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UPPER CRETACEOUS TRANSGRESSIVE SHORE ZONE DEPOSITS ('UNTERSBERGER MARMOR'Auct.) IN THE EASTERN PART OF THE TYROL (AUSTRIA): AN OVERVIEW

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With 7 figures and 2 plates

Abstract:
At several stratigraphic levels, the Upper Cretaceous of the Northern Calcareous Alps, Austria, contains sheets of carbonate-dominated shore zone deposits that formed as a result of a relative sea-level rise onto previously exposed parts of the Eo-Alpine accretionary wedge. The persistence of a relatively high morphologic gradient and a high rate of relative sea-level rise were prerequisites to the repeated formation of transgressive carbonate shore zone successions over large parts of Late Cretaceous times.
In the western part of the Northern Calcareous Alps, in a Turonian to Santonian succession four intervals of carbonate-dominated shore zone deposits are present, each in the transgressive systems tract of a depositional sequence. Both within an individual sequence and between successive sequences, the shore zone deposits show significant variations in thickness, lithology, stratal packages and sedimentary structures. These differences are ascribed to a transgression onto an articulated morphologic relief, which induced alongshore variations in accomodation space and energy regime.
The transgressive shore zone deposits formed in association with (a) retreating fan deltas and (b) by transgression of more or less steeply inclined to cliffed coasts onto the folded and thrusted, carbonate-dominated sedimentary successions of the Bajuvaric and Tirolic nappe systems. The shore zone successions are up to 40 meters thick and consist of highly variable relative amounts of beachface conglomerates, shoreface conglomerates and associated arenites. The arenites range in composition from arenites composed exclusively of carbonate rock fragments to arenites of mixed siliciclastic/carbonate-lithoclastic composition to, more rarely, hybrid arenites with admixed bioclastic material. The beachface conglomerates occur at the base of the marine transgressive successions, and typically consist of very well-rounded fine gravels to cobbles arranged in subparallel-horizontal to low-angle cross-stratified bedsets. The shoreface conglomerates are intercalated into thicker successions of arenites, and mainly occur in compound channel-fills that locally interfinger with adjacent, cross-laminated arenites. The sedimentary structures in the arenites indicate wave-dominated shorelines. Both the beachface conglomerates and the shoreface conglomerates are commonly devoid of fossils, despite the coeval shelves supported a rich biota. The paucity to absence of fossils in the conglomerates is interpreted as a result of a strong taphonomic bias towards non-preservation in the upper shoreface to beachface environment. In the arenites, the bioclastic fraction typically ranges from zero to about 30 percent. As a result of transgressive reworking, many of the bioclasts are bored, blackened, or are stained red.
Fossiliferous, transgressive shore zone deposits of Turonian and Coniacian age contain corals, rudists, chaetetids, corallines, echinids, bryozoans, miliolids, textulariaceans, ataxophragmines, nezzazatids, *Cuneolina*, *Dictyopsella*, *Montcharmontia* and, rarely, fragments from calcareous green algae. The Santonian transgressive shore zone deposits, by contrast, are characterized by diverse lagenids, branched bryozoans, echinid fragments, rhodoliths, crustose corallines, articulated brachiopods, globotruncanids, ataxophragmines, and sessile foraminifera. Rudists are very rare, and corals and calcareous green algae are absent. Several lines of evidence suggest that the 'foramol' composition of the Santonian transgressive shore zone deposits is neither a result of the coastal depositional system nor of taphonomic loss, but is related to climate or to paleoceanographic conditions.

Zusammenfassung:
Die Obere Kreide der Nördlichen Kalkalpen (Österreich) enthält in mehreren stratigraphischen Niveaus karbonat-dominierte Küstenablagerungen, die sich infolge einer marinen Transgression auf vorher freigelegte Anteile des Eo-Alpinen Akkretionskeils bildeten. Ein vergleichsweise steiles, langlebiges morphologisches Relief der transgredierten Landbereiche und eine hohe Rate des relativen Meeresspiegelanstiegs waren die Voraussetzungen für die wiederholte Ablagerung karbonat-dominierter transgressiver Küstenabfolgen über einen langen Zeitabschnitt der Späten Kreide.

Im Turon bis Santon des westlichen Teils der Nördlichen Kalkalpen kommen, jeweils im transgressiven Systemtrakt einer Ablagerungssequenz, insgesamt vier dickere Intervalle karbonat-dominierter Küstenablagerungen vor. Sowohl zwischen verschiedenen Sequenzen als auch innerhalb einer Sequenz weisen die transgressiven Küstenabfolgen deutliche Unterschiede in Dicke, Lithologien und Sedimentstrukturen auf. Diese Unterschiede sind Ausdruck einer Transgression auf ein gegliedertes morphologisches Relief, das zu küstenparalleler Schwankungen in Akkomodationsraum und mittlerer Wasserenergie führte.
Die beschriebenen Abfolgen bildeten sich (a) während der Transgression mehr oder weniger steil geneigter Kiesküsten bis Steilküsten auf den gefalteten Untergrund der karbonat-dominierten Abfolgen des bajuwarischen und tirolischen Deckenstapels, und (b) im Zusammenhang mit Fächerdelten. Die transgressiven Küstenabfolgen sind bis zu 40 Meter dick, und bestehen aus sehr veränderlichen Anteilen von Areniten und Konglomeraten des nassen Strandes und des Vorstrandes. Die Konglomerate des nassen Strandes liegen an der Basis der transgressiven Abfolgen, und bestehen meist aus sehr gut gerundeten Feinkiesen bis Grobkiesen, die in subparallelen Bänken bis niedrigwinklig-kreuzstratifizierten Bankgruppen angeordnet sind. Die Konglomerate des Vorstrandes sind in dickere Abfolgen von kreuzlaminierten Areniten eingeschaltet, und kommen als zusammengesetzte Kanalfüllungen vor, die örtlich mit den benachbarten, kreuzlaminierten Areniten verzahnen. Die sedimentären Strukturen in den kreuzlaminierten Areniten zeigen wellendominierte Küsten an. Die Konglomerate des nassen Strandes und des Vorstrandes sind fast stets fossilleer, obschon die benachbarten Schelfe eine reiche Lebewelt führten. Das Fehlen von Fossilien in den Konglomeraten wird als Ergebnis von Nichterhaltung, d. h. als taphonomischer Effekt interpretiert. In den Areniten liegt der Anteil an Biogenen meist zwischen Null und ungefähr 30 Prozent. Infolge transgressiver Aufarbeitung sind viele der Biogene angebohrt, geschwärzt oder rot imprägniert.
Fossilhältige transgressive Küstenablagerungen des Turon und Coniac enthalten Korallen, Rudisten, Chaetetiden, koralline Algen, Echiniden, Bryozoen, Milioliden, Textulariaceen, Ataxophragminen, Nezzazatiden, *Cuneolina*, *Dictyopsella*, *Montcharmontia* und selten auch Fragmente von Kalkgrünalgen. Die transgressive Abfolge des Santon dagegen ist charakterisiert durch Lageniden, verzweigte Bryozoen, Echiniden, Rhodolithen, krustose koralline Algen, artikulierte Brachiopoden, Globotruncaniden, Ataxophragminen und sessile Foraminiferen. Rudisten sind sehr selten, und Korallen und Kalkgrünalgen fehlen. Die „foramol"-Zusammensetzung der santonen Transgressionsfolge ist weder ein Ergebnis des Küsten-Ablagerungssystems noch von taphonomischem Verlust, sondern hängt möglicherweise mit veränderten klimatischen oder paläozeanographischen Bedingungen zusammen.

Introduction

Although recent gravelly and rocky shores are both widespread and often associated with each other (e. g. BARNES, 1977; SEMENIUK & JOHNSON, 1985), very few descriptions of their geological record exist (JOHNSON, 1988). Gravel shores and rocky shores are typical for coastal areas with high morphological gradients, and are particularly common along active margins (INMAN & NORDSTROM, 1971).

Because of their large scale, accretionary wedges can be classified as first-order morphologic features. Along active margins that are subject to marine transgression, like the Eo-Alpine accretionary wedge during Late Cretaceous times, records of gravelly and rocky shorelines should be quite common in the transgressive systems tract of depositional sequences (SANDERS, 1996a, b; SANDERS et al., 1997; compare also SEMENIUK & JOHNSON, 1985; JOHNSON et al., 1996).

In the Upper Cretaceous of the Northern Calcareous Alps, successions up to several tens of meters thick that formed in association with both gravelly shores and rocky carbonate shores are present at many locations. These deposits formed during transgression onto the Eo-Alpine accretionary wedge (cf. SANDERS et al., 1997), and provide a rare example for the repeated development of lithoclastic carbonate beach successions within successive depositional sequences. In the regional geologic literature, thicker transgressive successions of carbonate rock conglomerates and associated arenites are informally termed 'Untersberger Marmor' (e.g. TOLLMANN, 1976).

In the western part of the Northern Calcareous Alps, successions that formed in association with Late Cretaceous gravelly and rocky beaches are well-exposed. This paper provides a short overview of the transgressive shore zone deposits, their fossil assemblages and taphonomy. The coastal depositional systems are interpreted from the geologic record, and the significance of the fossil assemblages of the transgressive intervals is discussed.

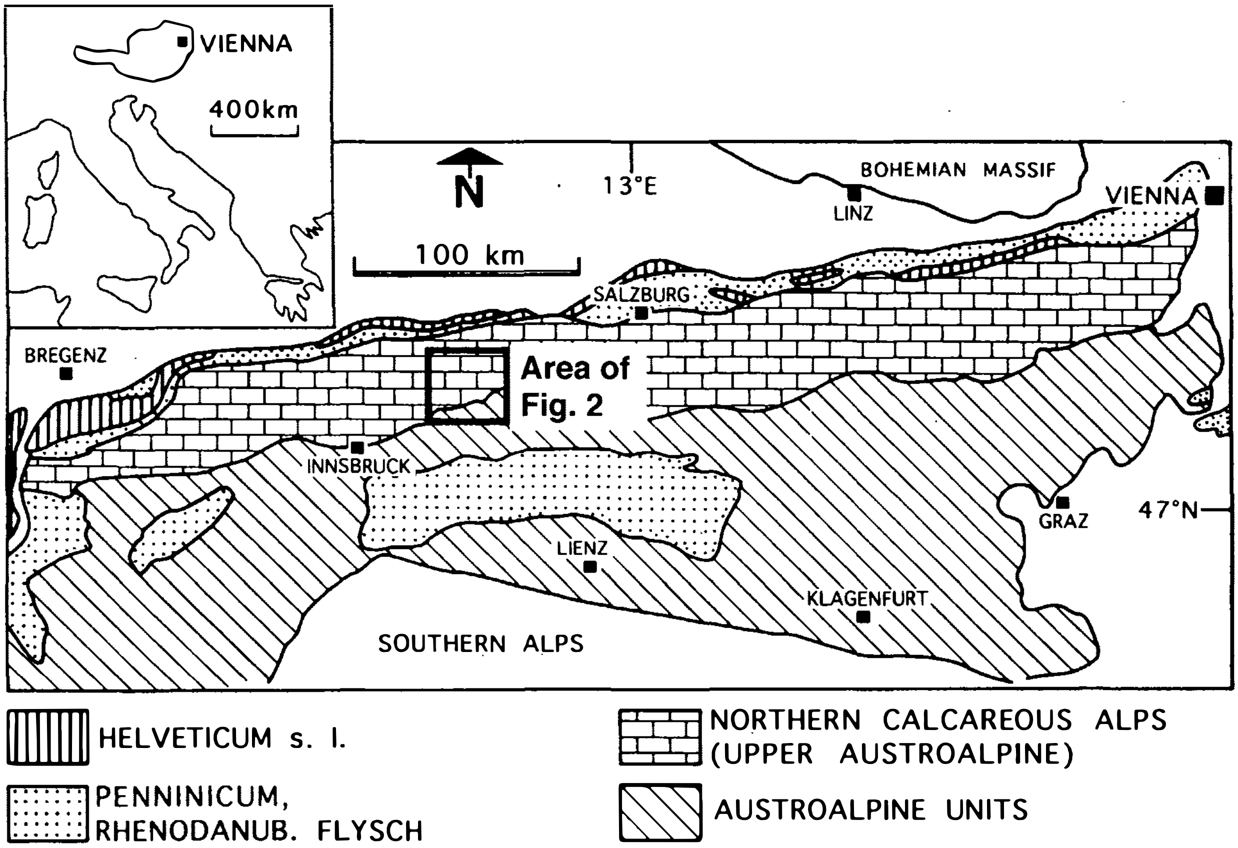

Fig. 1: Position of Austria in Europe (inset), and geological sketch of the Eastern Alps. The area considered in this paper is indicated by heavy black quadrangle.

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 in a mobile belt along the northern, passive continental margin of the larger Adriatic plate (CHANNELL et al., 1992). 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 that were thrust top-to-west to-northwest (RATSCHBACHER, 1987; RATSCHBACHER et al., 1989; FROITZHEIM et al., 1994) (fig. 2). Subsequent to the Eo-Alpine phase of thrusting and nappe formation, large parts of the Eastern Alps were subject to uplift and erosion, accompanied by extensional collapse of the rising orogen (PLATT, 1986; RATSCHBACHER et al., 1989). At least in the area of the Northern Calcareous Alps the erosion produced a deeply dissected morphology along the truncation surface at the base of the Upper Cretaceous. Subaerial exposure and a persistent morphologic relief of the basal truncation surface are recorded by a mature paleokarst below the truncation surface, by bauxite accumulations, and by the presence of deposits from alluvial fans and fan deltas both at the base and within the Upper Cretaceous succession. In the area described in this paper, the Gosau Group unconformably overlies Middle Triassic to Jurassic rocks of both the Bajuvaric and Tirolic nappe stacks of the Upper Austroalpine tectonic unit.

From Turonian to Santonian times, the exposed areas became re-submergent, and deposition of the Gosau Group started under overall high subsidence rates (WAGREICH, 1991). The Gosau Group is up to 2500 m thick, and is subdivided into the

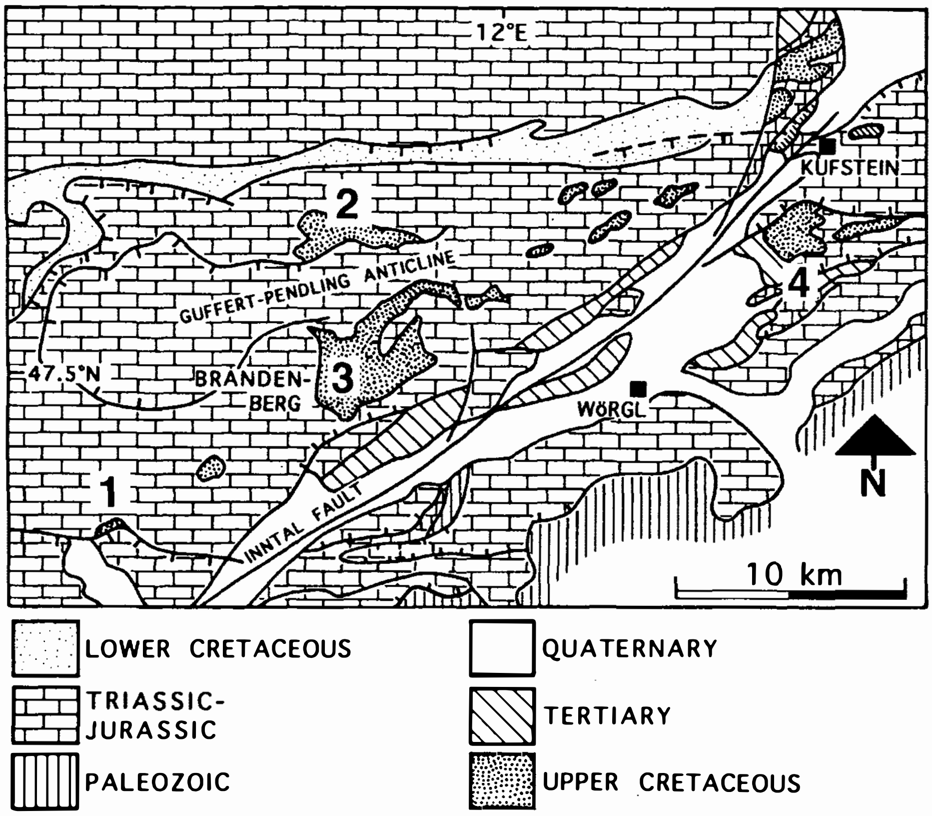

Fig. 2: Geological map of the Lower Inn Valley, with the Upper Cretaceous outcrop areas indicated (simplified from Brandner 1985). The former basement of the Northern Calcareous Alps is represented by metamorphic rocks of Paleozoic age (Northern Greywacke Zone). The Triassic-Jurassic succession is deformed into thrust nappes. The Triassic-Jurassic succession is overlain along a deeply incised truncation surface by Upper Cretaceous deposits which, in turn, are unconformably overlain by Tertiary strata. In the considered area, the Northern Calcareous Alps are cut by a sinistral strike-slip fault (Inntal Fault). The description of Upper Cretaceous shore zone deposits is derived from the outcrops labelled 1 to 4. 1 = Maurach, 2 = Brandenberg (northern part), 3 = Brandenberg (southern part), 4 = Eiberg.

Lower Gosau Subgroup (Upper Turonian to Campanian) that consists mainly of continental to neritic deposits, and the Upper Gosau Subgroup (Santonian to Eocene), which is made up by deep marine deposits (Wagreich & Faupl, 1994). In the Lower Gosau Subgroup, in the transgressive systems tracts of depositional sequences, sheets of conglomerates and of arenites composed largely of carbonate rock fragments are locally present that formed during transgression onto the exposed carbonate rock substratum (Sanders, 1996 a, b). The upper part of the transgressive systems tract and the highstand systems tract of the depositional sequences typically consist of shelf sandstones and shelf marls, and a few intercalated intervals of shallow-marine carbonates (Sanders et al., 1997). The Upper Cretaceous succession of the area considered in this paper ranges in age from ?Middle/Late Turonian in the northern part of the Brandenberg area to Maastrichtian at the southern margin of the area of Eiberg (see fig. 2).

Biostratigraphy

In the Upper Cretaceous succession, nannofossils, planktic foraminifera, ammonites and inoceramids provide precise biostratigraphic points of reference, and commonly allow for a chronostratigraphic resolution at biozone level to substage level. In the considered area, the Lower Gosau Subgroup ranges in age from ?Middle/Late Turonian to Late Santonian. For the data base of the

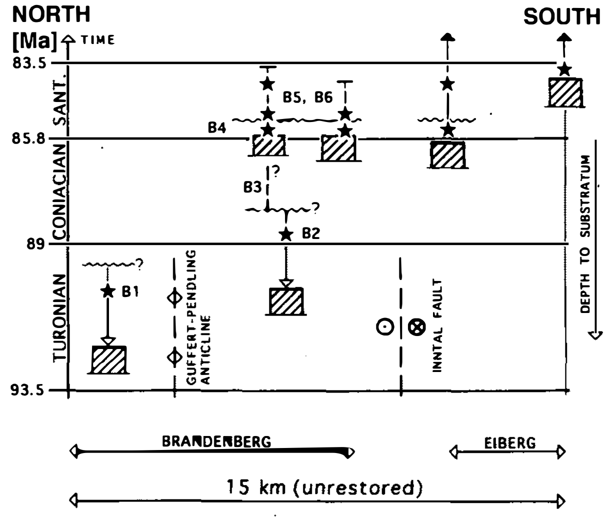

Fig. 3: Combined north-south chronostratigraphic and spatial relations of Upper Cretaceous succession in the area of Brandenberg and Eiberg, relative to the older substratum (cross-hatched). The northernmost, well-dated outcrop in Brandenberg is separated from the southern margin of outcrop at Eiberg by a lateral distance of about 15 km; this distance is unrestored for Tertiary compressive shortening. The trace of the Inntal Fault and the approximate position of the culmination of the Guffert-Pendling anticline are shown (see fig. 2). Numbers B1 to B6 refer to physical stratigraphic units as recognized in the area of Brandenberg. The asterisks indicate the levels with the most precise biostratigraphic datums (at the biozone level), and refer to the chronostratigraphic ordinate on the left margin of the diagram. The vertical distance of each asterisk to the underlying substratum (cross-hatched) indicates the vertical spatial distance of the most precise biomarkers from the local substratum, and refers to the ordinate 'depth to substratum' on the right margin of the diagram. From Brandenberg in the north to Eiberg in the south, an overall younging of the stratigraphic units that are in contact with the substratum is evident.

biostratigraphy of the Upper Cretaceous in the investigated areas see FISCHER (1964), Ibrahim (1976), HERM et al. (1979), Immel et al. (1982), WAGREICH (1992), SUMMESBERGER (1985), TRÖGER & SUMMESBERGER (1994), SUMMESBERGER & KENNEDY (1996), SANDERS et al. (1997), and SANDERS & BARON-SZABO (1997).

Overview

Following the definition of shore zone by INMAN & NORDSTROM (1971), shore zone deposits are designated as all the lithofacies that have been deposited under the predominant influence of a coastal hydrodynamic regime, i. e. mainly wave-induced currents and tidal currents. In the Upper Cretaceous succession, shore zone deposits from transgressive beaches as well as from regressive beaches are present. In the present paper, only the principal types of deposits are described that formed in association with transgressive beaches, whereas the regressive shore zone deposits are not considered.

From north to south, from the northern margin of outcrop in Brandenberg to the southern limit at Eiberg, the Upper Cretaceous successions that directly overlie the truncated substratum are successivly younger (fig. 3). The following description of the shore zone deposits is derived from the stratigraphic units B1 to B4 of Brandenberg, as well as from the Upper Cretaceous of Maurach (SANDERS, 1996 b) and Eiberg (IBRAHIM, 1976; GRUBER, 1995) (see figs. 2, 3). Within the outcrop area of the units B5 and B6, no shore zone deposits are preserved. Because of their differences with respect to lithologies, vertical organization and fossil content, the transgressive shore zone deposits of the Turonian to Coniacian part and of the Santonian part of the Lower Gosau Subgroup are described and interpreted separately.

Turonian and Coniacian shore zone deposits

With respect to grain size, the Turonian to Coniacian transgressive shore zone deposits are subdivided into (1) conglomerates and (2) arenites, which latter consist of variable mixtures of sand composed of carbonate rock fragments, siliciclastic sand, and bioclastic sand. The conglomerates and the arenites typically occur in close vertical association, but locally the entire transgressive shore zone succession consists of arenites.

According to their stratigraphic position, two types of conglomerates can be distinguished, (a) „basal marine conglomerates“ that are present at the base of the marine succession and that either overlie the older carbonate rock substratum or alluvial fan deposits along a wave ravinement sur-

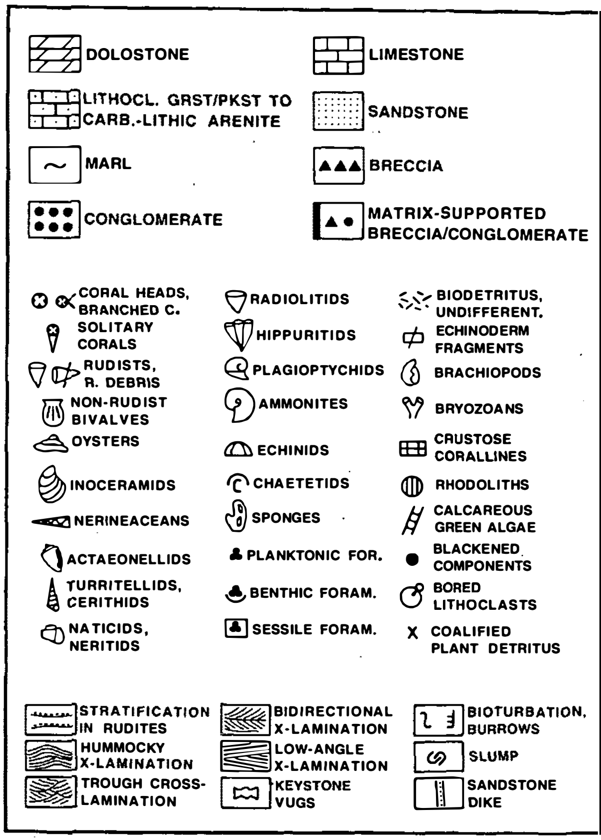

Fig. 4: Key to symbols used in figure 5.

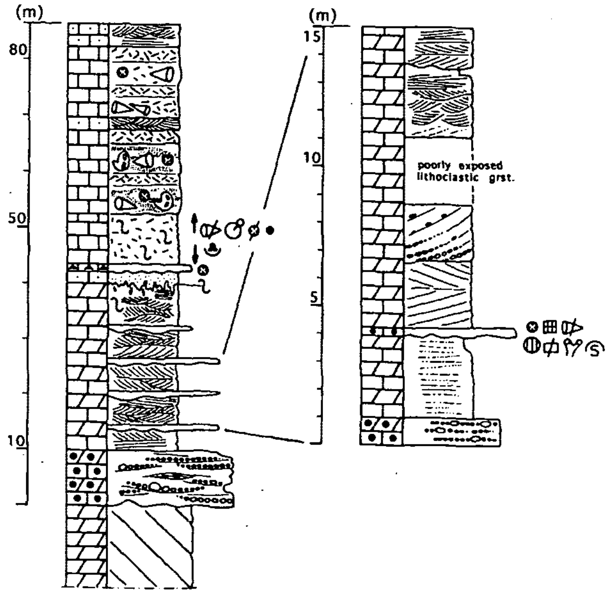

Fig. 5: Lower part of Upper Cretaceous succession in the area of Prinzkopf-Winterstube, Brandenberg (see figure 4 for legend). The substratum is overlain by an interval approximately 10 meters thick of poorly sorted, fine gravel to cobble conglomerates and coarse-grained arenites that are composed exclusively of carbonate rock fragments derived from the older substratum. The conglomerates are overlain by a package some tens of meters thick of arenites with intercalated intervals of conglomerate. Together the arenites and the conglomerates are arranged in upward fining packages (see inset). A package may consist of a conglomerate at the base, overlain by cross-stratified arenite which, in turn, may be topped by an interval of medium- to fine-grained arenites that show trough cross-lamination. Above the succession of arenites, a succession some tens of meters thick is exposed that consists mainly of rudist-coral limestones with intercalated intervals of bioclastic grainstone to packstone.

face, and (b) conglomerates within the marine shore zone succession. The basal marine conglomerates are devoid of fossils, and consist of carbonate rock clasts that are derived from the local substratum, mainly Ladinian to Early Jurassic limestones, dolomites and, locally, cherty limestones. The conglomerates build intervals up to 10 meters thick (fig. 5), and typically consist of well- to very well-sorted, fine to coarse gravels of broad rod-shape to highly spherical shape (plate 1/1). Locally, very well-rounded, spherical cobbles to boulders up to 60 cm in size are present, and may comprise a substantial portion of the sediment (plate 1/3). The conglomerate intervals consist of parallel-horizontal to low-angle cross-stratified bedsets, but locally show poor organization with respect to grain size and bedding. Truncated lenses up to a few decimeters thick of parallel-horizontal laminated or wave-ripple laminated arenite are locally intercalated. Intervals of basal marine conglomerates can be correlated along strike over several kilometers, and show significant lateral variations with respect to thickness, mean grain size and internal organization. In Brandenberg, at one outcrop a basal marine conglomerate is present that consists of poorly sorted, subrounded fine gravel to cobbles of carbonate rock. The clasts in this „poorly sorted basal conglomerate“ typically are more or less densely penetrated by *Trypanites* borings (including borings produced by lithophagids and by clionids). In the poorly sorted basal conglomerate, coral heads, nerineaceans and rudists are common.

The basal marine conglomerates typically are overlain by intervals up to some tens of meters thick of cross-laminated arenites with intercalated conglomerates (fig. 5). The cross-laminated arenites show parallel-horizontal lamination, stacked tangential-oblique cross-laminasets separated by reactivation surfaces and, locally, hummocky cross-laminasets. Levels with the trace fossil *Stelloglyphus* are present preferentially within arenites with parallel-horizontal lamination. In the parallel-horizontal and cross-laminated arenites, dewatering structures (thin fluidization channels, distorted cross-lamination) are common. In vertical section, a succession from predominantly parallel-horizontal laminated arenites into, higher up, arenites with stacked tangential-oblique cross-laminasets and, still higher up, to more or less bioturbated arenites with intercalated hummocky cross-laminasets is typical. The arenites range in composition from arenites composed exclusively of carbonate rock fragments to arenites of mixed siliciclastic/carbonate-lithoclastic composition to, more rarely, hybrid arenites with admixed bioclastic material.

The arenites are intercalated with intervals of conglomerates that mainly consist of fine gravels to cobbles of Triassic and Jurassic carbonate rocks and, subordinately, of well- to very well-rounded clasts of volcanic rocks, sandstones, and chert. These conglomerates occur as compound channel-fills up to several meters thick that locally interfinger with the cross-laminated arenites. Internally, the channel-fills consist of stacked conglomerate beds that show high-angle scours at their base. The truncation surface at the base of a compound channel-fill can locally be seen to grade into an otherwise inconspicuous reactivation surface within laterally adjacent arenites with stacked, inclined tangential cross-laminasets. Another variety of these conglomerates commonly consists of well-rounded medium gravels to cobbles. These conglomerates are present in ungraded to indistinctly graded beds up to a few decimeters in thickness. The beds show asymmetric and symmetric high-angle scours at their base, contain arenite rip-up clasts, and are intercalated into arenites with parallel-horizontal laminasets and/or tangential-oblique cross-laminasets. The top of these conglomerate beds is more or less plane. From the top of the beds, lithoclasts locally project upward.

The described conglomerates and the arenites commonly are arranged in stratal packages of a few meters to about 10 meters in thickness (fig. 5). Aside from a local, indistinct fining upward trend, the internal organization of these packages appears to be highly variable, but is always dominated by tangential-oblique cross-lamination, low-angle cross-lamination and, in the upper part of the transgressive successions, may also contain hummocky cross-laminasets. The basal marine conglomerates most commonly are devoid of fossils (see above). The cross-laminated arenites and/or the intercalated conglomerates, however, locally are fossiliferous (fig. 5). The fossils include fragments and more or less complete specimens of corals (coral heads and branched corals), hippuritids (*Vaccinites*), radiolitids, plagioptychids, ostreids, chaetetids, small rhodoliths and fragments from encrusting and branched corallines, echinids, branched and encrusting bryozoans, *Ethelia alba*, miliolids, textulariaceans, ataxophragmines, nezzazatids, *Cuneolina*, *Dictyopsella*, *Montcharmontia* and, rarely, fragments from calcareous green algae. Many bioclasts bear micrite rims, or are stained red. Blackened and bored carbonate rock clasts and bioclasts are common, and are locally encrusted by red algae and placopsilinids.

Interpretation

The position of the basal conglomerates at the base of the transgressive marine successions, the very well rounding and the high sphericity of the lithoclasts, and the internal organization of the conglomerates into parallel-horizontal- to low-angle cross-stratified bedsets all indicate that the basal conglomerates were deposited from a gravel beachface (beachface conglomerates; Nemec & Steel, 1984; Bourgeois & Leithold, 1984). The marked lateral variations of individual intervals of beachface conglomerates mainly with respect to thickness, internal organization, mean grain size, clast sorting and rounding, and fossil content most probably are a result of an interaction between an articulated morphology of the basal truncation surface and consequent alongshore changes in mean water energy.

Above the beachface conglomerates, in the intervals of arenites and intercalated conglomerates, the intervals of parallel-horizontal laminated arenites and/or low-angle cross-laminated arenites probably were deposited in a foreshore to upper shoreface environment. The described arenites with tangential-oblique cross-lamination record deposition in a wave-tide influenced shoreface environment. At least locally, larger dunes composed of lithoclastic carbonate sand appear to have existed in the shoreface. The hummocky cross-laminated arenites, in turn, record storm deposition in a lower shoreface to offshore-transitional environment.

In the transgressive successions, both the siliciclastic sand and at least a large portion of the sand-sized carbonate rock fragments were derived from fluvial input, and were distributed by longshore drift. Rivers that cross carbonate rock terrains may shed significant amounts of sand-sized carbonate rock fragments into the marine environment, where the sediment is distributed by longshore drift (cf. ZUSCHIN & PILLER, 1994). In the Upper Cretaceous of Brandenberg, fluviatile input of substantial amounts of sand-sized carbonate rock fragments is suggested by the observation that such particles also are common in sandstones that have been deposited in association with regressive shore zone successions (cf. SANDERS, 1997; SANDERS et al., 1997). In the transgressive shore zone successions, however, the abundance of sand-sized carbonate rock clasts particularly in the lower, beachface to upper shoreface portion of these successions indicates that biological erosion by boring organisms combined with physical coastal erosion by storm waves was a major source for the carbonate-lithoclastic sand.

The arenites that consist exclusively of carbonate rock fragments, and the arenites that consist of both carbonate rock fragments and less than 50 percent siliciclastic sand pose a problem in arenite classification. As discussed by ZUFFA (1985), in orogenic belts where cannibalization of older sediments is common, carbonate rock fragments may be carried to the sea by rivers and may originate from 'submarine sources'. If they are of fluviatile origin, these carbonate particles are classified as extrabasinal, but if they originated in the marine environment, they are intrabasinal (ZUFFA, 1985: 171f.). As mentioned, the carbonate rock fragments most probably were derived from both coastal erosion and fluviatile input. The carbonate rock fragment-arenites thus cannot be classified as 'carbonate extrarenites'. The interpretation that the composition 'carbonate extrarenite' can be used as a reference point on a classification tetrahedron, and indicates both the composition and the origin of the arenite within one term (ZUFFA, 1985: fig. 11, p. 184) thus is not valid in the present case. It is also not possible to classify the described Upper Cretaceous arenites as a hybrid between carbonate extrarenites and carbonate intrarenites, since the latter are defined to be of allochemical composition (ZUFFA, 1985). To date, it appears best to designate the discussed arenites with descriptive terms (see above).

The conglomerates that are intercalated into the cross-laminated arenites show diagnostic features of shoreface conglomerates, including their occurrence within channels and as compound channel-fills, the high-angle scours at the base of individual conglomerate beds, and the evidence for wave-incuded reworking of some of the bed tops (cf. NEMEC & STEEL, 1984; BOURGEOIS & LEITHOLD, 1984; LEITHOLD & BOURGEOIS, 1984). The clasts of the thin conglomerate beds with the basal high-angle scours and the projecting lithoclasts at their top may have been transported by a non-cohesive gravity flow (cf. NEMEC & STEEL, 1984). The asymmetric cross-section of many of the high-angle scours at the base of the conglomerate beds strongly suggests that they were excavated by currents at least with a predominant unidirectional component (LEITHOLD & BOURGEOIS, 1984), probably by flows of fluidal rheological behaviour (cf. SHANMUGAM & MOIOLA, 1997; SHANMUGAM et al., 1997). The presence of size-grading in some of the conglomerate beds indicates that these have been deposited by suspension fallout. During the stage of waning flow competence, however, at least some of the sediment-laden flows may have underwent a change to a state that prevented suspension fallout. The absence of size-grading and the projecting lithoclasts in some of the conglomerate beds suggests that, as dispersive pressure from clast collisions became the prime mechanism for clast support during waning flow competence, these flows may have passed through a short stage of rheological debris flow, which was then stopped by frictional freezing (compare SHANMUGAM & MOIOLA, 1997; SOHN et al., 1997). Enrichment of the gravels due to sand winnowing by fluid flows (AIGNER & FÜTTERER, 1978; CHIOCCI & CLIFTON, 1991) is impossible, since the vertically associated arenites are devoid of or contain only very few and significantly smaller lithoclasts. The marked rarity of burrows in the arenites also precludes an initiation of the high-angle scours from burrows (cf. LEITHOLD & BOURGEOIS, 1984; CHIOCCI & CLIFTON, 1991). In Brandenberg the high-angle scours were observed exclusively at the base of conglomerate beds. No high-angle scours were observed in sandstone that are filled by sandstone (LEITHOLD & BOURGEOIS, 1984; CHIOCCI & CLIFTON, 1991). Thus, a direct causal connection between conglomerate transport/deposition and the formation of the high-angle scours can be assumed. It is doubtful whether storm rip currents are powerful enough to transport a sheet of coarse gravels and cobbles by traction and saltation. To date, no recent analogues for high-angle scours are known (LEITHOLD & BOURGEOIS, 1984). Shoreface conglomerates like those exposed in the area of Brandenberg may be typical for shore zones with high gradients, including the subaqueous part of high-gradient fan deltas (cf. PRIOR & BORNHOLD, 1988).

In the successions of arenites and shoreface conglomerates, the overall vertical change from predominantly parallel-horizontal laminated arenites into arenites with inclined cross-lamination and, finally, into hummocky cross-laminated arenites, the overall vertical decrease in both bed thickness and amalgamation of the shoreface conglomerates, an overall fining-upward development, and the vertical increase in burrowing all indicate a deepening. Where the beachface conglomerates and the overlying arenites and shoreface conglomerates overlie alluvial fan deposits, they probably have been deposited in the subaqueous part of an active fan delta. As mentioned, in the fining upward stratal packages the sedimentary structures and their vertical arrangement appear to be quite complex, but always indicate sediment accumulation in a high-energy shoreface to foreshore environment. In this environment, periods of prevailing erosion may change with periods of prevailing accumulation, giving rise to very complex vertical arrangements of sedimentary structures.

In both the beachface and in the shoreface conglomerates, the absence or paucity of fossils can be ascribed to taphonomic loss related to the extremely abrasive upper shoreface to beachface environment of gravelly beaches. Along low-energy, wave-dominated gravelly shorelines of the recent Mediterranean, for instance, the beachface to proximal backshore is often devoid of even very robust shells (e. g. littorinid shells), although the closely adjacent shoreface environment supports a rich biota. During storms, the gravels are moved by wave uprush and backwash across the beachface, thereby destroying any shells. The fossiliferous, 'poorly sorted basal conglomerate' (see above) has been deposited along a coastal sector of very low wave energy, which allowed for the preservation at least of coral skeletons and the shells of nerineaceans and hippuritids. In the fossiliferous arenites, the mixing of skeletal fragments from organisms that preferred different habitats (quiet lagoonal environments: calcareous green algae, *Cuneolina*, *Dictyopsella*, *Montcharmontia*, sponges; agitated, open subtidal environments: massive corals, hippuritids), and the bioerosion and encrustation of many of the bioclasts indicate that a large portion of the bioclasts probably was reworked during transgression and that the assemblage is strongly time-averaged (cf. FÜRSICH & ABERHAN, 1990).

For successions that consist of coastal conglomerates and associated arenites that grade upsection into fossiliferous shelf deposits, the depositional system can be subdivided into a beachface-to-upper shoreface belt and a lower shoreface-to-offshore belt. The beachface-to-upper

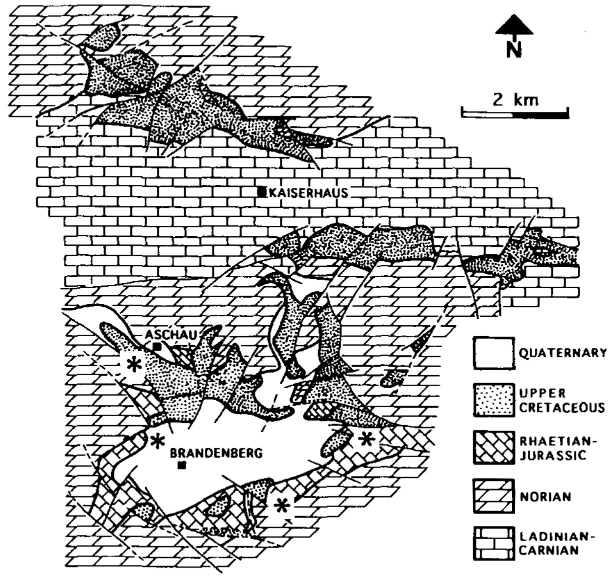

Fig. 6: Simplified geological map of the Brandenberg outcrop area. In the southern part of the area, erosional remnants up to some tens of meters thick of a karstified and truncated Upper Cretaceous succession composed mainly of shallow-water limestones are present. The location of the larger remnants is indicated by asterisks.

shoreface belt is characterized by conglomerates that are poor in or devoid of fossils because of extreme taphonomic loss in the highly abrasive, storm-wave dominated shore zone, although this zone nearly certainly was colonized by diverse organisms (gastropods, rudists, corals). In the lower shoreface-to-offshore belt the shelly biota were largely preserved.

Santonian shore zone deposits

The Santonian transgressive succession of Brandenberg and Eiberg overlies truncated and karstified carbonate rocks of Triassic, Jurassic and Late Cretaceous age. In Brandenberg, the Upper Cretaceous rocks below the Santonian succession are confined to small remnants of karstified shallow-water limestones; these remnants record subaerial exposure and strong erosion before and during the Santonian transgression (fig. 6) (SANDERS et al., 1997). At Eiberg, coral-rudist boundstones were found in one small, isolated outcrop closely above the older substratum (GRUBER, 1995), which thus may similarly represent an erosional remnant of a pre-Santonian carbonate rock succession.

The Santonian transgressive succession consists largely of clast- to lime mud matrix-supported arenites composed of carbonate rock fragments; these arenites typically contain a few percent to about 30 percent of biogens and, locally, a few percent of siliciclastic sand. Both in Brandenberg and at Eiberg, very poorly sorted, clast- to matrix-supported, lithic calcirudites (breccias and/or conglomerates) are locally present at the base of the Santonian (plate 1/2). The thickness of the calcirudite intervals varies from zero to about 20 meters within short lateral distances (see also IBRAHIM, 1976). The calcirudites typically consist of fine gravel- to cobble-sized lithoclasts of Triassic, Jurassic and Upper Cretaceous carbonate rocks that commonly are penetrated by *Trypanites*; isolated boulders up to more than one meter in size are also present. The calcirudites contain a matrix of arenites that are composed of carbonate rock fragments derived from the local substratum; the arenites locally contain admixed bioclastic material, mainly fragments from inoceramids and other non-rudist bivalves, bryozoans, echinoderms, smaller benthic foraminifera (incl. lagenids), a few ostracods and, locally, a few globotruncanids and radiolarians (see also IBRAHIM, 1976).

Locally, at and near the base of the Santonian transgressive succession, more or less well-rounded to highly spherical, isolated gravels to boulders of Triassic, Jurassic and Upper Cretaceous carbonate clasts float within the arenites (plate 1/3). At many locations, the described basal calcirudites are absent, and the substratum is directly overlain by a succession some tens of meters thick of arenites. Along the contact, the older carbonate rocks are either penetrated by *Trypanites*, or the surface of contact is plane and unbored. Near its base, the Santonian transgressive succession locally shows poorly defined horizontal parallel lamination and a few inclined tangential laminasets. Locally, near the base of the succession, beds of coarse gravel to cobble conglomerate with asymmetric high-angle scours at their base and projecting lithoclasts at their top are intercalated (plate 2/1). The lithoclasts may be unbored, or are penetrated by *Trypanites* (plate 2/2). Up-section, the arenites become bioturbated, contain an increasing amount of siliciclastic sand and a few beds with possible hummocky cross-lamination.

The arenites consist mainly of sand-sized carbonate rock fragments that are derived from the local Triassic to Upper Cretaceous substratum (see also GRUBER, 1995). Locally, isolated reworked bioclasts from Upper Cretaceous shallow-water lithologies are common, and include fragments from corals, rudists, and smaller benthic foraminifera. The isolated bioclasts are typically blackened or stained red, and may be heavily bored. The reworked coral fragments are strongly diagenetically altered (red/green staining, both skeleton and polyparia replaced by pseudosparite and/or blocky calcite spar). The biogenic fraction of the arenites is dominated by diverse lagenids (e. g. *Lenticulina*), fronds from branched bryozoans, echinoid fragments, rhodoliths of *Archaeolithothamnium*, fragments from encrusting corallines, and a few fragments from rudists and non-rudist bivalves, including inoceramids (plate 2/3). Subordinately, brachiopods (incl. rhynchonellids), globotruncanids, rotaliids, ataxophragmiines, placopsilinines, miliolids, textulariaceans, serpulid tubes, fish teeth, and a few radiolarians and radiolitid fragments are present. At least locally, globotruncanids and a few radiolarians are present from the base of the succession, or become fairly common within the first few meters of the succession, despite the entire succession of arenites is significantly thicker (see also IBRAHIM, 1976). In Brandenberg, in the lower part of the Santonian succession very rarely, isolated specimens of small radiolitids and small hippuritids were found, but most commonly are absent. In the arenites, many of the bioclasts are more or less fragmented and abraded. The larger bioclasts are locally encrusted by coralline algae and placopsilinines. Echinid spines and lagenid foraminifera often are perforated by microborings, whereas some of the miliolids are blackened. The encrustation of the bioclasts, and the microborings and blackening all suggest that the taphocoenosis is strongly time-averaged by transgressive reworking.

Interpretation

For the described succession, the local presence of a laterally discontinuous veneer of gravels to boulders from Triassic to Upper Cretaceous rocks embedded in a matrix of arenites, the sharp and locally bored contact between the truncated substratum and the transgressive arenite succession, the absence of sedimentary structures that indicate a foreshore environment, and the presence of globotruncanids even in the lowest part of the succession all suggest that the Santonian transgressive succession was deposited from a more or less steeply inclined to cliffed carbonate rock coast (cf. SEMENIUK & JOHNSON, 1985).

Rocky shores are features of erosion, and are characterized by a large difference between their depositional morphology and their geologic record. What is an impressive cliff coast at the time of transgression is recorded as a gently dipping sheet of transgressive lithologies above a plained, truncated substratum (FLINT & SKINNER, 1974; SEMENIUK & JOHNSON, 1985).

Both the facies associations from cliff coasts and the above described gravel coasts are not mutually exclusive as, in the Holocene, cliff coasts and gravel coasts often are laterally juxtaposed. Because of their typically articulated morphology, rocky to gravelly shorelines are characterized by a large and rapid lateral variability of their record both on a scale of individual headlands and embayments (hundreds of meters to kilometers) as well as on the scale of entire coastal segments (kilometers to tens of kilometers; cf. Semeniuk & Johnson, 1985) (fig. 7). Because of the lateral variability of high-gradient coastlines, particularly in areas that consist of karstified carbonate rocks, fan deltas thus may laterally co-exist with cliff coasts and with coastal sectors of relatively gentle gradient (fig. 7).

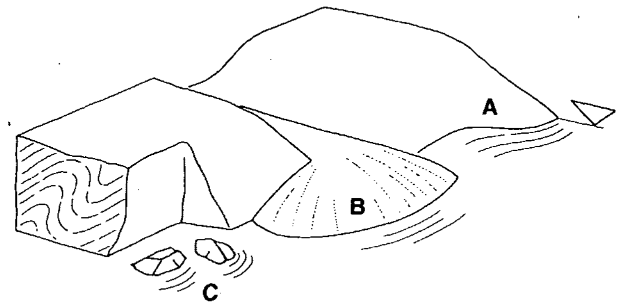

Fig. 7: Scheme of transgression onto carbonate rock substrate, and onto the subaerial part of fan deltas. A laterally highly variable coastal morphology is typical for high-gradient carbonate rock shorelines along active margins, including coastal sectors of relatively low inclination (A), fan deltas (B), and cliff coasts (C). Because of the articulated coastal morphology and a different relative rate or nature of processes (i. e. active sediment input along the fan deltas), the resulting transgressive record is highly variable in space and time. See text for further discussion.

As mentioned, the arenites and associated conglomerates are informally designated as 'Untersberger Marmor' (e. g. TOLLMANN, 1976). Based on occasional findings of rudists or corals, the Untersberger Marmor has been variously designated as 'reef-related' deposit. In the described outcrops of Untersberger Marmor in the eastern part of the Tyrol, an interpretation in terms of reef-related deposits is precluded, and an origin from transgressive gravelly to rocky shorelines is indicated. A cursory investigation of other outcrops of the Gosau Group (Gosau, Weisswasser, Gams) indicates that this interpretation at least largely holds also for the other outcrops of Untersberger Marmor.

Significance of sediment composition

In the Turonian to Coniacian shore zone deposits the common presence of corals, nerineacean gastropods and smaller benthic foraminifera that occur in the southern Tethyan realm (*Cuneolina*, *Montcharmontia*, *Dictyopsella*, Nezzazatidae; cf. SARTORIO & VENTURINI, 1988) clearly indicate a tropical depositional environment. In the Santonian transgressive succession both of Brandenberg and Eiberg, by contrast, the absence of corals, nerineaceans, of south tethyan smaller benthic foraminifera and calcareous green algae, the rare presence of rudists, and the richness of the sediment in bryozoans, echinoderms, red algae, fragments from non-rudist bivalves, and smaller benthic foraminifera of unspecific paleobiogeographic affinity (see also IBRAHIM, 1976; GRUBER, 1995) imparts a 'temperate' aspect to the sediment (cf. CARANNANTE et al., 1988; HAYTON et al., 1995; FORNOS & AHR, 1997). In thin section, the Santonian shore zone deposits are closely similar in character to transgressive sediments from fossil temperate carbonate shelves, as e. g. the Miocene temperate shelves on top of the peri-Adriatic platforms (cf. SIMONE & CARANNANTE, 1988; VECSEI & SANDERS, in press), and to sediment compositions from recent temperate carbonate shelves (cf. CARANNANTE et al., 1988; HAYTON et al., 1995; FORNOS & AHR, 1997).

In the succession of the Lower Gosau Subgroup, fossils from the Temperate paleobiogeographic realm are locally common, including inoceramids and other non-rudist bivalves, and gastropods. At least the major part of the Temperate zone fossils inhabited the middle to outer shelf, and their presence can be interpreted in terms of an at least episodic impingement of cooler shelf- to slope waters (see SANDERS et al., 1997, for discussion and references). Data from land plant assemblages of the Lower Gosau Subgroup suggest that the flora consisted mainly of forms adapted to a humid, temperate, and seasonally cooler climate (KERNER-MARILAUN, 1935; TYROFF, 1984). This is indirectly supported by the position of the Gosau depositional area near the northern limit of the tropical environment, at 30–35° northern paleolatitude (MAURITSCH & BECKE, 1987; DERCOURT et al., 1993). This paleolatitude most probably was affected by a monsoonal atmospheric circulation system (PARRISH & CURTIS, 1982).

While the Late Cretaceous shallow neritic environment was of subtropical-tropical character, the deeper neritic environment thus probably was subject at least to episodic incursions of cooler waters. Some mixing between temperate and tethyan faunal elements may be because of bioturbation and/or subsequent reworking, as in the neritic environment the record of environmental changes typically is blurred (e. g. ANDERSON et al., 1997).

Even along low-energy rocky coasts, water depths of more than 10 meters to some tens of meters are common closely seaward from or immediately seaward of the shoreline (e. g. BLANC, 1972; FORNOS & AHR, 1997). In the area of Brandenberg, at least locally water depths of some tens of meters along the fringe of the Santonian transgression are suggested by the presence of penecontemporaneous planktic foraminifera and radiolarians, and by the paucity of sedimentary structures that suggest a shore zone depositional environment of continuous water agitation. To judge from the few described examples of Late Cretaceous rocky shore successions, the sediment composition of the Santonian transgressive lithologies is more similar to rocky shore deposits from the Temperate realm (cf. SURLYK & CHRISTENSEN, 1974) than to rocky shore deposits from Late Cretaceous tropical environments, where encrusting corals and rudists are common (cf. JOHNSON et al., 1996). Along recent tropical rocky shores, corals are very common, as are coral reefs that are attached to steeply inclined to subvertical cliffs, or that may grow in small, sheltered embayments between cliff headlands (e.g. BARNES & HUGHES, 1988), even if the immediately adjacent water is some tens of meters deep (own obs.). If corals and rock-encrusting rudists (rudists of 'clinger' morphotype; SKELTON & GILI, 1991) are widespread faunal elements of Late Cretaceous rocky shores (cf. JOHNSON et al., 1996), corals and clinger rudists thus should be common in the Santonian transgressive shore zone deposits. This is not the case. In Brandenberg, in comparable shore zone deposits of Turonian to Coniacian age, the common presence of fossils of clearly tropical character further underscores that if such organisms had been present during the Santonian transgression, they became fossilized. The combined evidence thus strongly suggests that the sediment composition of the Santonian transgressive shore zone deposits provides a record of 'temperate' paleoceanographic conditions. The temperate aspect of the Santonian transgressive deposits may be related to climate, or to stratification of the water column, or to an episodic shifting of oceanic fronts.

Based on fossil land plants, the persistently tropical character of the depositional environment of the Gosau Group has been questioned much earlier by KERNER-MARILAUN (1935). BRINKMANN (1932) compared the cephalopod fauna from Eiberg to the cephalopod faunas from Germany. IMMEL et al. (1982) found similarities between the Santonian cephalopod fauna from Brandenberg and faunas from the South Temperate realm, and speculated on a possible influx of cooler waters from the Boreal Realm. Elsewhere in the Lower Gosau Subgroup, the presence of diagnostic temperate zone fossils provides clear evidence for the intermittent presence of cooler waters (KOLLMANN, 1980, 1992; DHONDT, 1987), and several lines of evidence now suggest that the Upper Cretaceous shelf successions of the Northern Calcareous Alps cannot be viewed as of tropical character throughout (see SANDERS et al., 1997 for full discussion and references). The entire area most probably was subject to environmental changes that are related to the position of the depositional environment close to or along the boundary between the Teythan and the Temperate realm, respectively. The described transgressive shore zone successions thus provide an hitherto unappreciated, additional record of environmental changes.

Conclusions

In the Upper Cretaceous of the Northern Calcareous Alps, carbonate-dominated shore zone deposits are present that formed as a result of a marine transgression onto previously exposed parts of the Eo-Alpine accretionary wedge. In the Turonian to Santonian succession of Brandenberg and Eiberg, four major intervals of transgressive carbonate-dominated shore zone deposits are present, each in the transgressive systems tract of a depositional sequence. The shore zone deposits show significant variations in thickness, lithology, stratal packages and sedimentary structures, as a result of a transgression onto an articulated morphologic relief, which induced alongshore variations in accomodation space and energy regime. The transgressive shore zone deposits formed in association with transgression of wave-dominated shorelines over (a) fan deltas and (b) over the inclined to cliffed carbonate-dominated substratum. The shore zone successions are up to 40 meters thick and consist of highly variable relative amounts of beachface conglomerates, shoreface conglomerates and associated arenites. Because of a strong taphonomic loss in the wave-dominated beachface to upper shoreface environment, both the beachface conglomerates and the shoreface conglomerates are commonly devoid of fossils. In the arenites, the bioclastic fraction typically ranges from zero to about 30 percent. As a result of transgressive reworking, many of the bioclasts are bored, blackened, or are stained red. The transgressive shore zone deposits of Turonian and Coniacian age contain corals, rudists, and smaller benthic foraminifera of south tethyan affinity. In the Santonian transgressive shore zone deposits, by contrast, corals, rudists and sponges are very rare to absent, and the sediment is of foramol composition. Several lines of evidence suggest that the „foramol" composition of the Santonian transgressive shore zone deposits is related to the presence of cooler waters.

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Plate 1

1: Interval composed of well-sorted, fine-grained conglomerates, interbedded with coarse-grained arenites that consist exclusively of carbonate rock fragments. Together, the arenites and the conglomerates are present in sharp-based, inversely graded beds that are arranged in a horizontal to low-angle cross-bedded fashion. Note the opposite direction of clast imbrication in the conglomerate strata in the middle and upper part of the figure, respectively. Pen for scale is 14 cm long. Nachbergalm, Brandenberg.

2: Top of substratum and base of Santonian succession near Mösl, Brandenberg. The substratum here consists of a large karstic dike filled by a megabreccia. The megabreccia is composed of lithoclasts derived from Jurassic formations (informal Pletzachkogel unit, Allgäu Formation), embedded in a matrix of unlithified terra rossa. The overhang at the top of the picture is the base of the Upper Cretaceous succession (arrow), with outweathering boulders of Triassic-Jurassic rocks embedded in an arenite composed of carbonate rock fragments. Towards the southeast (right margin of picture), the mentioned karstic dike is bounded by unkarstified limestones of the Pletzachkogel unit. Height of view approximately 20 meters.

3: Lower part of Santonian succession in the area of Unterberg, Brandenberg. Very well-rounded, highly spherical boulders of carbonate rocks, embedded in hybrid arenites. Hammer for scale is 33 cm long.

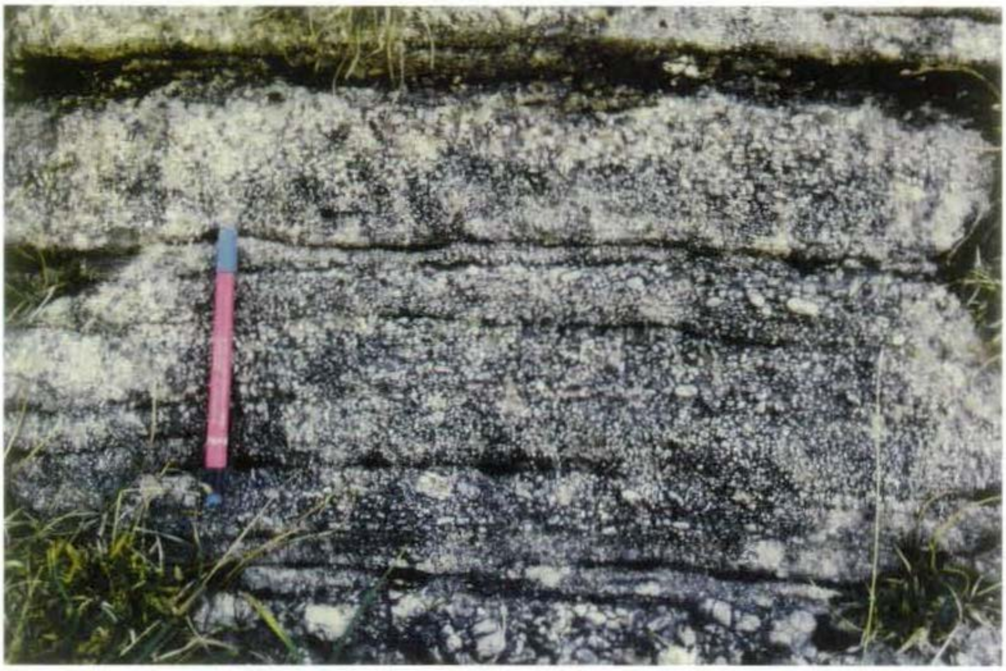

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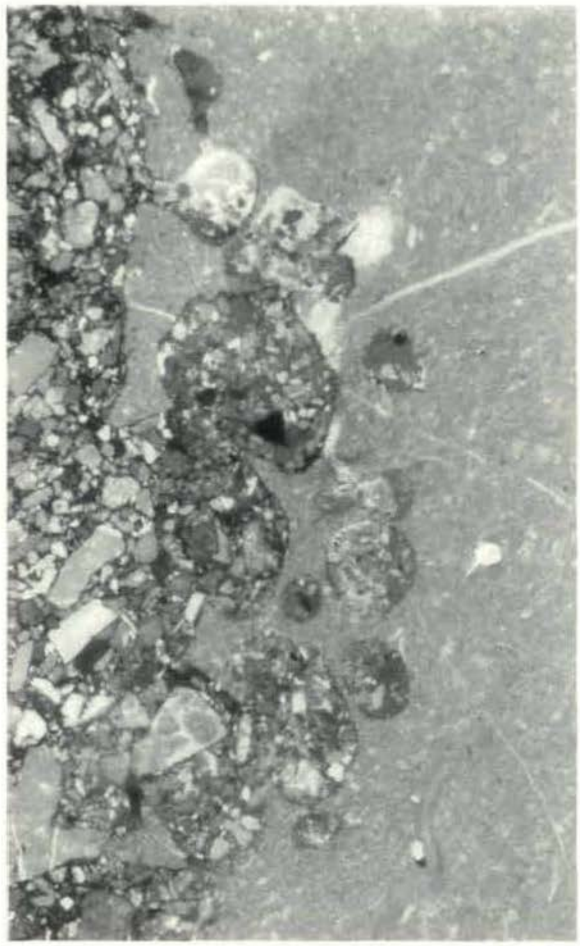
Plate 2

1: Bed of coarse gravel to cobble conglomerate, intercalated in horizontally laminated arenites. Note the subvertical, asymmetric scour at the base of the conglomerate bed, whereas the top of the bed is more or less even. From bottom to top of the bed, no size-grading of clasts is evident. From the top of the bed, locally clasts project upward (white arrowtips), and are partly draped by a coarse-grained arenite that comprises the matrix of the conglomerate bed. Pen for scale is 14 cm long. Unterberg, Brandenberg.

2: Thin section photomicrograph of a bored surface of a carbonate lithoclast within the arenites of the Santonian transgressive succession. Fracture of such a surface by biological and mechanical erosion yields very angular, fine gravel to sand-sized carbonate rock lithoclasts. 6.3 x, plane light.

3: Thin section photomicrograph of an arenite composed of carbonate rock fragments. Sample from the basal part of the Santonian transgressive succession at Voldöppberg, Brandenberg. Aside from sand-sized carbonate rock clasts, this arenite contains bryozoan fronds, rhodoliths of *Archaeolithothamnium*, and a few fragments from rudists and echinoderms. 6.3 x, plane light.

1



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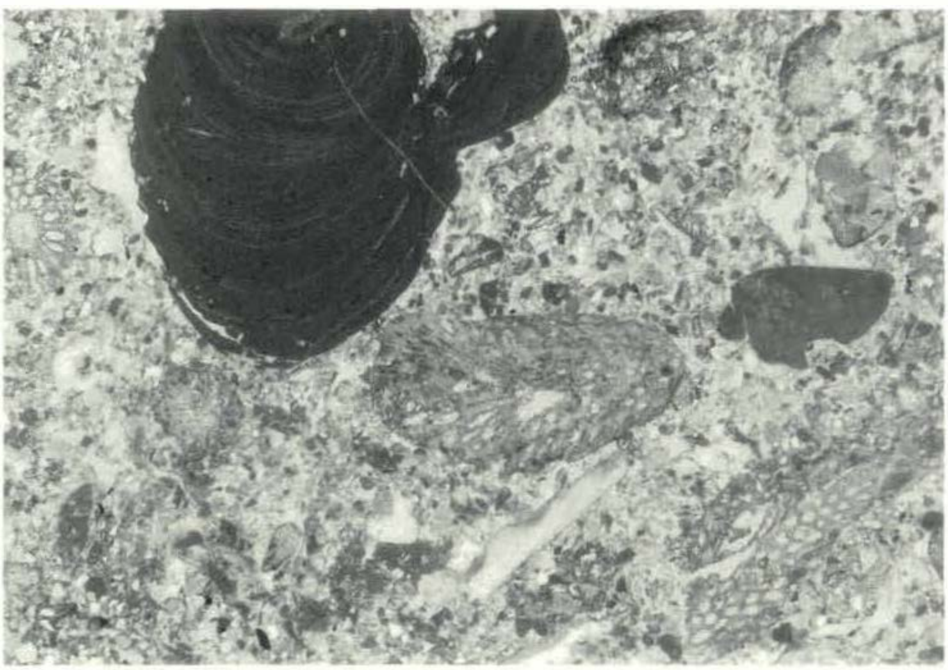

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