diagnostic of siliciclastic beachface conglomerates (see LÜTTIG, 1964; BLUCK, 1967; NEMEC & STEEL, 1984).

composition of carbonate clasts from the local substratum. The second type of conglomerate comprises shoreface conglomerates (SANDERS, 1997 b) (cf. BLUCK, 1967; LECKIE & WALKER, 1982; NEMEC & STEEL, 1984; BOURGEOIS & LEITHOLD, 1984). While the high-angle scours at the base of the beds probably were carved by unidirectional, fludal flows, at least the ungraded beds of coarse gravel- to cobble conglomerates with the projecting lithoclasts at their top record a short stage of rheological debris flow shortly before the flow, or at least the lower part of the flow dominated by traction, was stopped by frictional freezing (SANDERS, 1997 b) (cf. SOHN, 1997; SOHN et al. 1997).

The position of the third type of shallow-marine lithic calcirudites, i. e. the breccias at the base of the marine successions, their composition of lithoclasts derived from the local substratum, the locally associated shallow-marine megafossils, and the mixed calcilithic/shallow-water bioclastic matrix all indicate that these breccias have been deposited along the edge of marine transgression. Poorly sorted breccias that locally may have a fitted fabric and that contain marine bioclasts were described as typical deposits of the inter- to supratidal leading edge of a marine transgression onto a steeply inclined to cliffed carbonate rock substratum (SEMENIUK & JOHNSON, 1985). The con-

4.3.2 Fluvial conglomerates

At Brandenberg, an interval of conglomerate a few meters thick and at least some hundreds of meters in lateral extent is exposed that consists mainly of very well-rounded, imbricated cobbles of volcanics up to 3 dm in size, and some clasts of black quartz sandstones, carbonate rocks, and serpentinite. The base of the conglomerate interval shows longitudinal scours that are incised into limestones with shallow-marine molluscs (neritids, naticids, nerineids) (SANDERS et al., 1997: pl. 2/5). The conglomerate interval shows large-scale accretion bedding, and contains large lenses that consist of conglomerate at the base, overlain by sandstones with horizontal lamination and sets of tangential-oblique beds up about 60 cm thick. Locally, in the upper part of the interval the conglomerate is devoid of sandstone matrix, and is cemented by coarse calcite spar. This conglomerate is overlain by cross-laminated sandstone and, higher up, by marls that have been deposited in a paralic environment.

Interpretation: The composition mainly of well- to very well-rounded cobbles of volcanics, the accretion bedding within the conglomerate interval, its lateral extent of at least several hundred meters, and the overall fining-upward development all suggest that the conglomerate has been deposited within a fluvial channel. The steeply inclined accretion beds preclude an origin of the conglomerate from a beachface, whereas a tidal channel origin is precluded by the large size of the lithoclasts, the absence of marine fossils, and by the absence of marine burrows within the intercalated lenses of sandstone. In order to transport cobble-sized lithoclasts, at least the observed sector of the river must have had high flow velocities along a high morphological gradient, i. e. it fits the low-sinuosity bed load-dominated category of rivers (cf. RUST, 1978; MIALL, 1978; GALLOWAY & HOBDA, 1983).

4.4 Shallow-water carbonates

4.4.1 Bituminous limestones

Limestones of light brown to black colour that emit a „bituminous“ odour upon fracture occur in beds 10-30 centimeters thick, and build bedsets up to more than a meter in thickness. Three facies groups are distinguished. (1) Cryptmicrobially laminated mudstones to wackestones that occur in intervals up to about 10 cm thick, and that locally show shrinkage cracks, sheet cracks, and thin layers of algal chips and mud chips (Pl. 29/4). Dark brown to black mudstones to wackestones locally show parallel- to slightly flaser-like laminae that locally contain abundant ostracods. (2) Bioturbated to horizontally subparallel-laminated or thin-bedded mudstones to packstones with gastropods (*Melanopsis*, *Pyrgulifera*), small bivalves, characeans and ostracods (Pl. 29/5). The thin bedding is evident by slight vertical changes in colour associated with a change in the bioclasts, or their relative proportion. The boundaries between the laminae or the thin beds are commonly sharp and even. (3) Bioturbated or thin-bedded mudstones to bioclastic wackestones to packstones with a

highly variable relative proportion of cassiopids, cerithids, *Pyrgulifera*, small bivalves, textulariaceans, miliolids, rzehakinids, ostracods, fecal pellets and, locally, a few percent of silt- to sand-sized carbonate rock fragments and siliciclastic grains (Pl. 29/6). The bituminous limestones locally show a clotted texture because of abundant cryptmicrobial lumps about 0.1 mm to about 2 mm in diameter; the larger lumps typically show an internal texture of micropeloidal grainstone to packstone. The bituminous limestones commonly contain irregular networks of endichnial burrows of 0.5-1.5 cm in width that are filled by sandstone. The sandstone is typically confined to the burrows, but locally is connected with an overlying sandstone bed.

Interpretation: The bituminous limestones were deposited in shallow, schizohaline to freshwater lakes (SANDERS, 1996 c). Saline to mesohaline water is recorded by the association of cassiopids (cf. FÜRSICH, 1994) and smaller benthic foraminifera. In the limestones of facies group 2, oligohaline to fresh waters are indicated by *Pyrgulifera* and *Melanopsis* (HERM, 1977; FÜRSICH, 1994), by the poor biotic assemblage, and by the exclusive presence of characean fragments and/or thin-shelled ostracods. The cryptmicrobial lumps represent clumps of calcified or calcite-encrusted microalgae and cyanobacteria (cf. WETZEL, 1975; HALLEY & ROSE, 1977; DAVIS et al., 1995). Intermittent emergence and desiccation of the lakes are recorded by the cryptmicrobially laminated mudstones, and by the shrinkage cracks and sheet cracks. The organic matter content of the limestones, the overall paucity of bioturbation and the preserved lamination to thin bedding all indicate dysaerobic to anaerobic conditions at or closely above the sediment/water interface. Dysaerobic to anaerobic conditions may have been produced by input of organic matter from adjacent vegetation, coupled with consumption of oxygen due to microalgal/cyanobacterial metabolism and/or below submerged films of microalgae and/or cyanobacteria (cf. MEYER-REIL, 1993; FOUCH & DEAN, 1982). The sandstone-filled burrows are interpreted as tubular tempestites (WANLESS et al., 1988) or inundites (EINSELE & SEILACHER, 1991) that were filled into an open burrow network within a more or less cohesive, firm substrate (*Psilonichnus* ichnofacies; PEMBERTON et al., 1992). The existence of freshwater ponds is a prerequisite for the formation of the characean limestones which, in turn, implies a humid to seasonally humid climate and a high groundwater level (see TAFT & HARBAUGH, 1964; HALLEY & ROSE, 1977; ROBERTS et al., 1977). An at least seasonally humid climate and a high, stagnant to rising groundwater level is a prime prerequisite for peat accumulation and preservation (McCABE, 1984; CROSS, 1988); this fits the close vertical association or, locally, vertical contact between the bituminous limestones and thin coal seams (SANDERS, 1996 c).

4.4.2 Bioclastic wackestones to packstones

These build intervals less than a metre to nearly 10 m thick. The wackestones to packstones consist of variable relative proportions of rudist fragments, smaller benthic

foraminifera (mainly *Cuneolina*, *Nezzazatinella*, *Dictyopsella*, *Montcharmontia*, *Quinqueloculina*, lituolids, textulariaceans), fragments from calcareous green algae (e. g. *Neomeris*, *Permocalculus*, *Thaumatoporella*, *Boueina*), branched coralline algae, cerithiaceans, nerineaceans, calcisponges, stromatoporoids, ostracods, peloids, bryozoans, serpulids, echinoderms, rare brachiopods and coalified plant fragments. Locally, the bioclasts are coated by microbial-foraminiferal crusts, and a few of the bioclasts may be blackened. Less common varieties of this facies include (a) wackestones to packstones with abundant *Cuneolina* and/or miliolids and nezzazatids, (b) peloidal packstones with miliolids and calcareous green algae and, (c) very poorly sorted packstones that are rich in both micrite-rimmed and blackened bioclasts. In Brandenberg, an interval a few meters thick of very poorly sorted packstones composed of micritized, bored and blackened bioclasts (corals, rudists, calcareous green algae, nezzazatids, miliolids, echinoids, coralline algae, *Ethelia alba*, cerithiaceans, brachiopods, demosponges, ataxophragmiines, bryozoans, serpulid tubes, ostracods) and angular to rounded carbonate rock clasts from sand- to small-boulder size is present (Pl. 29/7; fig. 7C). The rock clasts are derived from the local Triassic substratum; they are penetrated by *Trypanites* and locally bear encrustations of coralline algae and cryptmicrobial crusts.

Interpretation: As indicated by their fossil content, the sediment texture and bioturbation, and by the micrite rims on many bioclasts, the bioclastic wackestones to packstones were deposited in shallow, open subtidal environments of overall low water energy (cf. WILSON, 1975; FLÜGEL, 1978; ENOS, 1983). Although all of the bioclasts in the wackestones to packstones were also observed in arenites and marls of shallow subtidal origin (see description below), *Cuneolina*, *Nezzazatinella*, *Dictyopsella*, *Montcharmontia* and calcareous green algae are significantly more common in the limestones. The interval of very poorly sorted packstones rich in blackened bioclasts and carbonate rock clasts accumulated during marine transgression on a low-energy, inclined shelf segment. This is indicated by the stratigraphic position of these packstones (see fig. 7C), as well as by their composition of bioclasts from open marine to lagoonal environments, and the widely different taphonomic states of preservation of the bioclasts. The blackening of bioclasts may result from reworking of transgressed coastal areas (cf. STRASSER, 1984; SHINN & LIDZ 1988). As indicated by *Trypanites* and the encrustations, at least a part of the sand- to boulder-sized clasts of Hauptdolomit and Wettersteinkalk were bathed in shallow marine waters before they became embedded in the limestone.

4.4.3 Bioclastic grainstones to packstones

These occur in intervals less than a meter to more than 10 m thick. The bioclastic limestones are locally arranged in bedsets that consist of a lower part of marly, bioturbated, wavy to nodular bedded, fine to medium bioclastic packstones, and an upper part of medium to coarse bioclastic grainstones to packstones; these are arranged in sets of

wavy to plane beds that locally show subparallel lamination. The bioclastic grainstones to packstones consist mainly of well-rounded, micrite-rimmed fragments from rudists and, subordinately, textularids, miliolids, lituolids, nezzazatids, cf. *Montcharmontia*, fragments from coralline algae, bryozoans, green algae (*Permocalculus*, *Neomeris*, *Boueina*), *Ethelia alba*, echinoderms, ostracods, Ataxophragmiinae, *Pienina oblonga*, oyster fragments, both blackened and red stained bioclasts, blackened mudstone intraclasts and, locally, a few percent of siliciclastic sand. Rarely, intervals of less than a metre in thickness are present that consist of very well-washed, pure mollusc-clastic grainstones with inclined lamination and horizontal lamination; these grainstones may contain *Trochactaeon*.

Interpretation: The sedimentary structures, the sorting, rounding and composition of the grains, and the fossil assemblage of the bioclastic grainstones to packstones indicate that they were deposited in an open, shallow neritic environment of medium to intermittently high water energy (cf. WILSON, 1975; FLÜGEL, 1978). The stratal packages of marly limestones and bioclastic limestones were deposited from carbonate sand bodies, and are broadly similar in thickness, vertical arrangement of bedding styles and facies, grain size and sorting to carbonate sand bodies described from gently inclined shelves. The bioturbation of the bioclastic limestones and the overall paucity of preserved hydrodynamic structures indicates that the sand bodies were only episodically active, possibly during storms (cf. WARD & BRADY, 1973; AIGNER, 1985; WANLESS et al., 1995). The intervals of well-washed grainstones with *Trochactaeon* probably were deposited close to fairweather wave base, possibly in association with partly emergent carbonate shoals in front of an open subtidal, muddy lagoonal environment (cf. WARD & BRADY, 1979; KENDALL et al., 1989).

4.4.4 Oyster limestones

These occur in beds up to about 80 cm thick of marly to sandy oyster floatstones. The oyster shells are up to more than 20 cm in length and up to several centimeters thick. The oysters are locally associated with pteriods, mytiloids, a few *Placunopsis*, small arcaceans, and inoceramids a few millimeters in size. The oyster shells most commonly are unbored, but rarely show perforations by clionids and by lithophagids. The matrix of the oyster floatstones is a grey to, locally, nearly black mollusc-clastic wackestone that commonly contains small coalified plant fragments; many of the plant fragments are replaced by pyrite. Locally, a few miliolids and ostracods are present in the matrix.

Interpretation: The oyster limestones were deposited in a quiet, shallow subtidal environment. The association of the oysters with more or less stenohaline, marine bivalves suggests that the oysters were situated, at least intermittently, in waters of normal marine to slightly reduced salinity (see also FÜRSICH, 1994), and possibly also of elevated nutrient level (cf. HECKEL, 1974). An overall reduced salinity is suggested by the typical absence of

clionid borings and lithophagid borings, and by the scarce microfauna in the matrix. Because, in shallow subtidal environments, salinity fluctuations may occur on a time scale below geologic resolution (cf. FÜRSICH, 1994: fig. 17), the co-occurrence of the oysters with the marine bivalves within the same bed not necessarily implies co-occurrence of living individuals. Similarly, the clionids and lithophagids may have bored the oyster shells some time after death of the mussels.

4.4.5 Nerineid limestones

These occur in intervals 10 cm to about 1.5 meters thick, and contain abundant shells of nerineaceans, commonly *Simploptyxis* and *Parasimploptyxis* (fig. 9). The shells mostly are 10-20 cm in length, and typically are abraded, fragmented and penetrated by diverse types of borings and, locally, are coated by cryptmicrobial crusts (Pl. 29/8). The nerineid limestones contain a matrix of bioclastic wackestone that locally is rich in silt-sized mollusc-clastic material and in rudist fragments. Aside from nerineids, small radiolitids and, more rarely, small hippuritids may be present, and locally are an inconspicuous, but common element of the fossil assemblage (fig. 9, fig. 10). The intervals of nerineid limestones locally develop from beds of „nerineid arenites“ (see below) by a gradual or sharp vertical disappearance of sand from the lime mud matrix. Some beds of nerineid limestone could be traced or correlated laterally over hundreds of meters. These beds show a very gently mounded shape. The thicker intervals of nerineid limestone are organized into several beds that are characterized by vertical changes in the content of nerineids and/or the content of siliciclastic sand to silt. The bedding planes are situated along thin layers of marly sandstone to marl or, locally, along thin layers rich in small, toppled rudists (fig. 10). Locally, beds and bedsets are present that consist of floatstones to packstones with a mass occurrence of ?juvenile nerineaceans of some millimeters to about 1 cm in length (Pl. 30/1; fig. 11).

Interpretation: The large nerineids evidently preferred a shallow subtidal, open lagoonal environment with a substrate of muddy sand to lime mud where they colonized, more or less in abundance, extensive areas (cf. VOGEL, 1968; ACCORDI et al., 1982; KOUYOUMONTZAKIS, 1989). Although the nerineid shells show evidence for coarse fragmentation and abrasion during high-energy events, and are disoriented by bioturbation, overall the nerineids are preserved at their place of living. This is also supported by the bioclastic wackestones to packstones rich in small nerineids.

4.4.6 Rudist limestones

Radiolitid limestones: These occur in intervals up to a few meters thick that locally can be traced over hundreds of meters, without significant change in thickness (fig. 7A, fig. 11). In radiolitid floatstones to rudstones, most of the rudist shells are preserved without the upper valve and

with the long axis of the lower valve subparallel to bedding, whereas the tabulae indicate that the rudists grew in an inclined to upright position (Pl. 30/2) (open/packed parautochthonous rudist fabric; SANDERS, 1996 a, d; SANDERS & BARON-SZABO, 1997). Locally, some *Vaccinites* and *Plagioptychus* are present. The matrix of the floatstones to rudstones is a bioturbated wackestone to packstone with toppled juvenile rudists, fragments of branched corals (cf. *Pleurocora*), red algae, calcareous green algae, echinoderms, bryozoans, serpulids, miliolids, nezzatatids, lituolids, placopsilinines, and fecal pellets; the rudist clasts commonly are bored by clionids and lithophagids, and may be encrusted by corallines, serpulids, microbialites, and sessile foraminifera. Locally, lenses less than a metre thick of floatstone composed of fragments from the radial funnel plates and from the upper valve (Pl. 30/3), and/or layers with abundant juvenile radiolitids floating parallel to bedding in a matrix of radiolitid-clastic wackestone (fig. 11) are intercalated. Where radiolitid limestones are overlain by arenites, the topmost 10 cm of the limestones may be mottled by burrows filled by arenite. More rarely, intervals of radiolitid bafflestones up to about 50 cm in thickness are present with the rudists preserved in growth position and with their free valve in place (autochthonous rudist fabric; SANDERS, 1996 a, d; SANDERS & BARON-SZABO, 1997). The matrix of the radiolitid bafflestones is a rudist-clastic

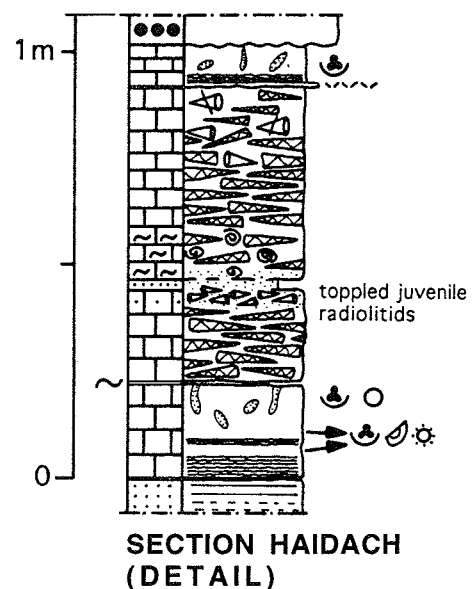


Fig. 10. Detail of section at Haidach, Brandenburg (see fig. 12 for stratigraphic position). Parallel-laminated arenites are sharply overlain by bituminous limestones that are arranged into thin packages of both wackestones-packstones of facies group 3 (see text for description) and cryptmicrobially laminated lime mudstones (Pl. 29/4). Burrows filled by sandstone are present near the top. The bituminous limestones are overlain by a bed of nerineid limestone that, in its lower part, contains a level of arenite with toppled juvenile radiolitids. In the upper part of the nerineid bed, a few small radiolitids are present (Pl. 29/8). The nerineid limestones are sharply overlain by cryptmicrobially laminated lime mudstones and, above, wackestones with smaller benthic foraminifera and with sandstone-filled burrows (Pl. 29/6). The limestones are overlain, along an erosive surface, by an interval of siliciclastic conglomerate.

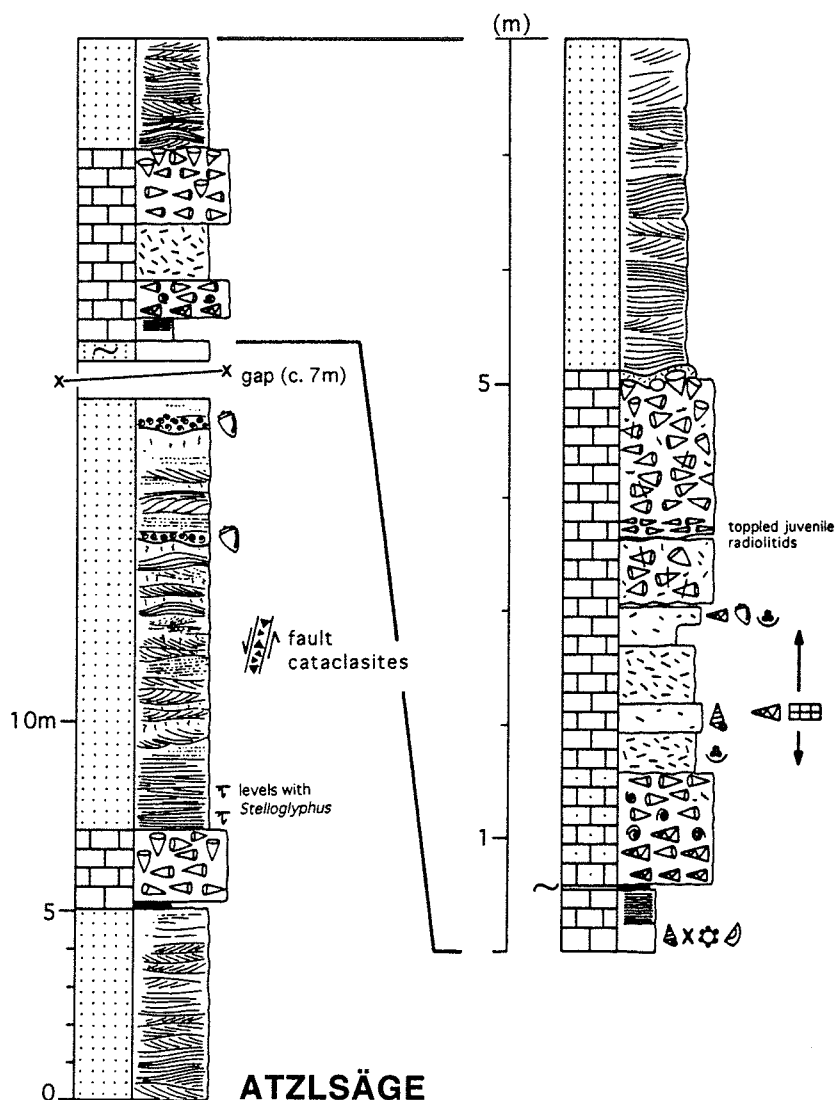


Fig. 11. Section at Atzlsäge, Brandenburg (see fig. 12 for stratigraphic position). The basal part of the section consists of arenites with festooned cross-lamination and *Ophiomorpha*. These arenites are overlain by a biostrome with a parautochthonous fabric of radiolitics and hippuritids. The biostrome is sharply overlain by low-angle cross-laminated arenites with *Stelloglyphus* and, higher up, by arenites that show tangential-oblique laminasets and sigmoidal laminasets. Two erosive-based beds with abundant, abraded shells of actaeonellids are intercalated. In this part of the section, normal faults associated with cataclasites that probably formed in an early, semilithified state are present (SANDERS, 1997 a). At the base of the upper part of the section (enlarged part), bituminous limestones rich in characean stems are present. Above, a bed is exposed that shows a vertical change from large nerineids at the base to nerineids, actaeonellids and radiolitics in the central part to a parautochthonous radiolitic fabric in its upper part. Up-section, a bedset of floatstones to rudstones with small nerineaceans, cerithiaceans and coralline algae (Pl. 30/1) is topped by a bed of limestone with large nerineids. It is overlain by a bed of radiolitic floatstone to rudstone. Above this bed, a thin layer of silty limestone with abundant toppled, small radiolitics is overlain by floatstones with disoriented radiolitics that are mostly preserved without the free valve. Higher up, the proportion of radiolitics embedded in an upright position increases. At the very top, upright radiolitics with preserved free valve are covered by a veneer of bioclastic grainstone. The bioclastic grainstone, in turn, is sharply overlain by sandstones with hummocky cross-lamination and oblique-tangential laminasets.

wackestone to mudstone in which bioclasts (small miliolids, small textulariaceans, small ostracods) are scarce to absent. In thicker intervals of radiolitic limestones, vertical transitions from parautochthonous to autochthonous fabrics and vice versa are common. Locally radiolitics, nerineids and, more rarely, actaeonellids and neritids are present within one bed (see also HERM, 1977: p. 264) or, within a single bed, gastropod limestones are gradually replaced, over a vertical distance of 10 to 30 cm, by radiolitic limestones (fig. 9, fig. 11).

Hippuritic limestones: These occur in intervals up to a few meters thick of more or less marly floatstones to rudstones to bafflestones with abundant hippuritids (fig. 7A). The thicker intervals of hippuritic limestones are laterally persistent at least over hundreds of meters without marked changes in thickness, and typically are dominated by slender shells of *Vaccinites „sulcatus“* (see SANDERS & BARON-SZABO, 1997) arranged in densely packed clusters. Locally, within erosional remnants of an Upper Cretaceous succession mainly of shallow-water limestones

(see fig. 5, fig. 14), biostromes with a packed rudist fabric rich in large *Vaccinites inaequicostatus* are present. In vertical section, the thicker intervals of hippuritid limestones typically consist of a lower part of floatstone with more or less disoriented clusters of hippuritids and with *Plagioptychus*, radiolitids, caprotinids, branched corals, and with a diverse, small-sized biota including echinoids, non-rudist bivalves, bryozoans and small thecideids. The upper part consists of a bafflestone with densely packed, inclined clusters of *Vaccinites „sulcatus“*, and a few intercalated *Plagioptychus*, radiolitids, small caprotinids, and small coral heads. Locally, however, the intervals of hippuritid bafflestones overlie a thin interval of coarse bioclastic limestone. The hippuritid limestones may be overlain by a thin biostrome composed of radiolitids (mainly *Radiolites*) with a wide-conical lower valve. Locally, intervals up to 1 metre thick of hippuritid limestones (*Hippurites*, *Vaccinites*) develop vertically from beds of nerineid limestones.

Interpretation: The sheet-like shape of the intervals of rudist limestones indicates that they formed from biostromes. The described parautochthonous fabrics composed mainly of adult rudists record episodic high-energy events, probably major storms. The scarcity of autochthonous radiolitid fabrics shows that the conditions necessary for strictly in situ-preservation, i.e. overall quiet conditions during rudist growth and rapid, persistent burial by lime mud were rarely met. In the radiolitid biostromes, the local abundance of fecal pellets, the evidence for burrowing and bioturbation, and the burrows filled by arenite indicate that churning of rudists by bioturbation was an important taphonomic process that led to a substantial modification of the biostrome fabric. Because of disturbance by burrowing, „quenched“ substrate colonizations and episodic storm destruction, during their accumulation, larger areas within a future biostromal lithosome intermittently may have been only scarcely colonized by living rudists. The common vertical association of large gastropods (nerineids, actaeonellids) with radiolitids and, subordinately, with hippuritids indicates that the gastropod shells provided a settling substratum (see HERM & SCHENK, 1971; SANDERS & BARON-SZABO, 1997).

4.4.7 Coral-rudist-sponge limestones

These limestones occur in intervals of typically a few meters to more than 10 m in thickness (fig. 7A, 7C; fig. 8; fig. 12) of more or less marly floatstones to, locally, boundstones with coral heads, branched corals (cf. *Pleurocora*), hippuritids, radiolitids, *Plagioptychus*, demosponges (including lychniskids), stromatoporoids, calcisponges (e.g. *Peronidella*), miliolids, *Cuneolina*, *Dictyopsella*, ostracods, fragments of calcareous green algae, alcyonarian sclerites and fecal pellets. The rudists most commonly are preserved without the free valve, and grew in intimate association with the corals and the sponges (Pl. 30/4). The matrix is either a bioclastic wackestone to packstone, or locally consists of irregularly laminated, micropeloidal packstone to grainstone (SANDERS et al., 1997: pl. 2/3) with

some fenestral pores and stromatactoid fabric, or of irregularly laminated lime mudstone with interspersed sessile foraminifera. The floatstones are mottled with burrows filled by bioclastic wackestone to packstone. In the floatstones to boundstones, the fossils typically are encrusted by corallines, bryozoans, serpulids, placospilines and rupertinines, sponges, cryptmicrobial crusts, and squamariaceans (Pl. 30/5). The intervals of floatstones to boundstones can laterally be traced or correlated over hundreds of meters, and show a gentle mound- to sheet-like shape. The scleractinian taphocoenosis is dominated by *Fungiina* and *Stylinina*, whereas *Faviina*, *Meandriina*, and *Heterocoeniina* are subordinate. Most of the corals are of plocoid or thamnasterioid growth form, whereas foliose to encrusting growth is less common (Pl. 30/6). The described floatstones and boundstones are vertically associated with bioclastic wackestones, bioclastic packstones to grainstones and, locally, thin intervals of very poorly sorted rudist-clastic rudstones with shelter pores. In addition, intervals about 1 dm thick of rudist-clastic beachrock are locally intercalated.

Interpretation: The texture, biota, the geometry of the intervals of coral-rudist-sponge limestones and the vertically associated limestones indicate that they accumulated from bioturbated, skeletal mounds in an overall quiet, shallow subtidal environment of episodic high water energy (cf. WILSON, 1975; ENOS, 1983; JAMES & BOURQUE, 1992; BOSENCE & BRIDGES, 1995; WANLESS et al., 1995; TEDESCO & WANLESS, 1995). The high biotic diversity of the mounds indicates an overall favourable environment. The patches of boundstone record the beginning of bioconstructions which, however, were frequently quenched by bioturbation, storm destruction and choking by plumes of suspended mud. The dominance of plocoid and thamnasterioid corals indicates soft substrata and high sediment input, including siliciclastic fines (see SANDERS & BARON-SZABO, 1997, for full discussion and references). The laminated micropeloidal grainstone to packstone and the cauliflower-like masses of micrite are interpreted as microbialites (cf. BEHR & BEHR, 1976; BURNE & MOORE, 1987; NEUWEILER et al., 1996).

4.5 Coal seams

Coal occurs in more or less impure seams of some centimeters to, rarely, about 40 cm in thickness. Individual seams typically show marked lateral variations in thickness, and often pinch out (see also AMPFERER, 1921). In Brandenburg, the coals are humic coals (vitrain, clarain); the macerals largely originated from plant detritus (SCHULZ & FUCHS, 1991).

4.6 Marls

4.6.1 Rooted marls

These typically are soft, dark grey to light grey, locally silty to sandy marls that occur in beds a few centimeters to about 3 dm thick. The marls are devoid of macrofossils except coalified plant fragments (Pl. 30/7) and, locally,

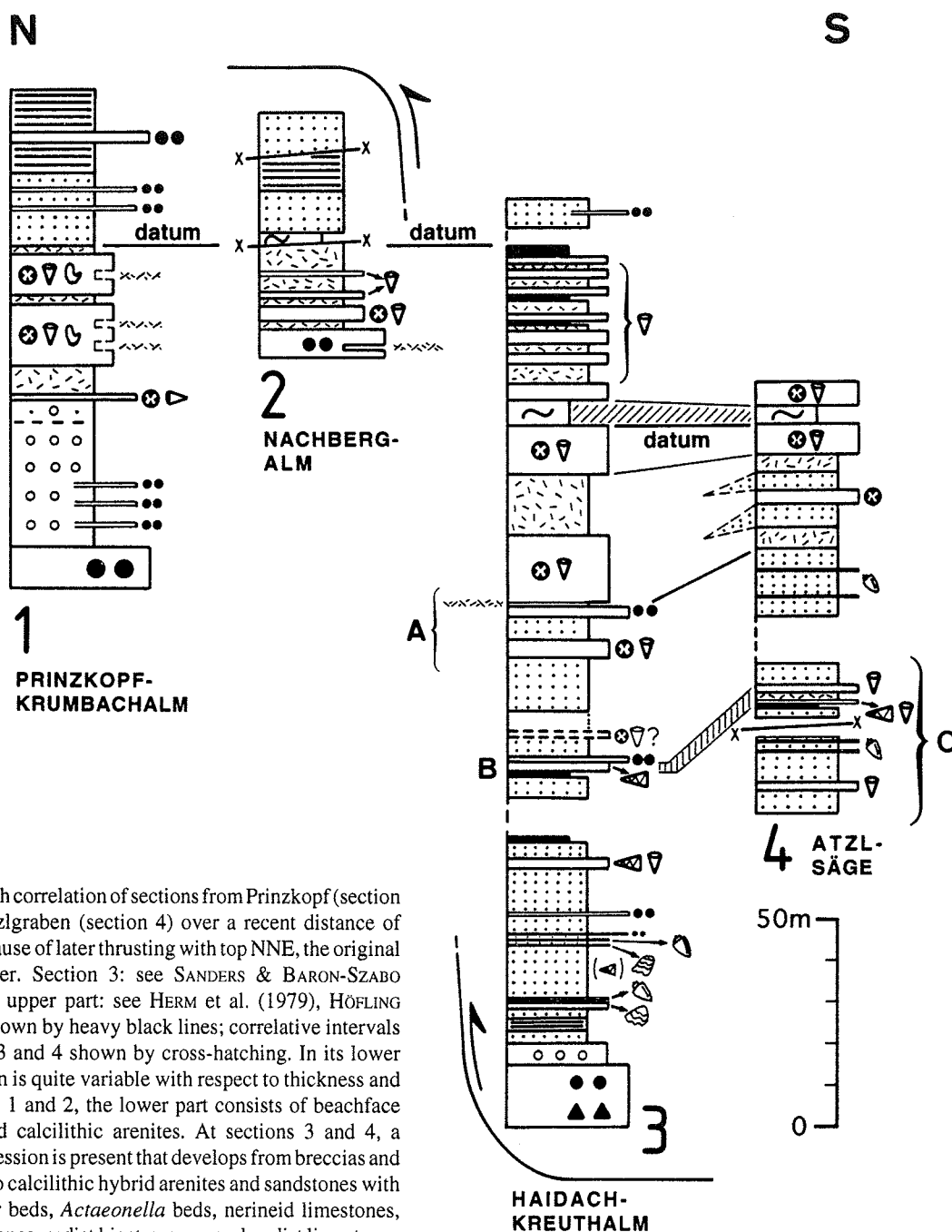


Fig. 12. North-south correlation of sections from Prinzkopf (section 1) to Atzlsäge-Atzlgraben (section 4) over a recent distance of about 2.5 km. Because of later thrusting with top NNE, the original distance was larger. Section 3: see SANDERS & BARON-SZABO (1997); section 4, upper part: see HERM et al. (1979), HÖFLING (1997). Datums shown by heavy black lines; correlative intervals between sections 3 and 4 shown by cross-hatching. In its lower part, the succession is quite variable with respect to thickness and facies. At sections 1 and 2, the lower part consists of beachface conglomerates and calcilithic arenites. At sections 3 and 4, a transgressive succession is present that develops from breccias and conglomerates into calcilithic hybrid arenites and sandstones with intercalated oyster beds, *Actaeonella* beds, nerineid limestones, bituminous limestones, rudist biostromes, coral-rudist limestones and beachface conglomerates. With the recent unrestored north-south distance, the thickness difference between section 1 and section 3 can be accommodated by a 3° slope of the basal truncation surface. The succession of shallow-water limestones in the middle part of each section shows a regular trend to increasingly thinner stratal packages and an increasing proportion of shallow subtidal to supratidal facies up-section (cf. SANDERS & BARON-SZABO, 1997). Above, a succession mainly of paralic cycles is present (SANDERS, 1996 c). A: position of fig. 8; B: position of fig. 10; C: position of fig. 11.

small bivalves, the gastropods *Melanopsis* and *Pyrgulifera*, characean fragments and cryptomicrobial lumps. Coalified plant rootlets descending from bedding planes are common („rooted marls“). Locally, layers up to a few centimeters thick of bioclastic material (*Pyrgulifera*, cassiopids, cerithids, small bivalves) and lenses of coal up to a few decimeters thick are intercalated. The „rooted marls“ locally show submillimetre- to millimetre-thin, even horizontal laminae or wrinkled laminae with fenestral pores. The laminae are defined by a vertical change in the content

of siliciclastic silt to sand, and/or by minute coal fragments. Locally, in the marls, nodules up to some centimeters in size are present that consist of finely crystalline carbonate with minute coal fragments, pyrite as framboids and as replacement of components, and clay and silt that are enriched along wispy pressure solution laminae.

Interpretation: The rooted marls and the associated coal seams were deposited in a schizohaline to freshwater swamp environment (cf. LARSONNEUR, 1975; HORNE et al., 1978). This is indicated by the paucity to absence of

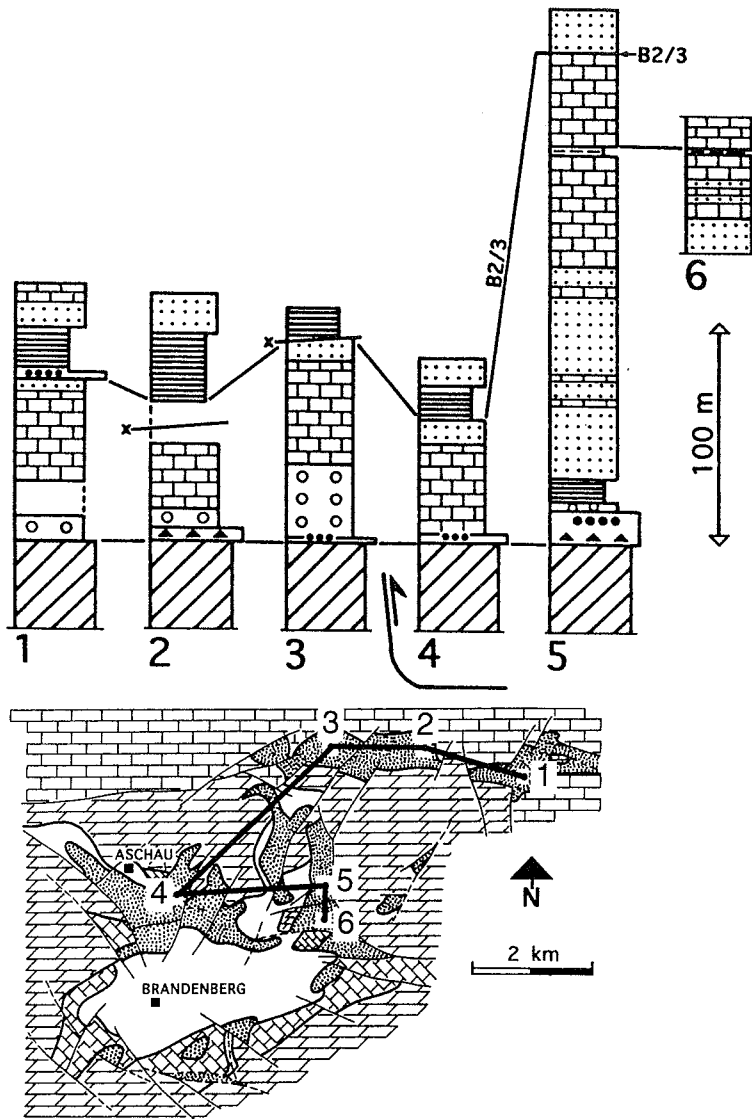


Fig. 13. Correlation of sections in part of the southern outcrop area of Brandenburg (inset shows position of sections; see fig. 5; legend as in fig. 3; open circles=calcilithic arenites). Datum is top of the substratum. Section 5: see SANDERS & BARON-SZABO (1997); section 6: see HERM et al. (1979); HÖFLING (1997). The sections 1, 2, and 3 are separated from sections 4, 5 and 6 by a thrust with top NNE (see fig. 12). Thick line labelled „B2/3“ corresponds to a sequence boundary as described in SANDERS et al. (1997). In their lower part, the sections essentially consist of lithic calcirudites, overlain by a succession mainly of arenites that records an overall deepening up-section. This lower, transgressive part of the sections exhibits marked lateral variations with respect to thickness and sedimentary facies. The middle part of each section consists of a well-mappable succession of coral-rudist limestones, rudist limestones and bioclastic limestones that records regressive carbonate shelf development (cf. SANDERS & BARON-SZABO 1997; SANDERS et al. 1997). The upper part of the sections, separated from the middle part by the B2/3 boundary, is characterized by fluvial conglomerates (section 1), arenites, and a cyclic paralic succession, overlain by arenites and neritic limestones.

macrofossils, the common rhizoliths, pyritized plant fragments and pyrite nodules within these marls, and their close vertical association with coal seams. An episodic marine influence on the environment of marl deposition is indicated by the locally intercalated layers of bioclastic material including cerithid and cassioid gastropods, which may have been swept in during episodic flooding of the swamps.

4.6.2 Lagoonal marls

These are sandy to silty, bioturbated marls that locally build intervals up to a few meters thick. They contain a diversified assemblage of bivalves and gastropods including *Cassiope*, *Terebralia*, *Tympanotonus*, *Cerithium zekeli* and other cerithiaceans and, locally, a few *Trochacteon*, *Actaeonella*, itieriids (*Sogdianella*), neritids and naticids (cf. *Tylostoma*). The arenitic bioclastic fraction mainly consists of fragments from molluscs, echinoderms, corallines, cryptomicrobial lumps, miliolids, textulariaceans, ostracods and coalified plant fragments. A continuum exists from these marls to arenites of lagoonal origin (see description below). In the marls, *Teichichnus*, *Skolithos*

and *Palaeophycus-Planolites* have been observed. At one location (fig. 12, section C), above a combined coral-rudist construction, marls are present with a mass occurrence of *Phelopteria* and, subordinately, inoceramids of assemblage zone 20 of TRÖGER (1989) (TRÖGER & SUMMESBERGER, 1994: p. 179; see also HERM et al., 1979), *Discotectus*, and echinoderm fragments, miliolids, litulids, serpulids, calcareous green algae, bryozoans, and coalified plant debris (HERM et al., 1979; SANDERS & BARON-SZABO, 1997). Locally, beds a few centimeters thick of bioclastic, sandy marl with *Phelopteria* are present at the vertical transition of facies from a marine lagoonal environment into the overall shallower environment of deposition of the bituminous limestones (regressive development), or vice versa (transgressive development) (fig. 9).

Interpretation: As indicated by their fossil content and the trace fossils, the described marls have been deposited in an overall quiet lagoonal environment. At least in the thicker interval of „*Phelopteria* marls“, the marly nature of the sediment combined with the common articulated preservation of the thin shells of *Phelopteria* indicates an environment of low water energy. The mass occurrence of *Phelopteria*, in turn, suggests particular ecological condi-

tions that favoured the abundance of this pterioid bivalve. Pterioids typically are epifaunal-byssate forms which live attached to algae or sea grass (STANLEY, 1972). A mass occurrence of such a bivalve thus suggests the presence of thickets of some algae or sea grass (cf. DEN HARTOG, 1970) in a high-nutrient environment, to sustain the abundant suspension-feeding bivalves.

4.6.3 Shallow neritic marls

These include bioturbated, fossiliferous, locally sandy to silty marls to marly limestones with trace fossils of the *Glossifungites-Cruziana* association. In the marls to marly limestones, bivalves are often preserved with both valves, and comprise infaunal and epifaunal forms, like veneroids (e.g. *Cardium* ? spp.), pterioids (e.g. *Neithea*, *Ostrea*, inoceramids, *Exogyra*), schizodonts (?isocardiids), arcaceans and modiolaceans. Radiolitids and hippuritids are rare to absent, and are always small. Among the gastropods, cerithiaceans, nerineaceans, trochids (e.g. *Discotectus*), aporrhais (*Aporrhais pes-pellicani*), naticaceans and neritids are represented. Solitary corals (*Placosmilia*, *Cyclolites*, and undetermined turbinolids), fragments of cf. *Pleurocora*, both thamnasterioid and plocoid coral heads, and calcisponges are fairly common. The coral heads most commonly are up to a few centimeters in size, but the polyparians are of normal diameter. Both irregular and regular echinoids are locally common. Accessory fossils include ostracods, miliolids, crustacean fragments, and fish teeth. The marls are locally dominated by or contain a mass occurrence of a certain group of molluscs, for instance cerithiaceans, *Discotectus*, or veneroids. Locally, in the marls, small coral heads and radiolitid fragments build clast- to matrix-supported layers less than a metre thick. The described marls are vertically intercalated with beds or bedsets of *Thalassinoides*-burrowed, hummocky cross-laminated arenites.

Interpretation: In these marls the fossil assemblage, the overall uniform distribution and abundance of fossils, and the presence of *Glossifungites-Cruziana*, of intercalated beds of hummocky cross-laminated arenites and beds of coarse bioclastic debris all indicate deposition in an episodically high-energy shallow neritic environment (SANDERS et al., 1997; RINE & GINSBURG, 1985; WELLS, 1988). The environment of marl deposition was favourable for colonization, but the small size of the molluscs and the corals, and the thamnasterioid and plocoid polyparia indicate that sediment stress was high. Sediment stress is also suggested by the common presence of *Placosmilia* and *Cyclolites*, which are identical in their skeletal morphology to recent mobile corals in areas of sediment stress (cf. GILL & COATES, 1977). Locally, the mass occurrence combined with the small size of the fossils from all taxonomic groups suggests that mass mortalities occurred, probably from choking of the community by mud (BRONGERSMA-SANDERS, 1957). The mud may have been suspended during major storms, or may have been brought into the sea by rivers in large plumes that were carried to the site of deposition by currents (e.g. ACKER & STEARN, 1990; BUSH, 1991).

4.6.4 „*Inoceramus* marls“

These marls are characterized by inoceramids, echinoids and ammonites (fig. 7B), and a silt- to sand fraction of bioclasts, carbonate rock fragments, chert, quartz, glauconite, serpentine, detrital micas and feldspar. The fossil content is highly variable with respect to abundance and diversity, and includes *Cyclolites*, *Placosmilia*, *Echinocorys*, *Micraster*, naticids, turritellids, fasciolarids, ammonites, and infaunal and epifaunal bivalves like nuculids, exogyrids, and large flat inoceramids of the Lower Santonian assemblage zone 26 of TRÖGER (1989) (*Cladoceramus undulatoplicatus*, *Platyceramus cycloides*, *Sphenoceramus* sp.; TRÖGER & SUMMESBERGER, 1994; p. 179; SUMMESBERGER, 1985; HERM et al., 1979; IMMEL et al., 1982). Locally, intervals are present that are characterized by inoceramids and echinoids. The biogenic fraction of the *Inoceramus* marls is characterized by variable relative amounts of globotruncanids, hedbergellids, heterohelicids, lagenids, ataxophragmines, textulariaceans, miliolids and other smaller benthic foraminifera, radiolarians, coalified plant fragments, crinoid calyxes, ostracods, and sponge spicules (see also FISCHER, 1964; IBRAHIM, 1976; HERM et al., 1979). The marls contain *Zoophycos* and *Chondrites*, and typically are burrow-mottled. Locally, the marls are faintly parallel-laminated, and contain pyrite nodules and framboidal pyrite. In addition, unbioturbated to partly bioturbated beds between 1 cm to a few centimeters thick of siltstone or of shallow-water bioclastic grainstone are locally intercalated in the marls.

Interpretation: The „*Inoceramus* marls“ probably accumulated in a deeper, muddy shelf environment of overall low water energy, as is indicated by the absence of thicker, coarse bioclastic layers, the absence of hummocky cross-laminated arenite beds, and by the articulated preservation of the delicate shells of the large, flat inoceramids in lying position (cf. MACLEOD, 1994). The completely preserved or only partly bioturbated, thin beds of fine-grained siliciclastic sandstone or of bioclastic packstone may represent distal storm beds. The pyrite nodules and -framboids indicate anaerobic conditions, at least within the sediment. The trace fossils *Chondrites* and *Zoophycos* are characteristic either for bathyal environments on the continental slope and rise (SEILACHER, 1967; COLLINSON & THOMPSON, 1989), and/or for conditions where bottom water is aerobic or dysaerobic and the interstitial water is anaerobic (BROMLEY & EKDALE, 1984; SAVRDA & BOTTJER, 1986, 1991; EKDALE & MASON, 1988). Nuculid bivalves and the large, flat inoceramids are considered as indicators of dysaerobic conditions in restricted shelf muds (see ABERHAN, 1994, and references therein). Regular and irregular echinoids typically are dominant in dysaerobic shelf muds (SAVRDA et al., 1984; RHOADS et al., 1991). The preservation of thin event beds, the common presence of pyrite nodules and framboids, the trace fossils and the local predominance of a low-diversity nuculid-inoceramid assemblage all indicate that some intervals of the „*Inoceramus* marls“ were deposited under dysaerobic to anaerobic conditions within the sediment. The presence of intervals with dense bur-

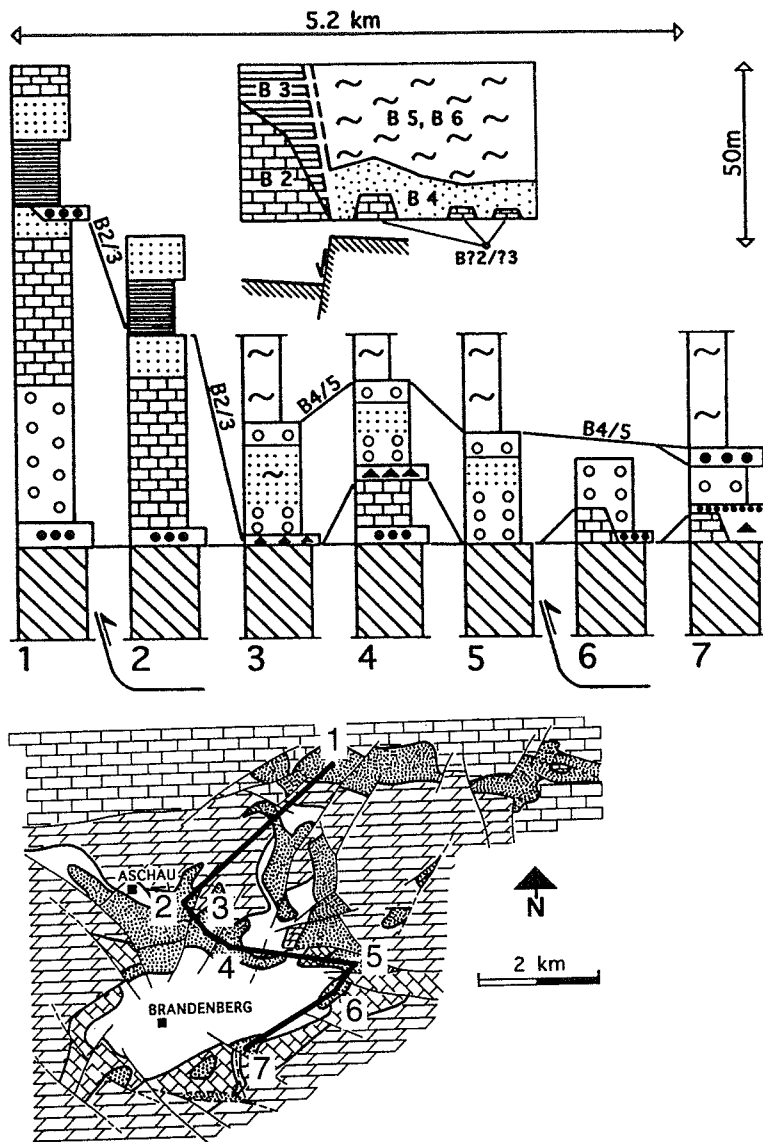


Fig. 14. Correlation of sections in part of the southern outcrop area of Brandenburg (inset shows position of sections; see fig. 5; legend as in fig. 3; open circles=calcilithic arenites) (from SANDERS, 1997 a). Datum is top of substratum. Thick lines labelled „B2/3“ and „B4/5“ correspond to sequence boundaries as described in SANDERS et al. (1997) and SANDERS (1997 a). Thrust planes with top NE to NNE are indicated. Inset figure on top shows the correlation of physical stratigraphic units along the transect covered by the sections. Sequence B2 consists of a lower part of lithic calcirudites and calcilithic arenites, and an upper part mainly of shallow neritic limestones. Sequence B3 is based by a fluvial conglomerate and/or a cyclic paralic succession which, in turn, is overlain by shore zone arenites and neritic limestones. Along the transect, from north to south, the sequences B2 and B3 (together of latest Turonian-Coniacian age) rapidly disappear, and the substratum is overlain by sequence B4 of Early Santonian age. In its lower part, sequence B4 consists of lithic calcirudites and bryozoan arenites; the middle part consists of marly arenites that pinch out towards the south. The top of sequence B4 consists of a sharp-based package of calcilithic hybrid arenites and, at the southern margin of outcrop, of a cobble conglomerate. The top of sequence B4 is a surface with a rugged morphology that is sharply overlain by the „*Inoceramus* marls“ of the successive sequence B5 (see fig. 7B; Pl. 31/8). Below sequence B4, erosional remnants composed mainly of Upper Cretaceous shallow-water limestones are locally present, and are subconcordantly overlain by the succession of B4.

row-mottling, however, preclude persistently dysaerobic to anaerobic conditions within or closely above the sediment. It is thus likely that fluctuations of oxygen level occurred, at least within the sediment, during and closely after deposition of the marls. The record of low oxygen content may result from impingement of the oceanic oxygen minimum layer onto the shelf and/or because of a high sediment accumulation rate.

4.7 Arenites

4.7.1 Paralic arenites

Two facies types are distinguished, (1) heterolithic arenites and mudstones, and (2) beds of bioclastic hybrid arenites.

(1) Together, heterolithic arenites and mudstones and horizontally-parallel laminated arenites to siltstones locally build intervals less than a metre thick. The heterolithic facies consists of lenticular- to flaser-bedded, well-sorted fine-grained arenite separated by drapes of siltstone-mudstone. Individual flasers consist of unidirectionally inclined laminasets; vertically stacked flasers typically show

bidirectionally inclined laminasets, separated by drapes up to a few millimeters thick of siltstone to mudstone rich in detrital micas. Locally, thin intervals of stacked climbing ripple laminasets are present. Aside from scarce, fine plant debris, fossils are absent. The horizontally-parallel laminated arenites consist of laminae of micaceous fine-grained sand to coarse silt, alternating with laminae of silt with fine coal debris. An interval a few decimeters thick of heterolithic arenites and mudstones was observed only at one location, whereas intervals up to about 10 cm thick of parallel-laminated arenites to siltstones are more common.

(2) The bioclastic hybrid arenites occur in beds several centimeters to approximately 30 cm thick that are sharply intercalated between „rooted marls“, and locally pinch out within less than a metre. These arenites show crude horizontal lamination or are mottled by burrows, and contain a scarce matrix of marl and/or a scarce, poorly developed carbonate cement. The arenites are very poorly to moderately well-sorted; the biogenic fraction includes *Cassiope*, *Cerithium* spp., *Actaeonella*, *Trochactaeon*, juvenile nerineids, *Pyrgulifera*, fragments from radiolitids, hippuritids, corals, echinoderms, red algae, and cryptmicrobial lumps.

Facies Association	Designation	Characteristic lithologies	Interpretation
1	Alluvial fan-fan delta deposits	Poorly to moderately sorted breccias and conglomerates with a matrix of red silty mudstone, cross-laminated calcilithic arenites, beachface conglomerates, shoreface conglomerates	Deposition from alluvial fans, and in the subaerial and subaqueous part of fan deltas
2	Fluvial to paralic (bay-estuarine) deposits	Siliciclastic conglomerates, „blocky“ unfossiliferous Sst., „massive“ to flaser-bedded marly Sst. to siltstone with oysters, infaunal bivalves and cerithiaceans	Deposition within river channels, and in bay/estuarine environments
3	Cyclic paralic deposits	Cross-laminated Sst., low-angle cross-laminated Sst., rooted marls, organic-rich („bituminous“) Lst., coal	Cyclic deposition from shoreface to marsh environments
4	Carbonate lagoonal deposits	Radiolitic bafflestones to rudst., floatstones to rudst. rich in nerineids and/or actaeonellids, sandy to marly bioclastic wkst. to pkst. with smaller benthic foraminifera and calcareous green algae, organic-rich („bituminous“) lime mudstones	Deposition in short-lived carbonate lagoons within an overall siliciclastic depositional environment
5	Shore zone deposits	Marine cliff talus breccias, beachface conglomerates, shoreface conglomerates, cross-laminated and low-angle arenites (Sst. to hybrid arenite to calcilithic arenite)	Nearshore deposition in association with transgressive gravelly to rocky shores (subtype 5a), with regressive sandy beaches (subtype 5b), and with tidal channel-swash platform/spit depositional systems (subtype 5c)
6	Siliciclastic shelf deposits	Hummocky cross-laminated Sst., bioturbated Sst and marls with ammonites, echinoids, infaunal and epifaunal bivalves, carnivorous gastropods, solitary corals, and planktic foraminifera (locally)	Deposition from a wave-dominated, inner to outer shelf environment
7	Carbonate shelf deposits	Floatstones to boundst. with colonial corals, rudists and skeletal sponges, rudist bafflestones to floatstones to rudstones, bioclastic grainstones. to packstones, bioclastic packstones to wackestones. with smaller benthic foraminifera and calcareous green algae, foraminiferal wackestones to packstones, peloidal packstones. to wackestones	Deposition on a small, but comparatively long-lived carbonate shelf

Tab. 1. Facies associations distinguished in the investigated area. Sst. = sandstone; Lst. = Limestone. See text for description of lithologies and discussion.

A mixture of more or less bored and micritized bioclasts with angular, unbored/unmicritized bioclasts is typical.

Interpretation: For the heterolithic arenites and mudstones, their sedimentary structures indicate that they have been deposited from siliciclastic tidal flats (e. g. KLEIN, 1977; WEIMER et al., 1982; RENNIE, 1987). Because of limited outcrop, the geometry of the interval of heterolithic sandstones to mudstones cannot be constrained; they may occur as the filling of a shallow tidal channel (e. g. BARWIS, 1978; WEIMER et al., 1982; RENNIE, 1987). The thin intervals of horizontally-parallel laminated arenites may be of high-intertidal and/or of eolian origin.

For the bioclastic hybrid arenites, the mixture of fossils from both normal-marine and paralic environments (cf. SANDERS et al., 1997), the poor sorting of both the sand and the bioclastic fraction, the relative thinness of the arenite beds, their sharp lower boundaries and their presence within successions of „rooted marls“ indicate that these arenites were deposited during high-energy events, possibly from storm washover lobes (cf. DEERY & HOWARD,

1977; MORTON, 1978) or during flooding of the paralic swamps by tsunamis (e.g. MINOURA et al., 1997).

4.7.2 Lagoonal arenites

These are locally marly, poorly to moderately well-sorted, fine- to coarse-grained sandstones to bioclastic hybrid arenites, typically with a matrix of more or less marly lime mud (Pl. 30/8). Aside from mollusc fragments, the biogenic fraction is characterized by highly variable amounts of actaeonellids, nerineaceans, cerithiaceans, radiolitids, oysters and other non-rudist bivalves, calcareous green algae, lituolids, textularids, miliolids, ataxophragmiines, ostracods, serpulids, bryozoans, echinoderms, fish teeth, cryptmicrobial lumps, fragments from calcified filamentous cyanobacterial colonies, coalified plant debris and fragments from branched corals. These arenites are mottled by endichnial burrows (incl. *Thalassinoides*) filled by muddy siliciclastic sand, mud-lined burrows, and burrows with spreiten. These arenites are locally associ-

ated with sandstones to calcilithic hybrid arenites that show inclined tangential- and sigmoidal cross-laminasets (fig. 11). Individual laminasets are about 50 cm in height, and may occur stacked, with a bidirectional or unidirectional dip of laminae in successive laminasets. The cross-laminated arenites locally contain a few abraded fragments from actaeonellids, nerineids, radiolitids, and red algae. Beds of arenite, very rich in abraded shells of *Actaeonella* („*Actaeonella* arenite“) (fig. 9; fig. 11) or of sandstone with a lime mud matrix and abundant nerineids („nerineid arenite“) are locally present. The beds of „*Actaeonella* arenite“ that are vertically associated with cross-laminated arenite show an erosive base, or are bioturbated.

Interpretation: The described arenites were deposited in a normal marine, lagoonal environment of overall moderate water energy (cf. e. g. GALLOWAY & HOBDA, 1983: p. 132; FINKELSTEIN & FERLAND, 1987). The cerithiaceans, the actaeonellids, nerineaceans, the ostreids and the pteriomorphs, the calcareous green algae and the miliolids all are characteristic for lagoonal environments. A portion of the bioclasts, like the radiolitid fragments and the rare coral fragments, may also have been brought into the lagoon by storm spillover. For the „*Actaeonella* arenites“ and the „nerineid arenites“ a modification of the gastropod beds by high-energy events is suggested by the erosive base of some of the beds, and by the coarse fragmentation and abrasion of many shells. The cross-laminated arenites that are locally associated with the bioturbated arenites were deposited under the influence of tides in a lagoonal environment (see e. g. DONSELAAR, 1989: table 1), probably in association with small tidal deltas (e. g. BOOTHROYD, 1978; GALLOWAY & HOBDA, 1983).

4.7.3 Tidal channel arenites

At a few locations, intervals up to about 3 meters thick are present that consist of a lower part either of marly, bioturbated arenite with coalified plant fragments and with shells of marine molluscs, or of arenite with stacked, unidirectionally inclined laminasets and inclined oblique-tangential cross-laminasets arranged in a bidirectional fashion (fig. 8). This lower interval is overlain, in the upper part of the arenite intervals, by a single or several stacked sets of oblique-tangential to sigmoidal beds up to about 80cm in height. Individual bedsets are laterally persistent over tens of meters (Pl. 31/1). Internally, at least some of the bedsets show bundles of sigmoidal laminae. The bedsets consist of medium-grained arenite and, locally, pebbly arenite. Between the unidirectionally inclined bedsets, flat lenses of arenite with oblique-tangential lamination with an opposite direction of lamina dip (relative to the underlying bedset), or subhorizontal, thin beds of fine gravel conglomerate are locally intercalated (Pl. 31/1). The upper part of the arenite intervals is either topped by an interval of sandstone with low-angle cross-lamination, or is topped by an interval of siliciclastic beachface conglomerate as described above (fig. 8).

Interpretation: The vertical succession and the nature

of sedimentary structures particularly the laterally extensive, unidirectionally inclined sets of sigmoidal to tangential-oblique beds, as well as the overlying intervals of low-angle cross-laminated sandstone or siliciclastic beachface conglomerate all suggest that the described arenites were deposited in association with tidal inlet-swash platform/spit depositional systems (cf. HOYT & HENRY, 1967; KUMAR & SANDERS, 1974; GALLOWAY & HOBDA, 1983; CHEEL & LECKIE, 1990; RICHARDS, 1994; VAN HETEREN & VAN DE PLASSCHE, 1997). The relative thinness of the channel-fills suggests a microtidal to low-mesotidal regime (cf. HAYES, 1980; IMPERATO et al., 1988; SIRINGAN & ANDERSON, 1993).

4.7.4 Shore zone arenites

These arenites range in composition from calcilithic arenites to calcilithic hybrid arenites to, less commonly, bioclastic hybrid arenites. They show low-angle cross lamination, tangential-oblique laminasets separated along erosive surfaces and, locally, sigmoidal cross-laminasets with well-preserved topsets. Unidirectionally inclined, oblique-tangential laminasets may be up to more than a meter in length, or are arranged in an epsilon cross-laminated fashion. Along the erosive surface between the laminasets locally thin lenses of siliciclastic conglomerates and/or more or less fragmented and abraded coral heads, hippuritids, radiolitids, potamidids, *Trochactaeon*, red algal fragments, fragments from diverse non-rudist bivalves, and a few smaller benthic foraminifera may be present. In the cross-laminated arenites, dewatering structures (thin fluidization channels, distorted inclined cross-lamination) are locally common. In the low-angle cross-laminated arenites, the bioclastic content (miliolids, textulariaceans, fragments from rudists, actaeonellids, oysters and other molluscs, red algae and echinoderms) amounts to a few percent at most. They typically are cemented by a first generation of thin, isopachous fringes of calcite or dolomite, and a second generation of blocky calcite spar or of dolomite (Pl. 31/2). The low-angle cross-laminated arenites locally contain levels with *Ophiomorpha* and/or *Stelloglyphus* (fig. 11).

Interpretation: The sedimentary structures and the trace fossils indicate that the described arenites were deposited in a wave-dominated shore zone environment. The arenites with the oblique-tangential cross-laminasets were deposited in an upper shoreface environment; the intervals of low-angle cross-laminated arenites with the isopachous fringes of carbonate cement record a foreshore environment (cf. CAMPBELL, 1971; CLIFTON et al., 1971; DAVIES et al., 1971; KRAFT, 1971; HEWARD, 1981).

Bryozoan arenite: These include calcilithic arenites to hybrid arenites with up to about 30% of bioclastic material, between zero to a few percent of siliciclastic sand and, locally, substantial amounts of glauconitized grains (Pl. 31/3, 4). The bryozoan arenites were deposited during a major Early Santonian transgression (cf. fig. 3, fig. 5; SANDERS, 1997 b) (cf. IBRAHIM, 1976; HERM et al., 1979; IMMEL et al., 1982; TRÖGER & SUMMESBERGER, 1994;

SUMMESBERGER & KENNEDY, 1996) that affected most of the Northern Calcareous Alps (WAGREICH & FAUPL, 1994). These arenites occur in successions up to about 20 m thick, and typically overlie a truncated substratum of Triassic to Upper Cretaceous rocks. Along the contact, the older carbonate rocks are either penetrated by *Trypanites*, or the contact is plane and unbored. The calcilithic arenite fraction is derived from the Triassic to Upper Cretaceous substratum. Isolated, reworked Upper Cretaceous bioclasts (e.g. corals, rudists, smaller benthic foraminifera) are common. The reworked bioclasts are blackened or stained red, coated by micrite rims and/or are bored by clionids and lithophagids; the intraskeletal pores typically are filled by dark red mudstone. The penecontemporaneous bioclastic fraction is characterized by branched bryozoans, lagenids, echinoid fragments, rhynchonellids, rhodoliths, fragments from encrusting corallines, fragments from inoceramids and oysters, rotaliids, textulariaceans, ataxophragmiines, placopsilinines, planktic foraminifera, and, locally, a few radiolitic fragments, sponge spicules and rare solitary corals (SANDERS, 1997 b). In the basal part of the succession, at a few locations these arenites show horizontal-parallel lamination and inclined cross-laminations, but most commonly are bioturbated. Locally, a veneer of gravels to boulders of Triassic to Upper Cretaceous rocks is present at the base of the successions of bryozoan arenites.

Interpretation: The local, basal veneer of gravels to boulders embedded in a matrix of arenites, the sharp and locally bored contact between the truncated substratum and the arenite succession, the paucity of sedimentary structures that indicate a foreshore environment, and the local presence of penecontemporaneous planktic foraminifera even in the basal part of the succession all suggest that the bryozoan arenites were deposited in front of a more or less steeply inclined to cliffed carbonate rock shore (SANDERS, 1997 b; cf. SEMENIUK & JOHNSON, 1985; FLINT & SKINNER, 1974; WHITE et al., 1984). The foreshore to upper shoreface of rocky shores is a zone of sediment by-pass, while in waters of about 10 m to nearly hundred meters in depth, sediment wedges up to a few kilometers in width may develop that slope towards a deeper shelf environment (FIELD & ROY, 1984). These wedges are composed of the sand derived from coastal erosion and an autochthonous bioclastic fraction (FIELD & ROY, 1984; BLANC, 1972). Such a deep neritic environment is favourable for the growth of branched bryozoans, and allows for the encroachment of planktic foraminifera and radiolarians and their mixing with benthic foraminifera (cf. BONE & JAMES, 1993; LI et al., 1996). The lateral variations in the basal part of the Santonian transgressive succession are ascribed to the marked lateral variability of rocky shores with respect to morphology, water depth and sediments (see e. g. LEWIS, 1977; DAVIS, 1978; ROY et al., 1980). The presence of glauconite is related to input of iron from areas with lateritic weathering in a subtropical to tropical, humid climate, combined with dysaerobic waters and/or anoxic-oxic interfaces above iron-reducing oceanic bottom waters or pore waters (FÖLLMI, 1989; GLENN & ARTHUR, 1990).

4.7.5 Shelf arenites

These typically consist of moderately to well-sorted, medium- to fine-grained sandstones to calcilithic hybrid arenites with a bioclastic content up to about 10 percent, and a matrix of marl to marly lime mudstone. The spectrum of macrofossils includes rudists, non-rudist bivalves, gastropods (e. g. potamidids), ammonites, fragments from branched corals, coral heads, solitary corals, echinoids, textulariaceans, ataxophragmiines, fragments from both branched and encrusting corallines, rhodoliths, bryozoan fronds, fragments from sponges, brachiopods, and coalified plant debris (Pl. 31/5). These arenites are bioturbated or burrow-mottled, and appear „massive“ to indistinctly bedded to, locally, wavy- to lenticular-bedded. The bioturbated arenites are interspersed with beds up to nearly 1 meter thick of well-sorted, fine to medium sandstone with hummocky cross-lamination (Pl. 31/6; see also SANDERS et al., 1997: pl. 1/6), or with sets of swaley cross-laminated sandstone beds. In addition, in bioturbated arenites, beds up to nearly 1 meter thick of shallow-water bioclastic grainstone to bioclastic hybrid arenite are sharply intercalated (Pl. 31/7). The thickest beds show a scoured base that is overlain by a fossiliferous (*Vaccinites*, radiolitics, coral heads) conglomerate of subangular to very well-rounded and bored carbonate rock clasts, and well- to very well-rounded clasts of volcanics, quartzite, chert and, locally, of serpentinite, ophicalcite and metabasalt; some of the lithoclasts are encrusted by bivalves, serpulids, bryozoans and red algae. More commonly, these beds consist of a lower, faintly parallel-laminated part of coarse sand- to fine gravel-sized bioclastic material, an upper, horizontally laminated part of medium- to fine sand-sized shallow-water bioclastic material and, locally, a topmost part with tangential-oblique cross-lamination. These beds are cross-cut by *Ophiomorpha* and, at their top, are bioturbated. Where these beds are intercalated into shelf arenites rich in serpentine, they are dolomitized.

Interpretation: The successions of bioturbated arenites with intercalated beds of hummocky cross-laminated arenites were deposited in a lower shoreface to offshore-transitional environment (e. g. WALKER, 1985; JOHNSON & BALDWIN 1986; WALKER & PLINT, 1992). The two-layer graded beds of bioclastic rudstone to grainstone that are sharply intercalated into the bioturbated sandstones are interpreted as tempestites (e. g. KREISA, 1981; AIGNER, 1985; WAGREICH, 1988) that, depending on proximity and the specific characteristics of individual storm flows show variation with respect to mean grain size, composition and thickness (AIGNER & REINECK, 1982; SWIFT, 1985). Since the bioclastic content of the arenites that are vertically associated with the tempestites commonly amounts to a few percent at most, the origin of the relatively pure bioclastic composition of the tempestites is unknown. Possibly, most of the bioclastic material of the tempestites was transported by alongshelf storm flows (see SWIFT, 1985; DUKE, 1990; SIRINGAN & ANDERSON, 1994) from laterally adjacent, unpreserved shelf areas dominated by biogenic sediments. Similarly, the coarse conglomeratic beds up to nearly one

meter thick that are sharply intercalated into the bioturbated shoreface sandstones may have been produced during storms. Storm-induced fluid flows may attain velocities of 1.5-2m/s (WALKER & PLINT, 1992; SIRINGAN & ANDERSON, 1994, and references therein) and, if they transform into gravity flows (shelf turbidites; TILLMAN, 1985; SWIFT, 1985; MYROW & SOUTHARD, 1996: p. 880), their capacity for far-distance transport of coarse-grained material was even higher (see WALKER 1985: p. 393f.). In these beds, at least a part of the large fossils and the lithoclasts must have been transported to the site of deposition, since the vertically associated, bioturbated sandstones are relatively poor in large fossils and lithoclasts.

5 FACIES ASSOCIATIONS

5.1 Facies association 1: Alluvial fan-fan delta deposits

This association builds successions a few meters up to about hundred meters thick mainly of alluvial fan conglomerates (fig. 3) that locally visibly onlap the older substratum (SANDERS et al., 1997: pl. 1/5). At their base, the successions may contain mass flow megabreccias and/or gravel sheet breccias and rhegolithic breccias. The successions of facies association 1 are dominated by alluvial fan conglomerates, whereas intervals up to a few meters thick of red silty mudstone and calcilithic arenites comprise only a minor part. The successions of alluvial fan conglomerates typically show an overall upward fining/thinning development, from a lower part of more or less amalgamated beds of poorly sorted, fine gravel to cobble conglomerates to a middle and upper part where the conglomerates become better sorted and rounded, amalgamation of conglomerate beds becomes less common, and intercalated intervals of red silty mudstone and arenites become more common and thicker (e. g. SANDERS, 1996 b; SANDERS et al., 1997). The upward fining/thinning development from local mass flow megabreccias at the base to well-sorted, medium to fine conglomerates near the top, both the vertically increasing proportion and thickness of intervals of terra rossa and arenites, and the overall increase in the sorting of the conglomerates up-section indicate a transition from a proximal fan to a mid-fan to distal fan environment (e. g. WAGREICH, 1988). The composition of the rudites in facies association 1 of clasts derived from the local substratum indicate that the fans were fed from small catchment basins situated within the Northern Calcareous Alps (FAUPL et al., 1987; WAGREICH, 1989; SANDERS, 1996 b).

The alluvial fan deposits are typically overlain by successions up to some tens of meters thick that consist of a beachface conglomerate at the base, overlain by cross-laminated shore zone arenites with intercalated shoreface conglomerate. These successions were deposited in the subaqueous part of a fan delta (SANDERS, 1996 b, 1997 b) (cf. ETHRIDGE & WESCOTT, 1984; McPHERSON et al., 1988; NEMEC & STEEL, 1988; WAGREICH, 1989). The intervals of shore zone arenites locally consist of packages that each is

composed of an interval of stacked festoon cross-laminates in the lower part, separated by a plane erosive surface from an overlying interval less than a metre thick with horizontal lamination. These bedsets occur in a stacked fashion, and are intercalated with shoreface conglomerates and beds of hummocky cross-laminated calcilithic arenites. Both the packages of festoon cross-laminated/low-angle cross-laminated arenite and the beds of hummocky cross-laminated arenites record a wave/storm-dominated upper shoreface environment (cf. DAVIDSON-ARNOTT & GREENWOOD, 1976; SHIPP, 1984; GREENWOOD & MITTLER, 1985; GREENWOOD & SHERMAN, 1986; PUTNAM et al., 1997).

5.2 Facies association 2: Fluvial to paralic deposits

Lithologies of this facies association include the described fluvial siliciclastic conglomerates and sandstones and the interval a few meters thick of „blocky“, unfossiliferous sandstones near the base of the Upper Cretaceous succession. The fluvial siliciclastic conglomerate is incised into an Upper Cretaceous lagoonal succession of marly arenites, nerineid limestones, and marly floatstones with a diverse shallow-marine mollusc biota (SANDERS et al., 1997: pl. 2/5). The „blocky“ sandstones, by contrast, sharply overlie poorly sorted alluvial fan breccias. In both cases, the fluvial deposits are a few meters to about 10 meters thick, and are overlain by lithologies deposited in paralic/estuarine to lagoonal environments (facies association 3; see below). The vertical succession from fluvial deposits into paralic/estuarine to lagoonal deposits indicates that the fluvial channels were backfilled during a base-level rise that subsequently led to establishment of paralic environments on top of the former fluvial channels (SANDERS et al., 1997; cf. e.g. PUTNAM et al., 1997).

5.3 Facies association 3: Cyclic paralic deposits

This association consists of a wide variety of facies that have been deposited in environments ranging from the siliciclastic marine shore zone to freshwater marl lakes (e.g. fig. 9; fig. 10). In successions built by lithologies of facies association 3, the constituent facies are arranged in distinct stratal packages („cycles“) that commonly record, from bottom to top, an upward shallowing of water depth („hemicyclothem“ of HERM, 1977).

Two main types of cycles are distinguished, (1) Group A cycles are a few meters up to about 10 meters thick, and commonly start with cross-laminated shore zone arenites or, less commonly, an interval 10 to 30 cm thick of shoreface conglomerate. The shore zone arenites typically show stacked, inclined tangential-oblique laminates, and are overlain by low-angle cross-laminated arenites that were deposited in the foreshore; these, in turn, are overlain by bituminous limestones, rooted marls and coal seams that together represent the upper part of a cycle. The group A cycles show a sharp to, locally, distinctly erosive base (SANDERS, 1996 c).

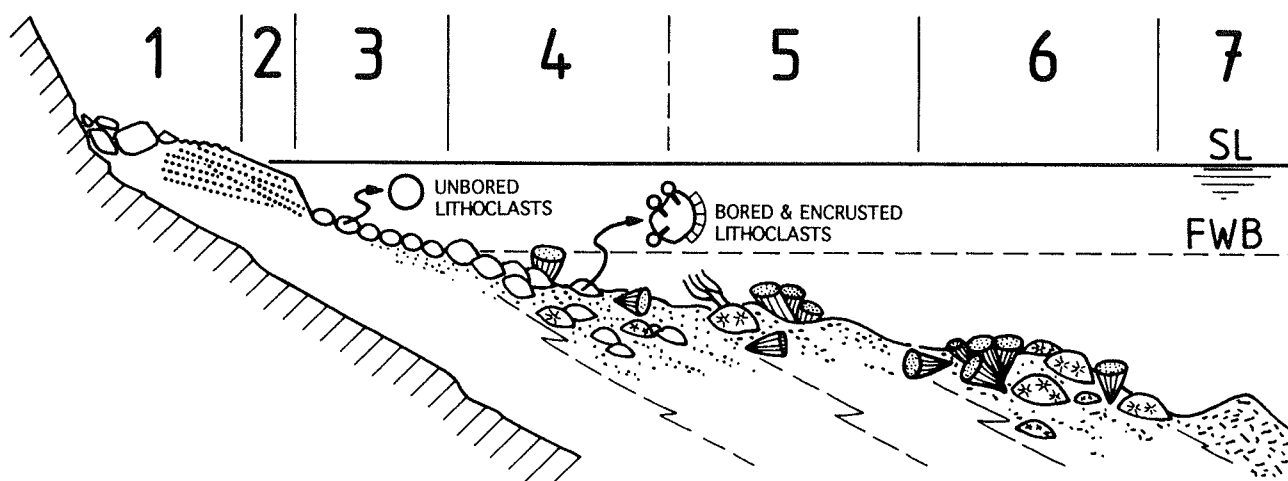


Fig. 15. Scheme of coastal cliffs fronted by gravel beach. SL=Sea-level; FWB=fairweather wave base. 1: Backshore, with local cliff collapse breccias. 2: Foreshore. The foreshore is steep and narrow, and terminates seaward with a plunge step. 3: Upper shoreface. Zone of unboiled, well-rounded medium gravels to small boulders. In this zone, the gravels to boulders are within fairweather wave base, but are moved only during storms. In the deposits of both zone 2 and 3, fossils are rare to absent. 4: Upper shoreface. Zone of bored and encrusted, well-rounded to subangular lithoclasts. In the energy regime of this zone, lithoclasts are at rest long enough to become bored and encrusted. Patches of litho-bioclastic sand, and shallow-water biota (rudists, algae, corals) are present. In this zone, the lithoclasts are moved only during heavy storms. Seaward, closely below to or within storm wave base, subtidal sand flats (5), coral-rudist bioconstructions (6) and subaqueous carbonate sand bodies (7) are present. Depending on the gradient of the substratum, rate of sea-level rise, and tidal range, this pattern may be more or less modified.

(2) Group B cycles are up to about 2 meters thick, and start with an interval of lagoonal marls to lagoonal arenites or, locally, arenites with a mass occurrence of either *Actaeonella* or of nerineid gastropods.

The lagoonal lithologies are sharply overlain by rooted marls, coal seams, bituminous limestone and intercalated beds of paralic arenites that together represent the upper part of a cycle (SANDERS, 1996 c; see also fig. 9). The bituminous limestones, rooted marls and coal seams in the upper part of both the group A cycles and the group B cycles are, in turn, arranged in „cycles“ a few centimeters to less than a metre thick; these small-scale cycles are not considered here. The paralic depositional system, including both types of cycles, is comparable to the Holocene paralic environment at Cape Sable, Florida (SANDERS, 1996 c).

5.4 Facies association 4: Carbonate lagoonal deposits

This association consists mainly of shallow-water carbonates from lagoonal to restricted marine environments. In this association, the carbonate facies are arranged in stratal packages that record an overall upward shallowing of depositional water depth, i.e. an upward shoaling „cycle“. Commonly, a single cycle or, less commonly, two such cycles are situated on the top of successions of arenites deposited in an inner shelf to foreshore environment.

The cycles typically range from less than a metre to about 2 meters in thickness, and start with an interval either of limestone with abundant nerineids and/or actaeonellids or with a radiolitid biostrome, overlain by bioclastic wackestone to packstone which, in turn, is topped by an

interval of bituminous limestone with smaller benthic foraminifera and/or with cryptomicrobial lamination that record complete shoaling. The bioclastic wackestone to packstone is typically thin, and is locally absent (fig. 10, upper part). Thin intervals of lagoonal marls (locally with *Phelopteria* and other non-rudist bivalves) may be present between the gastropod limestones and the overlying bituminous limestones. The deposition of facies association 4 thus occurred in carbonate lagoonal environments that, however, were quite limited in space and time.

5.5 Facies association 5: Shore zone deposits

In this association, according to the vertical arrangement of facies, three subtypes 5a, 5b and 5c are distinguished. Association 5a consists of a basal interval of shallow-marine calcirudite (beachface conglomerate, or a veneer of talus breccia to -megabreccia) that is overlain by shore zone arenites (incl. bryozoan arenites), locally with intercalated shoreface conglomerates. These successions are up to some tens of meters thick, and overlie the older substratum (fig. 7A, B, C). Up-section, the intervals of shoreface conglomerate become thinner, the shore zone arenites become bioturbated, and beds of hummocky cross-laminated arenites appear. The described association thus records transgression. Successions of facies association 5a are overlain by siliciclastic shelf deposits (facies association 6) or by carbonate shelf deposits (facies association 7).

Facies association 5b essentially consists of cross-laminated arenites deposited in a shoreface environment (with local shoreface conglomerates) and low-angle cross-

laminated arenites from a foreshore environment. In facies association 5b, the shoreface arenites are commonly overlain by the low-angle cross-laminated arenites from the foreshore, i. e. the facies succession records regression (cf. SANDERS, 1996 c). These regressive successions are locally overlain by deposits from facies associations 3 or 4. Less commonly, at the base of stratal packages some tens of meters thick, low-angle cross-laminated foreshore arenites (locally with associated beachface conglomerates) grade up-section into shoreface arenites (fig. 9, fig. 11).

Association 5c is present in intervals up to about 3m thick that probably were deposited from migrating tidal channel-swash platform/spit depositional systems (cf. RANDALL, 1977; GALLOWAY & HOBDAI, 1983), i.e. that consist of a lower part of arenites with stacked unidirectional and bidirectional, inclined laminasets and steeply unidirectionally inclined sets of accretion beds and an upper, relatively thin part of low-angle cross-laminated arenites or a beachface conglomerate. Successions of facies association 5c were observed above shallow neritic marls and above coral-rudist limestones (fig. 8). Although the vertical boundary between coral-rudist limestones and cross-laminated arenites appears sharp, thin sections show that the vertical transition from limestone to arenite was gradual and is mottled by burrows, but has been sharpened as a result of intergranular pressure solution in the arenites (Pl. 31/8).

5.6 Facies association 6: Shelf deposits

This facies association consists of shelf arenites, shallow neritic marls and/or „*Inoceramus* marls“ (fig. 7C). Both vertically and laterally, the relative proportion of arenites to marls is highly variable, and ranges from successions that consist exclusively of shelf arenites to

marl-dominated successions. In regressive siliciclastic shelf successions, in general the content of marl decreases with decreasing paleo-water depth; these successions typically consist in their lower part of shallow neritic marls with intercalated storm beds, and grade up-section by an overall thickening and increasing amalgamation of storm beds, into shelf arenites (SANDERS, 1996 b). Up-section, the shelf arenites record an overall increase in water energy by an increasing amount of preserved primary hydrodynamic structures (hummocky cross-laminasets, swaley cross-laminasets), and are overlain by facies association 5. In transgressive shelf successions, the vertical succession is the reverse. Locally, the sedimentary structures, the fossils and the vertically associated facies, however, indicate that the relative proportion of arenites to marls is mainly controlled by the energy regime along a shelf sector rather than by water depth. This is indicated for the described, fossiliferous shallow neritic marls which are intercalated with arenites deposited from tidal channels and from low-energy beaches.

5.7 Facies association 7: Carbonate shelf deposits

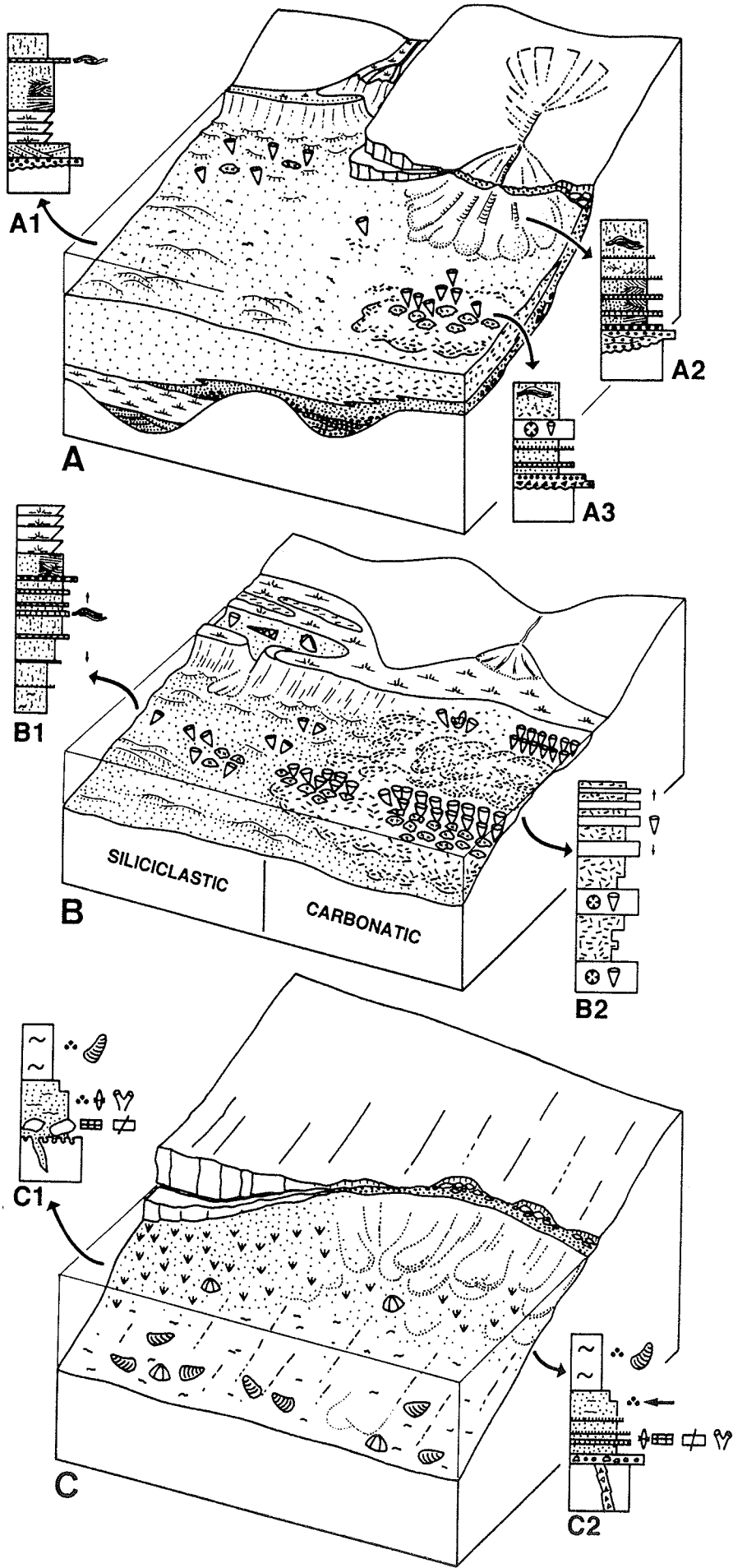
This facies association builds successions of shallow-water limestones up to nearly 100 m in thickness (fig. 7A; fig. 12) (SANDERS & BARON-SZABO, 1997). Within association 7, three main types can be distinguished. (7a) Stratal packages up to more than 20 m thick that consist of a coral-rudist mound at the base that is topped by a rudist biostrome which, in turn, are overlain by stratal packages of bioclastic grainstones to packstones and, locally, lagoonal marls. The stratal packages of bioclastic grainstones to packstones probably were deposited from episodically migrating dunes of bioclastic sand, in a more or less wide, dissipative shore zone (WRIGHT et al., 1979, cit. in LONG & ROSS 1989)

>>>

Fig. 16. Generalized schemes of facies distribution and -development in the Lower Gosau Subgroup of the investigated area (see text for further description and discussion). A: Turonian-Coniacian transgressive shelf, showing an articulated morphology along the basal truncation surface, and siliciclastic input by rivers and contemporaneous input of carbonate rock fragments from fan deltas. A1: Upon transgression, fluvial channels are back-filled, and are overlain by paralic successions which, in turn, are followed up-section by an upward-deepening succession mainly of shore zone to shelf arenites. A2: The subaerial part of fan deltas is overlain by an upward-deepening succession of calcilithic shore zone arenites with intercalated intervals of shoreface conglomerates, and bioturbated shelf arenites with intercalated beds of hummocky cross-laminated arenites. A3: Where the transgression occurred directly onto the older substratum, marine cliff talus breccias are overlain by an upward-deepening succession of calcilithic shore zone arenites with intercalated intervals of shoreface conglomerates; these, in turn, are overlain by coral-rudist mounds and associated bioclastic limestones and, higher up, by shelf arenites.

B: Turonian-Coniacian regressive shelf. B1: In areas of siliciclastic input, regressive shelf development is recorded by an upward-coarsening/shallowing succession from shelf marls/arenites into shore zone arenites, shoreface conglomerates and/or beachface conglomerates. Near the basin margin, paralic successions record cyclic deposition mainly in shoreface, lagoonal and marsh environments. B2: In areas of low siliciclastic input, small carbonate shelves with coral-rudist mounds, bioclastic sand bodies, and an open lagoon with rudist biostromes developed. Regressive carbonate shelf development is recorded by stacked stratal packages that become progressively thinner up-section and that record an overall shoaling of facies from inner shelf to lagoon.

C: Santonian transgressive shelf. C1: Transgression of rocky shores is recorded by a sharp vertical transition from a truncated carbonate rock substrate with neptunian dike-fills into shore zone arenites with branched bryozoans, corallines, echinid fragments, and planktic foraminifera. A veneer of gravels to boulders is locally present at the base. C2: Transgression of gravelly shores is indicated by beachface conglomerates which are overlain by shore zone arenites with intercalated intervals of shoreface conglomerates. Planktic foraminifera appear some distance up-section (arrow). The deeper shelf environment was characterized by deposition of marls with large inoceramids, echinids, ammonites and planktic foraminifera.



between an external facies belt of coral-rudist mounds and an open lagoonal environment (SANDERS & BARON-SZABO, 1997; SANDERS et al., 1997: fig. 7).

(7b) Rudist biostromes and bioclastic wackestones to packstones, and (7c) sponge-coral-rudist-microbialite limestones, bioclastic wackestones to packstones, thin intervals of bioclastic rudstones, and black pebble packstones. Each of the facies associations 7b and 7c builds successions up to a few tens of meters thick. Together, either the rudist biostromes or the sponge-coral-rudist-microbialite limestones and their respective associated lithologies are stacked into stratal packages of less than a meter to a few meters thick. At least some of these packages record a shoaling from a radiolitid biostrome or a sponge-coral-rudist-microbialite mound into wackestone to packstone to, finally, a black pebble packstone. Both facies association 7b and 7c formed in more or less calm, open subtidal to intertidal lagoonal environments that were episodically struck by storms. No facies indicative of muddy tidal flats has been found, like e. g. intervals of loferites, or upward shoaling cycles that could be ascribed to mudflat progradation or to migrating tidal channels.

6 THE LATE CRETACEOUS SHELF

6.1 Substrate morphology, tectonism

Both a pronounced and persistent relief of the truncation surface at the top of the substratum is indicated by the overall time-transgressive ?Middle/Late Turonian to Late Santonian „climb“ of the Upper Cretaceous deposits that immediately overlie the older substratum (fig. 4), by the mature paleokarst below the truncation surface, by the accumulations of pisoidic bauxite, by the alluvial fan-fan delta deposits, by a locally visible onlap of alluvial fan successions onto steeply inclined segments of the truncation surface (SANDERS et al., 1997: pl. 1/5), by mappable thinning and pinchout of alluvial fan successions onto the substratum, by mappable marked lateral variations in the thickness of the transgressive deposits and, ultimately, by the local interfingering of paralic marls with mass flow breccias that were derived from erosion of Triassic-Jurassic rocks (cf. SANDERS et al., 1997; SANDERS, 1997 a, b). During transgression, the morphology of the basal truncation surface influenced sea wave refraction and current flow, and induced alongshore variations both in water depth and -energy. This, in turn, influenced both the nature of the sediments deposited and the accommodation history during marine transgression.

The alluvial fan successions of some tens of meters to, rarely, about 100 meters are thin compared to successions in extension/strike-slip controlled basins, where alluvial fan successions hundreds to thousands of meters thick accumulate within a few Ma (e. g. MANSPEIZER, 1985; ANADON, et al. 1985; COLELLA, 1988; MARZO & ANADON, 1988; GAWTHORPE et al., 1994). Although the drainage basins of fans on faulted carbonate terrains are typically small (up to a few km²) and feed small, steep-gradient fan deltas (cf. PRIOR & BORNHOLD, 1988), within a few hun-

dreds of thousands of years the fan delta successions deposited are hundreds of meters thick adjacent to the fault hangingwall (e. g. GAWTHORPE et al., 1994). In the strike-slip controlled Central Alpine Kainach Gosau basin, the fan successions at the basin margins are hundreds of meters thick, and interfinger basinward with marls from paralic to marine environments and, higher up, probably also with turbidites (NEUBAUER et al., 1995). In the described Turonian-Coniacian succession, by contrast, thin alluvial fan-fan delta successions are overlain by deposits from shelf to paralic environments. In the recent outcrop area of the Turonian-Coniacian succession, the facies types, their distribution and thickness do not indicate a deposition close to the scarps of major active faults, and the lateral changes in thickness and facies probably largely result from onlap onto the deeply truncated substratum. Subsidence probably was largely accommodated by deep-seated detachment faults that were situated in areas where no Cretaceous deposits are present today, along the southern margin of the Northern Calcareous Alps, or southward thereof (FROITZHEIM et al., 1997; ORTNER & REITER, 1997). The evidence for an overall tectonic control over deposition of the Gosau Group (FAUPL et al., 1987; RATSCHBACHER et al., 1989; WAGREICH, 1991; WAGREICH & FAUPL, 1994; FROITZHEIM et al., 1997; SANDERS et al., 1997) and the local/intermittent lack of direct evidence for faulting thus appear compatible.

At Brandenberg, Late Cretaceous normal faulting and subaerial erosion are indicated by erosional remnants of an Upper Cretaceous succession of karstified shallow-water limestones below the subconcordantly overlying Santonian transgressive succession, by marked „jumps“ in the thickness of the Upper Cretaceous directly below the Santonian succession, and by the presence of normal fault cataclasites that probably formed in sandstones in an early, semilithified state (fig. 3, fig. 5; fig. 14). (SANDERS, 1997 a). In the area of Kufstein, in the substratum closely below the Upper Cretaceous neptunian dikes were found that are filled by angular lithoclasts of bryozoan arenites embedded in a matrix of wackestone with planktic foraminifera. The diagenesis in the lithoclasts records several phases of subaerial exposure, microkarstification and brecciation before the final embedding of the clasts. One or several phases of subaerial exposure, erosion and penecontemporaneous faulting thus is indicated for the time interval closely before and/or during the Early Santonian.

Thus, two stages in the evolution of the investigated area may be distinguished, (1) a Turonian-Coniacian phase with little direct evidence for faulting, and (2) a ?late Coniacian to Santonian phase with subaerial exposure, erosion and faulting. The morphologic relief at the base of the Upper Cretaceous succession thus was not only inherited from pre-Turonian subaerial erosion, but was also shaped by later faulting and erosion. A marine transgression during the Early Santonian commenced a marked deepening of facies that led to the deposition of the bryozoan arenites, the „*Inoceramus* marls“ and, finally, of the overlying deep-water succession of the Upper Gosau Subgroup (see fig. 14) (SANDERS, 1997 a, b).

6.2 Facies distribution and dynamics

Because of the difference between the Turonian-Coniacian and the Upper Coniacian-Santonian succession, separate reconstructions of the terrestrial to shelf environment are presented for each time interval (fig. 16).

Turonian to Coniacian: The dominance of siliciclastics indicates a persistent input by rivers that, at least within certain segments and within certain stages of their evolution, were low-sinuosity, bed-load dominated rivers. Similar characteristics might have pertained also to at least a part of nowadays unpreserved fluvial systems, as suggested by the siliciclastic shore zone conglomerates. The clasts of the conglomerates, however, may have been transported to the site of ultimate deposition by repeated cannibalization of older deposits during uplift of the Eo-Alpine orogen. The siliciclastic rivers co-existed with fan deltas that were fed from catchment basins within the Northern Calcareous Alps, and with rocky carbonate shores (fig. 16 A).

Because of incomplete preservation of depositional sequences, the landward part of the lowstand systems tract cannot be unequivocally distinguished from the base of the transgressive systems tract (see SANDERS et al., 1997, for discussion). In the transgressive systems tract, where fan deltas were present, these developed in an overall retrogradational fashion (fig. 16 A). The fan deltas were fringed by a gravelly beachface while, in the subaqueous part of the deltas, shore zone arenites and shoreface conglomerates were deposited. Where fan deltas were absent, transgression onto rocky carbonate headlands led to cliff coasts and gravelly beaches that are recorded by talus breccias, beachface conglomerates and successions of calcilithic shore zone arenites with associated shoreface conglomerates (fig. 7A, 7C, fig. 15). The reconstruction of the rocky to gravelly beach environment (fig. 15) is characterized by (1) a planation of the substratum by coastal erosion from an originally higher gradient to a lower gradient (see e. g. FLINT & SKINNER, 1974: p. 249; WHITE et al., 1984: p. 370), (2) a backshore to upper shoreface belt dominated by conglomerates and lithic carbonate sand that both are poor in or devoid of fossils, and (3) by a lower shoreface belt with bored and encrusted carbonate lithoclasts, lithic carbonate sand, bioclastic sand, corals and rudists that grades seaward into inner shelf deposits (biogenic limestones and/or siliciclastics). Adjacent to headlands or to fan deltas, sandy siliciclastic beaches were present. Siliciclastic gravel beaches were either associated with a sand-starved, transgressive beachface or, in a regressive context, with gravel spit barriers or swash platforms that locally overlie thin tidal channel-fills (fig. 8). In areas of high siliciclastic input, similar to Holocene transgressive records (e. g. SIRINGAN & ANDERSON, 1993; PUTNAM et al., 1997), deposition in fluvial-estuarine environments was followed by deposition in siliciclastic lagoonal to shoreface environments. In the transgressive systems tract, intervals of coral-rudist limestones and of rudist limestones range in thickness from less than a metre to a few meters, and are

intercalated into thicker successions of shelf arenites and shore zone arenites.

The siliciclastic highstand systems tract is characterized by an overall upward-coarsening succession from shelf marls into shelf arenites and shore zone arenites (section B1 in fig. 16). Deposition in the inner shelf to shoreface environment was dominated by waves, storm waves and storm-induced currents. Near the basin margin, the inner shelf to shoreface deposits are overlain by cyclic paralic successions (SANDERS, 1996 c; SANDERS et al., 1997). In the paralic successions, tides are only scarcely recorded as thin intervals of flaser-bedded, heterolithic arenites and mudstones. Overall, the scarce evidence of tide-influenced deposition from paralic to shelf environments, the thinness and the scarcity of tidal inlet-fills, the evidence for barrier islands backed by lagoons (cf. SANDERS, 1996 c), the co-existence of beach barriers and tidal inlets and the scarce record of tidal flats all indicate a microtidal to low-mesotidal environment (HAYES, 1975, cit. in BOOTHROYD, 1978: p. 289; BARWIS & HAYES, 1979, cit. in GALLOWAY & HOBDAI 1983: fig. 6-4; ISRAEL et al., 1987). In brackish or schizohaline parts of the lagoons, oyster banks accumulated. In normal saline lagoonal areas with a bottom of sandy mud, diverse infaunal and epifaunal bivalves thrived. In open lagoons with a bottom of sand to muddy sand radiolitids, nerineaceans, actaeonellids, coralline algae, calcareous green algae and smaller benthic foraminifera were present. Where a lagoon or a part thereof was shut off from siliciclastic input, radiolite biostromes, gastropod limestones, mounds with sponges, rudists and corals, and bioclastic packstone to wackestones were deposited. In the highstand, relatively thick „catch-up“ successions of coral-rudist-sponge limestones, rudist biostromes, and bioclastic limestones accumulated in areas that were protected from siliciclastic input (section B2 in fig. 16 B) (SANDERS & BARON-SZABO, 1997).

Upper Coniacian to Santonian: In Brandenburg, the part of the Santonian succession that belongs to the Lower Gosau Subgroup can be subdivided into two superposed, unconformity-bounded units that are interpreted as parts of depositional sequences (see fig. 3; SANDERS, 1997 a). In the lower unit, the transgressive systems tract consists largely of shallow-marine calcirudites overlain by bryozoan arenites with glauconite. The Santonian transgression took place onto a relatively steeply sloping to cliffed carbonate rock substrate (see above), either in association with rocky shores (section C1 in fig. 16 C) or with narrow, steep gravelly shorefaces (section C2 in fig. 16 C). The bryozoan arenites grade up-section into a package of marly, bioturbated shelf arenites with inoceramids and ammonites; the shelf arenites are interpreted as the highstand systems tract. At the top of the shelf arenites, a sharp-based package of calcilithic arenites with bioclastic material is present; the arenite package is topped by a deeply corrugated exposure surface (Pl. 31/8) (SANDERS, 1997 a). The exposure surface is directly, without intervening shore zone deposits, overlain by „*Inoceramus* marls“ that comprise the lower part of the overlying unconformity-bounded

unit. The „*Inoceramus* marls“ were deposited in a muddy, deeper shelf environment that was subject to episodes of dysoxia to anoxia, at least within the sediment. A reduced oxygen content may result from impingement of the oceanic oxygen minimum layer onto the shelf and/or because of a high accumulation rate of both clastic sediment and organic carbon. Towards their top, the „*Inoceramus* marls“ grade into thin-bedded, red marls that probably were deposited in a slope environment. These marls mark the transition into the Upper Gosau Subgroup.

7 CONCLUSIONS

The Turonian to Santonian succession was deposited above a deeply incised, articulated truncation surface on top of the Eo-Alpine orogen.

The combination of high rates of both subsidence and sediment accumulation with a shelf that was compartmentalized with respect to

- (a) morphology of the substratum,
- (b) river input of siliciclastics and contemporaneous input of carbonate clasts from fan deltas,
- (c) deposition of biogenic shallow-water carbonates,
- (d) water energy and -depth gave rise to a very wide spectrum of facies.

During Turonian to Coniacian times, the shelf was microtidal to low-mesotidal, and was dominated by waves, storm waves and storm-induced currents. Larger tidal flats (siliciclastic, carbonatic) were absent. In vegetated marsh swamps, schizohaline to freshwater marl lakes existed. Transgressions occurred onto fan deltas and deltas, or in association with gravelly to rocky shores. Transgressive successions from gravelly to rocky shores are overlain by regressive successions of shelf carbonates or shelf siliciclastics. Because of persistent siliciclastic input, deposition of shallow-water carbonates generally was confined to areally/temporally limited carbonate lagoons. A „catch-up“ succession of shelf carbonates about 100 m thick accumulated only in an area protected from siliciclastic input. In its preserved parts, the Turonian to Coniacian succession does not indicate deposition adjacent to major active faults. Lateral changes in thickness result, at least mainly, from onlap onto the articulated basal truncation surface. Fault-induced subsidence possibly occurred along major detachment faults outside the outcrop area.

During Coniacian to Early Santonian times, the older substratum and the overlying Cretaceous succession were subaerially exposed, faulted and deeply eroded. The following Early Santonian transgression took place with gravelly to rocky shores ahead of a narrow shoreface-inner shelf environment and a muddy, deep shelf. The transgression was associated with the influx of cooler and/or nutrient-rich waters, and heralds an overall deepening. In its early stage, the deepening was interrupted by at least one phase of subaerial exposure. Subsequently, neritic deposition was terminated by deepening into bathyal depths.

≠ACKNOWLEDGEMENTS

Heinz Kollmann, Herbert Summesberger, and Michael Wagneich, all at Vienna, are thanked for determination of some fossils, for discussions as well as for partake in the field, as are Karl Krainer, Hugo Ortner, Wolfgang Mette, and Volkmar Stingl, Innsbruck. Paul Enos, Kansas, and Iwan Stössel, Zürich, are acknowledged for discussions on the paleontology and ecology of rudists and for field visits. Josep Maria Pons, Barcelona, is thanked for his profound help and interesting discussions with respect to paleontology, sedimentology and ecology of rudists. Michael Wagneich, Vienna, and Karl Krainer, Innsbruck, provided careful reviews. Financial support from project P-10719 GEO is acknowledged.

REFERENCES

- ABERHAN, M. (1994): Guild-structure and evolution of Mesozoic benthic shelf communities. - *Palaios*, **9**, 516-545, Tulsa
- ACKER, K. L. & STEARN, C. W. (1990): Carbonate-siliciclastic facies transition and reef growth on the northeast coast of Barbados, West Indies. - *J. Sed. Petrol.*, **60/1**, 18-25, Tulsa
- ACCORDI, G., CARBONE, F. & SIRNA, G. (1982): Relationships among tectonic settings, substratum and benthonic communities in the Upper Cretaceous of Northeastern Matese (Molise, Italy). - *Geol. Rom.*, **21**, 755-793, Roma
- AIGNER, T. (1985): Storm Depositional Systems. Dynamic Stratigraphy in Modern and Ancient Shallow-Marine Sequences. - *Lecture Notes in Earth Sciences*, **3**, 174 pp., Berlin (Springer)
- AIGNER, T. & REINECK, H.-E. (1982): Proximity trends in modern storm sands from the Helgoland Bight (North Sea) and their implications for basin analysis. - *Senckenbergiana marit.*, **14**, 183-215, Frankfurt
- AMPFFERER, O. (1921): Über die kohleführenden Gosauschichten des Brandenberger- und Thierseer Tales in Tirol. - *Jb. geol. Staatsanst.*, **71**, 149-158, Wien
- ANADON, P., CABRERA, L., GUIMERA, J. & SANTANACH, P. (1985): Paleogene strike-slip deformation and sedimentation along the southeastern margin of the Ebro basin. - In: BIDDLE, K. T. & CHRISTIE-BLICK, N. (eds.): *Strike-Slip Deformation, Basin Formation, and Sedimentation*. - *Soc. Econ. Paleont. Min. Spec. Publ.*, **37**, 303-318, Tulsa
- BARDOSSY, G. (1982): Karst Bauxites. Bauxite Deposits on Carbonate Rocks. - *Developments in Economic Geology*, **14**, 1-441, Amsterdam
- BARWIS, J. H. (1978): Sedimentology of some South Carolina tidal-creek point bars, and a comparison with their fluvial counterparts. - In: MIALL, A. D. (ed.): *Fluvial Sedimentology*. - *Can. Soc. Petrol. Geol. Memoir*, **5**, 129-160, Calgary
- BEHR, K. & BEHR, H.-J. (1976): Cyanophyten aus oberjurassischen Algen-Schwamm-Riffen. - *Lethaia*, **9**, 283-292, Oslo
- BERTRAN, P., HÉTU, B., TEXIER, J.-P. & VAN STEIJN, H. (1997): Fabric characteristics of subaerial slope deposits. - *Sedimentology*, **44**, 1-16, Oxford
- BLANC, J. J. (1972): Observations sur la sédimentation bioclastique en quelques points de la marge continentale de la Méditerranée. - In: STANLEY, D. J. (ed.): *The Mediterranean Sea. A Natural Sedimentation Laboratory*. - 225-240, Stroudsburg (Dowden, Hutchinson & Ross)
- BLUCK, B. J. (1967): Sedimentation of beach gravels: Examples from South Wales. - *J. Sed. Petrol.*, **37/1**, 128-156, Tulsa
- BONE, Y. & JAMES, N. P. (1993): Bryozoans as carbonate sediment producers on the cool-water Lacedpede Shelf, southern Australia. - *Sedim. Geol.*, **86**, 247-271, Amsterdam (Elsevier)
- BOOTHROYD, J. C. (1978): Mesotidal inlets and estuaries. - In: DAVIS, R. A., Jr., (ed.): *Coastal Sedimentary Environments*, 287-360, New York (Springer)

- BOOTHROYD, J. C. & NUMMEDAL, D. (1978): Proglacial braided outwash: a model for humid alluvial fan deposits. - In: MIALL, A. D. (ed.): *Fluvial Sedimentology*. - Can. Soc. Petrol. Geol. Mem., **5**, 641-668, Calgary
- BOSENCE, D. W. J. & BRIDGES, P. H. (1995): A review of the origin and evolution of carbonate mud-mounds. - In: MONTY, C. L. V., BOSENCE, D. W. J., BRIDGES, P. H. & PRATT, B. R. (eds.): *Carbonate Mud-Mounds*. - Spec. Publ. int. Ass. Sediment., **23**, 3-9, Oxford (Blackwell)
- BOURGOIS, J. & LEITHOLD, E. L. (1984): Wave-worked conglomerates-depositional processes and criteria for recognition. - In: KOSTER, E. H. & STEEL, R. J. (eds.): *Sedimentology of Gravels and Conglomerates*. - Can. Soc. Petrol. Geol. Mem., **10**, 331-343, Calgary
- BRANDNER, R. (1985): *Geologie und Tektonik-Geologische und tektonische Übersichtskarte von Tirol*. - In: *Tirol-Atlas* (geleitet von Wilfried Keller). *Tiroler Heimat, Jahrbuch für Geschichte und Volkskunde*, Bd. 48/49, 1985; 3 Karten, 12 Seiten Text; Innsbruck
- BROMLEY, R. G. & EKDALE, A. A. (1984): *Chondrites*: A trace fossil indicator of anoxia in sediments. - *Science*, **224**, 872-874, Washington
- BRONGERSMA-SANDERS, M. (1957): Mass Mortality in the Sea. - In: HEDGPETH, J. W. (ed.): *Treatise on Marine Ecology and Paleocology*. - vol. 1. *Geol. Soc. Amer. Mem.*, **67**, 941-1010, Boulder
- BULL, W. B. (1972): Recognition of alluvial-fan deposits in the stratigraphic record. - In: RIGBY, J. K. & HAMBLIN, W. K. H. (eds.): *Recognition of ancient sedimentary environments*. - Spec. Publ. Soc. Econ. Pal. Min., **26**, 63-83, Tulsa
- BURNE, R. V. & MOORE, L. S. (1987): Microbialites: Organosedimentary deposits of benthic microbial communities. - *Palaios*, **2**, 241-254, Tulsa
- BUSH, D. M. (1991): Mixed carbonate/siliciclastic sedimentation: Northern insular shelf of Puerto Rico. - In: LOMARDO, A. J. & HARRIS, P. M. (eds.): *Mixed Carbonate-Siliciclastic Sequences*. - Soc. Econ. Pal. Min., Core Workshop, **15**, 447-484, Tulsa
- CAMPBELL, C. V. (1971): Depositional model-Upper Cretaceous Gallup beach shoreline, Ship rock area, northwestern New Mexico. - *J. Sed. Petrol.*, **41/2**, 395-409, Tulsa
- CARTER, C. H. (1978): A regressive barrier and barrier-protected deposit: depositional environments and geographic setting of the Late Tertiary Cohansay Sand. - *J. Sed. Petrol.*, **48/3**, 933-950, Tulsa
- CHANNELL, J. E. T., BRANDNER, R., SPIELER, A. & SMATHERS, N. P. (1990): Mesozoic paleogeography of the Northern Calcareous Alps-Evidence from paleomagnetism and facies analysis. - *Geology*, **18**, 828-831, Boulder
- CHEEL, R. J. & LECKIE, D. A. (1990): A tidal-inlet complex in the Cretaceous epeiric sea of North America: Virgelle Member, Milk River Formation, southern Alberta, Canada. - *Sedimentology*, **37**, 67-81, Oxford
- CHOQUETTE, P. W. & JAMES, N. P. (1988): Introduction. - In: JAMES, N. P. & CHOQUETTE, P. W. (eds.): *Paleokarst*. - 416 pp., New York (Springer)
- CLIFTON, H. E., HUNTER, R. E. & PHILLIPS, R. L. (1971): Depositional structures and processes in the non-barred high-energy nearshore. - *J. Sed. Petrol.*, **41/3**, 651-670, Tulsa
- COLELLA, A. (1988): Pliocene-Holocene fan deltas and braid deltas in the Crati Basin, southern Italy: a consequence of varying tectonic conditions. - In: NEMEC, W. & STEEL, R. J. (eds.): *Fan Deltas: Sedimentology and Tectonic Settings*. - 50-74, London (Blackie)
- COLLINSON, J. D. & THOMPSON, D. B. (1989): *Sedimentary Structures*. - 207 pp., London (Unwin Hyman)
- CROSS, T. A. (1988): Controls on coal distribution in transgressive-regressive cycles, Upper Cretaceous, Western Interior, U. S. A. - In: WILGUS, C. K., POSAMENTIER, H., ROSS, C. A. & KENDALL, C. G. St. C. (eds.): *Sea-Level Changes-An Integrated Approach*. - Soc. Econ. Pal. Min. Spec. Publ., **42**, 371-380, Tulsa
- DALRYMPLE, R. W. (1992): Tidal depositional systems. - In: WALKER, R. G. & JAMES, N. P. (eds.): *Facies Models. Response to Sea Level Change*. - Geol. Assoc. Canada, 95-218, St. John's
- DAVIDSON-ARNOTT, R. G. D. & GREENWOOD, B. (1976): Facies relationships on a barred coast, Kouchibouguac Bay, New Brunswick, Canada. - In: DAVIS, Jr., R. A. & ETHINGTON, R. L. (eds.): *Beach and nearshore sedimentation*. - Spec. Publ. Soc. Econ. Paleont. Min., **24**, 149-168, Tulsa
- DAVIES, D. K., ETHRIDGE, F. G. & BERG, R. R. (1971): Recognition of barrier environments. - *Am. Assoc. Petrol. Geol. Bull.*, **55**, 4, 550-565, Tulsa
- DAVIS, R. A., Jr. (1978): Beach and nearshore zone. - In: DAVIS, R. A., Jr., (ed.): *Coastal Sedimentary Environments*. - 237-285, New York (Springer)
- DAVIS, Jr., R. A., REAS, C. & ROBBINS, L. L. (1995): Calcite mud in a Holocene back-barrier lagoon: Lake Reeve, Victoria, Australia. - *J. Sed. Res.*, **A 65/1**, 178-184, Tulsa
- DECKER, K., MESCHEDÉ, M. & RING, U. (1993): Fault slip analysis along the northern margin of the Eastern Alps (Molasse, Helvetic nappes, North and South Penninic flysch, and the Northern Calcareous Alps). - *Tectonophysics*, **223**, 291-312, Amsterdam (Elsevier)
- DEERY, J. R. & HOWARD, J. D. (1977): Origin and character of washover fans on the Georgia coast, U. S. A. - *Trans. Gulf Coast Assoc. geol. Soc.*, **27**, 259-271, Houston
- DEN HARTOG, C. (1970): *The seagrasses of the world*. - 275 pp., Amsterdam (North Holland Publisher)
- DERCOURT, J., RICOU, L. E. & VRIELYNCK, B. (eds.) (1993): *Atlas Tethys: Paleoenvironmental maps*. - 22 maps, 307 pp. explanatory notes, Paris (Gauthier-Villars)
- DONSELAAR, M. E. (1989): The Cliff House Sandstone, San Juan Basin, New Mexico: Model for the stacking of „transgressive“ barrier complexes. - *J. Sed. Petrol.*, **59/1**, 13-27, Tulsa
- DUKE, W. L. (1990): Geostrophic circulation or shallow marine turbidity currents? The dilemma of paleoflow patterns in storm-influenced prograding shoreline systems. - *J. Sed. Petrol.*, **60**, 870-883, Tulsa
- EINSELE, G. & SEILACHER, A. (1991): Distinction of tempestites and turbidites. - In: EINSELE, G., RICKEN, W. & SEILACHER, A. (eds.): *Cycles and Events in Stratigraphy*. - 377-382, Berlin (Springer)
- EISBACHER, G. H. & BRANDNER, R. (1996): Superposed fold-thrust structures and high-angle faults, Northwestern Calcareous Alps, Austria. - *Eclogae geol. Helv.*, **89/1**, 553-572, Basel
- EKDALE, A. A. & MASON, T. R. (1988): Characteristic trace-fossil associations in oxygen-poor sedimentary environments. - *Geology*, **16**, 720-723, Boulder
- ELLIOTT, T. (1986): Siliciclastic shorelines. - In: READING, H. G. (ed.): *Sedimentary environments and facies*. - 155-188, Oxford (Blackwell)
- ENOS, P. (1983): Shelf Environment. - In: SCHOLLE, P. A., BEBOUT, D. G. & MOORE, C. H. (eds.): *Carbonate depositional environments*. - Amer. Assoc. Petrol. Geol. Mem., **33**, 268-295, Tulsa
- ETHRIDGE, F. G. & WESCOTT, W. A. (1984): Tectonic setting, recognition, and hydrocarbon reservoir potential of fan-delta deposits. - In: KOSTER, E. H. & STEEL, R. J. (eds.): *Sedimentology of Gravels and Conglomerates*. - Can. Soc. Petrol. Geol. Mem., **10**, 217-235, Calgary
- FIELD, M. E. & ROY, P. S. (1984): Offshore transport and sand-body formation: Evidence from a steep, high-energy shoreface, Southeastern Australia. - *J. Sed. Petrol.*, **54/4**, 1292-1302, Tulsa
- FINKELSTEIN, K. & FERLAND, M. A. (1987): Back-barrier response to sea-level rise, eastern shore of Virginia. - In: NUMMEDAL, D., PILKEY, O. H. & HOWARD, J. D. (eds.): *Sea-level fluctuation and coastal evolution*. - Spec. Publ. Soc. Econ. Paleont. Min., **41**, 145-155, Tulsa

- FISCHER, P. (1964): Geologisch-mikropaläontologische Untersuchungen in der Unteren Gosau von Brandenburg in Tirol. - Mitt. Bayer. Staatssammlg. Paläont. hist. Geol., **4**, 127-144, München
- FLINT, R. F. & SKINNER, B. J. (1974): Physical Geology. - 497 pp., New York (Wiley)
- FLÜGEL, E. (1978): Mikrofazielle Untersuchungsmethoden von Kalken. - 454 pp., Berlin (Springer)
- FÖLLMI, K. B. (1989): Evolution of the Mid-Cretaceous Triad. Platform Carbonates, Phosphatic Sediments, and Pelagic Carbonates Along the Northern Tethys Margin. - In: BHATTACHARJI, S., FRIEDMAN, G. M., NEUGEBAUER, H. J. & SEILACHER, A. (eds.): Lecture Notes in Earth Sciences. - 153 pp., Berlin (Springer)
- FOUCH, T. D. & DEAN, W. E. (1982): Lacustrine and Associated Clastic Depositional Environments. - In: SCHOLLE, P. A. & SPEARING, D. (eds.): Sandstone Depositional Environments. - Amer. Assoc. Petrol. Geol. Mem., **31**, 87-114, Tulsa
- FROITZHEIM, N., SCHMID, S. & CONTI, P. (1994): Repeated change from crustal shortening to orogen-parallel extension in the Austroalpine units of Graubünden. - Eclogae geol. Helv., **87/2**, 559-612, Basel
- FROITZHEIM, N., CONTI, P. & VAN DAALLEN, M. (1997): Late Cretaceous, synorogenic, low-angle normal faulting along the Schlinig fault (Switzerland, Italy, Austria) and its significance for the tectonics of the Eastern Alps. - Tectonophysics, **280**, 267-293, Amsterdam
- FÜRSICH, F. T. (1994): Palaeoecology and evolution of Mesozoic salinity-controlled benthic macroinvertebrate associations. - Lethaia, **26**, 327-346, Oslo
- GALLOWAY, W. E. & HOBDAV, D. K. (1983): Terrigenous Clastic Depositional Systems. - 423 pp., New York (Springer)
- GARDNER, J. (1979): The movement of material on debris slopes in the Canadian Rocky Mountains. - Zeitsch. f. Geomorph., **23**, 45-57, Berlin
- GAWTHORPE, R. L., FRAZIER, A. F. & COLLIER, R. E. LI. (1994): Sequence stratigraphy in active extensional basins: implications for the interpretation of ancient basin-fills. - Mar. Petrol. Geol., **11/6**, 642-658, Guildford
- GAWTHORPE, R. L., SHARP, I., UNDERHILL, J. R. & GUPTA, S. (1997): Linked sequence stratigraphic and structural evolution of propagating normal faults. - Geology, **25/9**, 795-798, Boulder
- GILL, G. A. & COATES, A. G. (1977): Mobility, growth patterns and substrate in some fossil and recent corals. - Lethaia, **10**, 119-134, Oslo
- GLENN, C. R. & ARTHUR, M. A. (1990): Anatomy and origin of a Cretaceous phosphorite-greensand giant, Egypt. - Sedimentology, **37**, 123-154, Oxford
- GRADSTEIN, F. M., AGTERBERG, F. P., OGG, J. G., HARDENBOL, J., VAN VEEN, P., THIERRY, J. & HUANG, Z. (1994): A Mesozoic time scale. - J. Geophys. Res., **99**, B12, 24,051-24,074, Washington
- GREENWOOD, B. & MITTLER, P. R. (1985): Vertical sequence and lateral transitions in the facies of a barred nearshore environment. - J. Sed. Petrol., **55/3**, 366-375, Tulsa
- GREENWOOD, B. & SHERMAN, D. J. (1986): Hummocky cross-stratification in the surf zone: flow parameters and bedding genesis. - Sedimentology, **33**, 33-45, Oxford
- GRUBER, A. (1995): Öffnung und Schliessung von Tertiärbecken im Bereich des Eiberger Beckens (Unterinntal, Tirol). Ein strukturgeologischer Beitrag zur Unterinntaler Scherzone. - Unpubl. diploma thesis, Univ. of Innsbruck, 144 pp., 110 figs., 4 enclosures
- HALLEY, R. B. & ROSE, P. R. (1977): Significance of fresh-water limestones in marine carbonate successions of Pleistocene and Cretaceous age. - In: BEBOUT, D. G. & LOUCKS, R. G. (eds.): Cretaceous Carbonate of Texas and Mexico. Applications to Subsurface Exploration. - Bureau of Econ. Geology and Univ. of Texas at Austin, Report of Investigations, **89**, 206-215, Austin
- HANDFORD, C. R. & LOUCKS, R. G. (1993): Carbonate depositional sequences and systems tracts-responses of carbonate platforms to relative sea level changes. - In: LOUCKS, R. G. & SARG, R. (eds.): Carbonate Sequence Stratigraphy. Recent Developments and Applications. - Am. Assoc. Petrol. Geol. Mem., **57**, 3-41, Tulsa
- HAYES, M. O. (1980): General morphology and sediment patterns in tidal inlets. - Sedim. Geol., **26**, 139-156, Amsterdam (Elsevier)
- HECKEL, P. H. (1974): Carbonate Buildups in the geologic Record: A review. - In: LAPORTE, L. F. (ed.): Reefs in Time and Space. Selected Examples from the Recent and Ancient. - Spec. Publ. Soc. Econ. Pal. Min., **18**, 90-154, Tulsa
- HERM, D. (1977): Zyklische Regressions-Sedimentation und Fossil-Vergesellschaftungen in der Gosau (Santonium) von Brandenburg/Tirol. - Mitt. Bayer. Staatsslg. Paläont. hist. Geol., **17**, 257-277, München
- HERM, D. & SCHENK, V. (1971): Parasitäre Epökie von *Radiolites* auf *Trochactaeon*. - N. Jb. Geol. Paläont., Mh. **1971**, B, 324-339, Stuttgart
- HERM, D., KAUFFMAN, E. & WIEDMANN, J. (1979): The age and depositional environment of the „Gosau“-Group (Coniacian-Santonian), Brandenburg/Tirol, Austria. - Mitt. Bayer. Staatssammlg. Paläont. hist. Geol., **19**, 27-92., München
- HEWARD, A. P. (1981): A review of wave-dominated clastic shoreline deposits. - Earth-Science Reviews, **17**, 223-276, Amsterdam
- HÖFLING, R. (1997): Eine erweiterte Riff-Typologie und ihre Anwendung auf kretazische Biokonstruktionen. - Bayer. Akad. Wiss., Mathematisch-Naturwiss. Klasse, Abh., Neue Folge, **169**, 127 pp., 31 figs., 34 tables, München
- HOOKE, R. LeB. (1967): Processes on arid-region alluvial fans. - J. Geol., **75**, 438-460, Chicago
- HORNE, J. C., FERM, J. C., CARUCIO, F. T. & BAGANZ, B. P. (1978): Depositional models in coal exploration and mine planning in Appalachian region. - Amer. Ass. Petrol. Geol. Bull., **62/12**, 2379-2411, Tulsa
- HOYT, J. H. & HENRY, V. J., Jr. (1967): Influence of island migration on barrier-island sedimentation. - Bull. geol. Soc. Am., **78**, 77-86, Boulder
- HUBBARD, D. K., OERTEL, G. & NUMMEDAL, D. (1979): The role of waves and tidal currents in the development of tidal-inlet sedimentary structures and sand body geometry: Examples from North Carolina, South Carolina, and Georgia. - J. Sed. Petrol., **49/4**, 1073-1092, Tulsa
- IBRAHIM, A. H. M. (1976): Biostratigraphische Untersuchungen mit planktonischen Foraminiferen in der Oberkreide des Gosau-Beckens von Eiberg. - Unpubl. Ph. D. thesis, Univ. of Munich, 170 pp., 19 figs., 11 tables, München
- IMMEL, H., KLINGER, H. C. & WIEDMANN, J. (1982): Die Cephalopoden des Unteren Santon der Gosau von Brandenburg/Tirol, Österreich. - Zitteliana, **8**, 3-32, München
- IMPERATO, D. P., SEXTON, W. J. & HAYES, M. O. (1988): Stratigraphy and sediment characteristics of a mesotidal ebb-tidal delta, North Edisto Inlet, South Carolina. - J. Sed. Petrol., **58/6**, 950-958, Tulsa
- ISRAEL, A. M., ETHRIDGE, F. G. & ESTES, E. L. (1987): A sedimentologic description of a microtidal, flood-tidal delta, San Luis Pass, Texas. - J. Sed. Petrol., **57/2**, 288-300, Tulsa
- JAMES, N. P. & BOURQUE, P.-A. (1992): Reefs and mounds. - In: WALKER, R. G. & JAMES, N. P. (eds.): Facies Models. Response to Sea Level Change. - Geol. Assoc. of Canada, 323-345, St. John's
- JOHNSON, H. D. & BALDWIN, C. T. (1986): Shallow Siliciclastic Seas. - In: READING, H. G., 1986, (ed.): Sedimentary Environments and Facies. - 229-282, Oxford (Blackwell)
- KENDALL, C. G. St. C., DILL, R. F. & SHINN, E. (1989): Guidebook to the giant subtidal stromatolites and carbonate facies of Lee Stocking Island, Bahamas. - 74 pp., Carolina (Dept. of Geology, University of South Carolina)
- KLEIN, G. deV. (1977): Tidal circulation model for deposition of

- clastic sediment in epeiric and mioclinal shelf seas. - *Sedim. Geol.*, **18**, 1-12, Amsterdam (Elsevier)
- KLEIN, G. de V. & RYER, T. A. (1978): Tidal circulation patterns in Precambrian, Paleozoic, and Cretaceous epeiric and mioclinal shelf areas. - *Geol. Soc. Amer. Bull.*, **89**, 1050-1058, Boulder
- KOLLMANN, H. A. (1980): Gastropoden aus der Sandkalkbank (Hochmooschichten, Obersanton) des Beckens von Gosau (Ö). - *Ann. Naturhistor. Mus. Wien*, **83**, 197-213, Wien
- KOUYOUMONTZAKIS, G. (1989): Les Nerineidae Zittel 1873 (Gasteropoda, Ctenobranchiata) du Crétacé supérieur sur le pourtour méditerranéen: révision systématique et paléobiogéographique. - *Géol. Médit.*, t. **XVI**, 1, 17-45, Marseille
- KRAFT, J. C. (1971): Sedimentary facies patterns and geologic history of a Holocene marine transgression. - *Geol. Soc. Amer. Bull.*, **82**, 2131-2158, Boulder
- KREISA, R. D. (1981): Storm-generated sedimentary structures in subtidal marine facies with examples from the Middle and Upper Ordovician of southwestern Virginia. - *J. Sed. Petrol.*, **51/3**, 823-848, Tulsa
- KUMAR, N. & SANDERS, J. E. (1974): Inlet sequence: a vertical succession of sedimentary structures and textures created by the lateral migration of tidal inlets. - *Sedimentology*, **21**, 491-532, Oxford
- LABAUME, P. (1987): Syn-diagenetic deformation of a turbiditic succession related to submarine gravity nappe emplacement, Autapie Nappe, French Alps. - In: JONES, M. E. & PRESTON, R. M. F. (eds.): *Deformation of Sediments and Sedimentary Rocks*. - *Geol. Soc. Spec. Publ.*, **29**, 147-163, London (The Geological Society)
- LARSONNEUR, C. (1975): Tidal deposits, Mont Saint-Michel Bay, France. - In: GINSBURG, R. N. (ed.): *Tidal Deposits*. - 21-30, New York (Springer)
- LECKIE, D. A. & WALKER, R. G. (1982): Storm- and tide-dominated shorelines in Cretaceous Moosebar-Lower Gates interval - outcrop equivalents of deep basin gas trap in western Canada. - *Bull. Amer. Assoc. Petrol. Geol.*, **66/2**, 138-157, Tulsa
- LEWIS, J. R. (1977): Rocky foreshores. - In: BARNES, R. S. K. (ed.): *The Coastline*. - 147-158, London (Wiley)
- LI, Q., MCGOWRAN, B., JAMES, N. P., BONE, Y. & CANN, J. H. (1996): Mixed foraminiferal biofacies on the mesotrophic, mid-latitude Lacedpede Shelf, South Australia. - *Palaios*, **11**, 176-191, Tulsa
- LONG, B. & ROSS, N. (1989): Revue et classification des barres d'avant cote. - *Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine*, **13/1**, 175-187, Pau
- LÜTTIG, G. (1964): Zur Gerölmorphologie von Transgressionskonglomeraten. - In: VAN STRAATEN, L. M. J. U. (ed.): *Deltaic and shallow marine deposits*. - *Developments in Sedimentology*, **1**, 253-256, Amsterdam
- MACLEOD, K. G. (1994): Bioturbation, inoceramid extinction, and mid-Maastrichtian ecological change. - *Geology*, **22**, 139-142, Boulder
- MANSPEIZER, W. (1985): The Dead Sea rift: Impact of climate and tectonism on Pleistocene and Holocene sedimentation. - In: BIDDLE, K. T. & CHRISTIE-BLICK, N. (eds.): *Strike-Slip Deformation, Basin Formation, and Sedimentation*. - *Soc. Econ. Pal. Min. Spec. Publ.*, **37**, 143-158, Tulsa
- MARZO, M. & ANADON, P. (1988): Anatomy of a conglomeratic fan-delta complex: the Eocene Montserrat Conglomerate, Ebro Basin, northeastern Spain. - In: NEMEC, W. & STEEL, R. J. (eds.): *Fan Deltas: Sedimentology and Tectonic Settings*. - 318-340, London (Blackie)
- MAURITSCH, H. J. & BECKE, M. (1987): Paleomagnetic investigations in the Eastern Alps and the southern border zone. - In: FLÜGEL, H. W. & FAUPL, P. (eds.): *Geodynamics of the Eastern Alps*. - 282-308, Wien (Deuticke)
- MC CABE, P. J. (1984): Depositional environments of coal and coal-bearing strata. - In: RAHMANI, R. A. & FLORES, R. M. (eds.): *Sedimentology of coal and coal-bearing sequences*. - *Spec. Publ. int. Ass. Sedim.*, **7**, 13-42, Oxford (Blackwell)
- MC PHERSON, J. G., SHANMUGAM, G. & MOIOLA, R. J. (1987): Fandeltas and braid-deltas: Varieties of coarse-grained deltas. - *Geol. Soc. Am. Bull.*, **99**, 331-340, Boulder
- MEYER-REIL, L.-A. (1993): Mikrobielle Besiedlung und Produktion. - In: MEYER-REIL, L.-A. & KÖSTER, M. (eds.): *Mikrobiologie des Meeresbodens*. - 38-81, Jena (Fischer)
- MIALL, A. D. (1978): Lithofacies types and vertical profile models in braided river deposits: a summary. - In: MIALL, A. D., (ed.): *Fluvial sedimentology*. - *Can. Soc. Petrol. Geol. Mem.*, **5**, 597-604, Calgary
- MIALL, A. D. (1985): Stratigraphic and structural predictions from a plate-tectonic model of an oblique-slip orogen: The Eureka Sound Formation (Campanian-Oligocene), Northeast Canadian Arctic Islands. - In: BIDDLE, K. T. & CHRISTIE-BLICK, N. (eds.): *Strike-Slip Deformation, Basin Formation, and Sedimentation*. - *Soc. Econ. Pal. Min. Spec. Publ.*, **37**, 361-374, Tulsa
- MINDSZENTY, A. (1984): The lithology of some Hungarian bauxites - a contribution to the paleogeographic reconstruction. - *Acta Geol. Hungarica*, **27/3-4**, 441-455, Budapest
- MINOURA, K., IMAMURA, F., TAKAHASHI, T. & SHUTO, N. (1997): Sequence of sedimentation processes caused by the 1992 Flores tsunami: Evidence from Babi Island. - *Geology*, **25/6**, 523-526, Boulder
- MORTON, R. A. (1978): Large-scale rhomboid bed forms and sedimentary structures associated with hurricane washover. - *Sedimentology*, **25**, 183-204, Oxford
- MYROW, P. M. & SOUTHWARD, J. B. (1996): Tempestite deposition. - *J. Sed. Res.*, **66/5**, 875-887, Tulsa
- NEMEC, W. & POSTMA, G. (1993): Quaternary alluvial fans in southwestern Crete: sedimentation processes and geomorphic evolution. - In: MARZO, M. & PUIGDEFABREGAS, C. (eds.): *Alluvial Sedimentation*. - *Spec. Publ. int. Ass. Sedim.*, **17**, 235-276, Oxford (Blackwell)
- NEMEC, W. & STEEL, R. J. (1984): Alluvial and costal conglomerates: their significant features and some comments on gravelly mass-flow deposits. - In: KOSTER, E. H. & STEEL, R. J. (eds.): *Sedimentology of Gravels and Conglomerates*. - *Can. Soc. Petrol. Geol. Mem.*, **10**, 1-31, Calgary
- NEMEC, W. & STEEL, R. J. (1988): What is a fan delta and how do we recognize it? - In: NEMEC, W. & STEEL, R. (eds.): *Fan Deltas: Sedimentology and Tectonic Settings*. - 3-13, Glasgow (Blackie)
- NEUBAUER, F., DALLMEYER, R. D., DUNKL, I. & SCHIRNIK, D. (1995): Late Cretaceous exhumation of the Gleinalm dome, Eastern Alps: kinematics, cooling history, and sedimentary response in a sinistral wrench corridor. - *Tectonophysics*, **242**, 79-98, Amsterdam (Elsevier)
- NEUWEILER, F., REITNER, J. & ARP, G. (1996): Controlling factors and environmental significance of organomicrite production and buildup development. - In: REITNER, J., NEUWEILER, F. & GUNKEL, F. (eds.): *Global and regional controls on biogenic sedimentation. I. Reef evolution*. *Research Repts.* - *Göttinger Arb. Geol. Paläont., Sonderb.* **2**, 185-192, Göttingen
- ORTNER, H. & REITER, F. (1997): Cretaceous large-scale normal faulting at the southern margin of the Northern Calcareous Alps - The Triassic south of the Inn Valley, Eastern Alps. - *Quaderni di Geodinamica Alpina e Quaternaria*, **4**, 89-91, Milano
- PARRISH, J. T. & CURTIS, R. L. (1982): Atmospheric circulation, upwelling, and organic-rich rocks in the Mesozoic and Cenozoic eras. - *Paleogeogr., Paleoclimatol., Paleocol.*, **40**, 31-66, Amsterdam (Elsevier)
- PEMBERTON, S. G., MAC EACHERN, J. A. & FREY, R. W. (1992): Trace Fossil Facies Models: Environmental and Allostratigraphic Significance. - In: WALKER, R. G. & JAMES, N. P. (eds.): *Facies Models. Response to Sea Level Change*. - *Geol. Ass. Canada*, 47-72, Ontario
- PLATT, J. P. (1986): Dynamics of orogenic wedges and the uplift of high-pressure metamorphic rocks. - *Geol. Soc. Amer.*

- Bull., **97**, 1037-1053, Boulder
- POLINO, R., DAL PIAZ, G. & GOSSO, G. (1990): Tectonic erosion at the Adria margin and accretionary processes for the Cretaceous orogeny of the Alps. - *Mém. Soc. géol. France*, **156**, 345-367, Paris
- PRICE, G. D., SELLWOOD, B. W. & VALDES, P. J. (1995): Sedimentological evaluation of general circulation model simulations for the „greenhouse“ Earth: Cretaceous and Jurassic case studies. - *Sedim. Geol.*, **100**, 159-180, Amsterdam
- PRIOR, D. B. & BORNHOLD, B. D. (1988): Submarine morphology and process of fjord fan deltas and related high-gradient streams: modern examples from British Columbia. - In: NEMEC, W. & STEEL, R. J. (eds.): *Fan Deltas: Sedimentology and Tectonic Settings*. - 121-143, London (Blackie)
- PUTNAM, P. E., KENDALL, G. & WINTER, D. A. (1997): Estuarine deposits of the upper Qishn Formation (Lower Cretaceous), Masila region, Yemen. - *Amer. Assoc. Petrol. Geol. Bull.*, **81/8**, 1306-1329, Tulsa
- RANDALL, R. E. (1977): Shingle foreshores. - In: BARNES, R. S. K. (ed.): *The Coastline*. - 49-61, London (Wiley)
- RATSCHBACHER, L. (1987): Strain, rotation, and translation of Austroalpine nappes. - In: FLÜGEL, H. W. & FAUPL, P. (eds.): *Geodynamics of the Eastern Alps*. - 237-243, Wien (Deuticke)
- RATSCHBACHER, L., FRISCH, W., NEUBAUER, F., SCHMID, S. M. & NEUGEBAUER, J. (1989): Extension in compressional orogenic belts: The Eastern Alps. - *Geology*, **17**, 404-407, Boulder
- RHOADS, D. C., MULSOW, S. G., GUTSCHICK, R., BALDWIN, C. T. & STOLZ, J. F. (1991): The dysaerobic zone revisited: a magnetic facies? - In: TYSON, R. V. & PEARSON, T. H. (eds.): *Modern and ancient continental shelf anoxia*. - *Geol. Soc. Spec. Publ.*, **58**, 187-199, London
- RICHARDS, M. T. (1994): Transgression of an estuarine channel and tidal flat complex: the Lower Triassic of Barles, Alpes de Haute Provence, France. - *Sedimentology*, **41**, 55-82, Oxford
- RINE, J. M. & GINSBURG, R. N. (1985): Depositional facies of a mud shoreface in Suriname, South America - A mud analogue to sandy, shallow-marine deposits. - *J. Sed. Petrol.*, **55/5**, 633-652, Tulsa
- RISCH, H. (1985): Gosau. - In: WOLFF, H.: *Geologische Karte von Bayern 1:25 000*. - Erläuterungen zum Blatt Nr. 8338 Bayrischzell, 94-99, München (Bayerisches Geologisches Landesamt)
- ROBERTS, H. H., WHELAN, T. & SMITH, W. G. (1977): Holocene sedimentation at Cape Sable, South Florida. - *Sedim. Geol.*, **18**, 25-60, Amsterdam
- ROY, P. S., THOM, B. G. & WRIGHT, L. D. (1980): Holocene sequences on an embayed high-energy coast: an evolutionary model. - *Sedim. Geol.*, **26**, 1-19, Amsterdam
- RUST, B. R. (1978): Depositional models for braided alluvium. - In: MIALL, A. D. (ed.): *Fluvial sedimentology*. - *Can. Soc. Petrol. Geol. Mem.*, **5**, 605-625, Calgary
- SALLER, A. H. & DICKINSON, W. R. (1982): Alluvial to marine facies transition in the Antler overlap sequence, Pennsylvanian and Permian of north-central Nevada. - *J. Sed. Petrol.*, **52/3**, 925-940, Tulsa
- SANDERS, D. (1996 a): Rudist biostromes on the margin of an isolated carbonate platform: The Upper Cretaceous of Montagna della Maiella, Italy. - *Eclogae geol. Helv.*, **89/2**, 845-871, Basel
- (1996 b): The Upper Cretaceous near Maurach (Tyrol, Austria). - *Geol.-Paläont. Mitt. Innsbruck*, **21**, 123-151, Innsbruck
- (1996 c): Cyclic paralic successions in the Lower Gosau Subgroup (Upper Cretaceous), Brandenburg, Austria. - *Zentralbl. f. Geol. Paläont.*, Teil I, **5/6**, 585-595, Stuttgart
- (1996 d): A classification of elevator rudist biostromes (Abstr.). - In: 5th Int. Cretaceous Symposium and 2nd Workshop on Inoceramids. Freiberg University of Mining and Technology, September 16-24, 1996, Abstracts, p. 153, Freiberg
- (1997 a): The Upper Cretaceous of Brandenburg (Northern Calcareous Alps, Austria) - *Gaea heidelbergensis*, **4**, 70-77; (Int. Assoc. Sedim., Excursion guide), Heidelberg
- (1997 b): Upper Cretaceous transgressive shore zone deposits ("Untersberger Marmor" Auct.) in the eastern part of the Tyrol (Austria): An overview. - *Geol. Paläont. Mitt. Innsbruck*, **22**, 101-121, Innsbruck
- SANDERS, D., KOLLMANN, H., SUMMESBERGER, H. & WAGREICH, M. (1996): Tethyan/temperate faunal mixing, Upper Cretaceous of the Northern Calcareous Alps (Austria) (Abstr.). - In: Fifth Internat. Cretaceous Symposium and Second Workshop on Inoceramids. Freiberg University of Mining and Technology, September 16-24, 1996, Abstracts, p. 67, Freiberg
- SANDERS, D., KOLLMANN, H. & WAGREICH, M. (1997): Sequence development and biotic assemblages on an active continental margin: The Turonian-Campanian of the Northern Calcareous Alps. - *Bull. Soc. géol. France*, **168/3**, 351-372, Paris
- SANDERS, D. & BARON-SZABO, R. (1997): Coral-rudist bioconstructions in the Upper Cretaceous Haidach section (Northern Calcareous Alps, Austria). - *Facies*, **36**, 69-90, Erlangen
- SAVRDA, C. E., BOTTJER, D. J. & GORSLINE, D. (1984): Development of a comprehensive oxygen-deficient marine biofacies model: Evidence for Santa Monica, San Pedro and Santa Barbara Basins, California continental borderland. - *Amer. Ass. Petrol. Geol. Bull.*, **68**, 1179-1192, Tulsa
- SAVRDA, C. E. & BOTTJER, D. J. (1986): Trace-fossil model for reconstruction of paleooxygenation in bottom waters. - *Geology*, **14**, 3-6, Boulder
- SAVRDA, C. E. & BOTTJER, D. J. (1991): Oxygen-related biofacies in marine strata: an overview and update. - In: TYSON, R. V. & PEARSON, T. H. (eds.): *Modern and ancient continental shelf anoxia*. - *Geol. Soc. Spec. Publ.*, **58**, 201-219, London
- SCHULZ, O. (1960): Bauxit in den Gosau-Schichten von Brandenberg (Tirol). - *Berg- u. hüttenmänn. Monatshefte*, **105/12**, 347-349, Leoben
- SCHULZ, O. & FUCHS, H. W. (1991): Kohle in Tirol: Eine historische, kohlenpetrologische und lagerstättenkundliche Betrachtung. - *Arch. f. Lagerstättenforsch. Geol. B.-A.*, **13**, 123-213, Wien
- SEILACHER, A. (1967): Bathymetry of trace fossils. - *Mar. Geol.*, **5**, 413-428, Amsterdam
- SEMENIUK, V. & JOHNSON, D. P. (1985): Modern and Pleistocene rocky shore sequences along carbonate coastlines, Southwestern Australia. - *Sedim. Geol.*, **44**, 225-261, Amsterdam
- SHINN, E. A. & LIDZ, B. H. (1988): Blackened Limestone Pebbles: Fire at Subaerial Unconformities. - In: JAMES, N. P. & CHOQUETTE, P. W. (eds.): *Paleokarst*. - 118-131, New York (Springer)
- SHIPP, R. C. (1984): Bedforms and depositional sedimentary structures of a barred nearshore system, Eastern Long Island, New York. - *Mar. Geol.*, **60**, 235-259, Amsterdam
- SIRINGAN, F. P. & ANDERSON, J. B. (1994): Modern shoreface and inner-shelf storm deposits off the East Texas coast, Gulf of Mexico. - *J. Sed. Res.*, **B 64/2**, 99-110, Tulsa
- SMITH, N. D. (1974): Sedimentology and bar formation in the upper Kicking Horse River, a braided outwash stream. - *J. Geol.*, **82**, 205-224, Chicago
- SOHN, Y. K. (1997): On traction-carpet sedimentation. - *J. Sed. Res.*, **67/3**, 502-509, Tulsa
- SOHN, Y. K., KIM, S. B., HWANG, I. G., BAHK, J. J., CHOE, M. Y. & CHOUGH, S. K. (1997): Characteristics and depositional processes of large-scale gravelly Gilbert-type foresets in the Miocene Doumsan fan delta, Pohang Basin, SE Korea. - *J. Sed. Res.*, **67/1**, 130-141, Tulsa
- STANLEY, S. M. (1972): Functional morphology and evolution of byssally attached bivalve molluscs. - *J. Paleont.*, **46/2**, 165-212, Tulsa
- STATHAM, I. (1976): A scree slope rockfall model. - *Earth Surface Processes*, **1**, 43-62, London (Wiley)
- STRASSER, A. (1984): Black-pebble occurrence and genesis in Holocene carbonate sediments (Florida Keys, Bahamas, and Tunisia). - *J. Sed. Petrol.*, **54/4**, 1097-1109, Tulsa
- SUMMESBERGER, H. (1985): Amonite Zonation of the Gosau Group (Upper Cretaceous, Austria). - *Ann. Naturhist. Mus. Wien*, **87/A**, 145-166, Wien

- SUMMESBERGER, H. & KENNEDY, W. J. (1996): Turonian ammonites from the Gosau Group (Upper Cretaceous; Northern Calcareous Alps, Austria), with a revision of *Barroisiceras haberfellneri* (Hauer, 1866). - Beitr. Paläont. Österr., **21**, 105-177, Wien
- SWIFT, D. J. P. (1985): Response of the shelf floor to flow. - In: TILLMAN, R. W., SWIFT, D. J. P. & WALKER, R. G. (eds.): Shelf sands and sandstone reservoirs. Soc. Econ. Pal. Min., Short Course Notes, **13**, 135-241, Tulsa
- SWIFT, D. J. P. & NIEDORODA, A. W. (1985): Fluid and sediment dynamics on continental shelves. - In: TILLMAN, R. W., SWIFT, D. J. P. & WALKER, R. G. (eds.): Shelf sands and sandstone reservoirs. - Soc. Econ. Pal. Min., Short Course Notes, **13**, 47-134, Tulsa
- TAFT, W. H. & HARBAUGH, J. W. (1964): Modern carbonate sediments of the southern Florida, Bahamas and Espirito Santo Island, Baja California: A comparison of their mineralogy and geochemistry. - Stanford Univ. Publ. geol. Sciences, **80**, 1-64, Stanford
- TEDESCO, L. P. & WANLESS, H. R. (1995): Growth and burrow-transformation of carbonate banks: comparison of modern skeletal banks of south Florida and Pennsylvanian phylloid banks of south-eastern Kansas, USA. - In: MONTY, C. L. V., BOSENCE, D. W. J., BRIDGES, P. H. & PRATT, B. R. (eds.): Carbonate Mud-Mounds. - Spec. Publ. int. Ass. Sedim., **23**, 495-521, Oxford (Blackwell)
- TILLMAN, R. W. (1985): A spectrum of shelf sands and sandstones. - In: TILLMAN, R. W., SWIFT, D. J. P. & WALKER, R. G. (eds.): Shelf sands and sandstone reservoirs. - Soc. Econ. Pal. Min., Short Course Notes, **13**, 1-47, Tulsa
- TOLLMANN, A. (1976): Der Bau der Nördlichen Kalkalpen. - 449 pp., Wien (Deuticke)
- TRÖGER, K.-A. (1989): Problems of Upper Cretaceous inceramid biostratigraphy and paleobiogeography in Europe and Western Asia. - Proc. 3rd Int. Cret. Symp., Tübingen 1987, 911-930, Stuttgart (Schweizerbart)
- TRÖGER, K.-A. & SUMMESBERGER, H. (1994): Coniacian and Santonian inceramid bivalves from the Gosau-Group (Cretaceous, Austria) and their biostratigraphic and paleobiogeographic significance. - Ann. Naturhist. Museum Wien, **96** A, 161-197, Wien
- VAN HETEREN, S. & VAN DE PLASSCHE, O. (1997): Influence of relative sea-level change and tidal-inlet development on barrier-spit stratigraphy, Sandy Neck, Massachusetts. - J. Sed. Res., **67/2**, 350-363, Tulsa
- VOGEL, K. (1968): Zur Lebensweise des Gastropoden *Nerinea*. - N. Jb. Geol. Paläont. Mh., Abt. B, **1968**, 181-184, Stuttgart
- WAGREICH, M. (1988): Sedimentologie und Beckenentwicklung des tieferen Abschnittes (Santon-Untercampan) der Gosauschichtgruppe von Gosau und Rußbach (Oberösterreich-Salzburg). - Jb. Geol. B.-A., **131**, 4, 663-685, Wien
- (1989): Coarsening-upward fan-delta sequences in the Lower Streiteck Formation (Santonian) of the Gosau Group near Gosau (Upper Austria). - N. Jb. Geol. Paläont. Mh., Abt. B, **1989/1**, 47-64, Stuttgart
- (1991): Subsidenzanalyse an kalkalpinen Oberkreideseerien der Gosaugruppe (Österreich). - Zentralbl. f. Geol. Paläont., **I**, 1645-1657, Stuttgart
- (1992): Correlation of Late Cretaceous calcareous nannofossil zones with ammonite zones and planktonic Foraminifera: the Austrian Gosau sections. - Cret. Res., **13**, 505-516, Cambridge
- WAGREICH, M. & FAUPL, P. (1994): Paleogeography and geodynamic evolution of the Gosau Group of the Northern Calcareous Alps (Late Cretaceous, Eastern Alps, Austria). - Paleogeogr., Paleoclimatol., Paleoecol., **110**, 235-254, Amsterdam
- WALKER, R. G. (1985): Cardium Formation 4. Review of facies and depositional processes in the Southern Foothills and Plains, Alberta, Canada. - In: TILLMAN, R. W., SWIFT, D. J. P. & WALKER, R. G. (eds.): Shelf sands and sandstone reservoirs. - Soc. Econ. Pal. Min., Short Course Notes, **13**, 353-402, Tulsa
- WALKER, R. G. & PLINT, A. G. (1992): Wave- and storm-dominated shallow marine systems. - In: WALKER, R. G. & JAMES, N. P. (eds.): Facies Models. Response to Sea Level Change. - 219-238, Ontario (Geol. Assoc. of Canada)
- WANLESS, H. R., TEDESCO, L. P. & TYRRELL, K. M. (1988): Production of subtidal tubular and surficial tempestites by Hurricane Kate, Caicos Platform, British West Indies. - J. Sed. Petrol., **58/4**, 739-750, Tulsa
- WANLESS, H. R., COTTRELL, D. J., TAGETT, M. G., TEDESCO, L. P. & WARZESKI, Jr., E. R. (1995): Origin and growth of carbonate banks in south Florida. - In: MONTY, C. L. V., BOSENCE, D. W. J., BRIDGES, P. H. & PRATT, B. R. (eds.): Carbonate Mud-Mounds. - Spec. Publ. int. Ass. Sedim., **23**, 439-473, Oxford (Blackwell)
- WARD, W. C. & BRADY, M. J. (1973): High-energy carbonates on the inner shelf, northeastern Yucatan Peninsula, Mexico. - Trans. Gulf Coast Ass. Geol. Soc., **23**, 226-238, Houston
- WARD, W. C. & BRADY, M. J. (1979): Strandline sedimentation of carbonate grainstones, Upper Pleistocene, Yucatan peninsula, Mexico. - Amer. Assoc. Petrol. Geol. Bull., **63/1**, 362-369, Tulsa
- WEIMER, R. J., HOWARD, J. D. & LINDSAY, D. R. (1982): Tidal Flats and Associated Tidal Channels. - In: SCHOLLE, P. A. & SPEARING, D. (eds.): Sandstone Depositional Environments. - Amer. Assoc. Petrol. Geol. Mem., **31**, 191-245, Tulsa
- WELLS, J. T. (1988): Accumulation of fine-grained sediments in a periodically energetic clastic environment, Cape Lookout Bight, North Carolina. - J. Sed. Petrol., **58/4**, 596-606, Tulsa
- WETZEL, R. G. (1975): Limnology. - 743 pp., Philadelphia (Saunders)
- WHITE, I. D., MOTTERSHEAD, D. N. & HARRISON, S. J. (1984): Environmental Systems. - 616 pp., London (Chapman & Hall)
- WILSON, J. L. (1975): Carbonate Facies in Geologic History. - 471 pp., New York (Springer)
- WILSON, P. (1990): Clast size variations on talus: some observations from Northwest Ireland. - Earth Surf. Proc. Landforms, **15**, 183-188, London (Wiley)
- WOLFF, H. (1985): Erläuterungen zum Blatt Nr. 8338 Bayrischzell. - 190 pp., München (Bayerisches Geologisches Landesamt)
- WRIGHT, L. D., CHAPPEL, J. THOM, B. G., BRADSHAW, M. P. & COWELL, P. (1979): Morphodynamics of reflective and dissipative beach and inshore systems: southeastern Australia. - Mar. Geol., **32**, 105-140, Amsterdam
- ZAITLIN, B. A., DALRYMPLE, R. W. & BOYD, R. (1994): The stratigraphic organization of incised-valley systems associated with relative sea-level change. - In: DALRYMPLE, R. W., BOYD, R. & ZAITLIN, B. A. (eds.): Incised-valley systems: Origin and Sedimentary Sequences. - Spec. Publ. Soc. Econ. Pal. Min., **51**, 45-60, Tulsa
- ZUFFA, G. G. (1985): Optical analyses of arenites: Influence of methodology on compositional results. - In: ZUFFA, G. G. (ed.): Provenance of Arenites. - 165-189, Dordrecht (Reidel)

Manuscript received January 10, 1998

Revised version accepted April 6, 1998