A3 Facies development of the Eastern Alpine Cretaceous with respect to algal associations

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1. Geologic framework

The characteristic structural feature of the Eastern Alps is the nappe architecture, a style of construction which is clearly expressed by the east–west striking imbricated tectonic units. From north to south a number of zones are distinguished: Molasse Zone, Helvetic Zone, Flysch Zone and, in the strict sense, the actual "Austroalpine", that is the nappe system consisting of the Northern Calcareous Alps and the Greywacke Zone as well as the southernly adjacent Lower (Middle) Austroalpine nappes (Gurktal Nappe and their equivalents: TOLLMANN 1989; see fig.1).

The decisive events that led to the present structural and morphological conditions were caused by plate tectonic forces, which took place during the Early and Mid-Cretaceous. These events were caused by the subduction process in the realm of the westalpine South Penninicum (Piemontais). To the north, South Penninicum was flanked by the Middle Penninicum (Briancon) and the North Penninicum (Valais) with the Flysch and the Helveticum (Marginal Helvetic Sea; TOLLMANN 1987, 1989; FlÜgel 1987; DECKER et al. 1987). As a result of geodynamic processes, the Austroalpine "block", which had already begun developing during the Early Mesozoic geosynclinal phase, was detached from its basement and transported northwards over the Penninic complex. During transport of the frontal nappe complexes, the Lower Austroalpine and the Middle Austroalpine Nappes (TOLLMANN 1959, 1963), were overthrusted by the Upper Austroalpine, the highest Austroalpine Nappe complex.

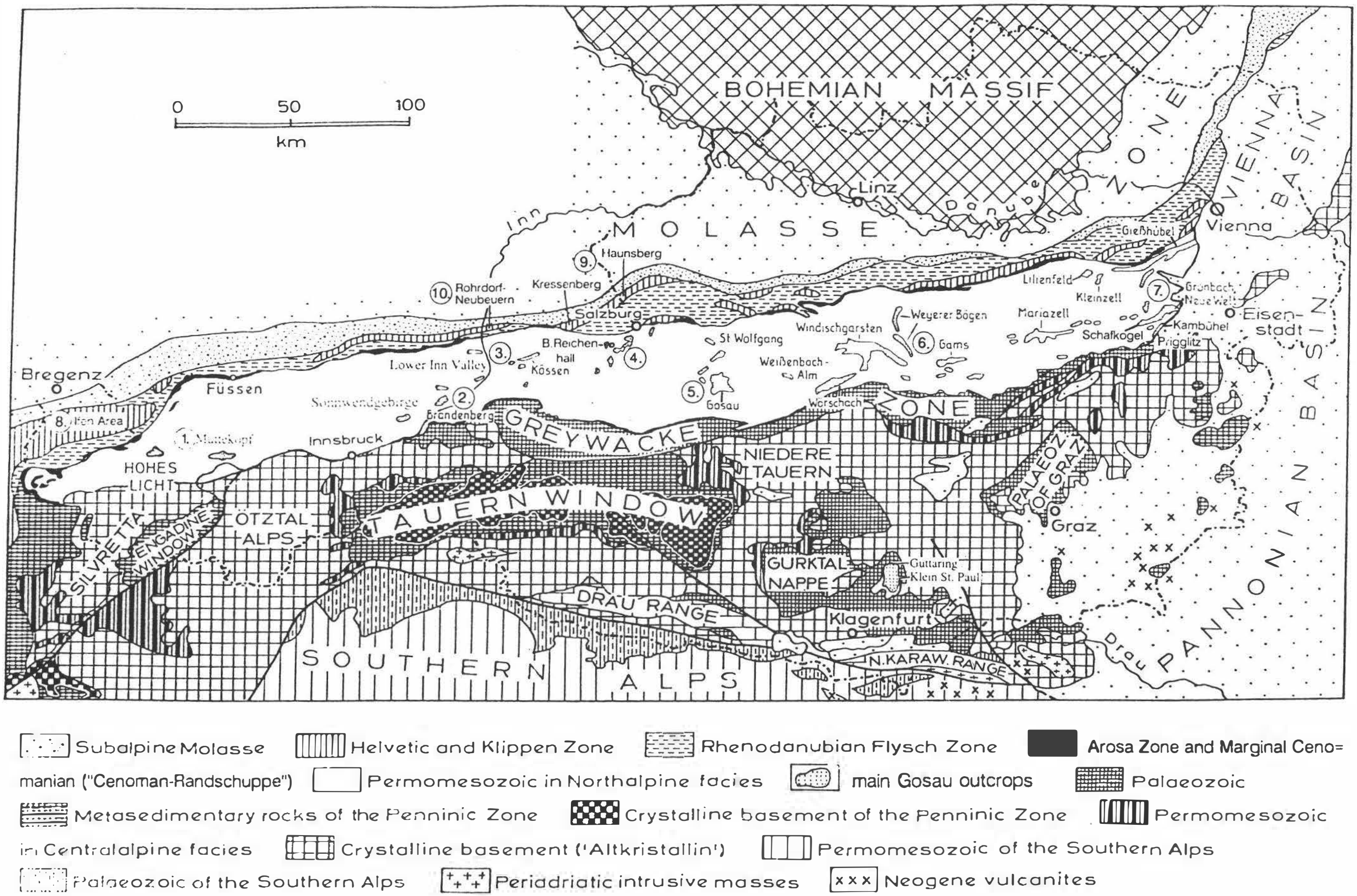
The development of the Alpine nappe system and its ensuing disintegration went hand in hand with sedimentation. Therefore, the distribution of land and sea, of deep– and shallow–water environments, especially the reef development, was closely influenced by the geodynamic processes during the Cretaceous–Paleogene. Platforms in shallow–water zones with biogenic buildups including algal associations developed not only in the Helvetic Zone, but also in the Austroalpine Belt. The deposits of Flysch and Ultrahelveticum, although having been formed during the time–period of Cretaceous to Paleogene, consist mainly of pelagic and turbiditic sediments with rare reworked shallow–water carbonates containing algae. For this reason these tectonic units will not be discussed any further here.

2. Helvetic Zone

The Helveticum is a distinct, east–west striking tectonic belt, extending from Upper Bavaria to northern Switzerland (fig.1). In the west it is wide, being composed of three facies zones.

Towards the east the Helvetic unit narrows increasingly, as a result of nappe overthrusting of southern tectonic units, so that south of Lake Chiemsee it has been completely overthrusted by the Flysch and the Northern Calcareous Alps (HAGN 1960; PFLAUMANN 1968; FREIMOSER 1972; ZACHER 1973; HERM 1981).

Fig. 1: Tectonic-geographic map of the Eastern Alps, showing the position of the main Cretaceous to Paleogene deposits of the Northern Calcareous Alps and the Helvetic Zone with regard to shallow-water carbonates (after FLÜGEL 1987; WAGREICH 1991; LEISS 1992 and present study).



A3

Northern Calcareous Alps

1. Muttekopf area (Upper Coniacian Upper Maastrichtian): shallow-water carbonates: Maastrichtian: as reworked components within turbidites and olistostromes (WOPFNER 1954; LEISS 1987; 1988a, b, 1992).

2. Brandenberg area (Upper Coniacian – Campanian): shallow-water carbonates: Upper Coniacian – Santonian: as clastic deposits and bioconstructions ("northern facies") (HERM et al. 1979; LEISS 1987, 1988a, b).

3. Lower Inn Valley area (Upper Coniacian – Middle Eocene): shallow-water carbonates: * Coniacian-? Lower Santonian: as transgressive series; * Maastrichtian, Paleocene, Eocene: as reworked components within turbidites and olistostromes (Kössen, Niederndorf, Sebi), as reworked pebbles within alluvial/fluvial fans of the Angerberg Beds (Upper Oligocene); * Upper Eocene – Lower Oligocene: as transgressive series (Oberaudorf Beds, Priabonian; Håring beds, Lower Oligocene). (HAGN 1967, 1981; ALLERSMEIER 1981; WEIDICH 1984; MOUSSAVIAN 1984).

4. Bad Reichenhall – Salzburg area (Coniacian – Upper Eocene): shallow-water carbonates: * Coniacian: as transgressive series (Glanegg); Lower Santonian: as transgressive series and rudist-dominated barrier reef (Untersberg; Lattenberg "Krönner Riff"); * Maastrichtian, Paleocene, Eocene: as turbidites and olistolites; * Lower Priabonian: as transgressive series and coral-algal biostromes (Eisenrichterstein) (HERM 1957; HILLEBRANDT 1962, 1981; HAGN 1967; HAGN et al. 1981; OBERHAUSER 1980; HÖFLING 1985; LEISS 1987, 1988a, 1988b; DARGA 1992).

5. Gosau – Abtenau – Rußbach area (Coniacian – Middle Eocen): shallow-water carbonates: * Coniacian – Lower Santonian: as transgressive series and coral-algal – and rudist-dominated bioconstructions / biolithites; * Uppermost Cretaceous – Middle Eocene: reworked components within turbidites and olistostromes (Schorn, Abtenau) (WILLE-JANOSCHEK 1966; TOLLMANN 1976; OBERHAUSER 1980; MOUSSAVIAN 1984: HÖFLING 1985; FAUPL et al. 1987; WAGREICH 1988).

6. Wörschach – Weyerer Bögen Gams area (Coniacian Lower Eocene): shallow-water carbonates: * Coniacian – ? Lower Santonian: as basal transgressive series; * Campanian – Upper Maastrichtian, Paleocene: as reworked components within turbidites and olistostromes (Wörschach) (JANOSCHEK 1968; POBER 1984; MOUSSAVIAN 1984; FAUPL et al. 1987; WAGREICH 1991).

7. Mariazell Grünbach/Neue Welt Gießhübel area (?Upper Coniacian Paleocene): shallow-water carbonates: * Coniacian – Lower Maastrichtian: as transgressive series, rudist-/dominated bioconstructions and siliciclastic carbonates (Grünbach/Neue Welt); * Upper Maastrichtian, Paaleocene: as sliding mass and reworked components within turbitides and olistostromes (Kambühel, N of Ternitz; Prigglitz; Schafkogel/Mooshuben; Gießhübel) (PLÖCHINGER 1967, 1980; TOLLMANN 1976; LEIN 1982; OBERHAUSER 1980; FAUPL et al. 1987)

Helvetic Zone

8. Allgäu – Vorarlberg (Upper Barremian Lower Aptian): Schrattenkalk platform carbonates, including bioconstructions (e. g. Ilfen area, W. of Oberstdorf) (ZACHER 1973; SCHOLZ 1984; BOLLINGER 1988).

9. Kressenberg area – Haunsberg area (Upper Paleocene – Lower Eocen; Southern Helvetic Zone): corallinacean-dominated biolithites and detrital carbonates ("Unterer Lithothamnienkalk) (TRAUB 1953; HAGN 1960, 1967; HAGN et al. 1981; GOHRBANDT 1963; VOGELTANZ 1970; KUHN 1992).

10. Rohrdorf – Kirchberg – Neubeuern area (Upper Middle Eaocen – Upper Eocene; Northern and Southern Helvetic Zone): corallinacean-dominated biolithites and detrital carbonates, "Lithothamnnienkalke", additionally other facies types of shallow-water carbonates as turbidites and olistolites (HAGN 1954, 1967, 1973; HAGN et al. 1981; DARGA 1992; HAUSER 1992).

The Helveticum developed on the Meso–European shelf during the Jurassic with shallow–water carbonates which are only exposed in the west, however. Deposition, which lasted up until Upper Eocene, consists of numerous sequences, indicating sea–level fluctuations, sedimentary diastems and condensation phases (WITT 1981; HERM 1982; TOLLMANN 1985).

The various Cretaceous formations and members developed for the most part on an extensive platform which on its southern flank was gradually subsiding and becoming increasingly differentiated (comp. ZACHER 1973; HERM 1981; BOLLINGER 1988; WYSSLING 1986; FÖLLMI 1989).

Facies differentiation may also be observed between the western and the eastern Helvetic Zone, which developed during Upper Cretaceous to Paleogene (HAGN 1960, 1978; HAGN et al. 1981 1981; HERM 1982, TOLLMANN 1985).

The so–called Ultrahelvetic Zone, which originally has been situated on the southern margin of the Helveticum ("Southern Facies"– sensu TOLLMANN 1985), is characterized by a variegated marly series ("Buntmergelserie"; Late Cretaceous–Paleogene), which is considered to represent deposits of the Meso–European continental slope.

It has been hypothesized that between the Ultrahelveticum and the Flysch Zone as a deep–sea trough a sill belt once existed, which locally formed submarine barriers (see HAGN 1960, 1978, HAGN et al. 1981; "Cetic Ridge").

Helvetic Platform carbonates containing bioconstructions and algae associations are limited to the time period Barremian–Early Aptian. The main area of distribution of the algae–bearing shallow–water carbonates lies in the vicinity of Allgäu–Vorarlberg (figs. 1,2,3).

2.1 Tectonic and palaeogeographic survey

In the Early Mesozoic the Helvetic area still had the characteristics of the Germanic facies realm. In the course of the Upper Jurassic this southern mobile margin of the Meso–European continent and respectively the northern margin of the Tethys, gradually became an autonomous depositional belt (compare also ZACHER 1973; SCHOLZ 1984; BOLLINGER 1988).

The integration of this zone into the Penninic realm began simultaneously with the development of the North Penninicum (Valais) and the opening of the South Penninic ocean. As a result of the diastrophism during Early Cretaceous, the North Penninic ocean, beginning in the south, became increasingly more differentiated so that, from south to north, three facies zones developed: the Flysch facies zone in the south, the Helvetic facies zone in the north and the Ultrahelvetic facies zone inbetween (a temporal and regional development). During Early Cretaceous the Helvetic facies zone was characterized by an extensive shallow–water environment, which was influenced by episodic sea–level fluctuations and which in a southernly direction passed into a continuously subsiding pelagic environment (OBERHAUSER 1968, 1978; HERM 1981; ZACHER 1973). The Schrattenkalk Formation evolved out of the predominantly pelitic Drusberg Formation.

As the result of a shallowing–upward process (BOLLINGER 1988) contemporaneously with the worldwide expansion of the "Urgonian Reefs", an extensive carbonate platform having bioconstructions first developed during Barremian to Lower Aptian. The growth of biogenic buildups with algal assemblages was regulated by the new palaeogeographic, climatic and environmental global conditions.

The demise of the reefs in the late Lower Aptian was directly connected with a drowning process of the Helvetic platform. The subsequent sediments (phosphorite–rich, condensed Luitre Beds, etc.; fig.3) and the palaeogeographic changes, which were being caused by geodynamic events, indicate new seaways and climatic and oceanographic changes (FÖLLMI 1989).

Climatic change and the evident influx of cold–currents appear to be the important regulatory factors resulting in the extinction of the bioconstructions in the Penninic realm. The changing palaeogeographic conditions and the continuous sea–level fluctuations led to the Upper Cretaceous gradually increasing facial differentiations within the Helvetic Zone, not only from north to south, but also from east to west. A general regression taking place towards the end of the Cretaceous and lasting into the Eocene led to the raising of the northern Helvetic margin (see chapter A4).

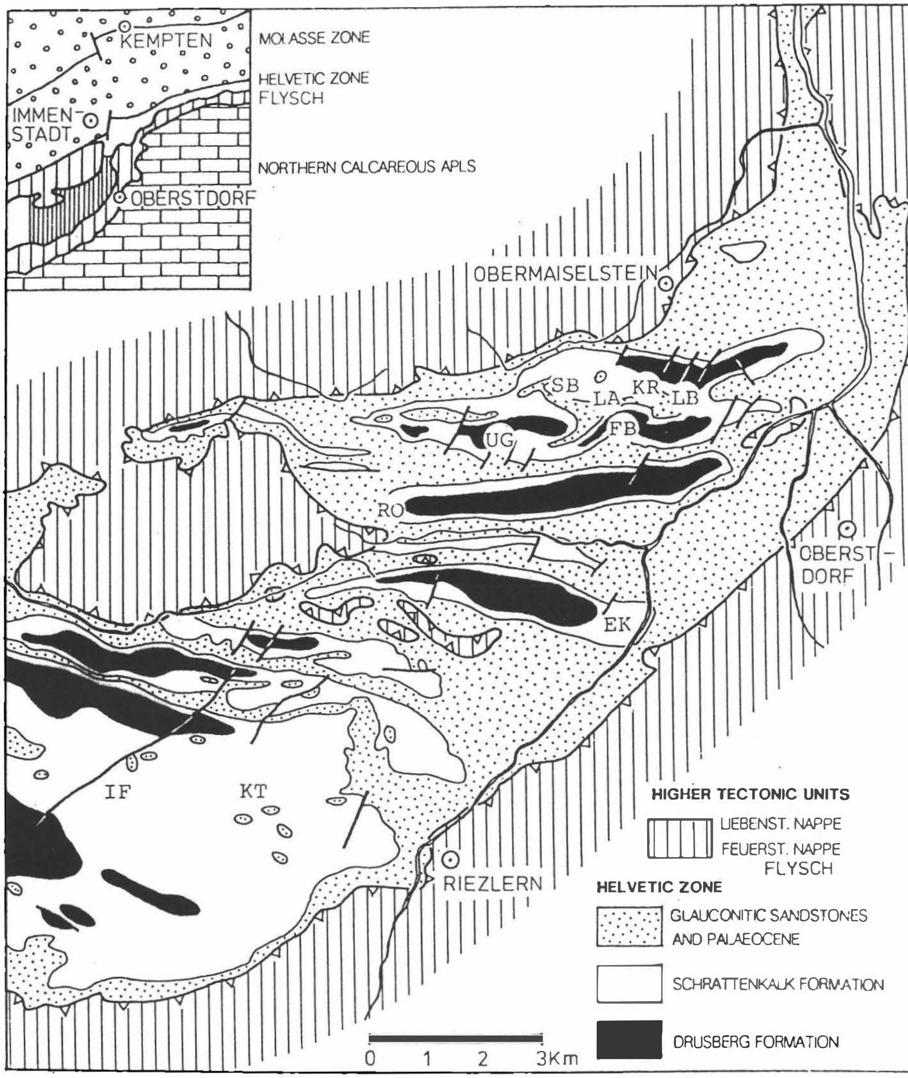
2.2 The Schrattenkalk carbonate platform

The evolution and increasing facies differentiation of the Helvetic platform began with the sedimentation of Schrattenkalk limestone. The platform developed into a shallow, gradually sloping ramp with internal and external facies areas (fig.3,4); initially, in lower Schrattenkalk, *Orbitolina* Beds and oolites, bioclast sandbars as well as intermittant mollusc beds and associations of encrusting organisms ("pioneer phase") were dominating; later, in upper Schrattenkalk, bioconstructions, consisting of encrusting, massive and columnar corals, demosponges and algae developed over the hard substrate which was previously stabilized by requieniid rudists or other molluscs or pioneering encrustors.

The Schrattenkalk Formation is younger in the north (Upper Barremian) than in the south (Lower Aptian), where it interfingers with the predominantly pelitic Drusberg Formation, which also constitutes the base of the platform sediments (ZACHER 1973; SCHOLZ 1984; BOLLINGER 1988; fig.3). This shows that the progradation of Schrattenkalk facies began in the north and that, during the time–period of Upper Barremiam to Lower Aptian, it formed a conjectured, over 20 km wide carbonate platform, which wedges out to the south.

2.2.1 Facies and algal associations

The isoclinal Schrattenkalk ramp may be subdivided from north to south into a number of facies areas: internal ramp, external ramp and muddy ramp ("muddy shelf", BOLLINGER 1988; fig. 4). These facies zones are extensive and they exhibit striking uniformity. The transitions between the individual facies zones occur gradually; the facies changes take place over relatively large distances. Locally limited thickets of biostromes and patch reefs, a few meters in diameter at the most and about 2.5 metres in thickness, characterize the reef facies in the internal and external ramp. These organic buildups, because of their high mud contents, may be considered to be reef–mounds. The most important sedimentological and palaeontological characteristics of the internal



Uncovered outline map of the Allgäu Helvetic Zone (after SCHOLZ 1984). Main outcrops: LB = start of Lochbach Road, EK = Engekopf, RO = Rohrmoos, JF = Gottesackerplatt, UG = Lower Gundalpe, FB = Falkenberg, LA = Lochbachalpe, SB = Schwarzenberg, KR = Källerucken, KT = Kürental

Fig. 2

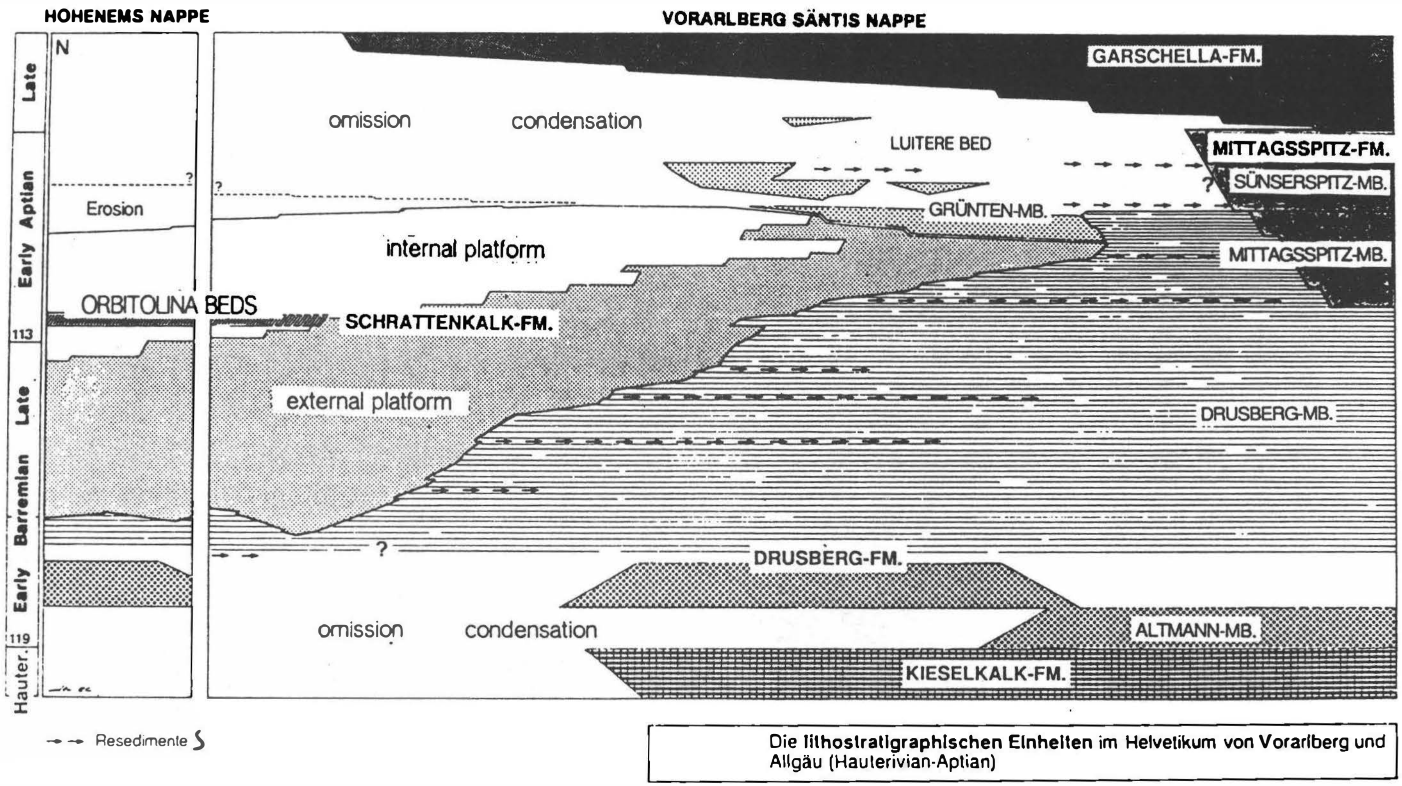
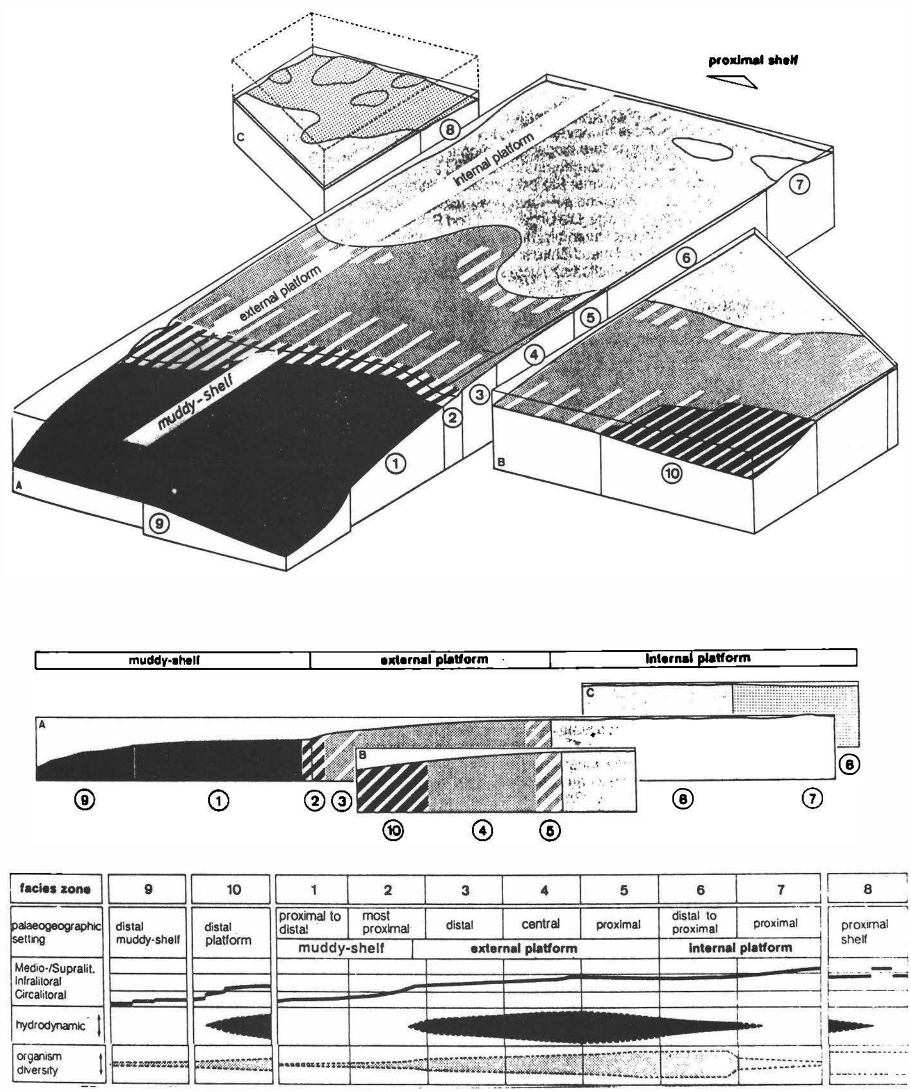


Fig. 3: (from BOLLINGER 1988)



Platform model: Facies zones of the Distal Eastern Helvetic Shelf (after BOLLINGER, 1988). Distribution of algae: Cyanobacteria and red algal associations occur within the bioconstructions of the internal and external platform, whereas the green algae are restricted to the internal platform.

Fig. 4

and external platform areas may be summarized as follows:

Internal platform (fig.5):
Generally reduced hydrodynamics, indicated by calcareous mud; highly diverse communities, mostly autoch thonous to para-autochthonous (especially orbitolinid foraminifera), encrusting to massive growth of coral-stromatoporid-chaetetid-dominated associations (pl.1), reduced growth of red algae and dendroid corals, occurrence of typical elements of the internal platform (rudists, green algae), strikingly intensive boring activity by molluscs, the development of intertidal and supratidal environments.

External platform:
Moderate to high hydrodynamics (BOLLINGER 1988), characterized by high mobility of the substrate; generally less diverse associations (mostly Orbitolinidae) except within the bioconstructions; the absence of rudist biostromes and green algae; massive growth of encrusting red algae; common occurrence of dendroid or branching algae and corals.

Algal associations (pl.1):
Cyanophytes and rhodophytes contribute significantly to the construction of the biogenic buildups and thickets. Their importance lies in their encrusting, sediment- and frame-stabilizing ability.
The red algae consist of solenoporaceans, corallinaceans and peyssonneliceans of low diversity. The abundance of individual species increases towards the external platform. The chlorophytes recorded belong to the dasycladaceans.

* Cyanophytes (cyanobacteria):
Multispecific morphotypes:
Oncoid/coated grains,
Tubiphytes sp.,
tubiphytoid morphotypes (pl.1/5),
morphotype-complex *Lithocodium/Bacinella*.

Monospecific forms:
Koskinobullina socialis CHERCHI & SCHROEDER,
Thaumatoporella sp.,
Rivularia sp.,
Pycnoporidium lobatum YABE & TOYAMA.

* Rhodophytes:
Solenoporaceae:
Solenopora urgoniana PFENDER (pl.1/1).

Corallinaceae:
Kymalithon belgicum (FOSLIE) LEMOINE & EMBERGER,
"Archaeolithothamnium" rude LEMOINE (pl.1/3),
Parakymalithon phylloideum (BUCH & DRAGASTAN) MOUSSAVIAN (pl.1/2,4),
Corallinaceae gen. et sp. indet.

Peyssonneliaceae:
Pseudolithothamnium album PFENDER,
Crassethelia suevica MOUSSAVIAN (pl.1/2),
Peyssonneliaceae gen. et sp. indet.

* Chlorophytes:
(according to SCHOLZ 1984; BOLLINGER 1988; pl.1/6).
Dasycladales:
Salpingoporella muehlbergii (LORENZ),
S. hasi CONRAD, RADOICIC & REY,
S.meliatae RADOICIC,
S.aff. biokovensis SOKAC & VELIC,

Pseudoactinoporella fragilis (CONRAD) CONRAD & PEYBERNES,
Carpathoporella fontis (PATRULIUS),
Heteroporella sp.,
Neomeris cf.
cretacea STEINMANN,
Acicularia elongata CAROZZI,
Acicularia sp.,
Boueina sp.

3. Austroalpine realm

3.1 Lower to Mid–Cretaceous (Berriasian–Turonian): allochthonous carbonates

The present geological situation only allows observations of the sedimentary development of the post–Turonian shallow–water Gosau group carbonates. Investigations of the reworked allochthonous carbonate components of the various deposits, sedimented during Early Cretaceous to Miocene in the Northern Calcareous Alps and the Molasse, show that Cretaceous shallow–water carbonates of Austroalpine origin were not limited to the Gosau group. On the contrary, numerous different shallow–water facies types of the Lower and mid–Cretaceous age have been preserved as olistoliths, turbidites and pebbles, which had their origin in other tectonic units. The facies and the algal flora of some of these characteristic facies types will be briefly discussed below.

3.1.1 Tectonic and paleogeographic survey

The compressional phases during the Lower and mid–Cretaceous, which were due to subduction in the Penninic ocean, caused on the one hand uplift and temporarily the installment of shallow–water environments on the forthcoming higher nappes, and on the other hand synorogenic sedimentation in the frontal pelagic basin and trenches of the tectonically active zones. The short time lasting shallow–water areas of the pre–Gosau Cretaceous, which once existed in various Austroalpine units, were soon eroded in consequence of elevation or covered tectonically by overthrusting ("Austrian Phase", "Mediterranean Phase" Albian–Turonian: TOLLMANN 1963, 1966, 1989).

3.1.2 Allochthonous carbonates of the northern margin of the Calcareous Alps

Relics of Lower to mid–Cretaceous shallow–water carbonates occur as olistoliths in the Losenstein Beds (Albian–Vraconian; pl.2/1,2,4)) and the Branderfleck Beds (Vraconian–Turonian; pl.2/3) of the northern–most i.e. tectonically lowest Austroalpine units: Marginal Cenomanian ("Cenoman–Randschuppe"), Allgäu Nappe, northern part of the Lechtal Nappe (GAUPP 1980, 1983; fig.6). The reworked carbonates are mainly found in the western part of the Calcareous Alps (Allgäu). Their primary depositional area was hypothetically situated in the north of the Upper Austroalpine, on already long ago eroded and subducted sills: "Rumunic Ridge" (Lower Austroalpine: GAUPP 1980, 1983) or "Ultrapienidic Ridge" (Middle Penninicum: TOLLMANN e.g. 1989).

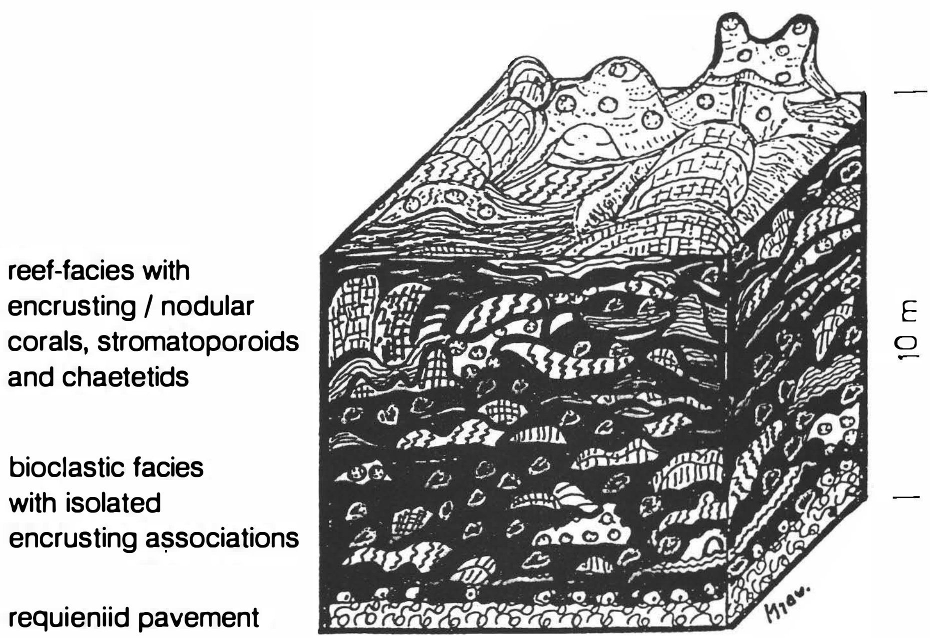
In the inner parts of the Calcareous Alps, especially in the region of the Inn and Salzach rivers, on the Lechtal Nappe as well as on the Tyrolian Nappe, numerous allochthonous, Lower and mid–Cretaceous deposits occur, which are also found as eroded pebbles in younger Cretaceous and Paleogene sediments, for example the reworked carbonates of the Gosau deposits (pl.2/3).

Facies and algal associations
Case study: Losenstein Beds.
The manifold reworked Cretaceous shallow–water carbonates of the Losenstein Beds are distributed within the time interval of Berriasian to Albian, where a sure documentation for the interval Hauterivian to Lower Barremian is missing (compare also GAUPP 1983). The components of Upper Barremian to Lower Aptian are clastic, foraminifera–rich sediment types; the facies indicates a litoral environment influenced by sea–level fluctuations.
The most abundant carbonate olistoliths are of Aptian to Albian age. They are mainly part biolithits, biosparites or biomicrites with in part strong influx of terrigenous detritus. The biolithits are predominantly composed of sheet– to mound–like corals, demosponges (chaetetids, stromatoporoids) and the algal groups cyanophytes, corallinaceans, peyssonneliaceans. Encrusting foraminifera (Placopsilinidae, Coskinophragmatidae) are rare.

The most abundant algae of the Albian pebbles are (pl.2/1,2,4):
Kymalithon belgicum (FOSLIE) LEMOINE & EMBERGER,
Paraphyllum primaevum LEMOINE,
P. amphiroaeforme (ROTHPLETZ) LEMOINE and
Agardhiellopsis cretacea LEMOINE.

3.2 Late Cretaceous (Gosau group)
The Austroalpine Gosau sediments were deposited discordantly over the previously folded nappe systems in numerous basins during the time–period of Coniacian to Eocene (fig.6). The Gosau deposition started as a result of a tectonically controlled transgressional cycle and lasted only in some of the basins until Eocene (figs.1,6). The exposures of the Late Cretaceous shallow–water carbonates of the Upper Austroalpine (Northern Calcareous Alps, Central Alps) were mainly deposited during the interval Coniacian to Santonian. Algal associations occur for the most part in the biogenic buildups and clastic carbonates. The youngest Gosau deposits of the Austroalpine units are represented by deep–water basin sediments, in which, towards the top, usually synorogenic intercalations occur. These are olistostromes and turbidites. They contain reworked shallow–environment material with biolithits and algal flora (figs.1,6).
In the following two Gosau basins containing the above mentioned sediments have been chosen in order to briefly describe their development and algal contents.

3.2.1 Tectonic and palaeogeographic survey
Towards the end of the mid–Cretaceous time, the subduction processes led to the collision of the Austroalpine with Middle Penninicum ("Mediterranian phase": TOLLMANN e.g. 1986, 1989). At the beginning of Late Cretaceous, the essential features of the nappe structure had already been established, so that this region (Northern Calcareous Alps and Central Alps) was for the most part dry land undergoing erosion (TOLLMANN 1976; OBERHAUSER 1980; HERM 1982; FAUPL et al. 1987; LEISS 1988 a, b, 1990 a, b; WAGREICH 1991). Extensive lateritic products and



Schematic reconstruction of a small Schrattenkalk moud reef within the internal ramp: A substrate stabilizing requieniid pavement becomes colonized by isolated encrusting associations dominated by corals (e.g. *Polytremacis, stylinidae*) and demospongia (e.g. *Diparistomaria, Chaetetopsis*). By increasingly dense growth of encrusting - nodular metazoa, red algae and cyanophyceae a small mound reef develops. (after MOUSSAVIAN, unpubl.)

Fig. 5

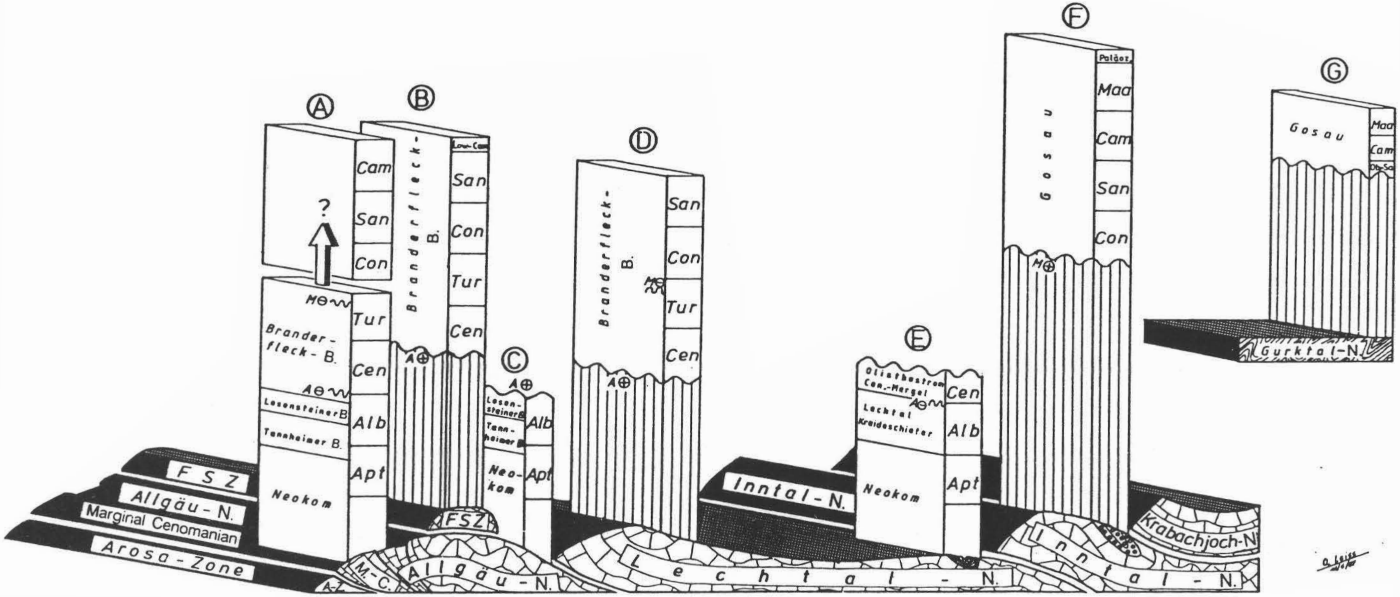


Fig. 6. Stratigraphic ranges of Cretaceous deposits within the various nappe systems in the western part of the Northern Calcareous Alps (compiled by LEISS, 1990, based on various authors).
A = Marginal Cenomanian ("Randcenoman"), B = Falkensteinzug (FSZ) = oulier of the anterior end of Lechtal-Nappe/Stoffelmühle, C = Allgäu-Nappe, D = northern part of Lechtal-Nappe/Branderschrofen, E = southern part of Lechtal-Nappe/Griesbachalm, F = Muttekopf-Gosau, G = Middle Styrian Gosau.

Fig. 6

fan–regimes document thorough weathering, erosion and marked relief–formation of the Upper Austroalpine Nappe Complex during the mid–Cretaceous desiccation period.

At the latest, starting with Coniacian, the transgression coming from the north, northwest or from a lateral direction reached the inner part of the Calcareous Alps. The ingressing Gosau sea first entered the morphologically deeper lying basins and depressions (lower nappes), whereas the higher areas (topographic highs, higher nappes) later became inundated with rising sea–level (LEISS 1988 a,b). The diachronic inundation of the different Gosau basins and the varying sedimentary conditions, which were being controlled by compressional tectonics, led to the formation of diachronous and different sequences of bedding. The topographic highs during Coniacian and Santonian were initially characterized by shallow–water sedimentation, beginning with clastic deposits, which in many areas change to rudist– or rudist–coral–dominated facies (e.g. Brandenberg, Salzburg–Reichenhall, Grünbach Gosau).

After a phase of subsidence, which, during Santonian, affected large parts of the western and middle Calcareous Alps, a renewed, tectonically controlled, regional shallowing upward process led again to the formation of shallow–water areas with biogenic buildups in some of the basins (e.g. Gosau basins of Brandenberg, Wolfgangsee, Gams).

The general increased subsidence of the entire Northern Calcareous Alps took place in late Upper Cretaceous, where the southeastern areas (Grünbach–Neue Welt) were first effected during Maastrichtian.

Continued subsidence until Paleogene led to the integration of the Calcareous Alps into the pelagic regime and increasing synorogenic sedimentation. The compressive intraplate–troughs, which were characterized by steep southern slopes, became the depocenters of the olistostrome and turbidite erosional materials, which had their sources in the topographically higher, southernly–adjacent nappes (LEISS 1990 a,b,c). The eroded shallow–water carbonates and organism associations in the olistostromes and turbidites of Maastrichtian to Eocene age document that contemporary platforms existed on top of the adjacent Upper Austroalpine nappes in the south and that they were gradually disintegrating (see chapter A4 Paleogene).

3.2.2 Facies and algae associations

Case study: Brandenberg Gosau

In the Brandenberg basin the transgressional sequence began in Early Coniacian with clastic sediments over the terrestrial formations. In the course of this development, the northern and northeastern parts of the basin remained under the influence of shallow–water sedimentation and then experienced regressive tendencies during Early Santonian. At the same time, the southern adjacent basin area experienced increasing subsidence (HERM et al. 1979; LEISS 1988 a, b; 1990 a; fig.7).

An over 40 m thick sequence along the Kreuthergraben ("Atzlgraben", SE Brandenberg; fig.7) documents the shallow–marine environment of the "northern facies" showing an interbedding of biogenic sediments with predominantly lithoclastic and partly terrigenous deposits. The two bioconstructions that occur in the section are a coral–algal–

dominated biostrome (pl.3) and an *Hippurites*–buildup (compare HÖFLING 1992). Thanks to the activity of the encrusting and binding red algae and corals the biostrome could develop on instable, arenitic substrates of an open marine subtidal environment. Further associated organisms were bryozoans, sponges and encrusting foraminifera. The rudist–buildup evolved initially towards the top of the section in a lagoonal environment, in which the last coral–algal encrustations had almost been completely replaced by the rudists. This small monospecific bioconstruction is built up in a bouquet–like arrangement by the species *Hippurites sulcatus* (HERM et al. 1979, HÖFLING 1992). Reef–dwelling organisms occur only sporadically. Encrusting activities are limited substantially to the cyanophytes (including the morphotype–complex *Lithocodium / Bacinella*) and agglutinating foraminifera. This facies is replaced upwards by a rudist–coral–dominated facies, in which chlorophytes also begin to appear beside red algae.

Algal associations
The distribution of the algal flora and their frequency depends upon the respective facies type.

Coral–algal–biostromes:
In this facies type chlorophytes are absent. Cyanophytes decrease in comparison to rhodophytes which are absolutely dominant in the encrustations. The most frequently occurring forms are (pl.3):
Parachaetetes sp.,
Sporolithon gosaviense (ROTHPLETZ),
S. cretaceum (PFENDER) and
Pseudolithothamnium album PFENDER
Peyssonneliaceae gen. et sp. indet,
Pycnoporidium sinuosum JOHNSON.

Rudist–bioconstructions:
The organism diversity is strongly reduced. There is a complete absence of green algae. The red algae only appear at the base and on the top of the buildups. The only abundant elements are cyanophytes (especially *Lithocodium/Bacinella*).

Rudist–coral–biostromes: The organism diversity is distinctly higher in this facies. The most frequent algae belong to the corallinaceans and dasycladaceans, e.g.
Neomeris sp.,
Cymopolia sp.,
Acicularia sp.,
Halimeda sp.

Case study:
Gosau of Salzburg – Bad Reichenhall
The Gosau sea invaded the lower lying regions first (Glanegg, Tyrolian Nappe). It began in the Middle Coniacian with the deposition of clastic series, later, as a result of increased subsidence, pelagic sedimentation took place (compare HERM 1962, 1981; LEISS 1988 a, b; 1990 a; MOUSSAVIAN et al. 1990; fig.8). As a consequence of a continuous sea–level rise the higher nappe system (Juvavic Nappe Complex with their uppermost unit Berchtesgaden Nappe) is finally inundated in Lower Santonian. Along the front of this tectonic unit (Untersberg-Lattenberg) a coarse– to medium–grained, clastic transgressional series is initially deposited followed by the sedimentation of biogenic carbonates; now a *Hippurites*–dominated barrier reef complex, with various subfacies, begins to develop

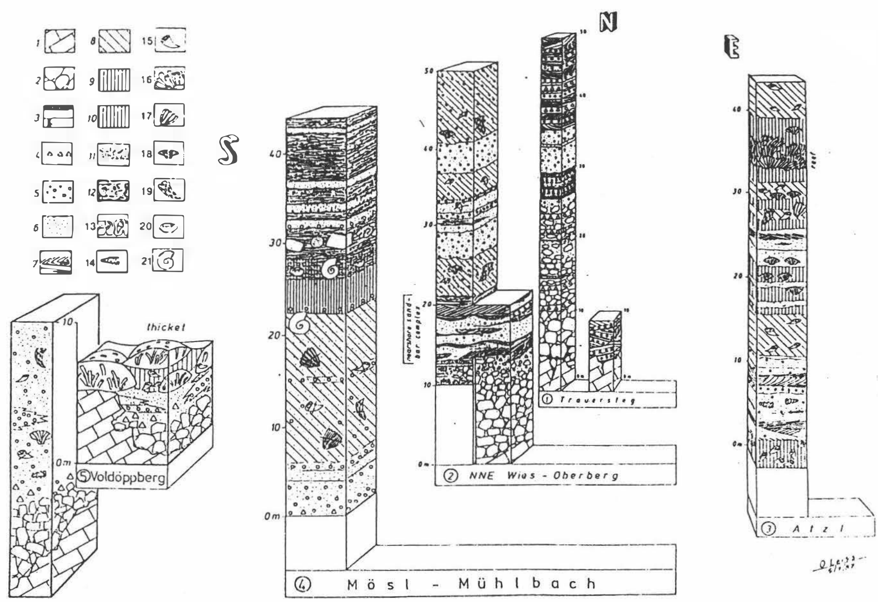
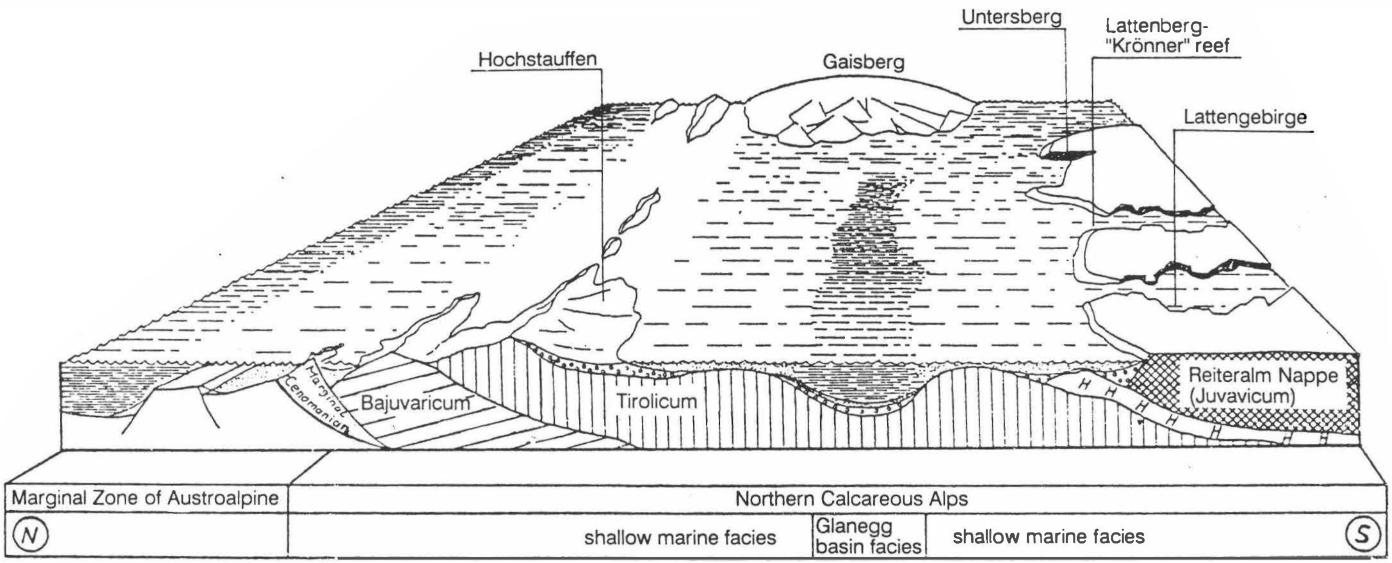


Fig. 7

Selected profile columns of the Brandenberg Gosau Basin, representing different sedimentological and biofacial developments during the Upper Coniacian.

Profile 1 (Trauersteg) shows the retrogressive development of an alluvial piedmont regime.
Profile 2 (Oberberg) illustrates a nearshore sand bar complex with differentiated facial relations in the lower part, overlain by a thick succession of reworked sediments (sandstones, conglomerates).
Profile 3 (Atzlgraben") shows a shallow water environment, characterized by siliciclastic and biogenic carbonates, coralgal and hippuritid bioconstructions.
Profile 4 (Mösl-Mühlbach) represents the basin facies of pre-gosauic formed intra-plate-throughs.
(after LEISS 1987).

1., Triassic beds
2., block breccia
3., laterite/(bauxite) - lateritic-bauxitic wack-/packstone
4., fine breccia
5., conglomerate/pebbles
6., massive sandstone, litharenite
7., litharenite with stratified structures
8., litho-/bioclastic calcarenite, sparitic matrix
9., litho-/bioclastic wackestone
10., litho-/bioclastic packstone
11., brackish siltite/mudstone
12., sheeted hemipelagic marls
13., plasticlasts - bioclasts, -morpha
14., Gastropoda, mostly Cerithiidae and Nerinacea
15., Hippuritacea, mostly Radiolitidae
16., Hippuritidae-cluster/-ticket
17., Bivalvia, e.g. Cardiidae, Nerineidae, Pectinidae, Arcidae
18., colonial corals, e.g. Actinacis multilamellata, Polytremacis partschi
19., cyclostomatic bryozoans
20., irregular echinoids - Atelostomata
21., Cephalopoda - Ammonoidea

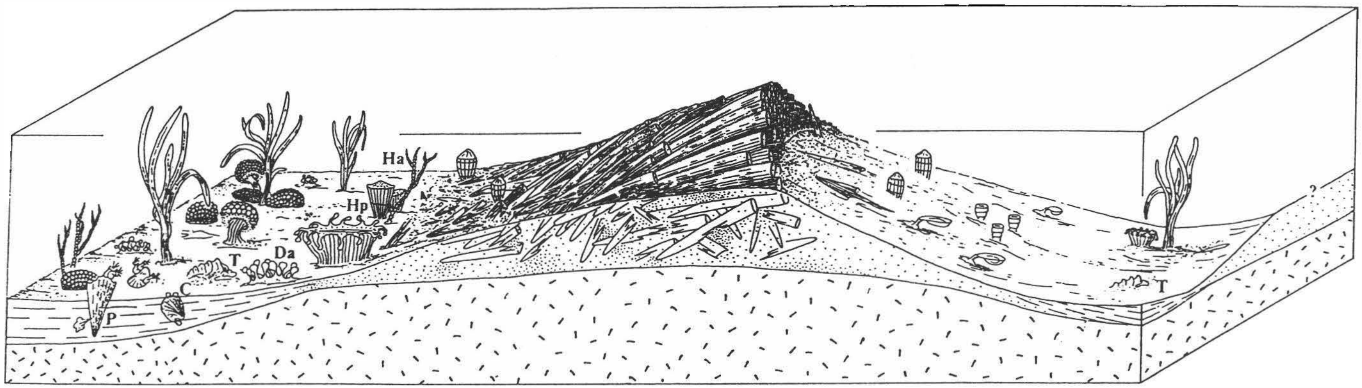


Paleogeographic reconstruction of the Gosau Deposits in the Reichenhall - Salzburg - Basin during (Upper Coniacian) - Lower Santonian. Large areas of former dry land are submerged, only geographic highs (peaks and plateaus of Reiteralp Nappe (Juvavicum) and Tirolicum) remain above sea level. The central part of the basin (Glanegg bassin facies) is located in the Tirolicum, in front of the Juvavic Nappe. In the shallow marine area at the margin of the Juvavic Nappe rudist dominated barrier reefs develop (Lattenberg- "Krönner" Reef) (after LEISS, 1987).

Fig. 8

Fig. 9a

	backreef - lagoonal zone		hippuritid bioconstruction	forereef detrital zone	forereef lagoonal zone	detrital zone of adjacent bioconstruction
Invertebrate associations:	epibenthic coral-trochid-naticid-assoc.	epibenthic radiolitid-assoc.		sessile terebratulid-sponge-assoc.	epibenthic trochid-potamidid-coral-assoc.	



algal associations:	epibenthic udoteacean-dasycladacean-assoc. encrusting corallinacean-peyssonneliacean-assoc.	encrusting cyanophycean-assoc. (incl. *Lithocodium/ Bacinella*, *Pycnoporidium*)	*Lithocodium*-soleonoporacean-assoc.

Abbreviations: Ha = *Halimeda*, Da = dasycladaleans, C = *"Cardium"*, Hp = *Hippurites*, P = *Pinna*, T = *Trochus*

Schematic reconstruction of the Lattenberg biohermal hippuritid-bioconstruction and adjacent recifal palaeoenvironments with invertebrate and corresponding algal associations (after: HÖFLING 1985, not to scale).

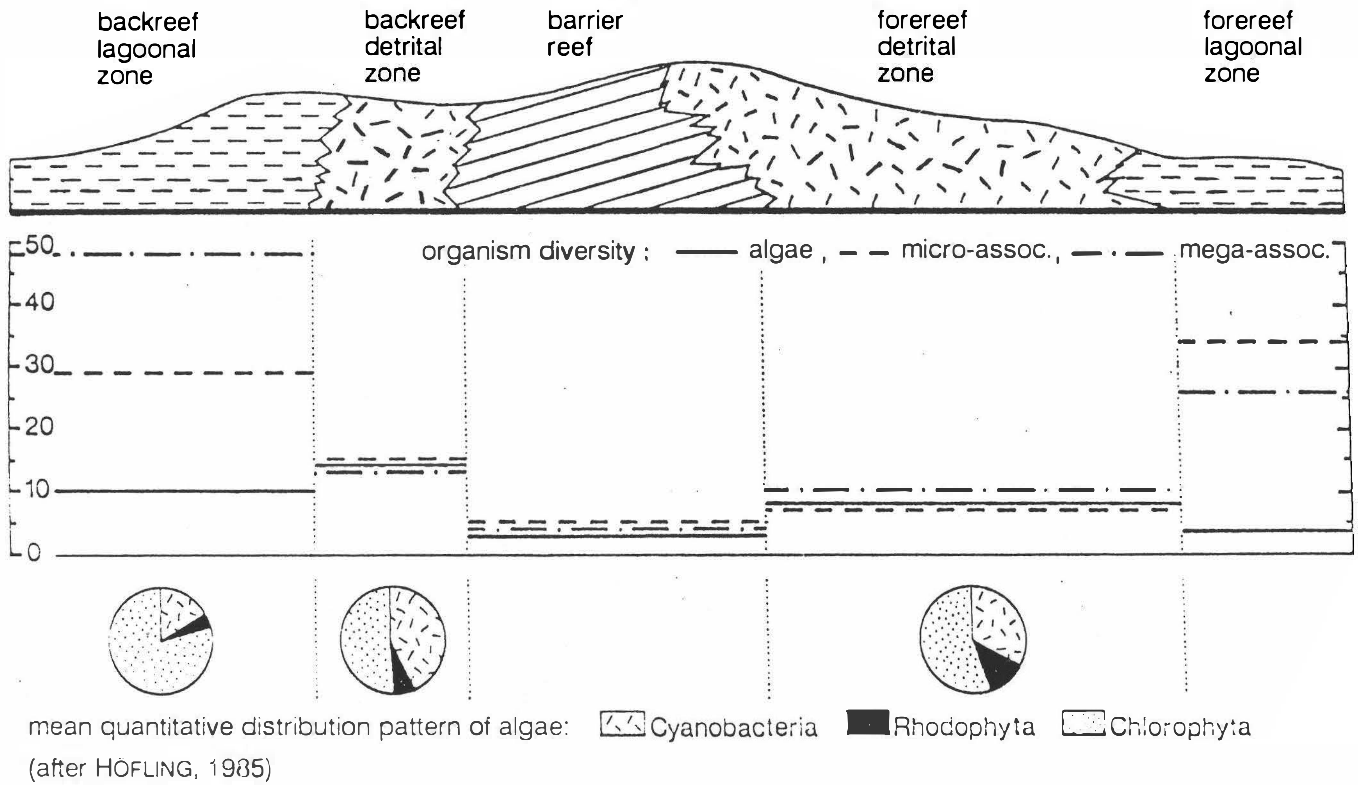

backreef
lagoonal
zone
backreef
detrital
zone
barrier
reef
forereef
detrital
zone
forereef
lagoonal
zone
50
40
30
20
10
0
organism diversity : algae , micro-assoc. , mega-assoc.
mean quantitative distribution pattern of algae: Cyanobacteria Rhodophyta Chlorophyta
(after HÖFLING, 1985)

Fig. 9b

(HÖFLING 1985; figs.8,9). The construction of the reef begins with a population of a single species (*H. gosaviensis*) growing one upon the another in an in clined manner within an extensive lagoon (fig.9a, b). The reefs demise in the course of a drowning process due to increasing subsidence. The distribution of the algae in particular facies zones (pl.4) shows a similar pattern as the Brandenberg rudist buildups. Algal diversity was strongly limited within the *Hippurites*-framework itself. Here, cyanophyte encrustations, especially *Lithocodium/Bacinella* flourished best. The optimal habitat for rhodophytes and chlorophytes was the backreef lagoonal environment behind the current-exposed *Hippurites* populations (fig.9a, b).

References

See chapter A 4. Paleogene

Plate 1:

Algal associations of the Schrattenkalk carbonate platform, Helvetic Zone (Upper Barremian-Lower Aptian)

Fig.1: *Solenopora urgoniana* PENDER Locality: Iten area, Allgäu. x 8.

Fig.2: Encrustation microsuccession between *Crassethelia suevica* MOUSSAVIAN (a) and *Parakymalithon phylloideum* (BUCUR & DRAGASTAN) MOUSSAVIAN (b). Locality: Grünten, Allgäu. x15.

Fig.3: *Kymalithon belgicum* (FOSLIE) LEMOINE & EMBERGER, depicting its characteristic sporangial "sori". Locality: Untere Gundalpe west of Oberstdorf, Allgäu. x 32.

Fig.4: *Parakymalithon phylloideum* (BUCUR & DRAGASTAN) MOUSSAVIAN, showing plumose basal part (hypothallus) and spo- rangial receptacle. Locality: Grünten, Allgäu. x 80.

Fig.5: A tubiphytoid morphotype as characteristic crustbuilder reefal facies (compare MOUSSAVIAN 1992, pl.24/4). Locality: Untere Gundalpe west of Oberstdorf, Allgäu. x 30.

Fig.6: Pelmicrite-cyanophytes-rich microfacies with dasycladacean debris (*Salpingoporella* sp.). Locality: Lochbachstraße west of Oberstdorf. x 20.

A3

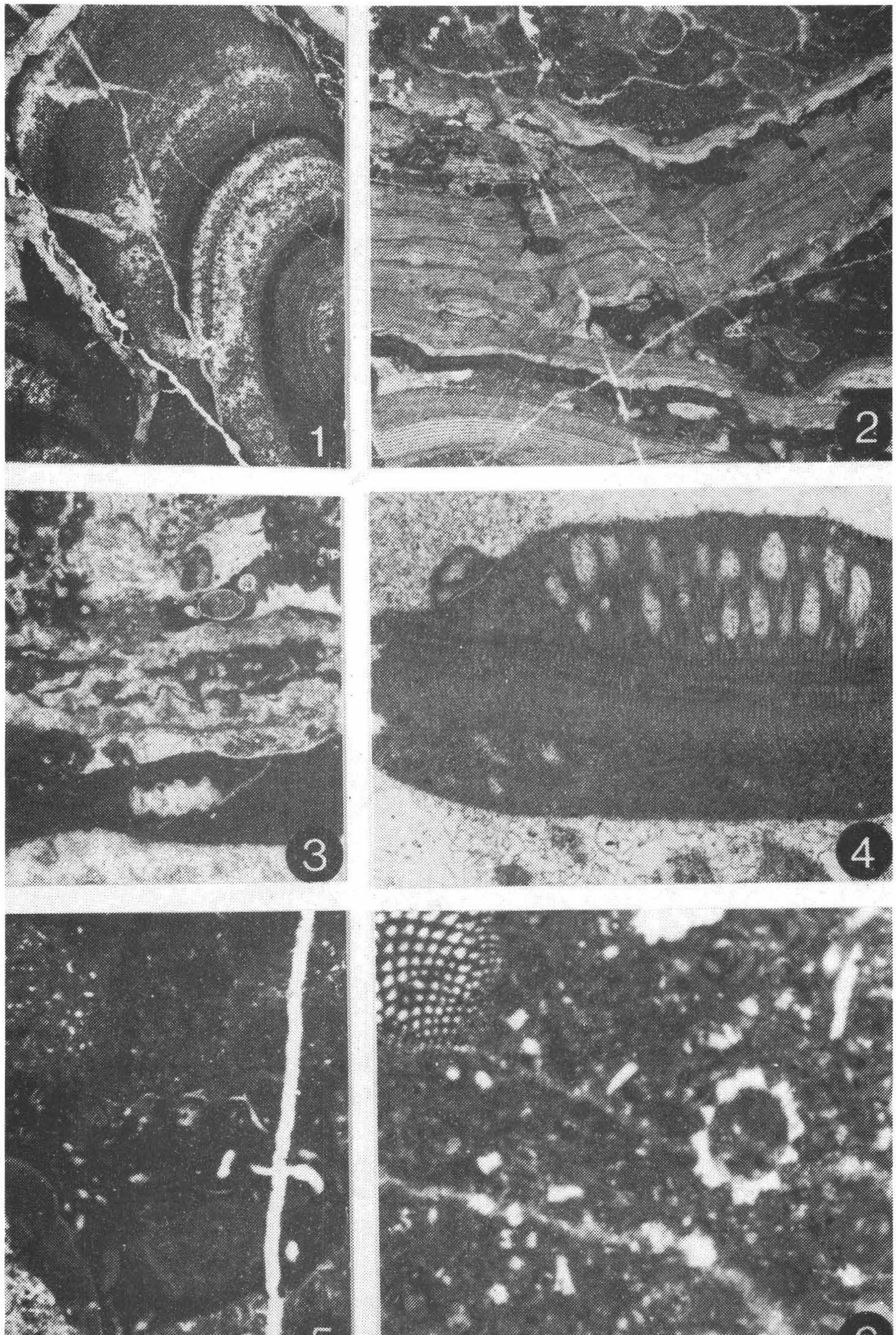


Plate 2

Algal associations of the allochthonous mid-Cretaceous carbonates within different Cretaceous deposits, Northern Calcareous Alps

Fig.1: *Kymalithon belgicum* (FOSLIE) LEMOINE & EMBERGER with the cavities of sporangial "sori". Reworked Albian packstone within the Losenstein Beds Albian). Locality: near Füssen, Allgäu. x 80.

Fig.2: *Agardhiellopsis cretacea* LEMOINE. Reworked Albian packstone within the Losenstein Beds (Albian). Locality: near Füssen, Allgäu. x 80.

Fig.3: *Sporolithon* sp.intergrown by nubeculariid foraminifers. Reworked Cenomanian biolitite within the upper Branderfleck Beds (Turonian). Locality: Branderfleck near Füssen, Allgäu. x 80.

Fig.4: *Paraphyllum amphiroaeforme* (ROTHPLETZ) LEMOINE. Reworked Albian packstone within the Losenstein Beds (Albian). Locality: near Füssen, Allgäu. x 80.

Fig.5: Red algal association composed of *Solenopora* sp. (a), *Agardhiellopsis cretacea* LEMOINE (b), *Paraphyllum primaevum* LEMOINE (c) and other branching forms. Reworked Albian packstone within the clastic Gosau deposits (Upper Coniacian). Locality: Oberwössen, Chiemgau. x 7.

A3

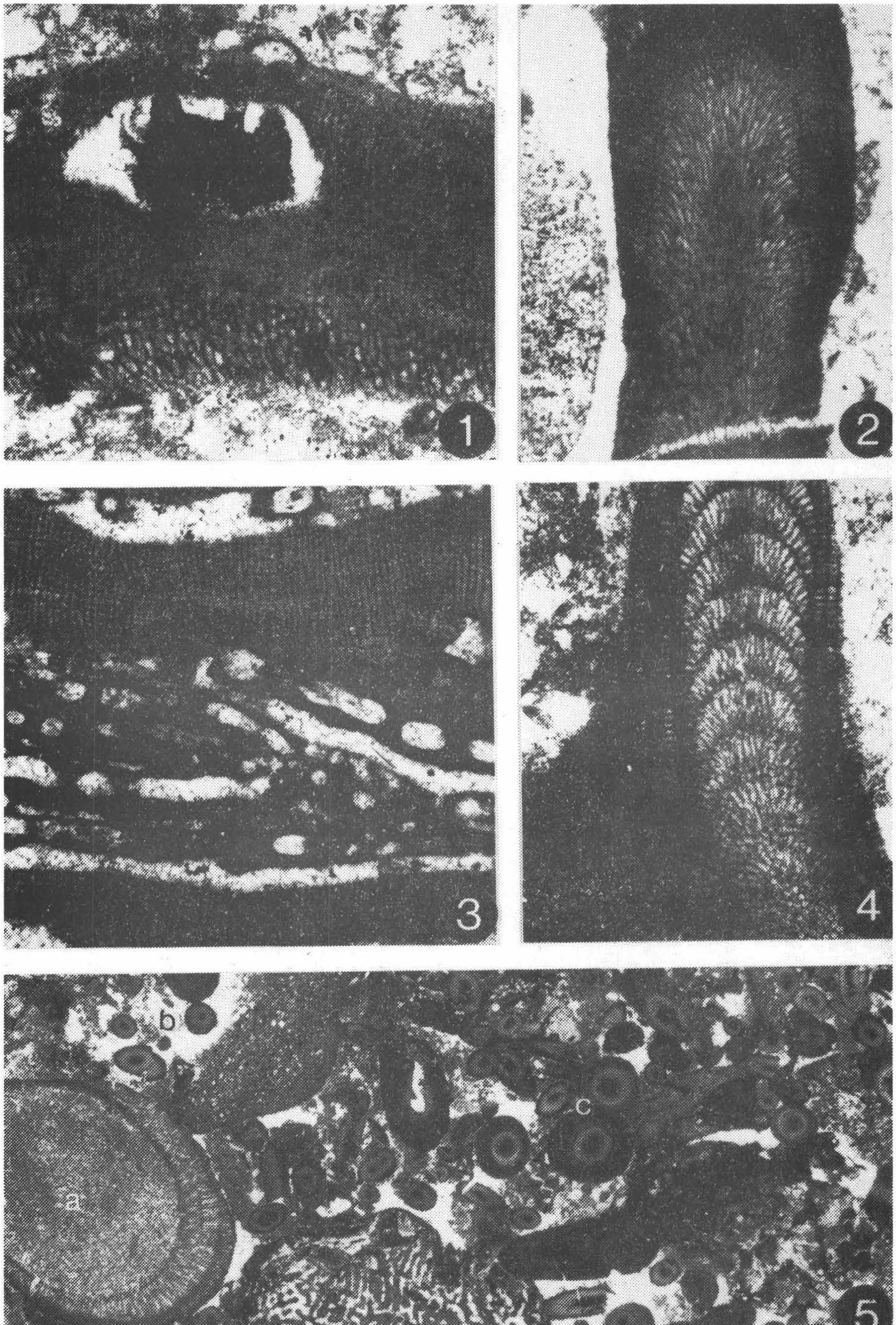


Plate 3

**Algal associations of the Gosau Group:
Brandenberg Gosau basin, Northern Calcareous Alps.**

Fig.1: Algal encrustation microsuccession: *Pseudolithothamnium album* (PFENDER) (a), Peyssonneliaceae gen. et sp. indet (b), *Sporolithon* sp. (c) interwoven by cyanophyte crusts. Coral-algal biostromes of the "northern facies" (Upper Coniacian) . Locality: Kreuthergraben SE of Brandenberg. x 7.

Fig.2: Coral-algal microsuccession composed of *Sporolithon gosaviense* (ROTHPLETZ) and *Microsolena* sp. (compare Moussavian 1992). Coral-algal biostromes of the "northern facies" (Upper Coniacian). Locality: Kreuthergraben SE of Brandenberg. x 8.

Fig.3: *Sporolithon cretaceum* (PFENDER), covering a rudist shell. Rudist-coral biostromes of the "northern facies" (Upper Coniacian). Locality: Kreuthergraben SE of Brandenberg. x 8.

Fig.4: Encrustation microsuccession between *Pycnoporidium sinuosum* JOHNSON und *Pseudolithothamnium album* PFENDER. Coral--algal biostrome of the "northern facies" (Upper Coniacian). Locality: Kreuthergraben SE of Brandenberg. x 22.

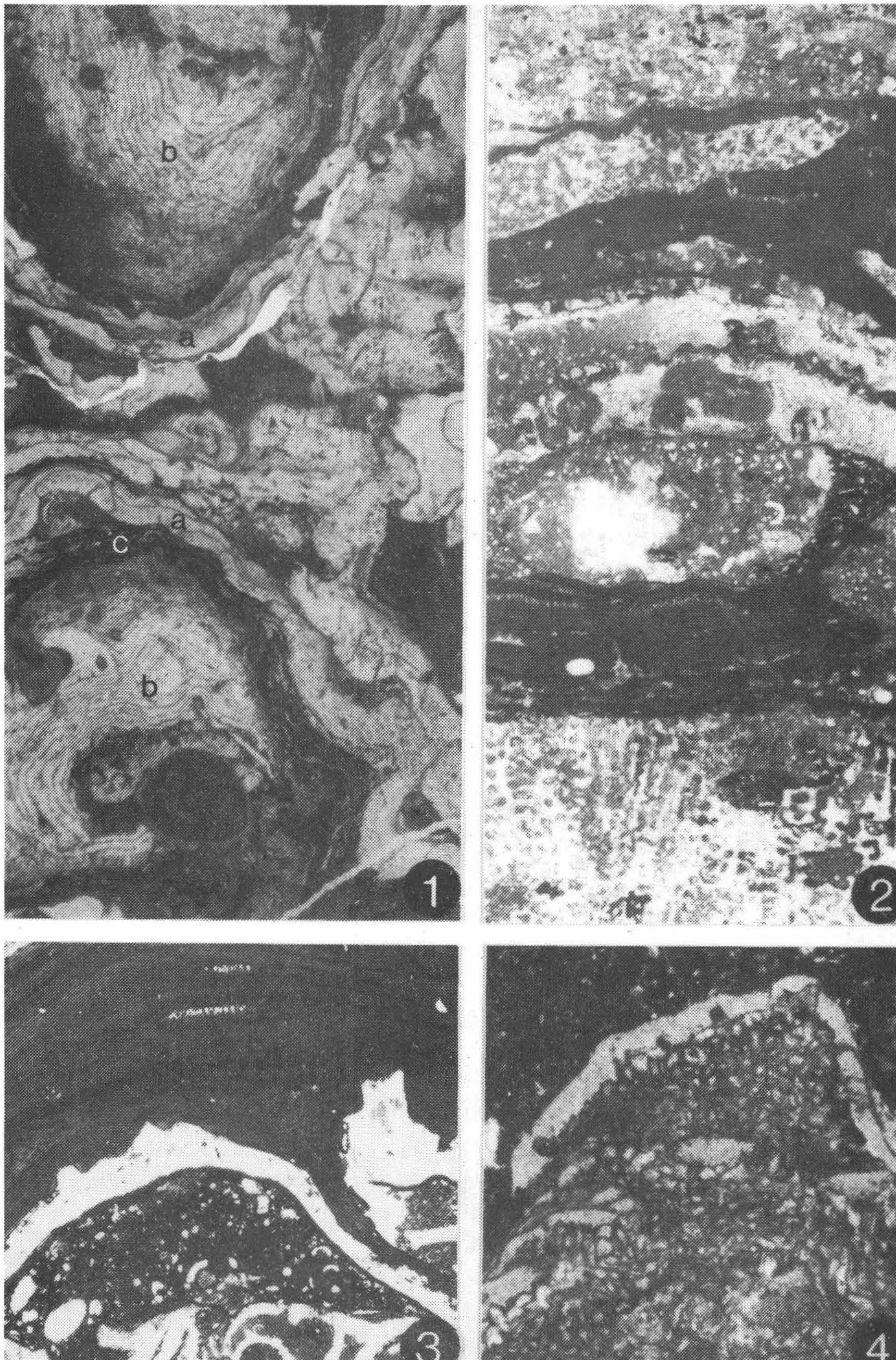

b
a
a
c
b
1
2
3
4

Plate 4

Algal associations of the Gosau Group:
Salzburg Reichenhall Gosau basin, Northern Calcareous Alps

Fig.1–5: *Hippurites* barrier reef complex (Lower Santonian)

Fig.1: Cyanophyte crusts as the most frequent postmortal elements within the *Hippurites* framework. Locality: Lattenberg, Bad Reichenhall. x17.

Fig.2: Morphotype complex *Lithocodium / Bacinella* as an important binding organism within the *Hippurites* framework and the forereef lagoonal zone. Locality: Lattenberg, near Bad Reichenhall. x80.

Fig.3: *Halimeda* sp. (and other Chorophythes) characterizing the backreef lagoonal zone Locality: Lattenberg, near Bad Reichenhall. x16.

Fig.4: Fragments of *Marinella lugeoni* PFENDER (a) and *Lithocodium* -- also coral encrustations (b) occur in the backreef lagoonal zone. Locality: Lattenberg, near Bad Reichenhall. x21.

Fig.5: *Sporolithon gosaviense* (ROTHPLETZ). The branching specimens of this coralline alga indicating the to reduced water energy of the backreef lagoonal environment. Locality: Lattenberg, near Bad Reichenhall. x21

A3