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THE UPPER CRETACEOUS NEAR MAURACH (TYROL, AUSTRIA)

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With 5 figures and 5 plates

Abstract:

Near Maurach (Tyrol, Austria), an Upper Cretaceous succession is exposed that was deposited in a terrestrial to marine transitional environment. The succession overlies a substratum of limestones of Jurassic and Early Cretaceous age, and is interpreted as part of a mixed siliciclastic-carbonate depositional sequence.

The lower part of the Upper Cretaceous succession consists of lithoclastic calcirudites that were deposited from alluvial fans. These calcirudites are part of the lowstand and/or of the transgressive systems tract. The calcirudites are sharply overlain, in the transgressive systems tract, by a shoreface conglomerate and by a package more than 25 m thick of cross-laminated lithoclastic grainstones. The grainstones were deposited in the foreshore to lower shoreface. The lithoclastic carbonate sand probably resulted from the combination of bioerosion (boring), coastal erosion of rocky carbonate shores, and marine transgressive reworking of alluvial fans. The grainstones are followed up-section and probably interfingered with shallow-water limestones (with corals and rudists) and calcarenaceous sandstones. The calcarenaceous sandstones are overlain by inner shelf marls with marine fossils (bivalves, gastropods, corals, rudists), and with intercalated beds of hummocky cross-laminated sandstone. The succession from the shoreface conglomerate to the calcarenaceous sandstones and, possibly, the lowest part of the marls comprises the transgressive systems tract. The maximum flooding surface could not be located. At the top of the Upper Cretaceous succession, sandstones with marine fossils (molluscs, corals) are exposed that show megaripple- and hummocky cross-lamination. These sandstones were deposited in a nearshore, high-energy depositional environment, and record shelf progradation in the highstand systems tract. Aside from siliciclastic grains (quartz, chert, feldspar, serpentine), the sandstones invariably contain a significant amount of sand-size carbonate lithoclasts.

In the western part of the outcrop, the described succession is deformed to a north-vergent syncline with a subvertical southern limb. Along the southern limit of outcrop, the contact between Rhaetian limestones and the Upper Cretaceous deposits is locally offset by east-west striking faults. In the easternmost part of the outcrop, the Upper Cretaceous is exposed in an anticline with subvertical limbs of reduced stratigraphic thickness. The anticline is deformed into thrust slices, and cut by roughly east-west striking, steep faults.

Zusammenfassung:

Bei Maurach (Tirol, Österreich) ist eine Abfolge der Oberen Kreide aufgeschlossen, die in einem terrestrischen bis neritischen Bereich abgelagert wurde. Diese Abfolge liegt über Kalken des Jura und der Unteren Kreide und wird als Teil einer gemischt siliziklastisch-karbonatischen Sequenz interpretiert.

Der Tiefstand/transgressive Systemtrakt besteht aus lithoklastischen Kalziruditen, die von alluvialen Schuttfächern abgelagert wurden. Im transgressiven Systemtrakt werden diese Kalzirudite scharf überlagert von einem Küstenkonglomerat und einer mehr als 25 m dicken Abfolge von kreuzlaminierten, lithoklastischen Grainstones. Die Grainstones wurden im Bereich des nassen Strandes bis unteren Vorstrandes abgelagert. Der lithoklastische Karbonatsand stammt wahrscheinlich aus dem Zusammenwirken von Bioerosion (Bohrung) mit Erosion von felsigen Karbonatküsten und der marin-transgressiven Aufarbeitung von alluvialen Schuttfächern. Die Grainstones werden von Flachwasserkalken (mit Korallen und Rudisten) und kalkarenitischen Sandsteinen überlagert, mit denen sie wahrscheinlich auch seitlich verzahnten. Die kalkarenitischen Sandsteine werden von Mergeln des inneren Schelfs überlagert, die marine Fossilien (Muscheln, Schnecken, Korallen, Rudisten) und Sandsteinbänke mit „hummocky“ Kreuzlamination enthalten. Die Abfolge vom Küstenkonglomerat bis zu den kalkarenitischen Sandsteinen und möglicherweise auch der untere Abschnitt der Schelfmergel bilden zusammen den transgressiven Systemtrakt. Die Fläche, welche die höchste erreichte Wassertiefe anzeigt (maximum flooding surface), konnte nicht geortet werden. Das Dach der Oberkreide-Abfolge bilden Sandsteine mit marinen Fossilien (Mollusken, Korallen), und häufiger Megarippel-Kreuzlamination und „hummocky“ Kreuzlamination.

Diese Sandsteine wurden beim Vorbauen des Schelfes im Hochstand-Systemtrakt in einem küstennahen, hochenergetischen Milieu abgelagert. Neben siliziklastischen Körnern (Quarz, Hornstein, Feldspat, Serpentin) enthalten die Sandsteine stets einen bedeutenden Anteil an sandkorngrossen Karbonatgesteins-Lithoklasten.
Im westlichen Abschnitt des Aufschlusses ist die beschriebene Abfolge in eine nordvergente Synklinale mit einem subvertikalen Südschenkel verformt. Entlang der südlichen Aufschlussgrenze ist der Kontakt zwischen der Unterlage (Rhätkalke) und der Abfolge der Oberen Kreide örtlich durch Ost-West streichende Störungen versetzt. Im östlichsten Teil des Aufschlusses bildet die Abfolge der Oberen Kreide eine Antiklinale mit subvertikalen Schenkeln von reduzierter stratigraphischer Mächtigkeit. Die Antiklinale ist zusätzlich in kleine Überschiebungseinheiten zerlegt und wird von ungefähr Ost-West streichenden, steilen Störungen durchsetzt.

1. Introduction

Near Achensee in the Tyrol, Austria, between the village Maurach (975 m) and the location Schichthals (1603 m), Upper Cretaceous deposits are exposed in a southwest-northeast striking valley (fig. 1). These deposits were known since the last century (Pichler, 1869, cit. in Wähner, 1903: 17; see also Wähner, 1903; Ampferer, 1908; Spengler, 1935).

The lithologies of the Upper Cretaceous succession were hitherto not mapped, and no stratigraphic section existed. The Upper Cretaceous near Maurach is the westernmost in a belt of outcrops of Upper Cretaceous deposits that extends for approximately 40 kilometers to the east. The succession described in this paper provides an example for the development of a mixed siliciclastic-carbonate sequence in an area of high morphologic gradient, and for the formation of a thick interval of lithoclastic grainstones by marine transgressive reworking.

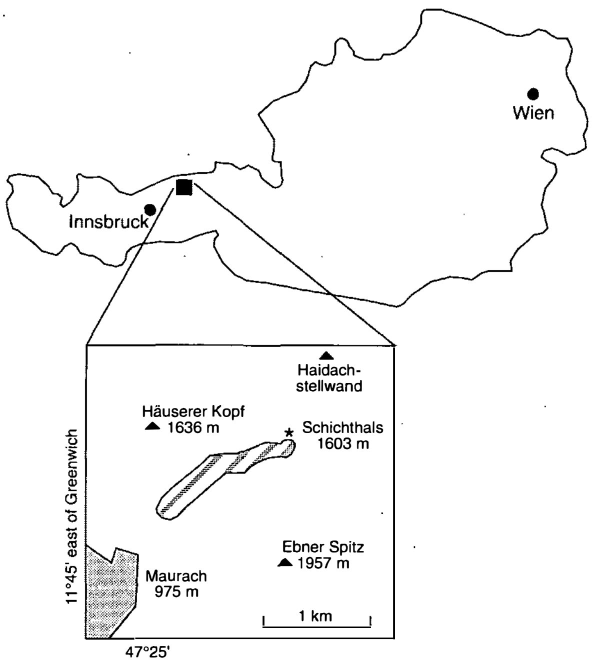

Fig. 1: The considered area (black quadrangle) is situated approximately 40 km to the east of Innsbruck, Austria. The Upper Cretaceous succession (cross-hatched in inset figure) is exposed in a southwest-northeast striking valley between the village Maurach (975 m) and the location Schichthals (1603 m).

2. Geologic setting

During Early to Late Jurassic times, the area of the Northern Calcareous Alps was part of the Austroalpine microplate that was situated along the northern, passive margin of the Adriatic plate (Channell et al., 1992; Faupl & Wagreich, 1992; Wagreich & Faupl, 1994). Since the latest Jurassic, the Austroalpine microplate has been involved in convergence, with consequent thrusting and formation of nappes (Ratschbacher, 1987; Wagreich & Faupl, 1994; Ring, 1995; Froitzheim et al. 1996).

During the late Early Cretaceous, probably as a result of orogenic uplift associated with extensional unroofing (Dewey, 1986; Platt, 1986; Ratschbacher et al., 1989), large parts of the Northern Calcareous Alps were subaerially eroded. In the area of the Northern Calcareous Alps, subaerial erosion and active tectonism produced a deeply dissected morphology. From Turonian to Santonian times, the largest part of the exposed

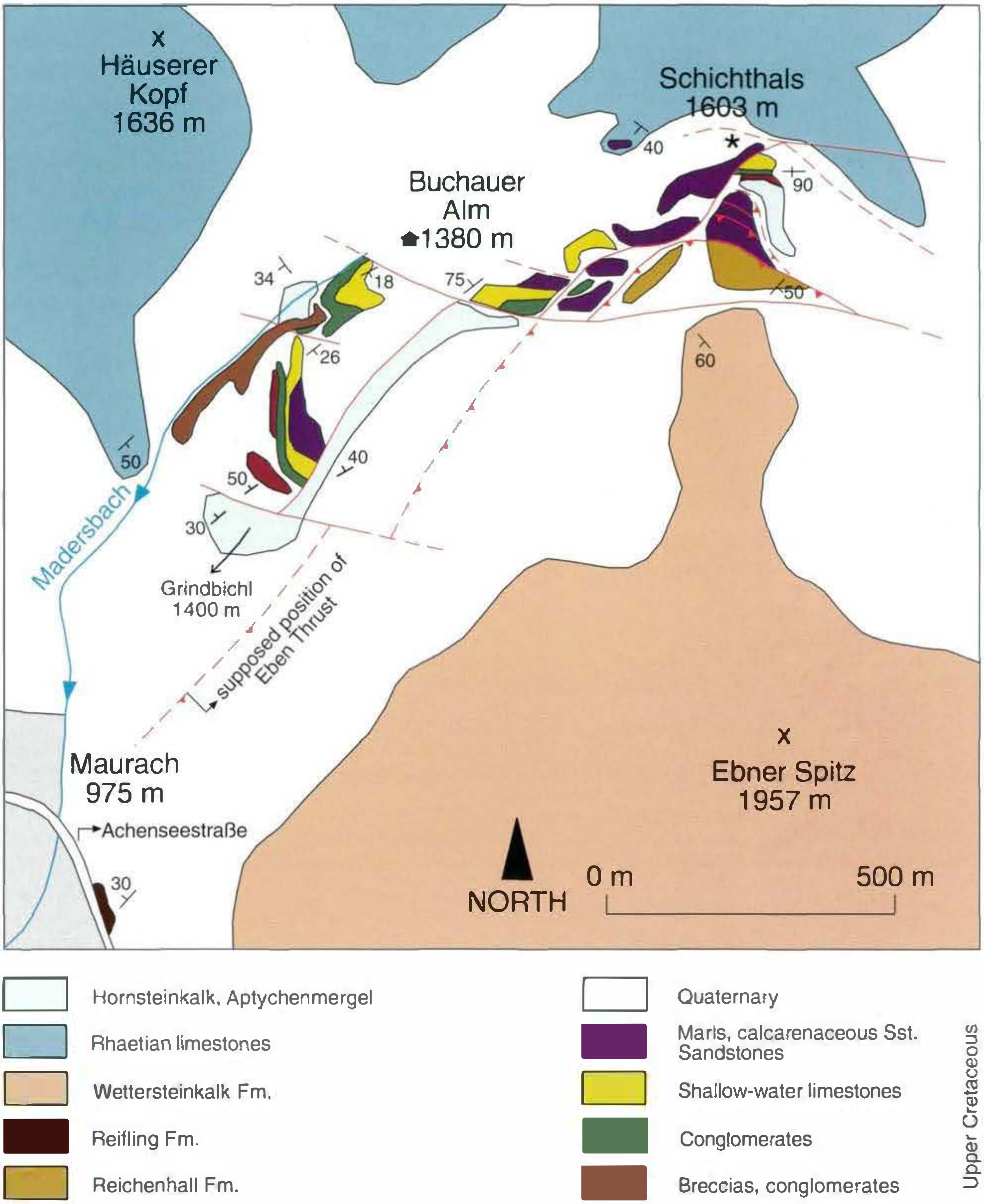

Fig. 2: Simplified geological map of the Upper Cretaceous succession. In the western part of the outcrop area, the Upper Cretaceous succession is deformed in a northwest-vergent syncline with a steep to subvertical southern limb and a moderately steeply dipping northward limb. The succession is cut by approximately east-west striking faults. In the eastern part of the outcrop, at Schichthals, the succession is deformed into an anticline with subvertical limbs which, in turn, are internally deformed in thrust slices. At Schichthals, the Upper Cretaceous overlies a succession that probably can be assigned to the Aptychen Formation (Lower Cretaceous), and is overthrust by limestones and dolomites of the Reichenhall Formation.

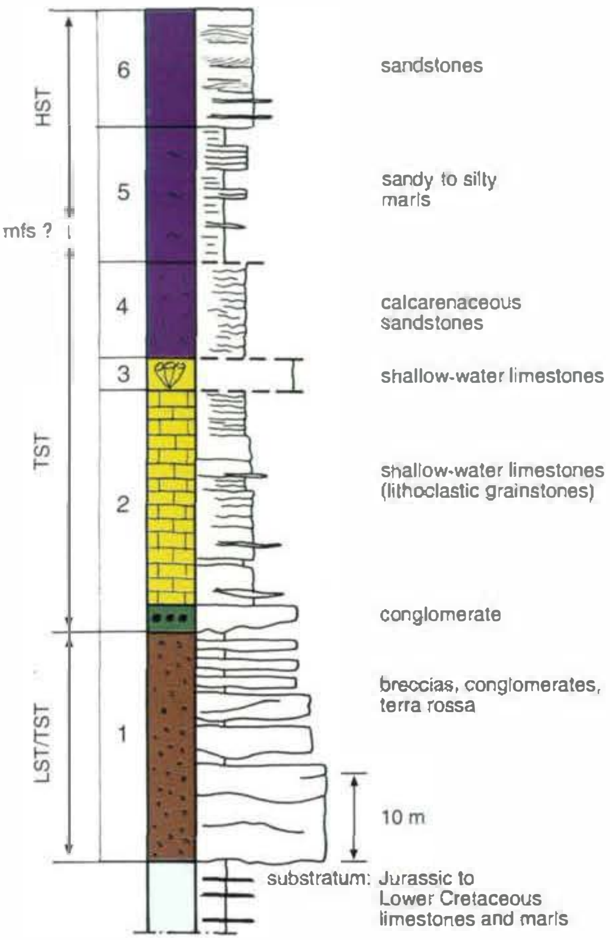

Fig. 3: Restored section of the Upper Cretaceous succession, with the main lithologies and the sequence stratigraphic interpretation indicated. Numbers refer to stratal packages as described in the text. The stratigraphic position of the shallow-water limestones (package 3) is tentative. The vertical transition between the calcarenaceous sandstones (package 4) and the overlying marls (package 5) is tectonically overprinted in all outcrops; the original thickness of the packages 5 and 6, respectively, thus is poorly constrained.

areas became re-submergent. Following re-submergence, a succession up to more than 2500 m thick of terrestrial to pelagic deposits formed. This succession comprises a group of lithostratigraphic formations, the Gosau Group, that ranges in age from Late Turonian to Eocene (WAGREICH & FAUPL, 1994).

The Gosau Group is subdivided into the Lower Gosau Subgroup (Upper Turonian-Campanian) that consists of terrestrial to neritic deposits, and the Upper Gosau Subgroup (Santonian-Eocene), which consists of deep-marine deposits (WAGREICH & FAUPL, 1994). Paleomagnetism indicates that the Gosau was deposited at approximately 30°N (compare MAURITSCH & BECKE, 1987). In the Lower Gosau Subgroup, the local presence of accumulations of bauxite along the basal unconformity, coal seams, the karstification of Gosau limestones, the common presence of limestones deposited in freshwater and restricted marine environments, and the lack of arid tidal flat facies and sabkha evaporites all indicate a subtropical to tropical, at least seasonally humid climate (cf. MINDSZENTY, 1984; RAHMANI & FLORES, 1984; D'ARGENIO & MINDSZENTY, 1986).

The described Upper Cretaceous succession near Maurach is part of the Lower Gosau Subgroup. In the considered area, before deposition of the Gosau Group, the older substratum was thrusted in nappes towards the west to northwest during the eo-Alpine phase of deformation (RATSCHBACHER, 1987; EISBACHER & BRANDNER, 1995). During Late Eocene to Oligocene times, i.e. during the meso-Alpine phase of deformation, both the previously deformed substratum and the overlying Upper Cretaceous deposits were again involved in folding and thrusting towards the north to northeast (AMPFERER, 1908; SPENGLER, 1935; EISBACHER & BRANDNER, 1995; see also DECKER et al., 1993). The last deformation occurred by strike-slip faulting that probably was associated with the Miocene strike-slip movement along the Inntal Fault some kilometers to the south (compare EISBACHER & BRANDNER, 1995; ORTNER, 1995; see also DECKER et al., 1993).

3. Methods

The Upper Cretaceous succession was subdivided in stratal packages that each is characterized by a distinct lithologic association. These packages were mapped in the field on a scale of 1 : 5000 (fig. 2); their reconstructed vertical arrangement is shown in a generalized section (fig. 3). Approximately 70 polished slabs and 28 thin sections were used for the documentation of the lithologies. No strictly quantitative clast analysis has been made for lithoclastic rudites; their clast spectrum was determined semiquantitatively by inspection of approximately 100 lithoclasts in the field, and by some thin sections. 14 samples from marine marls were tested for nannofossils. In addition, several fossils of non-rudist bivalves and rudists were extracted from the marls.

4. Biostratigraphy

The Upper Cretaceous deposits are poorly dated. In shallow-water limestones, the presence of *Vaccinites* indicates a Late Turonian to Maastrichtian age. In marine marls, the nannofossil assemblages are strongly dominated by reworked Lower Cretaceous nannofossils. Among the Lower Cretaceous nannofossils, *Eiffellithus turriseiffeli*, *Eprolithus floralis*, *Glaukolithus diplogrammus*, *Prediscosphaera* spp., *Watznaueria barnesae*, *Zeugrhabdotus erectus*, *Cribrosphaera ehrenbergerii*, and nannoconids are common. In one sample, however, the assemblage of *Lucianorhabdus* sp., *Quadrum gartneri*, *Praediscosphaera cretacea*, *Biscutum* sp., and *Cylindralithus* sp. suggests an age interval between the start of the Turonian and the Early Coniacian. Due to both the poor preservation of the nannofossils and the extensive reworking, this age is only tentative. The Gosau at Schichthals thus is of ?Turonian-?Early Coniacian age, but may also be younger.

5. Triassic-Jurassic succession

In the area between Ebner Spitz in the south and the Rofan massif in the north, the oldest exposed rocks are assigned to the Reichenhall Formation (Scythian to lower Anisian; TOLLMANN, 1976) (fig. 3), that here consists mainly of „bituminous“ dolomites, bioturbated marly dolomites, dolomitic limestones, laminated dolomite, cellular dolomite, thin beds of dark green sandstone, and strongly deformed layers of gypsum.

In the considered area, chert-bearing limestones of the Reifling Formation (Anisian p.p.) are exposed only in an outcrop at approximately 990 m along the road „Achenseestrasse“. The next younger rocks are the Ladinian to Lower Carnian Wettersteinkalk Formation, which comprises the main part of Ebner Spitz. The Wettersteinkalk Formation contains thick-bedded, dark grey boundstones with isopachous cements, and dasycladacean grainstones to rudstones. The larger part of the Wettersteinkalk Formation consists of meter-scale upward shoaling cycles that contain laminated limestones/dolomites and loferites at their top.

Rocks of Middle to Late Carnian age (Nordalpine Raibl Formation) and of Norian age (Hauptdolomit Formation) (see TOLLMANN, 1976) are not exposed in the considered area. At the western limit of the considered area, along the western slope of Häuserer Kopf, marls and marly limestones of the Kössen Formation (Rhaetian) are present. The Kössen Formation is rich in fossils, including *Rhaetavicula*.

The most common rocks both along the northern and the southern limit of the Upper Cretaceous outcrop are the so-called Rhaetian limestones (see TOLLMANN, 1976). The base of the Rhaetian limestones is not exposed. Up-section, they grade into packages of graded beds of shallow-water bioclastic limestones with intercalated spiculitic mudstones/wackestones. The shallow-water bioclastic limestones are mainly grainstones that consist of well-rounded and well-sorted, fine to coarse sand bioclastic material, locally with oolitic coatings. Locally, meter-bedded shallow-water bioclastic limestones, and indistinctly bedded to "massive" floatstones with branched corals (*Lithodendron*) are exposed. The floatstones are part of indistinctly bedded to "massive" intervals up to some tens of meters in thickness. The Rhaetian limestones are overlain by pink to dark red Liassic limestones that are rich in echinoderm debris, ammonites, and "manganese" crusts to nodules. These limestones are also present in dikes up to some tens of meters wide that locally crosscut the Rhaetian limestones.

At approximately 1260 m the unconformable contact between cherty limestones and the overlying Upper Cretaceous deposits is exposed. The cherty limestones comprise a succession at least 25 m thick, and consist of evenly decimeter-bedded, spiculitic mudstones to wackestones with radiolaria. Locally, these limestones contain intercalated graded beds of shallow-water bioclastic material. These limestones are closely similar to the Jurassic „Hornsteinkalke" of the Rofan massif (compare AMPFERER, 1950). Above Häusererbichl, at approximately 1120 m, the sedimentary contact between Rhaetian limestone and the Upper Cretaceous as mapped by AMPFERER (1950) could not be re-visited; the area now is blocked by buildings. At Schichthals, the Upper Cretaceous succession is in contact with chert-bearing marly limestones and marls that probably can be assigned to the Lower Cretaceous Aptychen Formation ("Aptychenmergel"; see SPENGLER, 1935); the contact, although primary, is tectonically overprinted. Most commonly, however, the contact between the Upper Cretaceous and the substratum is covered or is overprinted by Alpine deformation. In the following, the stratal packages of the Upper Cretaceous succession are described. The environmental interpretation of each lithology is given immediately after its description.

6. Upper Cretaceous

Package 1: Breccias and conglomerates

In the western part of the outcrop area, breccias and conglomerates are exposed at the base of the Upper Cretaceous (figs. 2, 3). Because of Alpine deformation and incomplete exposure, the thickness of the rudites is poorly constrained (plate 1/1). Along Madersbach, the rudites reach approximately 30 m in thickness and throughout consist of clasts that were derived from the local substratum (limestones, dolomites and, subordinately, chert-bearing limestones and chert). The basal 10 m of the succession consist of poorly to very poorly sorted, clast-supported conglomerates with scattered megaclasts of limestone up to some decimeters in size. At least some of the megaclasts consist of Rhaetian buildup limestones with large *Lithodendron*. The scarce matrix of the basal rudites is a sandy to silty, dark red terra rossa. The beds of the basal rudites are up to some meters thick.

In its upper 20 m, the package of lithoclastic rudites consists mainly of poorly to moderately well-sorted, clast-supported conglomerates that occur in beds some decimeters to some meters thick (plate 1/2, 1/3). The thicker beds are stratified or appear „massive". Within a bed, no size grading of the components was observed. The base of the beds is plane to erosive. The conglomerates typically consist of moderately to very well-rounded clasts of some centimeters in size, but well-rounded clasts of up to 2 dm in size locally are present.

The clast spectrum is composed as follows (approximately in decreasing abundance): yellow to light brown weathering, locally finely laminated, spiculitic radiolarian wackestones to packstones (in some clasts with chert nodules), mudstones (in some clasts with chert nodules), shallow-water bioclastic grainstones to packstones that, at least in part, are of Rhaetian age (with *Aulotortus sinuosus*, in addition to coated grains, ooids, and fragments from molluscs, serpulids, echinoderms, and brachiopods, byrozoans, *Tubiphytes*), light red to light brown weathering, well sorted, fine to coarse sand bioclastic grainstones with ?glauconite, floatstones to bafflestones with ?rhynchonellids, fenestral mudstones, ooid grainstones, clasts of ?Jurassic lithoclastic breccias (consisting of shallow-water limestones embedded in a well-lithified matrix of red lime mudstone), echinoderm-bioclastic grainstones and, rarely, light grey limestones (?Wettersteinkalk, ?Rhaetian limestone). The conglomerate beds are vertically separated by layers some decimeters thick of terra rossa. In these layers, thin lenses of lithoclastic conglomerates are locally intercalated. The top of the package of lithoclastic rudites is an interval of dark red, sand-bearing terra rossa.

Interpretation

The lithoclastic rudites were deposited from alluvial fans. This is indicated by the combination of their coarse-grained nature, the very poor to moderate sorting, the clast spectrum that is derived from the local substratum, the poorly lithified matrix, the sheet-like shape and the poor internal organization of most beds, and the vertical succession of lithoclastic rudites and intercalated beds of terra rossa (compare HOOKE, 1967; BULL, 1972; SALLER & DICKSINSON, 1982; ETHRIDGE & WESCOTT, 1984; HAYWARD, 1985; MCPHERSON et al., 1988). In the lower part of the succession, the absence of grading, the unstratified, clast-supported gravel beds to stratified beds with imbricated gravels, and the absence of large-scale bedforms indicate that they were deposited from mass flows (ETHRIDGE & WESCOTT, 1984; MCPHERSON et al., 1988). Approximately in the middle part of the package, the erosively based beds of moderately well-sorted conglomerates composed of well-rounded, medium gravel to small boulders are similar to channel lags of stream floods (eg. NEMEC & POSTMA, 1993; see also WAGREICH, 1988). The thinner-bedded, moderately well-sorted conglomerates with comparatively thick, intercalated beds of "terra rossa" and green clays might have been deposited from sheet floods (BULL, 1972; ETHRIDGE & WESCOTT, 1984; NEMEC & POSTMA, 1993). The intercalated intervals of terra rossa and green clay record slow deposition and, possibly, incipient soil development (cf. NEMEC & POSTMA, 1993).

In the package of the lithoclastic rudites, the vertical succession suggests an overall transition from a proximal fan environment to an outer fan environment, or to the subaqueous portion of a fan delta (cf. NEMEC & STEEL, 1984; ETHRIDGE & WESCOTT, 1984; WAGREICH, 1988). For reasons discussed below, it is improbable that the upper part of the succession represents the subaqueous part of a fan delta. The composition of the rudites mainly of rock clasts identical to the rocks of the sedimentary substratum suggests that the rudites were fed from a comparatively small drainage basin.

Package 2: Conglomerate and grainstones

This unit is approximately 30-35 m thick and overlies the lithoclastic rudites along a sharp, erosive boundary (fig. 3; plate 2/1). The basal part of this package consists of an interval up to some meters thick of moderately well- to well-sorted, coarse to medium lithoclastic conglomerate (figs. 3, 4; plate 2/2). The conglomerate consists mainly of subrounded to well-rounded clasts of limestone and, subordinately, cherty limestones and chert. The limestone clasts are bioclastic grainstones and packstones, spiculitic mudstones to packstones, ooid grainstones and, rarely, boundstones with ?demosponges, corals and Miliolacea (including *Nautiloculina*). Some clasts of bioclastic limestones are silicified. The clasts of cherty lime-

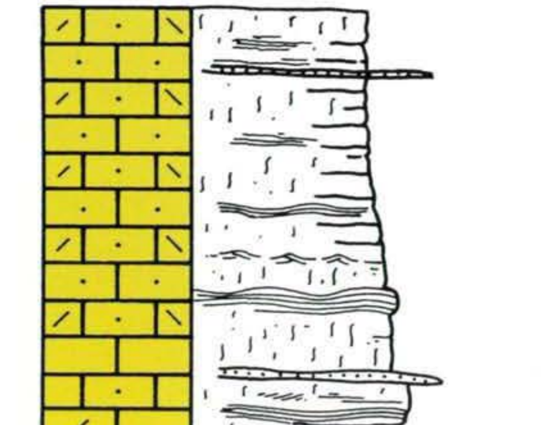

Fig. 4: Part of the transgressive systems tract (package 2: compare figure 3), with sedimentary structures indicated. See text for further description and discussion.

stones typically are spiculitic mudstones to packstones. Clasts of chert, including dark red radiolarite are also present. In the conglomerates, debris from corals (including cf. *Astrocoenia*, and other forms) locally is common.

The matrix of the conglomerate is a moderately well-sorted, medium to coarse grainstone. This grainstone consists mainly of angular to subrounded carbonate lithoclasts and angular chert clasts, but also contains some fragments from echinoderms, radiolitids, bryozoans, and textularids.

The conglomerate is overlain by a succession of lithoclastic grainstones (fig. 4). The lower meters of the grainstone succession appear unbedded, but show well-developed plane parallel lamination, low-angle cross lamination, and megaripple cross-laminasets. In outcrop, the lamination is evident mainly by outweathering grains of chert. In the lower and middle part of the grainstone succession, layers and lenses of fine to medium, lithoclastic conglomerates are intercalated; these range from a few centimeters to some decimeters in thickness, and consist mainly of very well-rounded clasts of chert and, subordinately, carbonate rocks. The fabric ranges from clast-supported conglomerate to pebbly grainstone. The lateral and upper boundaries of the conglomerate layers and lenses typically are gradational.

Higher up, in the main part of the grainstone succession, the grainstones occur in plane beds between some decimeters to more than a meter in thickness. Neither a distinct vertical trend in bed thickness nor an organization of the succession into packages of beds was recognized. Only locally, the beds show a gently downward-convex, erosive base (plate 2/3). Within the beds, plane parallel lamination, low-angle cross-lamination and megaripple cross-laminasets are common. More rarely, hummocky cross-lamination was observed. Often the sedimentary structures are more or less disrupted by burrows. Burrows are indicated by discordant, diffuse patches of disoriented, outweathering chert grains, and by outweathering burrows on the underside of bedding planes. The bedding planes are accentuated by layers of marly sand that range between a millimeter to some centimeters in thickness. The minor bedding planes bear millimeter-thin horizons of marly sand, are even to wavy, and laterally often fade out into a stylolite surface and, finally, into unstylolitized limestone. The major bedding planes are continuous on the scale of individual outcrops (some tens of meters), and are characterized by layers up to some centimeters thick of marly sandstone. The major bedding planes are intercalated with a vertical spacing of some decimeters to some meters; no distinct trend of vertical spacing was recognized. The layers of marly sandstone are poorly lithified, friable, and contain coalified plant debris. The vertical transition from a grainstone bed into a layer of marly sand occurs over a few centimeters by an increase in both stylolitization and bioturbation. At the base of the overlying, outweathering grainstone bed, numerous large, epichnial-endichnial burrows (mainly *Callianassa*) are evident (plate 3/1).

Throughout the succession, the grainstones consist of moderately well- to very well-sorted, coarse to medium sand that is strongly dominated by carbonate lithoclasts (plate 3/2). Aside from the carbonate lithoclasts, a subordinate fraction of chert grains (commonly 5–30%) and biogens is present. In the lower part of the succession, the carbonate lithoclasts are typically very angular (with concave surfaces) to subrounded. The very angular grains are of needle-like triangular to elongate-rectangular outline (plate 3/3). The carbonate rock clasts consist of microsparite, spiculitic wackestones to packstones, radiolarian wackestones, bioclastic and peloidal grainstones, ooid grainstones, pseudosparite, and clasts of blocky calcite spar (plate 4/1, 4/2). The chert clasts are typically very angular to subangular. A portion of the chert clasts is derived from silicified radiolarian-spicule packstones. The biogenic fraction of the lithoclastic grainstones commonly ranges between less than 1% to 15%, and includes debris from echinoderms, molluscs, rare bryozoans, textulariaceans, and red algae, including small rhodoliths of *Archaeolithothamnium*. The biogens are well- to very well-rounded, and typically show thin micrite rims. Locally, an accessory amount of quartz and silicified radiolarians is present in the grainstones. The grainstones are cemented by isopachous fringes of dog tooth spar that is overlain by blocky calcite spar.

The upper part of the succession consists mainly of grainstones of subrounded to well-rounded carbonate lithoclasts with micrite rims and, rarely, with overgrown red algae. Aside from chert, siliciclastic grains like quartz, feldspar, and reworked silicified radiolarians locally comprise up to 50% of the sediment, i. e. the rock is a calcarenaceous sandstone. Towards the top, the biogens include debris from molluscs, rudists, echinoderms, corallinaceans (*Archaeolithothamnium*), miliolids, both bi- and triserial textulariaceans, and fine, coalified plant debris.

Interpretation

The conglomerates that overlie the alluvial fan succession along a sharp, erosive surface probably result from marine transgressive reworking of the alluvial fans (NEMEC & STEEL, 1984; MAEJIMA, 1988; NEMEC & POSTMA, 1993). This is suggested by the overall identical clast spectrum of the conglomerates as compared to the alluvial fan deposits. According (1) to the relative thinness of the conglomerate, and (2) the lack of clear-cut stratification, and (3), above, the presence of the described grainstone succession, the conglomerate would classify as a "shoreface conglomerate" (compare NEMEC & STEEL, 1984; LEITHOLD & BOURGEOIS, 1984).

Above the conglomerate, in the succession of lithoclastic grainstones, the sedimentary structures record deposition in a nearshore environment. In the basal part of the succession, the subparallel- to low angle cross-laminated grainstones probably were deposited in the foreshore to upper shoreface, respectively. The megaripple cross-laminated grainstones and the bundles of low angle cross-laminated grainstones in the middle part of the succession indicate a shoreface environment. The upper part of the succession that consists of beds with hummocky cross-lamination, and of megarippled and bioturbated grainstones probably was deposited in a lower shoreface environment (see KOMAR, 1976; WALKER & PLINT, 1992; ANTIA et al., 1994). The intercalated lenses and stringers of conglomerates may have formed under the influence of storms (compare LEITHOLD & BOURGEOIS, 1984, 1988; DE CELLES, 1987). In the lithoclastic grainstones, there is no evidence for significant tidal influence, like e.g. bidirectional megaripple laminasets, sigmoidal bundles, or herringbone cross bedding (compare HAYES, 1980; ALLEN, 1982; KREISA & MOIOLA, 1986). The preserved hydrodynamic structures and their vertical succession record the predominant influence of waves in the foreshore to transitional environment of a wave- and storm-dominated coast (compare HOWARD & REINECK, 1981). The vertical sequence from the conglomerate at the base to bioturbated and hummocky cross-laminated sandstones at the top is broadly similar to transgressive successions described from other ancient, wave-dominated coastlines (e.g. BOURGEOIS, 1980).

In the lithoclastic grainstones, the locally high amount of very angular to subangular grains of carbonate rocks may provide a clue to the derivation of the calciclastic material. Bioerosion of living and dead carbonate substrata became important since Jurassic times. Among the producers of approximately 1 mm to 10 cm deep borings clionid sponges, polychaetes, bivalves, barnacles, gastropods, bryozoans and foraminifera are most prominent. The typical end product of carbonate substrate destruction by boring organisms are angular to very angular grains, i. e. grains with concave surfaces. (see WARME, 1970, 1977; FÜTTERER, 1974; FREY & SEILACHER, 1980; ACKER & RISK, 1985; KENDALL et al., 1989; BROMLEY & ASGAARD, 1993; VÉNEC-PEYRÉ, 1996). In recent carbonate depositional environments, silt- to sand-sized calciclastic material derived from the breakdown of clionid-perforated carbonate substratum may comprise up to approximately 30% of the sediment, and locally even more (FÜTTERER, 1974; DOMINGUEZ et al., 1988). The clasts derived by clionid boring commonly are rapidly rounded by micritization, waves and currents (KOBLUK & RISK, 1977; see also BATHURST, 1971); the large contribution of bioerosion-produced sediment to the sediment budget thus is commonly underestimated (FÜTTERER, 1974; ACKER & RISK, 1985).

On recent rocky carbonate shores, the combined action of shallow to deeply tiered carbonate boring taxa results in very effective rock bioerosion (RASMUSSEN & NEUMANN, 1988). Since the described lithoclastic grainstones were deposited in a nearshore environment, the potential for grain rounding was very high. Lithoclastic grainstones with a high proportion of very angular grains probably were only preserved upon rapid burial during events of high net accumulation, possibly during and immediately after storms.

The calciclastic material of the grainstones thus was probably derived from a rocky shore and/or from reworking of the underlying alluvial fan succession (SANDERS, 1996). Limestone cliffs are eroded at rates of some meters to more than 10 meters per 100 years by the combined effects of (1) hydraulic pressure from wave impact, (2) boring by organisms, and (3) episodic cliff collapse (KING, 1972, and references therein; KOMAR, 1976). Cliff erosion by boring organisms typically ranges between 0.25 cm/a to approximately 2 cm/a (KOMAR, 1976). In addition to cliff erosion, the coastal reworking of the alluvial fans most probably yielded large amounts of calciclastic material. The alluvial fan gravels both provided a large surface area for bioerosive attack, and were easily abraded by waves (SANDERS, 1996).

Package 3: Shallow-water limestones

The shallow-water limestones include bioclastic grainstones to packstones and rudstones, and are present in intercalations up to some decimeters thick within the upper part of the lithoclastic grainstones. The bioclastic grainstones to packstones are composed of bioclasts derived from molluscs (including rudists), corals, echinoderms, and red algae. In addition, miliolids, textulariaceans, and some small, rounded lithoclasts (limestone, chert) are present. The bioclastic rudstones are mainly composed of coral debris embedded in a matrix of bioclastic grainstone.

At one location in the central part of the outcrop area, an interval at least 4 m thick of bioclastic rudstones to boundstones (fig. 3; plate 4/3) and, subordinately, bioclastic grainstones to packstones is present. The rudstones to boundstones are rich in coral heads and red algae, whereas rudists are subordinate. In the boundstones, the corals are encrusted by placopsilinid foraminifera, coralline algae, serpulids and possible cryptmicrobial crusts. Both radiolitids and hippuritids, including *Vaccinites*, are present and locally are encrusted by red algae. In addition, clasts of calcareous algae (?codiaceans), textularids, miliolids, and sponges were observed.

Interpretation

From their position within the section, and the local interval of rudstones to boundstones, the shallow-water bioclastic limestones are interpreted as autochthonous to parautochthonous deposits. The limestones possibly were deposited from small accumulations of bioclastic material that were surrounded by areas of sand of mixed calciclastic-siliciclastic composition (see below). In areas of mixed carbonate-siliciclastic deposition, an interfingering and/or patchy distribution of carbonates and siliciclastics is common (e.g. PILKEY et al., 1979; MORELOCK et al., 1983; MOUNT, 1984). The interval of rudstone to boundstone, with intercalated layers of grainstone/packstone is interpreted as an incipient stage of substrate stabilization and buildup development (compare WILSON, 1975).

Package 4: Calcarenaceous sandstones

In the central part of the outcrop area, a package of calcarenaceous sandstones is preserved that, in its basal to middle part, probably interfingers laterally with the described carbonate-lithoclastic grainstones and shallow-water limestones (fig. 3). At Schichthals and along the road to Buchauer Alm, the calcarenaceous sandstones are absent due to Alpine tectonics. In the field, the calcarenaceous sandstones weather out like limestones. Their original thickness is estimated at approximately 15 to 20 m. The calcarenaceous sandstones are wavy to indistinctly bedded, bioturbated, and are of grey colour with a light blue tint upon fracture. Locally, intervals up to 3 m thick of bioturbated, coarse lithoclastic sandstone with admixed bioclastic material are present. In their upper 5 m, the calcarenaceous sandstones are marly and contain non-stylolitic solution seams.

They calcarenaceous sandstones consist mainly of moderately well- to well-sorted, fine to medium sand of mixed siliciclastic/bioclastic composition. The siliciclastic grains are mainly angular grains of quartz, chert and, subordinately, feldspar. The calciclastic fraction includes mollusc debris (including debris from radiolitids and hippuritids), echinoderm fragments, miliolids, diverse textulariaceans, ataxophragmiines (attached on fragments of corals and molluscs), debris from branched corals, coralline algae, *Pseudolithothamnium album*, bryozoan fronds, rare brachiopods, and angular to rounded carbonate rock grains. Coalified plant debris ranging from less than 1 mm to approximately 1 cm in size is often admixed and, locally, is enriched in thin horizons. Blackened bioclasts are locally common. Typically, the coarser bioclastic grains are rounded to well-rounded and show micrite rims. Overall, the content of bioclastic material decreases up-section.

Interpretation

The calcarenaceous sandstones represent a common type of sediment of the outer nearshore to shelf environment of mixed siliciclastic-carbonate depositional environments (MORELOCK & KOENIG, 1967; MORELOCK et al., 1983; FRIEDMAN, 1968; SCHNEIDERMANN et al., 1976; PILKEY et al., 1979; MOUNT, 1984; BUSH, 1991). The shallow-water bioclastic material probably is a mixture of autochthonous and parautochthonous components. The common bioturbation of the calcarenaceous sandstones, the parautochtonous shallow-water bioclastic material, and the intercalated packages of coarse sandstone suggest that the calcarenaceous sandstones were deposited in a transitional environment (compare WALKER & PLINT, 1992; ANTIA et al., 1994).

Package 5: Sandy marls

In the western part of the outcrop area, a package approximately 30 m thick of sandy marls is present (fig. 3). Towards the top of the package, the sandy marls contain an increasing amount of sandstone beds, and grade up-section into sandstones. In the eastern part of the outcrop area, at Schichthals, the sandy marls are approximately 9 m thick, but are strongly deformed.

The sandy marls are friable and unbedded. The marls contain a relatively diverse marine biota, mainly thin-shelled bivalves and gastropods. The bivalves typically range from 1–3 cm in length, and are most commonly preserved with both valves. Larger modiolacean bivalves of some centimeters in size are fairly common. Locally, "nests" rich in small bivalves are present. The bivalve fauna includes small schizodonts (?isocardiids), pectinids (*Neithea*), and small ostreids. From the gastropods, cerithiaceans and gastrpods with siphons were recognized. Solitary corals, fragments of branched corals, and coral heads (including *Astrocoenia*) up to 1 dm in size, some miliolids and echinoderm fragments, and rare *Vaccinites*, radiolitid debris and fish teeth were found. Coalified plant fragments of typically sub-millimeter to some millimeters in size are common in the marls. In thin section, the sandy marls are rich in angular to subrounded siliciclastic grains (chert, subordinately quartz) and are thoroughly bioturbated. Rounded carbonate rock grains locally comprise a significant fraction of the sediment. The matrix is a marly, lithified carbonate mud.

Towards their top, the marls contain sharply intercalated beds of sandstone. The base of the sandstone beds locally is gently incised. The beds typically are 20–40 cm thick, but may be up 70 cm thick; they show subparallel lamination and hummocky cross-lamination. In their lower and middle part, the sandstone beds contain some debris from solitary corals (including *Placosmilia*), chaetetids, small coral heads, and fragments from branched corals and rudists. In thin section, the sandstone beds consist of laminated, well- to very well-sorted, winnowed, fine to medium sand. Aside from very angular to subrounded grains of chert and quartz, elongated-triangular to well-rounded carbonate rock grains (mainly grains of microsparite and grains of blocky calcite spar) comprise a significant fraction of the sediment. An accessory fraction (<1%) of these sandstones are silicified radiolarians.

Package 6: Sandstones

The sandy marls are overlain by a succession of, locally marly, sandstones (fig. 3). These comprise the topmost preserved package of the described Upper Cretaceous succession. The sandstone package is approximately 15 m in thickness to the upper limit of outcrop. The marly sandstones contain a taphocoenosis similar to the taphocoenosis of the sandy marls described above. In addition, rare shells of *Vaccinites* were found. The sandstones occur in "massive", unbedded intervals up to some meters thick, and in sets of beds some decimeters thick. Locally, near the base of the sandstone succession, a few graded, up to 4 dm thick intervals of siliciclastic conglomerates were found. The sandstones show subparallel lamination and, rarely, small flute casts at the base of beds. Locally, the sandstone beds contain clast- to matrix-supported layers of well-rounded clasts of siltstones. Intercalated in the sandstones are beds of very well-cemented, well-washed, calcarenaceous sandstones with parallel lamination and hummocky cross-lamination. These beds contain very well-rounded lithoclasts up to some centimeters in size (carbonate rocks, ?Gosau sandstones), mud chips and bioclastic material, including debris from bivalves, small nerineids, branched corals (cf. *Pleurocora*) and *Placosmilia*.

In thin section, the sandstones consist of well- to very well-sorted, laminated to more or less bioturbated, fine to medium sand composed mainly of carbonate rock grains, chert fragments and, subordinately, quartz (plate 5/1, 5/2). Accessories are feldspar, fragmented spiculae, a very well-sorted fraction of small, silicified radiolarians, miliolids, textulariaceans, small fragments from echinoderms and molluscs, and rare mica flakes. Some sandstone beds are entirely devoid of fossils. The chert and quartz grains are angular to subrounded. The carbonate rock grains typically are a mixture of angular grains with rounded grains, and always comprise a significant to, locally, dominant fraction of the sediment. No matrix is present. The sandstones are cemented by thin isopachous fringes of calcite, overlain by blocky calcite spar.

At Schichthals, closely below the tectonic contact with the Reichenhaller Formation along the Eben Thrust, within a thrust slice the sandstones contain isolated, well-rounded carbonate lithoclasts up to some decimeters in size, and intercalated conglomerate intervals. The conglomerates are clast-supported and consist of moderately to poorly sorted fine gravel to blocks up to approximately 4 dm in size. The lithoclasts are carbonate rocks and limestones with chert nodules, chert clasts, and some lithoclasts of ?Gosau sandstone. The larger lithoclasts are commonly subrounded to very well-rounded, but subangular chert clasts also are common. The carbonate lithoclasts often are deeply perforated by Trypanites. Fragments of corals including large, bioeroded fragments of cf. *Astrocoenia* are admixed. The conglomerate beds are coarse-tail graded, and at least some of the beds are inversely graded at their base. The matrix is a moderately well-sorted, medium to coarse calcarenaceous sandstone composed mainly of carbonate lithoclasts, quartz, chert and poorly sorted, angular mollusc fragments.

Interpretation

The sandy marls with intercalated beds of hummocky cross-laminated sandstones were deposited in an inner shelf environment ("mud belt") that was punctuated by episodic storms (compare McCave, 1972, 1985; Harms et al., 1982; Howard & Reineck, 1981; Dott & Bourgeois, 1982; Hobday & Morton, 1984; Nottvedt & Kreisa, 1987 Walker & Plint, 1992). In the marls, the common presence of small bivalves preserved with both valves suggests an at least episodically high rate of sediment accumulation. Only the ?modiolacean bi-

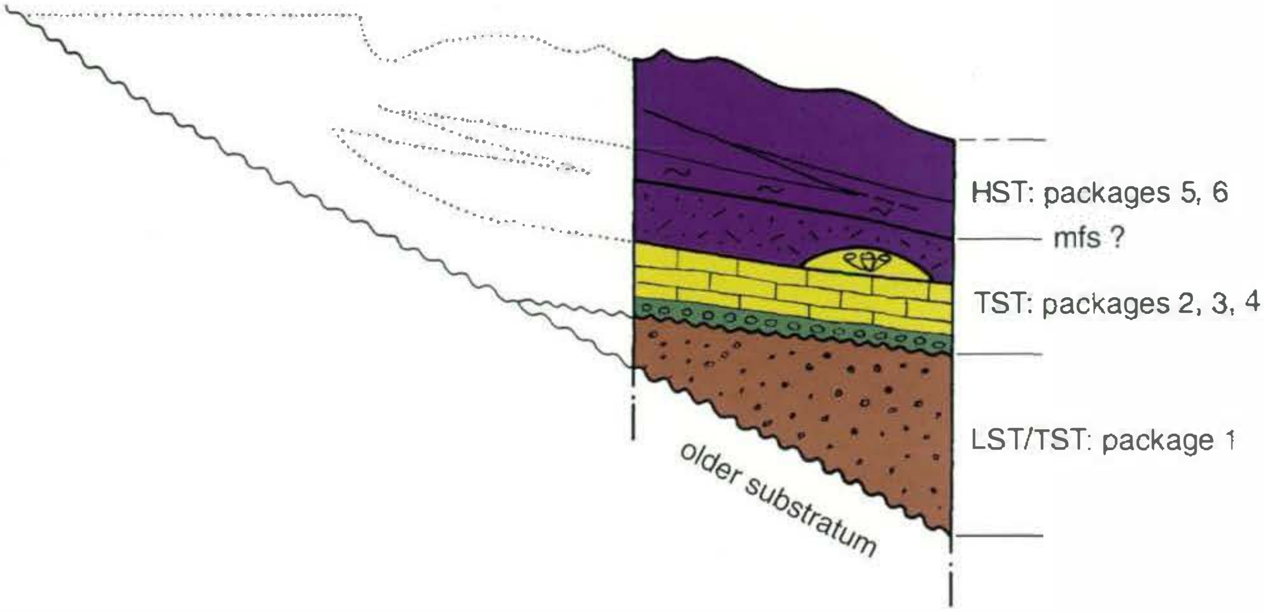

Fig. 5: Reconstruction of the sequence stratigraphic position of the described lithologic units (heavy lines), their position within systems tracts, and their possible lateral relationships (dotted). The alluvial fan deposits (package 1) occupy a position in the lowstand and/or the transgressive systems tract. They are overlain, in the transgressive systems tract, along a ravinement surface by a beach conglomerate and lithoclastic grainstones (package 2). The grainstones are overlain by and, possibly, originally interfingered in their upper part with shallow-water limestones (package 3) and calcarenaceous sandstones (package 4). The highstand systems tract consists, in its lower part, of silty marls (package 5) that contain an upward increasing number of sandstone beds with hummocky cross-lamination. The marls are overlain by sandstones with hummocky cross-lamination and megaripple laminasets (package 6); these sandstones comprise the uppermost preserved part of the highstand systems tract.

valves commonly reach some centimeters to 1 dm in length. Bivalves of this morphotype are well-adapted to shallow, fine-grained shelf environments (ABERHAN, 1994). In the intercalated, hummocky cross-laminated beds of sandstone, the high percentage of very angular carbonate rock grains indicates persistent erosion of fan delta conglomerates and/or of rocky shores (see discussion above).

The combined upward thickening/upward sandier succession of marls to overlying sandstones is interpreted as the progradation of the nearshore environment of a storm-dominated shelf (see DOTT & BOURGEOIS, 1982; WALKER, 1985; JOHNSON & BALDWIN, 1986; WALKER & PLINT, 1992). The original input of the siliciclastic sand most probably took place by rivers. Subsequently, the sand was redistributed by longshore currents, and transported offshore mainly by wave-induced and meteorological currents (cf. FIELD & ROY, 1984; HOBDAY & MORTON, 1984; JOHNSON & BALDWIN, 1986).

At Schichthals, the coarse conglomerates and the sandstones were deposited in a nearshore environment. This is indicated by both the size and the rounding of the *Trypanites*-perforated lithoclasts, in addition to the admixed fossils. A shelf or deeper water origin of the conglomerates and the sandstones is improbable because of the sedimentary structures of the sandstones, the absence of mud matrix, and the absence of fossils that would indicate an outer shelf to slope environment, like e.g. inoceramids, ammonites, and planktic foraminifera.

7. Sequence stratigraphic interpretation

The Upper Cretaceous succession near Maurach is interpreted as a single depositional sequence (fig. 5; see also fig. 3). The alluvial fan succession at the base (package 1) is situated in the lowstand systems tract (LST) and/or the transgressive systems tract (TST). In alluvial fan successions overlain by marine strata, in the absence of complete lateral and vertical control, the transgressive surface may be similar to other flooding surfaces in the TST (compare HAQ, 1991; DALRYMPLE et al., 1994; ZAITLIN et al., 1994). The surface at the base of the beach conglomerate that overlies the alluvial fan deposits thus can only be classified as a marine flooding surface. The alluvial fans thus are assigned to the LST/TST.

The alluvial fans are topped by the ravinement surface at the base of the overlying beach conglomerate. Together, the shoreface conglomerate and the overlying lithoclastic grainstones, shallow-water limestones, and calcarenaceous sandstones (packages 2 to 4) comprise the TST. The overlying sandy marls and sandstones (packages 5 and 6) are present in the highstand systems tract. The maximum flooding surface should be situated in the lower part of the marls, but could not be located. Together, the marls and the overlying sandstones record highstand shelf progradation.

In the sandstones, the intercalated conglomerates of carbonate lithoclasts perforated by *Trypanites* suggest that (a) coastal erosion of rock cliffs proceeded farther shorewards, and/or (b) that coarse carbonate lithoclastic material was reworked from alluvial fans. In any case, the proximity of a subaerial morphologic relief during highstand deposition is indicated.

8. Tectonic deformation

The Upper Cretaceous deposits are deformed between the Rofan massif to the north and the overthrust Reichenhall Formation and Rhaetian limestones to the south (fig. 2). In plan view, the tectonic contact of the Rhaetian limestones with the Upper Cretaceous deposits shows longer, northeast-striking segments that change laterally with segments that strike approximately to the east. Locally, in the northeast-striking segments, in Rhaetian limestones southeast-dipping slickensides with a subvertical lineation were observed. The east-striking segments of the contact, by contrast, are subvertical and locally show slickensides with a subhorizontal lineation.

In the western part of the outcrop area, the syncline formed by the Upper Cretaceous deposits has a roughly northeast-striking axis that dips southeast. The syncline becomes wider and less intensely deformed to the southwest; to the east it is intensely deformed into small thrust slices. The southeastern limb of the syncline is largely sheared off and overthrust by the Rhaetian limestones or, at Schichthals, by the Reichenhall Formation of Ebner Spitz.

At Schichthals, the substratum (Aptychen Formation) and the Upper Cretaceous together comprise a tight anticline with subvertical limbs. In addition, the Upper Cretaceous succession is reduced in stratigraphic thickness, and is deformed in thrust slices. The core of the anticline consists of strongly deformed, more or less marly, chert-bearing limestones of the Aptychen Formation. The contact between the Aptychen Formation and the overlying Upper Cretaceous deposits is tectonically strongly overprinted. Near the contact, the chert-bearing limestones of the Aptychen Formation are deformed to a cataclastic breccia. The breccia is overlain, at the northern limb of the anitcline, along a subvertical contact by lithoclastic calcirudites with a matrix of terra (alluvial fan deposits; see above). Along the southern limb of the anticline, Reichenhall Formation overlies Upper Cretaceous sandstones along a steeply southwest-dipping contact. In addition, the southern limb is crosscut by numerous subvertical fault planes with subhorizontal to gently inclined lineation and slickensides

To the north of Schichthals, in the southern part of the Rofan massif, Rhaetian limestones are exposed along strike with an overall dip to the southwest. Close to the north of Schichthals, the summit of Haidachstellwand is bound to the west by an approximately north-striking, subvertical fault. Along the fault, a megabreccia with a dark red matrix is present. In addition, along the southern crest of Haidachstellwand, a megabreccia is exposed that consists of blocks of up to more than 10 m in size. Between the blocks, a scarce matrix of dark red sediment is present. There appears to be no sharp boundary between the megabreccia and the surrounding limestones; the megabreccia is discordantly intercalated in the succession. At Haidachstellwand, a set of subvertical, approximately east-west striking faults is present.

Along the road "Achenseestrasse", at approximately 990 m near Maurach, a succession of chert-bearing, nodular limestones of the Reifling Formation (Anisian p.p.) is exposed (see fig. 2). Farther to the southeast, stratigraphically higher up, Wettersteinkalk Formation is nearly continuously exposed along Achenseestraße.

Discussion

The strongly deformed, brecciated limestones in the core of the anticline at Schichthals are similar to light grey, chert-bearing limestones and reddish marls of the Aptychen Formation in the Rofan massif (WÄHNER, 1903; SPENGLER, 1935). The cataclastic breccia along the boundary between the chert-bearing limestones and marls and the overlying Upper Cretaceous has been termed "Schichthalsbreccie" by WÄHNER (1903). The "Rotes Konglomerat" of AMPFERER (1908) probably designates the Upper Cretaceous alluvial fan conglomerates that overlie the cataclastic breccia.

The northward-striking, megabreccia-bearing fault along Hochalpstein-Haidachstellwand is of uncertain significance. No fault-confined megabreccia has been observed in the Upper Cretaceous at Schichthals. In the western and central part of the outcrop area, the Upper Cretaceous deposits are in tectonic contact with Rhaetian limestones, and overlie chert-bearing limestones similar to the Jurassic chert-bearing limestones ("Hornsteinkalke") of the Rofan massif. This indicates that the Upper Cretaceous succession was deposited in the area of the future Rofan massif. The Eben Thrust which marks the tectonic boundary between the Rofan massif and the southerly adjacent Eben Spitz is marked by the base of the Reichenhaller Formation. Over large parts of the western flank of Ebner Spitz, the westward continuation of the Eben Thrust is covered. The mentioned outcrop of Reifling Formation (Anisian p.p.) and, stratigraphically higher up, Wettersteinkalk Formation along Achenseestrasse implie that the trace of the Eben Thrust is situated, with an overall northeast-strike, between the Rhaetian limestones of Grindbichl (1400 m) and the Reifling limestones at Maurach (975 m). A small, but topographically marked valley that extends from the northern crest of Ebner Spitz at 1650 m to below Grindbichlkopf at approximately 1150 m probably marks the trace of the Eben Thrust.

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Plates

Plate 1

Fig. 1: Outcrop along the western face of Schichthals, approximately 1600 m altitude. The subvertical contact between Aptychenmergel (A) and the Upper Cretaceous succession (right part of picture) is marked by an arrow. Below the contact, the Aptychenmergel is brecciated. The Upper Cretaceous succession is tilted subvertical, and youngs towards the right (north). The Upper Cretaceous starts from a basal interval of coarse conglomerates with a matrix of terra rossa. The conglomerates are overlain by a succession dominated by lithoclastic grainstones (g) which, in turn, are followed up-section by calcarenaceous sandstones and marls (m). At the northern end of outcrop, an interval approximately 10 m of sandstones (s) is exposed. Width of view approximately 300 m.

Fig. 2: Part of succession of clast-supported conglomerates with thin, intercalated intervals of terra rossa. The conglomerates are composed of very poorly sorted, subangular to moderately well-rounded, fine gravel to small boulder lithoclasts. The lithoclasts consist of a wide variety of carbonate rock types that, at least in their largest part, are derived from the local substratum. Outcrop along dirt road to Buchauer Alm, 1200 m. Width of view approximately 10 m.

Fig. 3: Detail from conglomerate beds in the lower part of fig. 2. In the lower conglomerate bed, note the absence of grading up to the thin interval of terra rossa at head of hammer. The upper interval of terra rossa contains thin, clast- to matrix-supported lenses of medium to coarse conglomerates. Outcrop along dirt road to Buchauer Alm, 1200 m. Hammer for scale is 33 cm long.

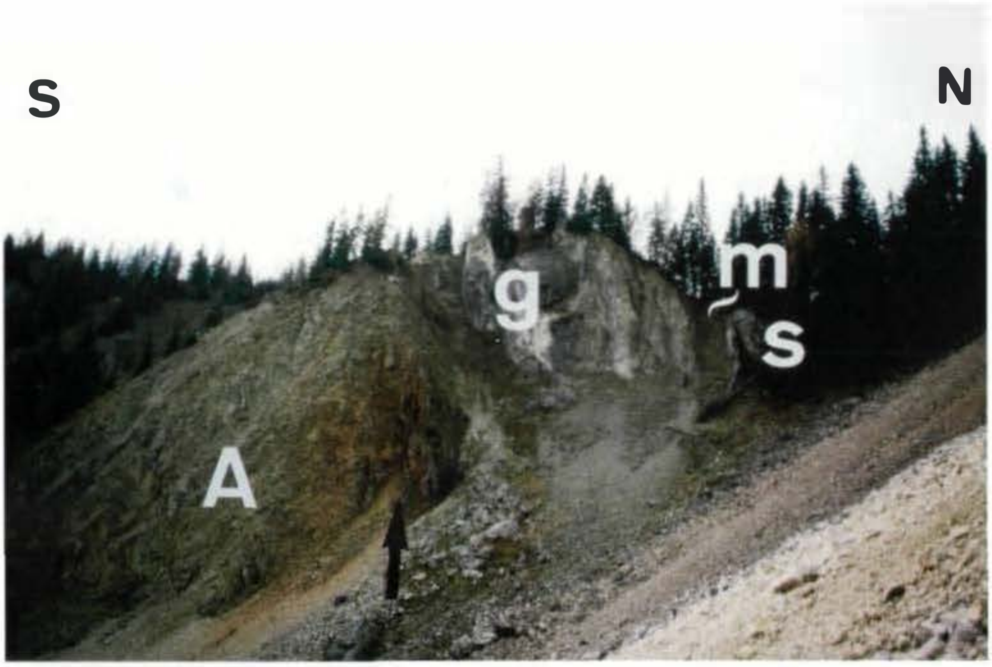
S
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Plate 2

Fig. 1: Sharp, erosive boundary between interval of terra rossa in the lower part and grey weathering conglomerates and lithoclastic grainstones in the upper part of the picture, respectively. Outcrop along dirt road to Buchauer Alm, approximately 1260 m. Width of view approximately 50 m.

Fig. 2: Detail from the grey weathering conglomerate of fig. 1. The conglomerate is clast-supported, and is composed of subangular to very well-rounded lithoclasts embedded in a matrix of lithoclastic grainstone. The lithoclasts are derived from the local substratum, and consist of limestones, cherty limestones and chert. Outcrop near dirt road to Buchauer Alm, approximately 1270 m. Hammer for scale is 33 cm long.

Fig. 3: Detail of succession of lithoclastic grainstones. The succession is indistinctly even to slighty wavy bedded; individual bedding planes commonly fade out laterally into a stylolite and, finally, into unstylolitized limestone. In the central part of the photo, a convex-downward bedding plane is present that fades out towards the left. Width of view approximately 14 m. Outcrop along dirt road to Buchauer Alm, approximately 1280 m.

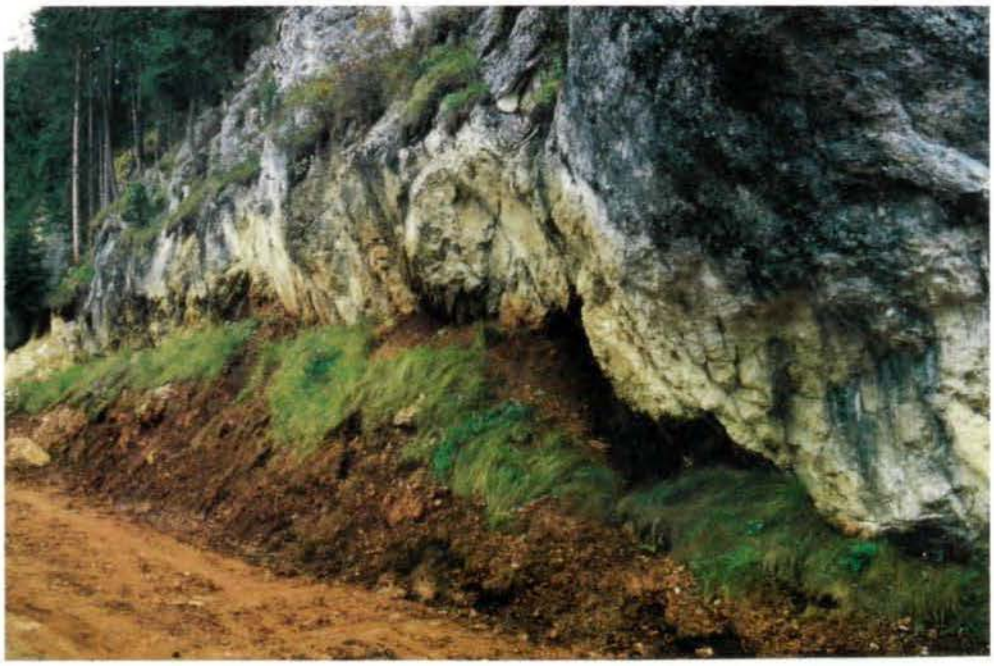


Plate 3

Fig. 1: Base of major bedding surface in a succession of lithoclastic grainstones. Along the bedding surface, numerous epichnial-endichnial burrows (*Callianassa*) with a diameter between less than a centimeter to several centimeters are present. Pen for scale is 14 cm long. Outcrop along dirt road to Buchaueralm, approximately 1285 m.

Fig. 2: Thin section of very well-sorted, medium sand lithoclastic grainstone. Both the dark grey and the medium gray sand grains consist of carbonate rocks; the light grains are chert. Note the angular to poorly rounded, elongate shape of the carbonate rock grains. Parallel polars, 8x. Scale bar = 0.5 cm.

Fig. 3: Detail of photo shown in fig. 2. Note the very angular to poorly rounded, elongated-rectangular to elongated-triangular shape of many carbonate rock grains. The light specks in some grains are silicified radiolarians. These lithoclasts are probably derived from the Hornsteinkalk Formation which underlies the Upper Cretaceous succession. Parallel polars, 16x. Scale bar = 1 mm.

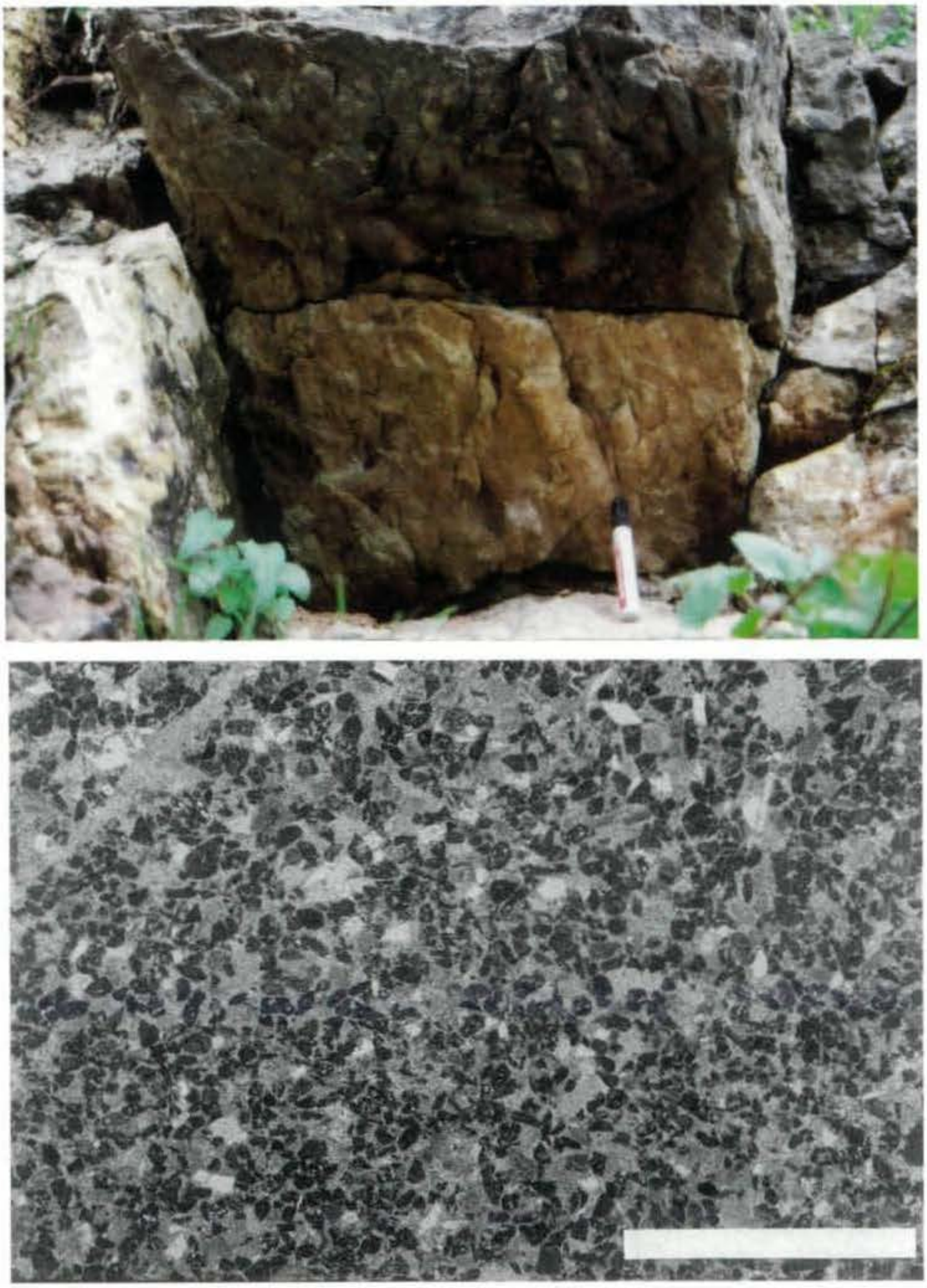
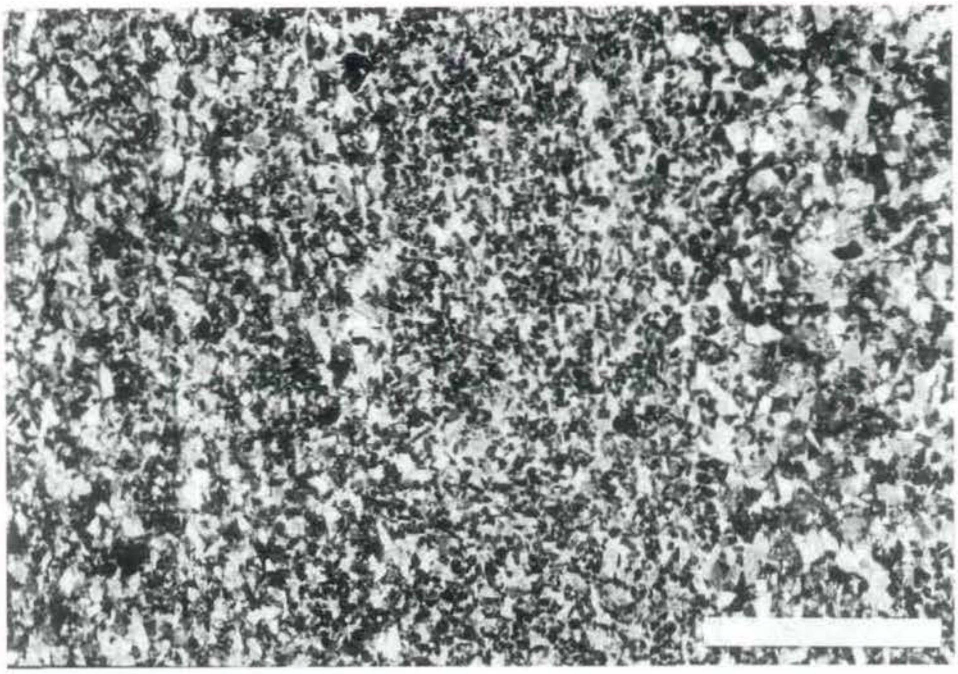


Plate 4

Fig. 1: Thin section of megaripple-laminated lithoclastic grainstone. Note the thickness of the laminae, and the very well-sorted, fine to medium sand of individual laminae. Parallel polars, 6.3x. Scale bar = 0.5 cm.

Fig. 2: Thin section of moderately well sorted, fine to medium lithoclastic grainstone. The larger components consist of chert (c), and of blocky calcite spar (arrow). Note the thin micrite fringe around the clast of blocky calcite spar. Parallel polars, 12.5x. Scale bar = 0.25 cm.

Fig. 3: Thin section of boundstone with corals, small rudists, encrusting coralline algae, sessile foraminifera, serpulids, sclerosponges and, possibly, encrusting hydrozoans and cryptmicrobial crusts. Parallel polars, 6.3x. Scale bar = 0.5 cm.



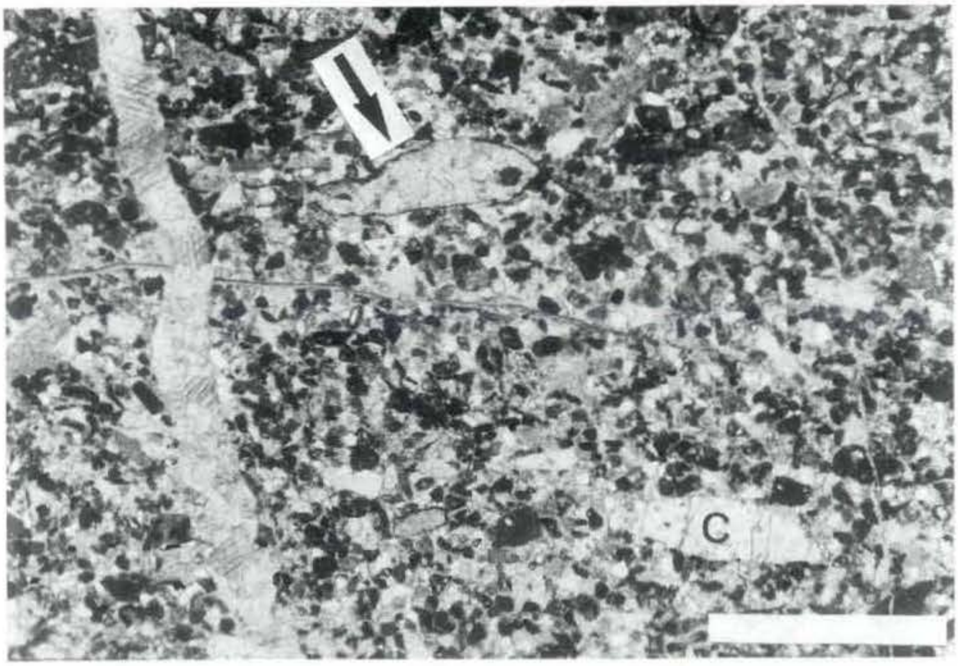

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Plate 5

Fig. 1: Thin section of well-sorted, bioturbated, medium sandstone composed of approximately equal portions of siliciclastic grains (chert, quartz and, minor, feldspar) and carbonate rock lithoclasts. Parallel polars, 11x. Scale bar = 0.5 cm.

Fig. 2: Thin section of well-sorted, fine sandstone composed of roughly 90% siliciclastic grains and 10% carbonate rock grains, and some biogens (middle part of photograph). The siliciclastic fraction is mainly composed of angular grains of chert and quartz, some grains of altered feldspar and, possibly, some serpentine grains. The carbonate rock lithoclasts are subrounded to well rounded. Crossed polars, 20x. Scale bar = 1mm.