FACIES	24	1-24	Taf. 1-4	13 Abb.	--	ERLANGEN 1991

Paleoceanography and Rotational Block Faulting in the Jurassic Carbonate Series of the Chiemgau Alps (Bavaria)

Paläo-Ozeanographie und Kippschollentektonik in den jurassischen Karbonatabfolgen der Chiemgauer Alpen (Bayern)

Klas S. **Lackschewitz**, Uwe **Grützmacher** and Rüdiger **Henrich**, Kiel

KEYWORDS: ALPINE BASIN AND SWELL FACIES - PSEUDOPELOID FACIES - PALEOCEANOGRAPHY OF THE TETHYS - ROTATIONAL BLOCK FAULTING - NORTHERN CALCAREOUS ALPS -JURASSIC (MALM)

SUMMARY

The Jurassic carbonate series of the Lechtal and Allgäu Nappes in the central part of the Northern Calcareous Alps reflect formation of orogen-parallel structures with swells and basins. Regional facies patterns display the morphologies of the various depositional environments.

During the Middle Jurassic, an elongated swell evolved parallel to the overall structural strike in the central part of Lechtal Nappe, while in the southern part a basin started to subside. This configuration reflects the initial stage of rotational block faulting on the southern continental margin of the Tethys. Similar structural and facies settings were also established in the northern part of the Lechtal Nappe and in the southern Allgäu Nappe. Synsedimentary tectonics induced a variety of downslope sediment mass movements and increased facies differentiation on the slopes. In the upper section of the middle Jurassic sequences red nodular limestones with frequent intercalations of intraformational breccias and conglomerates indicate downslope sediment movements.

During the Oxfordian, the Tethyan-wide deposition of radiolarites also covered the basin in the southern Lechtal Nappe.

Contemporaneous deposition of pelagic radiolarian-bearing limestones dominated on the slope of the surrounding northern swell, while its peak was covered by a shallow water carbonate facies, e.g. a specific pseudopeloid and oolithic facies, which was also injected downslope into the pelagic facies.

The Oxfordian to Tithonian section reveals a characteristic pelagic carbonate facies succession, e.g. with Protoglobigerina facies at the base, followed by a *Saccocoma* facies and a calpionellids facies on top.

In the northern Lechtal Nappe and in the Allgäu Nappe various similar radiolarite basins with intersected swells were discovered.

1 INTRODUCTION

Seen from the view of a paleoceanographer the Jurassic is one of the most interesting periods in the Earth's history because of the evolution and radiation of modern calcareous plankton in the oceans. The equatorial circulation of the Tethyan ocean and the surrounding wide tropical shelves of Pangaea probably provided favorable conditions for this major step in plankton evolution. In addition, the paleogeographic situation provides one of the best documented examples for case studies on the interaction between synsedimentary tectonics of a young rifting ocean basin and pelagic sedimentation on surrounding tropical shelves. The purpose of this paper is to analyse the establishment of pelagic facies during the Jurassic and to evaluate the synsedimentary tectonics from detailed facies mapping and identification of tectonically induced sediment mass movements. These studies were carried out in parts of the Chiemgau Alps, where the Lechtal and Allgäu Nappes bear a differentiated pelagic calcareous and siliceous facies succession. The models presented in this article are based on field mapping and detailed facies studies on selected key locations carried out by a group of Master's candidates (Hebbeln, 1987; Grützmacher, 1988; Lackschewitz, 1987; Ruhland, 1987; Suhr, 1989). As part of previous work in the area the basic stratigraphic and tectonic patterns were recognized, while modern facies analyses were carried out only by Antoniadis(1975) and Diersche (1980).

Address of the authors: Dipl. Geol. K. S. Lackschewitz, Dipl. Geol. U. Grützmacher, Dr. R. Henrich, GEOMAR, Forschungszentrum für Marine Geowissenschaften, Wischhofstrasse 1-3, D-2300 Kiel

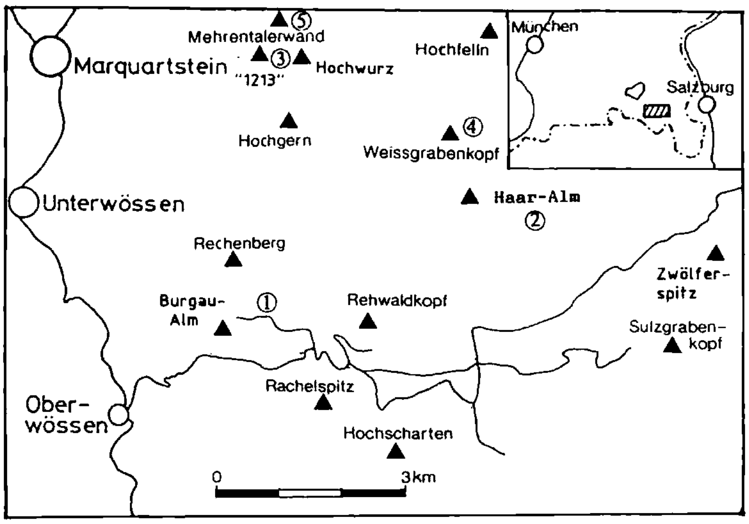


Fig. 1. Study area with the location of the profiles ; 1= Burgau-Alm syncline, 2= Haar-Alm region, 3= Hochwurz region, 4= Weißgrabenkopf region, 5= Mehrentaler Wand.

The basic geological maps of the studied area were compiled by DOBEN (1970) and GANSS (1967), based on various earlier investigations. DOBEN (1962) established the stratigraphic framework for the Jurassic/Cretaceous boundary based on Calpionellids successions. ANTONIADIS (1975) developed the Liassic stratigraphy in the area based on ammonites and provided a first sedimentological and facies concept for the red nodular Liassic limestone (Adnet Limestone). DIERSCHE (1980) conducted sedimentological studies in the investigated area and gave an overview on overall paleoceanographic and paleogeographic evolution during the Jurassic in the central part of the Northern Calcareous Alps. He specifically commented on the depositional aspects of pelagic carbonates and the radiolarites.

METHODS

Based on a distinction of facies belts in the field about 500 hand specimens were taken along profile sections and outcrops for the purpose of microfacies analysis. From each sample a polished slab was prepared and, depending on macroscopic complexity, one or more thin sections were made. Thin sections were investigated microscopically, applying the well-established methods of a classical microfacies analysis (FLÜGEL 1982) and diagenetic features were noted.

Two different treatments were used for the micropaleontological studies. Marly limestones were disintegrated in a hydrogen peroxid solution in order to isolate the benthic foraminifer associations. Subsequently the residue was sieved through a 63µm sieve. Radiolarian-bearing limestones were dissolved in an acetic acid solution. Radiolarian tests were picked out from the residue under a binocular, mounted on a SEM-carrier, spattered with coal and gold/palladium and investigated under the SEM.

Formation		Thickness	Environment	
			deposition area	characteristic deposits / features
upper Malm	Aptychen limestone	30m	basin	pelagic limestone-facies with calpionellids and a rich nannofossil flora
lower Malm	Radiolarite	10m	basin	basin deposits, predominantely radiolarite and radiolarian-rich pelagic carbonates
Dogger	Red nodular limestone	10m	basin	siliceous limestones; red nodular limestones with intraformational reworking, locally olistolith masses
	Siliceous limestone	140m		
lower Dogger to upper Lias	Basin marly limestones	10m	basin	marls and marly limestones / intensively bioturbated
Lias	Adnet beds	10m	swell and slope	Ammonitico rosso facies, crinoidal limestone and sponge spiculite-bearing limestone
Rhaetian	Rhaetian limestone	300m	shallow marine platform	cyclic, sub / peritidal deposits, e. g. loferites, oolites and tidal laminates
	Kössen beds	50m	shallow marine basin	dark, bituminous marls and marly limestones with a high clastic supply and coral mud mound reefs
Norian	Hauptdolomit	800m	dolomitic platform	wide extended dolomitic platform with humid tidal flats

Fig. 2. Upper Triassic and Jurassic sequence of the Rechenberg/Rehwaldkopf region (Lechtal nappe, southern sector). Sedimentary development during the Upper Triassic displays a dolomitic platform environment which is overlain by Rhaetian shallow water limestones. The depositional patterns of the Lias Adnet beds reveal neritic swell and slope environment, while the Upper Lias to Lower Dogger marly limestones reflect typical basin facies. The Dogger series in the basin are composed of siliceous limestones. Red nodular limestones in the Upper Dogger section reveal frequent intraformational reworking. The lower Malm is represented by radiolarites and radiolarian-rich limestone deposition in the basins. The radiolarites are overlain by a pelagic carbonate deposits, the Aptychen beds.

Formation		Thickness	Environment	
			deposition area	characteristic deposits / features
Malm	Aptychen limestone	3m	basin	pelagic limestone-facies with calpionellids and a rich nannofossil flora
	Red nodular limestone	30m	swell	red nodular pelagic carbonates with specific facies successions e. g. pseudopeloids, Protoglobigerina, Saccocoma and Calpionellids on a tectonically active swell
Dogger	Echinoderm-rich limestone	-100m	swell and slope	resedimented crinodial limestones facies with chert nodules and intraformational conglomerates
lower Dogger to upper Lias	Siliceous limestone	- 10m	basin	siliceous limestone with dark chert nodules
lower Lias	Basin marly limestone	130m	basin	marls and marly limestones with intensive bioturbation, intercalation of turbidite beds
Lias	Adnet beds	30m	swell and slope	red nodular neritic biomicrites and breccia beds
Rhaetian	Rhaetian limestone	-180m	shallow marine platform	cyclic tidal deposits with loferites, oolites and tidal laminates
	Kössen beds	-130m	shallow marine basin	shallow shelf basin with clastic supply, mud mounds and coquina tempestites
Norian	Hauptdolomit	-500m	dolomitic platform	wide extended dolomitic platform with humid tidal flats and stromatolites

Fig. 3. Upper Triassic and Jurassic sequence of the Hochgern/Weißgrabenkopf region (Lechtal nappe, northern sector). The Upper Triassic carbonate series reflect a widely extented carbonate platform with Hauptdolomit and Rhaetian limestones. Kössen beds record shelf basin facies. The Lias Adnet beds are comprise red nodular biomicrites which were formed in a neritic environment in the northern Haar-Alm region. At the same time, marly lithologies reveal a typical basin facies intercalated with turbidite beds in the Hochgern/Weissgrabenkopf region. During the Upper Lias to Lower Dogger chert nodules occur more frequently. In the Upper Dogger sections of resedimented crinoidal limestones with intraformational conglomerates indicate downslope transport. The Malm section displays red nodular limestone with characteristic pelagic facies successions, e.g. Protoglobigerina facies, *Saccocoma* facies and calpionellids facies, deposited on the slope of a swell. The top of the swell was covered by a pseudopeloid shallow water facies. Red nodular limestones are overlain by the nannoplankton-rich Biancone facies of the Aptychen beds.

2 REGIONAL SETTING AND STRATIGRAPHY

The geographic setting of the area investigated is shown in Fig. 1.

The Rechenberg-Hochgern-Weißgrabenkopf-Mehrentaler Wand region belongs to the Lechtal and Allgäu nappes. The stratigraphic sequence comprises the Upper Triassic to the Lower Cretaceous (Figs. 2-4).

The spatial distribution of facies and sediment thicknesses, as found in outcrops in the field, delineates compressional tectonic features and fold belts that have been created during the Alpine orogeny. The regional tectonic setting reveals a pile of three prominent nappes overthrusted on each other from South to North, with the southernmost Tyrolian nappe on top underlain by the northward following Lechtal Nappe and Allgäu Nappe.

Due to latter compressional tectonics the Tyrolian Nappe has overridden the underlying nappe pile in the central part of the Northern Calcareous Alps by a wide distance and is now exposed close to the northern rim of the Alps. The so formed Tyrolian arc is a major tectonic feature in the middle part of the Northern Calcareous Alps. Additionally, it is characterized by intensive wedging. The area studied is situated at the northwestern margin of the Tyrolian arc. The internal structure of the nappes reflects overall strike parallel fold belts that have been strongly affected by compressional tectonics; principally with better preserved northern flanks of anticlines and synclines and often tectonically intensively reduced southern flanks.

The sedimentary development of the Hochgern-Rechenberg-Weissgrabenkopf-Mehrentaler Wand region (Fig. 2-4) during the Upper Triassic is dominated by a dolomitic platform environment (Hauptdolomit) which is overlain by up to 300m of Rhaetian shallow water limestones and shelf basinal marls and limestones (Kössen beds). The Rhaetian limestones display typical shallow water platform facies, often with cyclic patterns of deposition, including loferites, tidal laminates, birdseye mudstones, biomicrites, oolithic facies and subtidal biogenic mudstones with a typical benthic foraminifera fauna dominated by *Triasina hantkeni* MAJZON.

The Kössen beds are formed by dark gray to black marls and limestones. Intercalations of mud mound reefs and coquina tempestites record shallow shelf basin environmental settings. Clastic supply, e.g. clay and subordinate quartz sand, was delivered onto the Rhaetian carbonate platform from a northern hinterland, e.g. the Vindelizian landmass.

Breccia beds at the base of the Liassic Adnet limestone indicate a first break-up of the Triassic carbonate platforms,

Formation		Thickness	Environment	
			deposition area	characteristic deposits / features
Malm	Aptychen limestone	- 20m	basin	pelagic limestone-facies with calpionellids and a rich nannofossil flora; locally dark chert nodules
	Red nodular limestone	-180m	swell	red nodular pelagic carbonates with specific facies successions e. g. pseudopeloids, Protoglobigerina, Saccocoma and Calpionellids on a tectonically active swell
Dogger	Echinoderm-rich limestone	60m	swell and slope	resedimented crinodial limestone facies
lower Dogger	Siliceous limestone	80m	basin	siliceous limestone with dark chert nodules and chert beds
Lias	Siliceous limestone	10m	basin	siliceous limestones in spiculites facies; intensively bioturbated
	Hierlatz-limestone	40m	swell and slope	crinoidal sparitic limestone, locally breccia beds
Rhaetian	Rhaetian limestone	-100m	shallow marine platform	cyclic tidal deposits with loferites, oolites and tidal laminates
	Kössen beds	10m	shallow marine basin	shallow shelf basin with clastic supply, mud mounds and coquina tempestites
Norian	Hauptdolomit	-250m	dolomitic platform	wide extended dolomitic platform with humid tidal flats and stromatolites

Fig. 4. Upper Triassic and Jurassic sequence of the Mehrentaler-Wand region (Allgäu nappe, southern sector).
The Upper Triasssic limestone succession consists of Hauptdolomit shallow water facies covered by shallow marine deposits of Rhaetian limestones. Liassic resedimented echinoderm-rich limestones (Hierlatz facies) reflect a swell and slope environment. Siliceous limestones record the transition to basin and slope environmental settings during the Upper Lias to Lower Dogger. During the Dogger, deposition of echinoderm-rich limestones give evidence of an uplift of a new swell. Red nodular limestones at the base of the Malmian limestone succession record swell and slope environmental settings. They comprise a pseudopeloid facies, Protoglobigerina facies, *Saccocoma* facies and calpionellids facies. The top of the Malmian succession is characterized by the Biancone facies of the Aptychen beds.

which was caused by initial rifting in the Tethyan Ocean. During this phase of rifting, the Upper Triassic platform was fragmented by synsedimentary block-faulting, which built up a complex pattern of submarine highs and basins (Lemoine & Trümpy 1987).

In addition to the tectonic movements, the Rhaetian topography on the shelf is redrawn in the depositional patterns of the Lias sediments. The red Lias limestones, which contain abundant echinoderms, generally form in a neritic environment. They comprise red nodular biomicrites (Adnet Limestone, Fig. 2 and 3), reddish crinoidal limestone (Hierlatz limestone, Fig. 4) and red sponge spicule-bearing biomicrites (Spiculites, Fig. 2) with occurrence of *Involutina liassica* (Jones) in all these facies. These red nodular and sponge spicule-bearing biomicrites often reveal hardgrounds, Fe/Mn-crusts and early cementation features. The nodular structure is predominantly a result of early diagenetic differential cementation, which in turn may be modified by later mechanical compaction and pressure solution processes (Mullins 1983, Bathurst 1987). The Lias basin facies, 'Fleckenmergel' series, is formed by marls and marly and partly siliceous limestones intercalated with calcareous turbidite beds (Pl. 1/6). In the area studied the Hochgern-Weißgrabenkopf profiles include an up to 150m thick 'Fleckenmergel' series (Fig. 3). Dark chert nodules are irregulary distributed in the limestone beds. The gray marly limestones frequently record intensive bioturbation with typical *Zoophycos-Chondrites-Planolites* ichnofacies. During the uppermost Lias to Lower Dogger (age assignment made by the benthic foraminifera assemblage; species list see page 8), chert nodules and spiculites occur more frequently, indicating habitats with laterally extended siliceous sponge communities growing on the slopes of rapidly subsiding Liassic basins.

Deposition of siliceous limestones continued in the entire area during the Lower to Upper Dogger as evidenced by the occurrence of *Lytoceras* cf. *rasile* Vacek, *Chondroceras* sp., *Skirroceras latidorsum* (Weisert) and *Otoites* sp. ex. aff. *contractus* (Sowerby) in the middle part of the siliceous limestone succession with a Bajocian age (Franz 1967). The lower part of the entire Lias and Dogger siliceous section comprises limestones of predominantly dark colour, e.g. dark gray to dark brownish gray, while the upper part reveals lighter colours with light brownish grey to whitish hues. In the Upper Dogger sections a pronounced regional facies differentiation has been recognized. The profiles from the northern region, i.e. Haaralm region (Fig. 6), show thick resedimented sparitic crinoidal limestone units which have been affected by various phases of silicification. Resedimentation phenomena include intraformational breccias and conglomerates as well as downslope transport and fragmentation of early dark gray chert nodules formed during the initial stages of diagenesis. During downslope transport of the echinoderm-rich sediments, broadly ex-

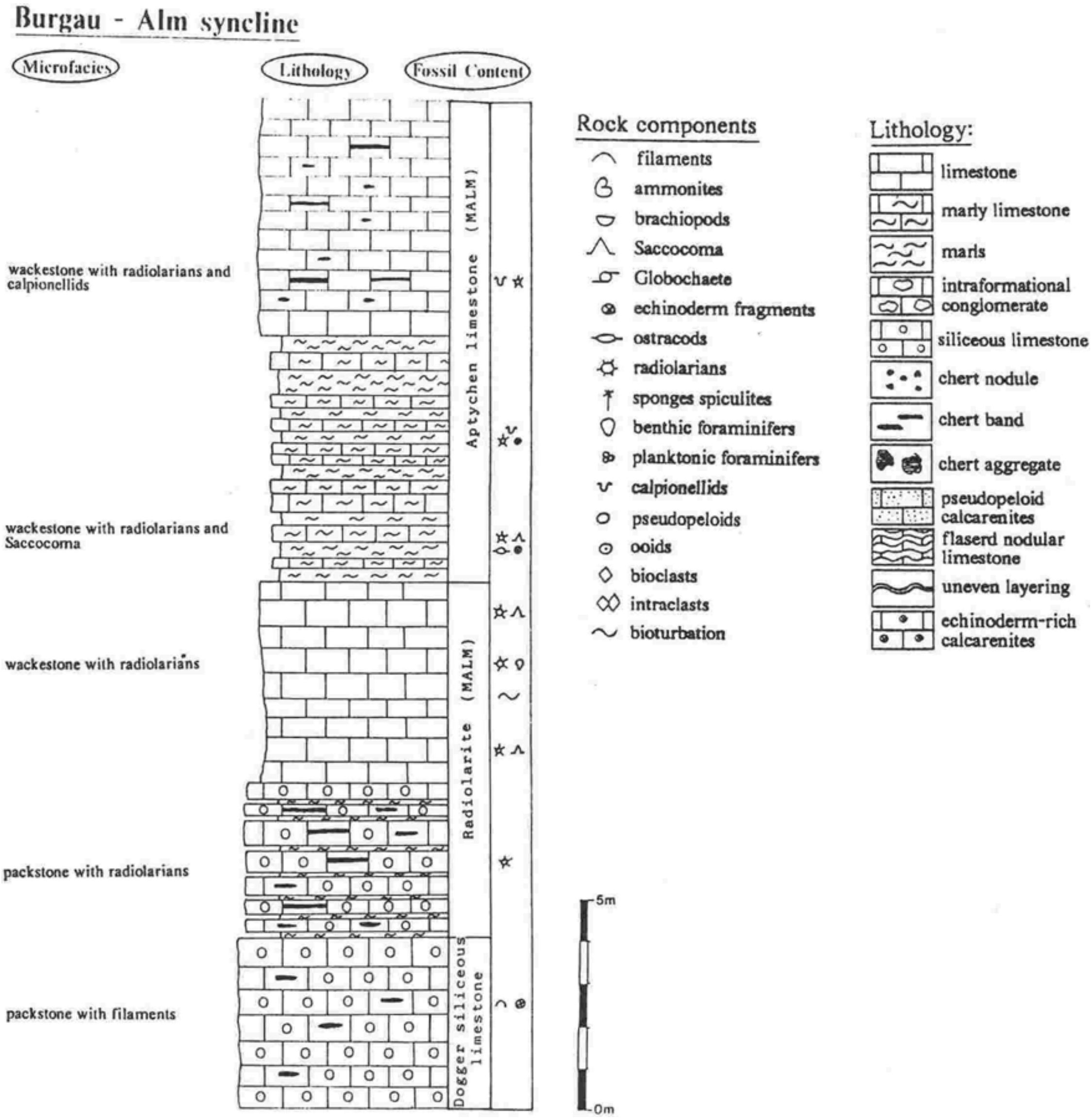


Fig. 5. Dogger and Malm series of the southern Lechtal Nappe (Burgau-Alm syncline): Basin facies with Dogger siliceous limestone followed by Oxfordian to Kimmeridgian radiolarite deposition. The upper part of the radiolarite consists of 5m thick radiolarian-rich limestones. An alternation of greenish marly limestones and marls, nannoplankton-rich Biancone limestones with typical black lenticular chert nodules comprises the Tithonian on top of the profile.

tended siliceous sponge habitats were incorporated into the mass flows.

The Upper Dogger age of the resedimented echinoderm-rich units is confirmed by a foraminiferal fauna dominated by *Protopeneroplis striata* Weynschenk (Steiger & Wurm 1980). In the southern region, i.e. Rechenberg, Rehwaldkopf, Zwölferspitz area, red nodular limestones cover brownish siliceous Middle to Upper Dogger limestone and are overlain by Oxfordian/Kimmeridgian radiolarite thus giving evidence of an Upper Dogger age. The red nodular limestones reveal frequent intraformational reworking and, at one locality in the Hochscharten region, an olistholith mass (Fig. 2). The red nodular and marly limestones show clear evidence of redeposition indicated by a difference in the fossil content and colour between intraclasts and the matrix. The olistholith mass consists of a Rhaetian limestone block several cubic meters in size with attached Kössen beds embedded in a reddish sedimentary melange of resedimented upper Dogger nodular limestones facies. The appearance of this olistholith mass close to the nappe boundary of the Tyrolian and Lechtal Nappes resulted in a very intensive later tectonic overprint of the sedimentary melange. A synsedimentary origin of the entire structure is evidenced by a similar matrix/clast relationship in the olistholith mass as described above for the Rechenberg-Rehwaldkopf-Zwölferspitz Dogger intraformational breccias.

The Oxfordian is represented by radiolarite and radiolarian-rich limestone deposition in the basins (Fig. 5), while the swells are covered with red nodular Protoglobigerina -bearing limestones (Fig. 6-9), including *Protopeneroblis striata* Weynschenk (Pl. 2/2). The lowest portion contains ammonites, notably *Euaspidoceras* cf. *tietzi* (Neumayr), a species characteristic of the lower Oxfordian (Doben 1970). The Kimmeridgian to Tithonian series in the basins are composed of marly reddish and greenish limestones and marls at the base and, on the top, of Biancone limestones

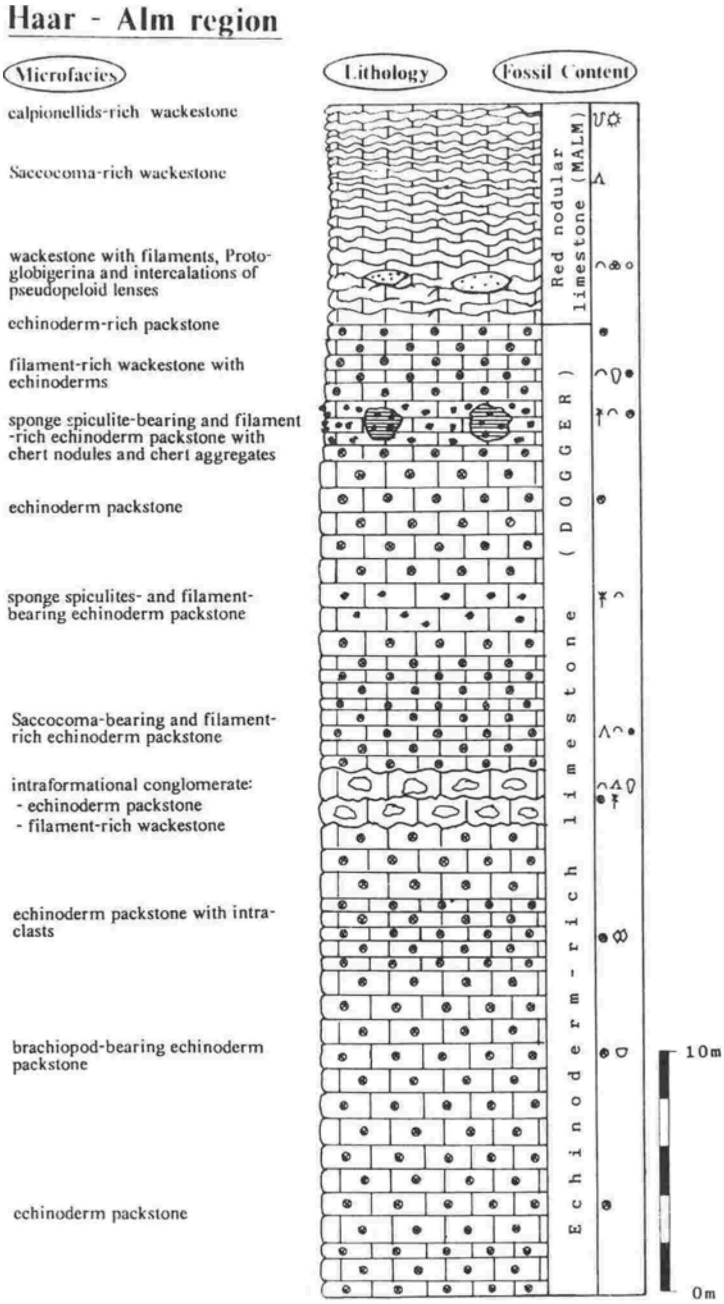


Fig. 6. Dogger and Malm series of the northern Lechtal Nappe (Haar-Alm-region): Swell and slope facies with Dogger echinoderm-rich limestone with frequent intercalations of intraformational breccias and chert aggregates. The upper part of the profile is comprised of red nodular limestones with a characteristic pelagic carbonate facies succession, e.g. Protoglobigerina facies at the base followed by a *Saccocoma* facies and calpionellids facies on top. In addition, this sequence contains intercalations of pseudopeloid lenses in the lower part of the section.

with typical black lenticular chert nodules (Fig. 5). Red nodular limestones in *Saccocoma* and calpionellids facies (Fig. 6-8) were contemporaneously deposited on the swells . In addition, the Oxford to Tithonian swell sequence contains intercalations and lenses of downslope injected sand sheets with a whitish pseudopeloid and oolithic facies (Fig. 6-9). The radiolarite shows a thickness of a few meters, whereas the red nodular limestone, reaches a maximium thickness of 100 m. The radiolarites were deposited close to the CCD (Garrison & Fischer 1969) and far below the compensation depth of aragonite. The evaluation of the bathymetry during radiolarite sedimentation is very difficult because the CCD has apparently fluctuated in time and space. In addition, the radiation of calcareous nannoplankton and planktonic foraminifers in mid- to late Jurassic time marked a significant change in the distribution of biogenic pelagic sediments. According to ammonite stratigraphy, the alpine radiolarites cover the Oxfordian and Lower Kimmeridgian (Diersche 1980), whereas the section in the southern Lechtal Nappe has been studied previously by Doben (1970), who dated the top of the radiolarites by the occurrence of *Cylindroteuthis obeliscus* (Phillips) and *Duvalia ensifer* (Oppel) to the transition of Kimmeridgian/Tithonian.

The red nodular limestones in Protoglobigerina, *Saccocoma* and calpionellids facies were deposited from the Oxfordian to the Upper Tithonian (Gall 1970). The radiolarites and the red nodular limestones are overlain by typical Biancone pelagic limestone facies, the Aptychen beds.

Based on calpionellids stratigraphy (Doben 1962), the Biancone facies of the Aptychen beds were deposited in the areas with a previous radiolarite sedimentation from the Upper Tithonian to the Jurassic/Cretaceous boundary, whereas the Aptychen beds which cover the red nodular limestones were formed in the uppermost part of Upper Tithonian (Doben 1970).

3 MICROFACIES OF STRATIGRAPHIC UNITS

3.1 Lias swell facies

Three different lithofacies types were deposited on swells during Lias time: a) red nodular biomicrites (Adnet Limestone), b) reddish crinoidal limestone (Hierlatz Limestone) and c) red siliceous spiculites (Spiculite Limestone); (Fig. 10).

3.1.1 Adnet limestone

Wackestones containing various amounts of echinoidal fragments, ammonites, belemnites, bivalves, gastropods, brachiopods, ostracods and benthic foraminifera are the most typical microfacies in Adnet limestone (Pl. 1/4). The foraminifera assemblage includes *Involutina liassica* (Jones), *Dentalina* sp., *Glomospira* sp., *Frondicularia* sp., *Nodosaria* sp., *Astacolus* sp. and *Ophtalmidium* sp..

Sedimentary structures include enrichment of fossil debris in lenses and pockets, Fe/Mn-encrustation, hardgrounds and scattered pebbly mudstones. Early intraclasts, e.g. semilithified to soft sediment clasts, were affected by mechanical deformation during downslope transport and were often later encrusted by Fe/Mn encrustations. The hardground formation and early diagenetic nodules represent the early

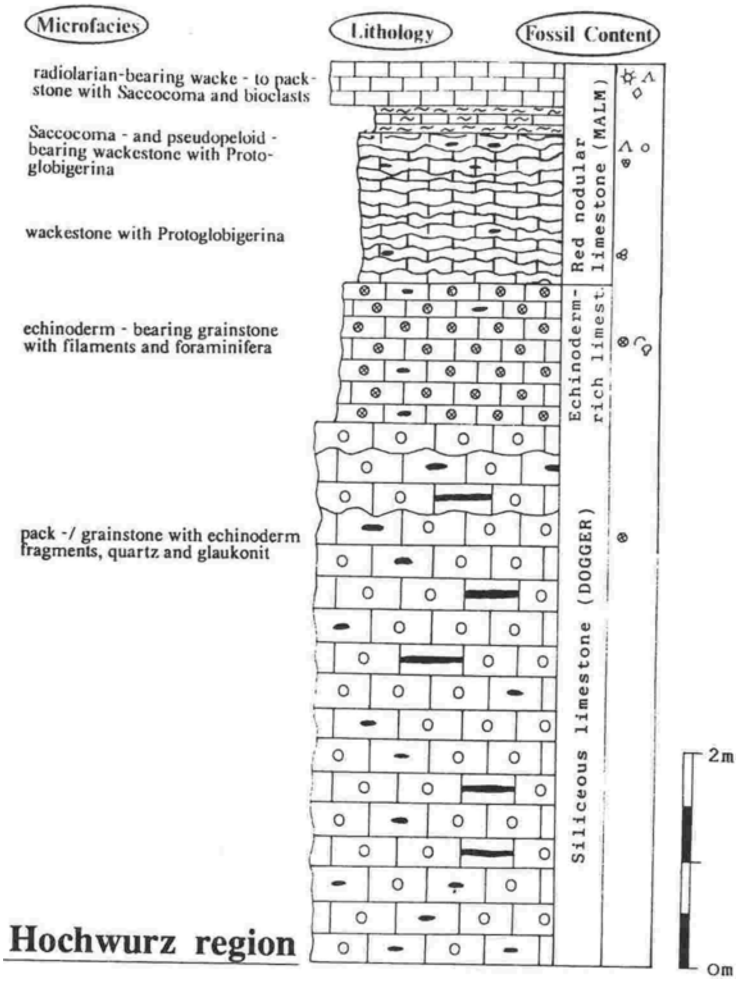


Fig. 7. Dogger and Malm series of the southern Allgäu Nappe (Hochwurz region): Basin facies with Dogger siliceous limestones dominate the lower part of the profile. Echinoderm-rich limestones were deposited during the Upper Dogger. The Malmian lithologies consists of red nodular limestones.

stages of diagenesis (Mullins 1983) and are a result of patchy cementation of the sediment by high-Mg calcite and aragonite cements (Scholle et al. 1983). Varying sedimentation rates and non-sedimentation followed by mechanical compaction lead to differential cementation (Bathurst 1987). The degree of winnowing by currents may have controlled the interstital porosity of sediment and, thus, the degree of submarine cementation. As result carbonate nodules may have developed during early submarine diagenesis. Additionally, pressure-dissolution played a roll late in the diagenetic history and produced dissolution seams and fitted fabric (Bathurst 1987). Hardground formation is favored by a long period of contact between sediment and seawater, indicating slow sediment accumulation frequently associated with bottom current activity. Biogenic debris, as well as intraclasts, are strongly affected by contemporaneous Fe/Mn encrustation and boring activity.

3.1.2 Hierlatz limestone

Hierlatz limestone consists of echinoderm debris with high abundances of crinoidal fragments and various amounts of brachiopods, ostracods, gastropods and benthic foraminifera (*Lenticulina* sp., *Frondicularia* sp., *Nodosaria* sp.). The matrix content is generally low and intensive boring takes place. Horizontal stratification and occassionally graded bedding indicate current activity (Schott, 1984). But it has to be stressed that the appearance of these sedimentary features can occur even at very low current velocities due to the highly porous stereom structure of the echinoderm debris. A common diagenetic phenomenon is the precipitation of syntaxial 'rim cement' around echinoderm remains. Syntaxial cements fill up the intraskeletal lattices (Pl. 1/2).

3.1.3 Spiculites

The spiculites and sponge spicule-bearing limestones consists of wackestones to packstones with high abundances of sponge spicules (Pl. 1/1) and admixtures of echinoderm fragments, benthic foraminifers, ostracods and brachiopods. Weak bottom current activity may be indicated by a parallel long axis orientation of the sponge spicules.

Siliceous microfossils were partly dissolved during early diagenesis and silica was repreciptated as red chert nodules. In general, the chert nodules are formed by microquartz or chalcedony. Chalcedony appears in thin-section as a sheal of length-fast fibres (Pl. 1/5). The botryoidal form with radiation sphere bundles indicates initial precipitation of Opal-CT which was later converted to chalcedony (Keene 1983).

Liassic swell environment

The geometry and temporal relationship of the Lias microfacies succession (Fig. 10) reveals neritic swell and slope environments that were swept by variable bottom current activities. The bottom currents also provide favorable conditions for lithification, specifically for hardground formation on the swell tops and slopes that were covered with condensed nodular limestones of Adnet facies. Hardgrounds were colonized by encrusting foraminifera and crinoids, intensely bored by various organisms and precipitated with various phases of Fe/Mn encrustation. A rich benthic fauna with bivalves, gastropods, brachiopods and benthic foraminifera enhabitated these hardgrounds. On the slope of the swells, rich sponge communities attributed to spiculite facies. A swell position of these highly siliceous limestones is evidenced by lateral facies transitions to the resedimented echinoderm-rich limestones and to condensed biomicrites of Adnet type as their basement. Downslope sediment transport frequently gave rise to the formation of pebbly mudstones, which were injected into the Fleckenmergel basin facies.

3.2 Lias basin facies

3.2.1 Basin marly limestone

Wackestones with variable amounts of calcite-replaced

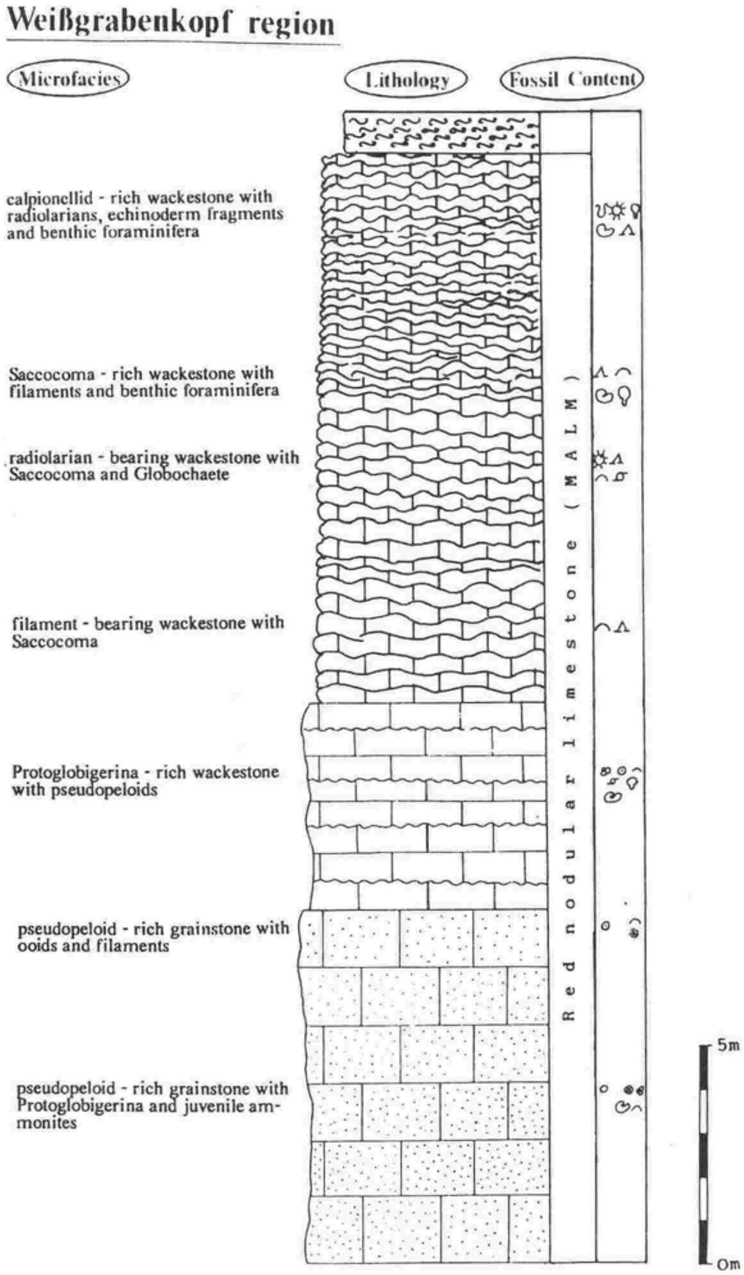


Fig. 8. Facies development in the Malmian red nodular limestone (northernmost Lechtal Nappe, Weißgrabenkopf): Environmental succession on a subsiding swell with downslope injected shallow water pseudopeloid grainflows followed by a characteristic pelagic carbonate series with Protoglobigerina facies, *Saccocoma* facies and calpionellids facies. The top of the profile is covered by the Cretaceous Neocom Aptychen marly limestones.

sponge spicules, filaments (*Bositra* valves), foraminifera, ostracods and echinoderm are the most common microfacies types in the marl series. A foraminifera assemblage from the uppermost marly limestone series includes *Ammodiscus* sp., *Astacolus* sp., *Dentalina varians* TERQUEM, *Dentalina commininis* D'ORBIGNY, *Dentalina tenustriata* TERQUEM, *Citharina* sp., *Cornuspira orbicula* (TERQUEM & BERTHOLET), *Lingulina* aff. *tenera* BORNEMANN, *Proteonina* aff. *ampullacea* (BORNEMANN) corresponding to the Upper Lias to the Lower Dogger. Sedimentary structures include thin intercalations of weakly graded and laminated echinoderm debris, turbidites and a set of bioturbation features. The turbidite sequences are characterized by a sharp contact at the base, a graded main phase with mudclasts of up to 4mm diameter in the upper part and a fine lamination on the top (Pl. 1/6). Their main detrital components are skeletal debris (e.g. filaments, sponge spicules and radiolarians) from nearby submarine highs. Bioturbation features reveal the typical bathyal set of the *Zoophycos-Chondrites-Planolites* ichnofacies (Pl. 1/7). Non-carbonate mineralogy of the basin marls displays minor amounts of quartz and mica; the dominant clay minerals are illite, chlorite and smektite. The grayish colour of the basin marly limestone is due to high organic carbon contents and pyrite. Pyrite is formed as a result of bacterial reduction of sulphate in porewaters by anerobic bacteria as they degrade organic matter (THOMSEN & VORREN 1984). Hence, pyrite is often concentrated in organic-rich microenvironments within sediments (HUDSON 1982). Scanning-electron microscope (SEM) investigations revealed the occurence of two shapes of pyrite, octrahedral spherules and framboids of pyrite (Pl. 1/3).

Environmental interpretation

The marly sucession reveals a typical basin facies (Fig. 10). Sponge populations at the slopes and within the basin contributed siliceous particles to the sediment locally. Turbidites transported muds rich in biogenic debris and arenites into the basin. This and layers enriched with echinoderm debris indicate downslope injections of biodetrital components from nearby swells. The *Zoophycos-Chondrites-Planolites* ichnofacies indicates typical bathyal conditions with water depths below the lower storm wave base, and the rich benthic soft bottom fauna reveals oxygenated bottom water conditions. Input of sediment was probably rather high, as is evidenced by overall high sedimentation rates and high organic carbon contents introduced into the sediments, inducing wide spread sulphate reduction diagenesis. The rhythmic alteration of limestones and marls seems to be caused by episodic pulses of terrigenous supply (e.g. clay and minor amounts of quartz sand) rather than by dissolution cycles. The large amounts of clay minerals and rare quartz grains in the marls indicate an episodically high input of clastic terrigenous weathering products into a relatively narrow basin. During advanced opening the basin became too wide to allow large amounts of weathering products to reach its central part as described for the depositional history of the North Atlantic Ocean by EHRMANN & THIEDE (1986).

Further evidence for this interpretation is the large thickness of Liassic Allgäu series (up to 1300m) in the western part of the Northern Calcareous Alps (JAKOBSHAGEN 1965), where the basin was thought to have grown narrower and to transit along a transform fault into the North Atlantic rift system (LAUBSCHER & BERNOULLI 1982).

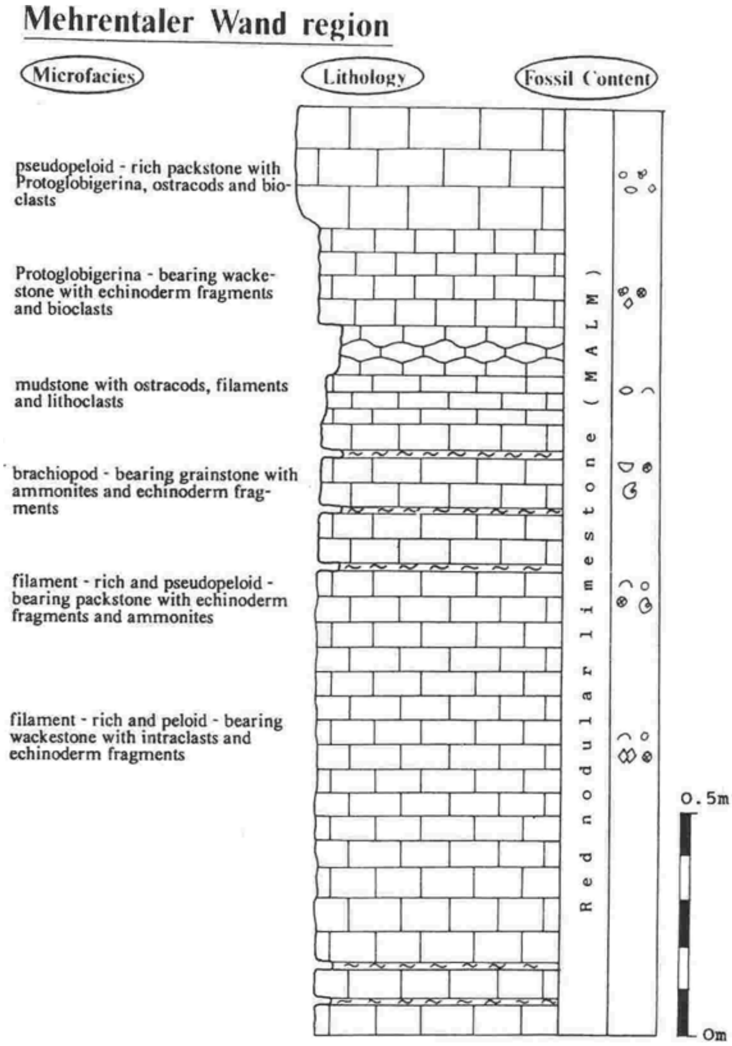


Fig. 9. Malmian red nodular limestone facies development (southern Allgäu Nappe, Mehrentaler Wand): Swell and slope environment is represented by red nodular limestones. The lower part of the red nodular limestone succession is dominated by pseudopeloid-bearing filament facies while the upper part reflects Protoglobigerina facies followed by the pseudopeloid facies.

3.3 Dogger facies

3.3.1 Siliceous limestone

The Liassic basin marly limestones gradually pass into a limestone series richer in chert, the siliceous limestones. The wackestones/packstones contain abundant sponge spicules (Pl. 2/1), filaments, rare benthic foraminifera and ostracods, as well as minor amounts of radiolarians, *Saccocoma* and echinoderm fragments. The siliceous microfossils are generally calcite-replaced. The matrix is sometimes silicified. The limestones commonly show darker infills caused by a high bioturbation rate in a light-brownish matrix. In many cases a high bioturbation activity is indicated by well-developed burrows (Pl. 1/8). Occasionally, layers enriched with filaments (Pl. 1/10) and echinoderm debris may point to slightly elevated bottom current velocities.

Environmental interpretation

The Dogger siliceous limestone reflects intensive development of sponge communities in the basin and on its slopes (Fig. 11). This indicates a shift in sediment supply to the basin with a decrease in terrigenous input and the establishment of more local biogenic sediment sources, e.g. mainly biogenic opal and filaments. The sedimentation rate decreases consequently and the supply of resuspended organic matter to the seafloor is reduced. The bottom waters were fully oxygenated (as evidenced by a rich benthic fauna).

3.3.2 Echinoderm-rich limestone

The most common components of the echinoderm packstones/grainstones are crinoid fragments (Pl. 2/3). Echinoid spines (*Cidaris*), holothurian sclerites, ostracods, fenestrate bryozoans, brachiopods (*Rhynchonellidae* sp. and Terebratulidae sp.), belemnites, molluscan shells (*Pecten* sp.) and benthic foraminifera (*Lenticulina* sp., *Frondicularia* sp., *Protopeneroblis striata* WEYNSCHENK) also occur. In the silicified sections enrichments of filaments and sponge spicules can be identified, the latter giving evidence of in place mobilisation and reprecipitation of silica. Rim cements around particles document early diagenetic cementation. Important information on sedimentation processes can be gained from intercalations of intraformational conglomerate and breccia beds. The intraformational conglomerates consist dominantly of light-brownish clasts (Pl. 1/11) with two characteristic microfacies types:

a. packstones composed of echinoderm debris
b. filament-rich wackestones

The matrix is micritic with abundant criniodal sceletal debris.

The breccias in the upper part of the echinoderm-rich limestone reveal very poor sorting mixtures of various lithologies. Intraclasts are predominantly angular, and occasionally subrounded with diameters of up to 10cm. The matrix consists mostly of sparite and is occasionally silicified. The lithoclasts are composed of silicified echinoderm debris and spicule-bearing wackestones.

Environmental interpretation

The echinoderm-rich limestone facies patterns clearly reflect a tectonically induced rearrangement of the basins and swells in the central Lechtal Nappe (Fig. 11), with a differentiation of the intrabasinal topography. An uplift of a huge swell in the central Lechtal Nappe including parts of the former northern basin (Fig. 10) induced by synsedimentary tectonics, established the morphologic framework for the deposition of the echinoderm-rich limestone (Fig. 11). Indicators for these processes are resedimentation phenomena observed in the echinoderm-rich limestones with intraformational brecciation of early chert nodules and downslope mass movements incoporating huge sponge communities, the latter were finally remobilized in place to form cubic meter sized brown chert aggregates (Fig. 6). The new slope

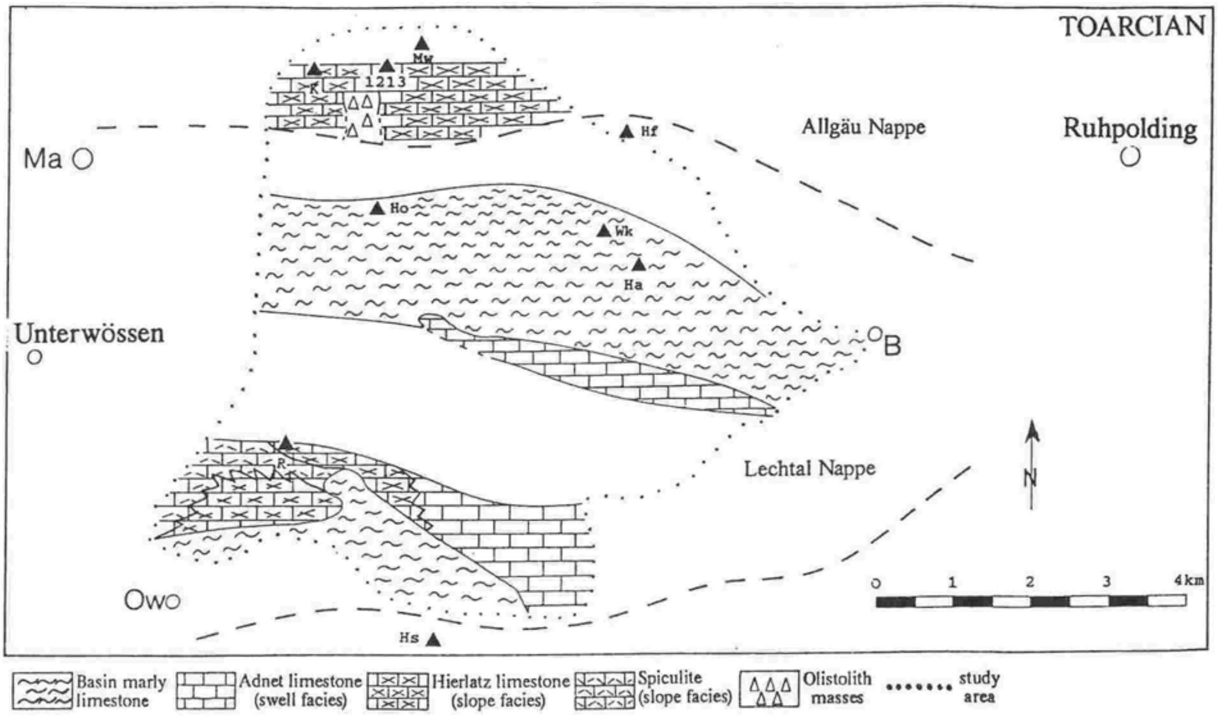


Fig. 10. Facies map of Upper Liassic basin and swell facies (Lechtal Nappe and southern Allgäu Nappe).
During the Toarcian, a southern basin with marly limestones and an adjacent swell covered with condensed nodular limestones of Adnet facies is seen in the southern and middle Lechtal Nappe. Towards the west this swell seems to slope down as evidenced by a spiculite facies and resedimented echinoderm-rich Hierlatz limestones. Northward the swell transits into a basin with marly limestone deposition. Further northward across the nappe boundary into the Allgäu Nappe, a second swell is exposed.
(Ma= Marquartstein, Uw= Unterwössen, Ow= Oberwössen, B= Brand, Ru= Ruhpolding; Ha= Haar-Alm, Hf= Hochfelln, Ho= Hochgern, Hs= Hochscharten, K= Kobelwand, Mw= Mehrentaler Wand, R= Rechenberg, Wk= Weißgrabenkopf)
Facies patterns are displayed in the present-day tectonic constellation.

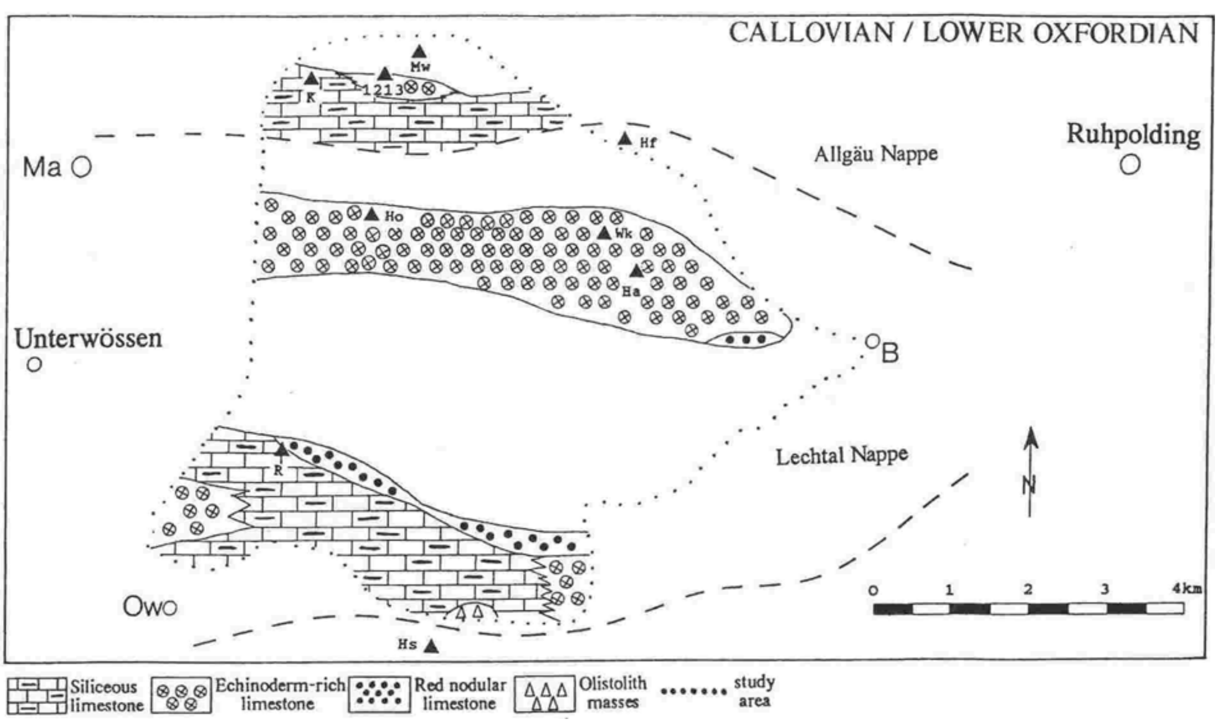


Fig. 11. Facies map of Upper Dogger to Lower Malm basin and swell facies (Lechtal Nappe and southern Allgäu Nappe).
The Callovian/Lower Oxfordian configuration shows a broad swell covered with thick echinoderm-rich limestone units in the central Lechtal Nappe. Red nodular limestone deposited on the swellslope at its southeastern margin and in the southern Lechtal Nappe bear evidence of downslope mass movements (e.g. intraformational reworking). South and north of the swell siliceous limestones were infilled into basins. Furthermore, the southern basin shows outcrops of echinoderm-rich limestone facies at the western and eastern boundary of the area investigated. This may indicate downslope injections of echinoderm-rich sediments from nearby swells. Intensive downslope mass wasting is documented by an olistholith mass of siliceous limestones in the southern Lechtal Nappe. (for abbreviations see Fig.10)

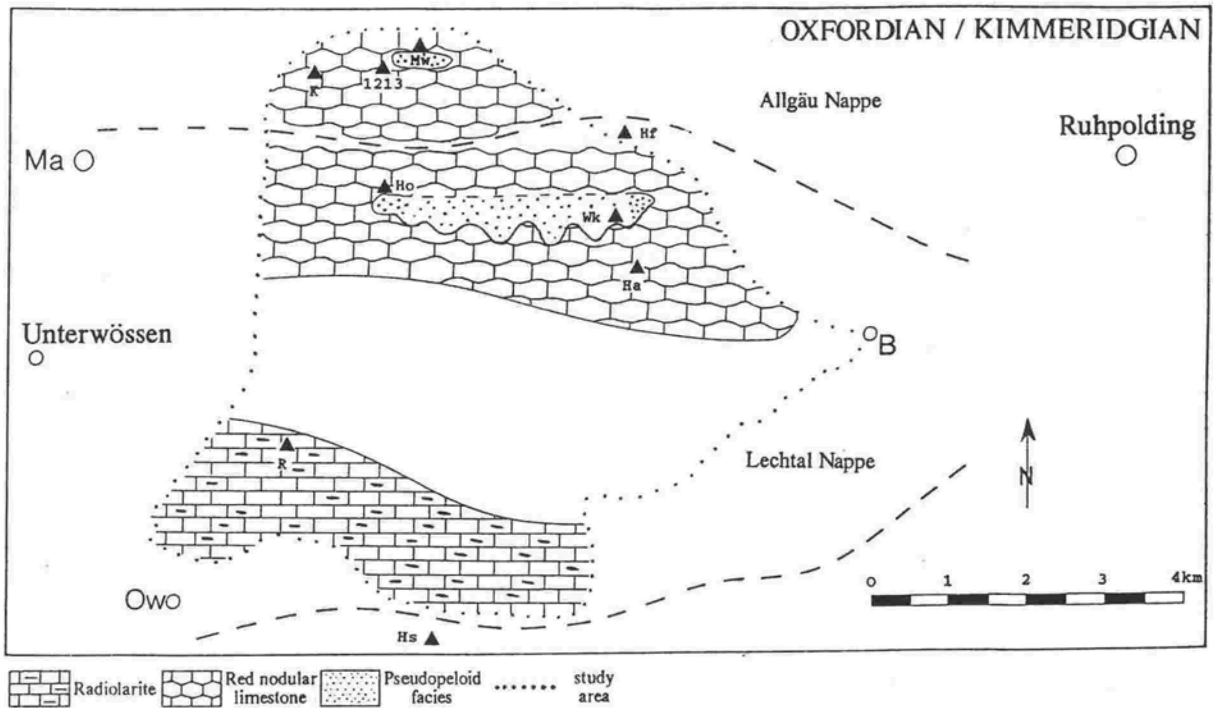


Fig. 12. Facies map of Lower to Middle Malm basin and swell facies (Lechtal Nappe and southern Allgäu Nappe.
During the Oxfordian/Kimmeridgian radiolarites covered the basin in the southern Lechtal Nappe while the swells in the northern Lechtal Nappe and southern Allgäu Nappe display deposition of pelagic red nodular limestones. On the tops of the swells a shallow water pseudopeloid facies was formed and injected downslope. (for abbreviations see Fig.10)

was intensively colonized by crinoids, echinoids and siliceous sponges.

3.3.3 Red nodular limestone

Nodules and matrix contain different amounts of fossil debris. In general, the matrix is always enriched by fine-grained echinoderm detritus compared with the nodules . In addition, the micritic groundmass of the nodules contains abundant filaments and sponge spicules, which are not found in the matrix between the nodules. In some instances echinoderm rich intraclasts were found. The matrix often contains detrital quartz, and biogenic admixtures consist of filaments, radiolarians, *Saccocoma*, ostracods and benthic foraminifers (e.g. *Glomospira* sp.). According to the totally different composition of the matrix and the nodules, intraformational redeposition of different source sediments is clearly indicated. The red nodular limestones (Pl. 1/9) reflect intensive pressure solution processes with frequent stylolitisation. Stylolites cut the matrix and the nodules in the same way, thus affirming that a late diagenetic pressure solution must have taken place after deposition of the nodules.

Environmental interpretation

The Dogger red nodular limestones clearly show evidence for intraformational reworking of various calcareous and siliceous basin facies. The biogenic constituents (e.g. filaments and calcareous nannoplankton) were mainly contributed from these pelagic realms with an admixture of benthic organisms predominantly sponges, crinoids and echinoids. Echinoderm-rich intraclasts document the interfingering of echinoderm-rich limestone with the red nodular limestones. The rather low thickness of the entire unit and the character of sediment mass relocation (pebbly mudstones, debris flows), partly winnowed by current reworking, suggest the development of local deeper swell areas. Their sediment cover became instable, possibly because of synsedimentary tectonic activity, and was transported down slope into deeper parts of the basin.

3.4 Malm facies

3.4.1 Radiolarite

Fig. 5 shows a general sucession of radiolarites and radiolarian-bearing pelagic carbonates. Typical radiolarites consist of quartz-filled radiolarian skeletons in a micritic or silicified matrix (Pl. 3/7). Most radiolarians are replaced by spherulitic chalcedony, but some are preserved as microcrystalline quartz or calcite. The radiolarian assemblages indicate a Callovian to Berriasian age (Pl. 4/1-18). The radiolarites contain minor amounts of benthic foraminifers (*Lenticulina* sp.), *Saccocoma* , sponge spicules, echinoderm fragments and mollusc shells. Sedimentary structures include parallel lamination caused by enrichment of radiolarian tests along discrete levels. In most instances opal has been replaced by quartz, calcite and hematite. The clay-mineral assemblage displays illite and illite/chlorite mixed-layers, an alteration product of volcanic ash (Diersche 1980). SEM investigations record coccoliths in a fine grained carbonate matrix with varied stages of recrystallization (Pl. 3/8). Flaser structures are a result of pressure solution during late diagenesis.

Environmental interpretation

During the Oxfordian the Tethyian widespread, nearly uniform deposition of radiolarites and radiolarian-bearing pelagic carbonates indicates a predominance of pelagic conditions. Episodic ash input (Diersche 1980) documents increased volcanic activity which can be related to increased opening of the Penninic Ocean. In addition, a transgression and a deepening of the basins at the continental margin of the Adriatic plate can be observed. The problem of establishing reliable water depth criteria during that time remains an open and controversial question. Furthermore, the actual depth of the CCD cannot be estimated because the Oxfordian is a period with a worldwide shift in plankton communities. However, the very low sedimentation rates of the radiolarites, in the range of a few mm/ky, are of the same dimension as the values observed for radiolarian-rich muds in the recent subtropical Pacific. Much has been speculated about the Tethyian wide radiolarite deposition. A high productivity belt in the tropical Tethyian Ocean (Weissert 1979) driven by upwelling in the equatorial divergence zone was proposed to be the major cause. But following the principle of actualism and considering the low linear sedimentation rates (LSR), the radiolarites could also be understood as deposits of a silica-rich estuarine ocean basin (Berger 1970, 1974). Enrichment of radiolarian tests along discrete levels parallel to the stratification planes may indicate bottom current activities that outline the pathways of contour currents in the Radiolarite basins.

3.4.2 Malmian red nodular limestone

Four microfacies types are found in the nodular flaser-structured limestones of the Oxfordian to Tithonian, which have been described in the older literature as the 'Ruhpoldinger Marmor'. These are the Protoglobigerina facies, the *Saccocoma* facies, the calpionellids facies and the 'pseudopeloid facies'.

The following discription of the microfacies sucessions in the Malmian red nodular limestone is arranged in its stratigraphic context (Fig. 8 and 9), beginning with the oldest facies.

Protoglobigerina facies

This facies forms wackestones with Protoglobigerina (partly broken tests), radiolaria (spumellaria) and fossilated zoospores of the planktonic chlorophyta *Globochaete alpina* Lombard. Protoglobigerina is represented by *Globuligerina* Bignot & Guyader and *Conoglobigerina* Morozova (Grigelis & Gorbatchik 1980). Tests are often filled with brown micrite (Pl. 3/ 6). Biogenic admixtures consist of ostracods, echinoderm debris, bivalve fragments and ammonites. In a section several meters high at the Mehrenthaler Wand, all these biogenic components have been strongly enriched in cross-bedded biogenic packstones and grainstones (Fig. 9). Pseudopeloids are very rarely observed in thin-sections. Since the aragonitic shells of juvenile ammonites are well preserved in this facies type, one can imply that these sediments were deposited above the ACD. The interpretation of this facies involves pelagic deposition over submarine swell and its slopes (Elmi 1990).

Pseudopeloid facies

This facies is comprised of grainstones (Fig. 8) and packstones (Fig. 9), with a predominance of pseudopeloids of 100-300 μm diameter. Sometimes the nucleus of the dark pseudopeloids show biogenic components such as Protoglobigerina (Pl. 2/4), filaments, echinoderm fragments (Pl. 2/5) and nannofossils (Pl. 2/7). In addition, ooids with radial structures occur, showing all stages of transition into the micritized pseudopeloids (Pl. 2/6). Bathurst (1971) has described peloids which derive from micritized bioclasts as bahamite peloids. In comparison with this, the presence of ooids with radial structures in the peloidal sediments from the Mehrentaler Wand and Weißgrabenkopf region indicates that they stem from micritized ooids. Similar ooids have been studied by Jenkyns (1972), who found pelagic nannofossils included in some of the ooids. Jenkyns (1972) considered these ooids to be analogous to micro-oncolites, growing through algal accretion, and suggested that theyformed somewhere within the euphotic zone. The term 'pelletooids' has been used to describe limestones with peloids which originate by recrystallization of bioclasts and ooids (Blatt et al. 1972). But pellets have been interpreted as excrements of sediment and plankton feeders (Flügel 1982), so the authors have proposed the name 'pseudopeloid' for limestone particles which represent micritized grains such as ooids.

Typical pelagic faunal elements such as Protoglobigerina in the nucleus of the ooids (Pl. 2/4) show that the submarine swells were still influenced by open marine water circulation. Most of the ooids have been micritized to pseudopeloids. Depositional features display graded bedding (Pl. 3/2), cross bedding, intraformational reworking (Pl. 2/9) and lense shaped sediment bodies composed of coarser peloids. These peloidal sediments represent a microfacies that is characterized by mass movements. The submarine pseudopeloid-sands were transported downslope and redeposited on other parts of the swell itself. In outcrops and hand specimens, lens-shaped pseudopeloid layers are intercalated in red nodular wackestones of calpionellids and Protoglobigerina facies (Pl. 3/1). It is thus obvious that the pseudopeloid grainstones form sand sheets that have been injected downslope into pelagic wackestones.

Saccocoma facies

The *Saccocoma* facies is symptomatic of a high number of free-swimming planktonic crinoids. About 80% of the bioclasts consist of skeletal elements of the species *Saccocoma alpina* Lombard (Pl. 3/5). Filaments, shell fragments, calcified and/or micritized radiolarians, *Globochaete*, ammonites, benthic foraminifera and ostracods are also found in the thin-sections.

Calpionellids facies

The upper part of the Malm red nodular limestone

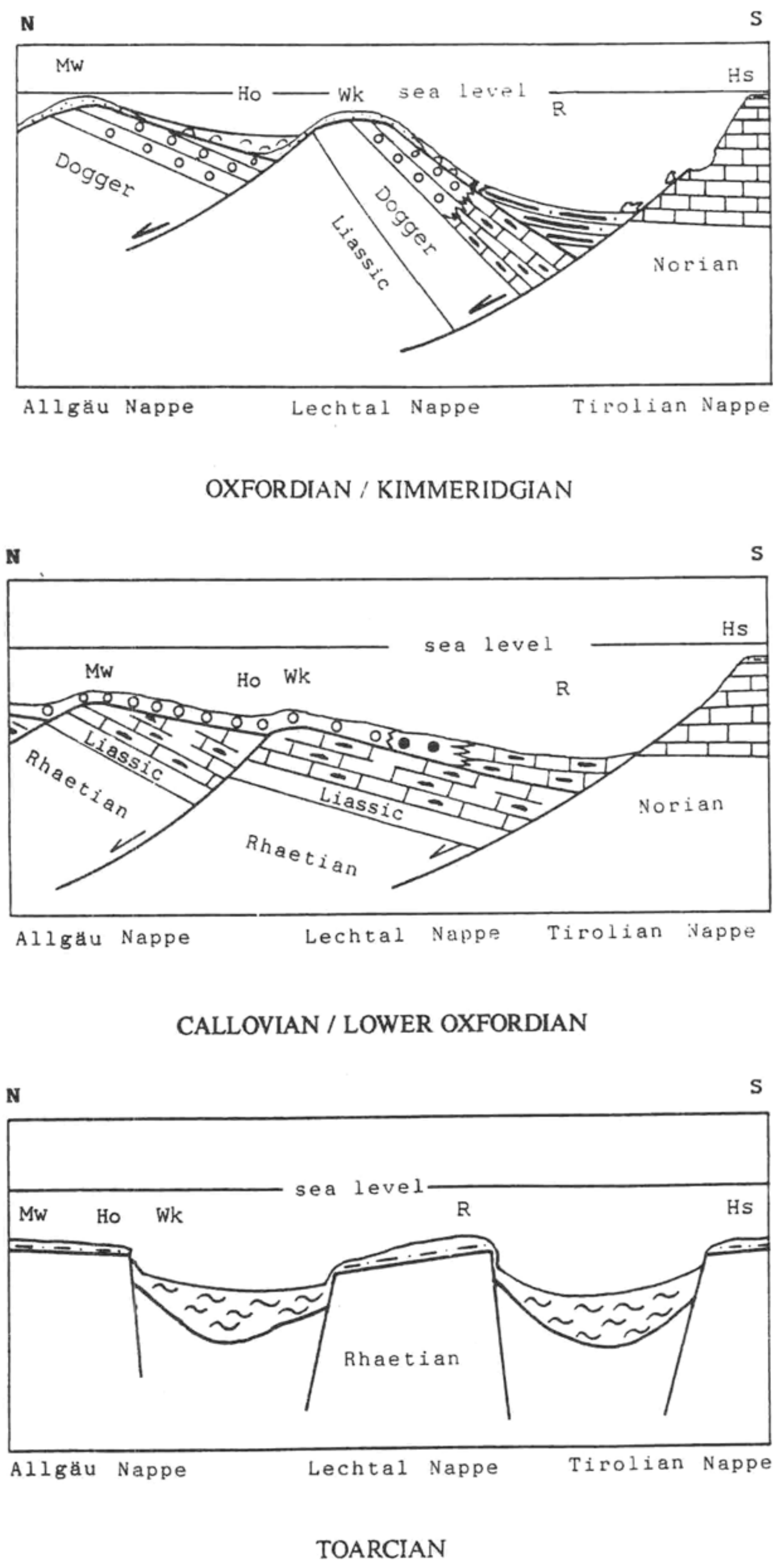
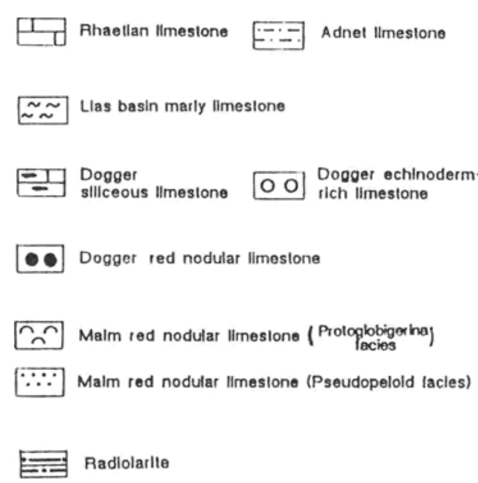


Fig. 13. Schematic model of synsedimentary rotational block faulting on the southern continental margin of the Tethys as deduced from Jurassic facies configurations in the Lechtal and Allgäu Nappes. (Hs= Hochscharten, R= Rechenberg, Wk= Weißgrabenkopf, Ho= Hochgern, Mw= Mehrentalerwand)

This paleoceanographic configuration from the Toarcian depicts Adnet beds on swells and marly limestones in the basins. The submarine relief results from fragmentation and differential subsidence of the Rhaetian platform and Kössen beds. During the Dogger, rotational block faulting caused a step by step northward breakdown of the sedimentary sections on the Adriatic plate at the southern continental margin of the Tethys. The Callovian/Lower Oxfordian situation shows a southward dipping slope covered by echinoderm-rich limestones bearing strong evidence of downslope mass wasting. Furthermore, red nodular limestones deposited on deeper sectors of the slope also contain intraformationally reworked breccia and conglomerate beds. Southward, the red nodular limestones transit into siliceous basinal limestones. Subsequent progressive uplift of the swell during the Upper Oxfordian and the Kimmeridgian initiated the formation of a shallow water pseudopeloid facies on the swell top, which was also injected downslope into the pelagic red nodular carbonates on deeper parts of the slope.



reveals a predominance of calpionellids (Fig. 8). In a mudstone to wackestone fabric, calpionellids that belong to the group of the tintinnids, dominate the bioclastic contents with their calcified test. Additionally, ammonites (often juvenile forms), aptycha, fish-teeth, ostracods, filaments, fragments of *Saccocoma*, calcified radiolaria and forminifera are found. Intraformational redeposition is evidenced by intraclasts (Pl. 3/3) of the same lithology but with a different hue and microfossil density (Pl. 3/4).

3.4.3 Aptychen limestone

The typical Bianconne facies consistes of pelagic wackestones with a predominance of calpionellids with abundant coccoliths in the fine grained matrix. In the basal part of the sections these wackestones also bear a rich radiolarian fauna. In addition, enrichment of *Saccocoma* is observed at various horizons along discrete levels parallel to overall stratification. In the central part of the beds lenticular black chert nodules and layers are often observed.

Environmental interpretation

The Aptychen limestone documents one of the most prominent shifts in the evolution of the modern plankton ecosystems. It marks the first time at which extensive pelagic carbonates were deposited in the Tethyian Ocean. This gave rise to a drop of the CCD with deposition of pelagic calcareous sediments over a very wide water depth range.

4 PALEOCEANOGRAPHIC AND TECTONIC MODEL

Various paleogeographic models of the Jurassic series have been presented in the past, stressing the importance of synsedimentary graben tectonics during early phases of rifting in the Tethyian Ocean (LEMOINE & TRÜMPY 1987, BICE & STEWART 1990, ELMI 1990). Evidence for this is provided by synsedimentary tectonic features, e.g. deep-reaching Neptunian dykes and block faulting of the Triassic platforms (ELMI 1990, KÄLIN & TRÜMPY 1977), as well as by extensive mass movements on the evolving slopes (BERNOULLI & JENKYNS 1970, SCHLAGER & SCHLAGER 1974).

Facies patterns of the Jurassic series from the Chiemgau Alps suggest a modified tectonic setting, e.g. synsedimentary rotational block faulting on the southern continental margin of the Tethys Ocean, similar to the model described by EBERLI (1988). The early evolution of this tectonic setting can be studied in the facies development of the Lias and Dogger series, while the Malm depositional reconstructions reflect the final stage of rotational block faulting. Although we have no direct observations on the fault scarps, most probably because of a intensive later compressional tectonic overprint, we have strong evidence for such synsedimentary tectonics from regional facies relationships.

The close vicinity and interfingering of far offshore shallow water carbonate facies (e.g. pseudopeloid and oolithic facies) with the pelagic muds and oozes reflects large topographic gradients on asymmetric swells. From south to north in the Lechtal- and Allgäu Nappes, the swell top facies depicts progressively deeper environments based on a missing of pseudopeloid facies in the northern Allgäu Nappe, as verified by additional field mappings. This provides evidence for a step by step northward breakdown at the southern continental margin of the Tethys Ocean. In addition, the slopes of the swells are commonly characterized by intraformational reworking and downslope mass movements. Fig. 13 summarizes the model of synsedimentary rotational block faulting deduced from facies settings in the area investigated.

The Lias transgression flooded the partly emerged Triassic platforms and caused a general deepening. Subaerial exposure is indicated by erosional structures on the Upper Rhaetian reefs (SCHÄFER 1979). Initially, deposition of red nodular limestones of Adnet facies on swells and marly limestones in the basins was controlled by the Triassic topography, e.g. Rhaetian platforms and Kössen basins. The resultant facies setting in the area investigated shows a swell with Adnet facies in the south, passing northward into a basin with marly limestone deposition (Fig. 10). Towards the west this swell shows outcrops of a spiculite facies and a echinoderm-rich Hierlatz limestone. Sponge spicule-bearing limestones reflect intensive development of sponge communities on its slope and the resedimented echinoderm-rich limestones indicate downslope sediment movements. Further northward, a second swell with Hierlatz limestones is exposed. During Liassic time, synsedimentary tectonics led to the fragmentation and differential subsidence of the Rhaetian platform, producing swells separated by deeper basins (Fig. 13). During the Dogger, general subsidence progressed and tectonic movements increased the relief of swells and basins. The Liassic swell in the southern Lechtal Nappe no longer existed but became part of a larger southward dipping slope which transits into a basin with siliceous limestones (Fig. 13). The siliceous basin facies in the southern Allgäu Nappe reflects a tectonically induced rearrangement of the Liassic swell covered by Hierlatz limestones. Outcrops of echinoderm-rich limestone facies at the northern boundary of this basin and at the western and eastern boundary of the basin in the southern Lechtal Nappe (Fig. 11) may indicate downslope injections of echinoderm-rich sediments from nearby swells. Intensive downslope mass wasting is documented in the variously redeposited, partly silicified echinoderm-rich limestones on the swell in the northern Lechtal Nappe as well as in the deposition of resedimented red nodular limestones and olistholith masses of siliceous limestones in the southern Lechtal Nappe (Fig. 11).

Contemporaneously, the sedimentologic and stratigraphic record indicate an incipient stage of a new swell in the southern Allgäu Nappe (Fig. 11).

Fig. 13 shows the final stage of rotational block faulting with development of deep fault scarps during Oxfordian/Kimmeridgian. As a result, the swell formed during the Dogger (Fig. 11) was uplifted close to the sea level. On the tops of the swells, e.g. the previously existing swell in the Lechtal Nappe and the new swell in the Allgäu Nappe, a pseudooolithic shallow water facies was deposited and injected downslope into the pelagic limestone facies on the deeper slope (Fig. 12).

Contemporaneous to the Malmian red nodular limestone in Protoglobigerina and *Saccocoma* facies, radiolarite sedimentation prevailed in the basin of the southern Lechtal Nappe (Fig. 12). In the Upper Malm, the radiation of plankton production resulted in the uniform deposition of pelagic limestones covering swells and basins.

We conclude that rotational block faulting has been a major synsedimentary tectonic process on the southern continental margin of the Tethys Ocean. Comparable synsedimentary tectonic patterns characterize the early rifting period of the N-Atlantic in the Biscaya region during the Early Cretaceous. Here the Northern Armoricanian margin was dissected by rotational block faulting along listric fault scarps (MONTADERT et al. 1979a,b; DEREGNAUCOURT & BOILLOT 1982). In addition, similar tectonic settings are well known from the modern passive margins of young rifting basins, as for example the continental margins of the Red Sea (MONTENAT et al. 1986).

ACKNOWLEDGEMENTS

We gratefully acknowledge discussions and reviews of the manuscript by F. Böhm and A. Reitner. We thank A. Kohly and W. Reimers (Kiel) for their help in thin section preparation. We are indebted to Drs. D. Spiegler (Kiel) and T. Steiger (Munich) for the determination of benthic foraminifers and radiolarians. We owe special thanks to C. Samtleben and W. Reimann (operation of the SEM) and U. Schuldt (photographic assistance). Sincere thanks to P. Goldschmidt and J. Welling for correcting the English text.

REFERENCES

ANTONIADIS, P. (1975): Zur Paläogeographie des Lias in den mittleren Chiemgauer Alpen.- 167 p., 4 pls, Ph. D. Munich

BATHURST, R.G.C. (1971): Carbonate sediments and their diagenesis.- Dev. Sediment., 12, 620pp., 359 figs., Amsterdam

— (1987): Diagenetically enhianced bedding in argillaceous platform limestones: stratified cementation and selective compaction.- Sedimentology, 34, 749-778, Amsterdam

BERGER, W.H. (1970): Biogenous deep-sea sediments: Fractionation by deep-sea circulation.- Geol. Soc. Amer. Bull., **81**, 1385-1402, New York

— (1974): Deep-sea sedimentation.- In: BURK, C.A. & DRAKE, C.D (eds.): The Geology of continental margins.- 213-241, New York

BERNOULLI, D. & JENKYNS, H.C. (1970): A Jurassic basin: the Glasenbach gorge, Salzburg, Austria.- Verh. Geol. B.-A., **1970**, 504-531, 2 figs., 6 pls., Wien

BICE, D.M. & STEWART, K.G. (1990): The formation and drowning of isolated carbonate seamounts: tectonic and ecological controls in the northern Apennines.- Spec. Publ. int. Ass. Sediment., **9**, 145-168, 11 figs., Tulsa

BLATT, H., MIDDLETON, G. & MURRAY, R. (1972): Origin of sedimentary rocks.- 653pp., New Jersey

DERGNAUCOURT, D. & BOILLOT, G. (1982): Structure géologique du Golfe de Gascogne.- Bull. Bureau de Recherches Géologiques et Minieres (2), **I**, 149-178, Orléans

DIERSCHE, V. (1980): Die Radiolarite des Oberjura im Mittelabschnitt der Nördlichen Kalkalpen.- Geotekt. Forsch., **58**, 1-217, 45 figs., 3 pls., Stuttgart

DOBEN, K. (1963): Über Calpionelliden an der Jura/Kreide Grenze.- Mitt. Bayr. Staatssamml. Paläont. Hist. Geol., **3**, 35-50, 6 pls., Munich

— (1970): Geologische Karte von Bayern 1:25 000, Erl. Blatt Nr. 8241 Ruhpolding.- Bayr. Geol. Landesamt, 156p. , 44 figs., Munich

EBERLI, G.P. (1988): The evolution of the southern continental margin of the Jurassic Tethyan ocean as recorded in the Allgäu formation of the Austroalpine nappes of Graubünden.- Eclogae geol. Helv., **81**/1, 175-214, 18 figs., Basel

EHRMANN, U. & THIEDE, J. (1986): Correlation of terrigenous and biogenic sediment fluxes in the North Atlantic Ocean during the past 150 my.-Geol. Rdsch., **75**/1, 43-55, 8 figs., Stuttgart

ELMI, S. (1990): Stages in the evolution of late Triassic and Jurassic carbonate platforms: the western margin of the Subalpine Basin (Ardeche, France).- Spec. Publ. Int. Ass. Sediment., **9**, 109-144, 29 figs., Tulsa

FLÜGEL, E. (1982): Microfacies analysis of limestones.- 633pp., 78 figs., 53 pls., Berlin

FRANZ, U. (1967): Der Dogger in der Oberwössener Mulde.- In: GANSS, O. (ed.): Geologische Karte von Bayern, 1: 25000, Erl. Bl. Nr. 8240 Marquartstein.- Bayr. Geol. Landesamt, 67-74, 3 figs., Munich

GALL, H. (1970): Die Stratigraphie des Jura in der Kalkalpinen Randzone des Hochgern-Vorlandes.- In: DOBEN, K. (ed.), Geologische Karte von Bayern, 1: 25.000, Erl. Bl. Nr. 8241 Ruhpolding.- Bayr. Geol. Landesamt, 29-64, 3 figs., Munich

GANSS, O. (1967): Geologische Karte von Bayern 1: 25000, Erl. Blatt Nr. 8240 Marquartstein.- Bayr. Geol. Landesamt, 276 p., 33 figs., Munich

GARRISON, R.E. & FISCHER, A.G. (1969): Deep-water limestones and radiolarites of the Alpine Jurassic.- Soc. Econ. Paleont. Mineral. Spec. Publ. **14**, 20-56, 22 figs., Tulsa

GRIGELIS, A. & GORBATCHIK, T. (1980): Morphology and taxonomy of Jurassic and Early Cretaceous representatives of the Superfamily Globigerinacea (Favusellidae).- J. Foram. Res., **10**, 180-190, 1 fig., 1 pl., Washington

GRÜTZMACHER, U. (1988): Grosskartierung zwischen Haaralm und Nesselauer Schneid in den Chiemgauer Alpen.- unpubl. diploma thesis, 1-133, 66 figs. Univ. Kiel, Kiel

HEBBELN, D. (1987): Geologie und Stratigraphie zwischen Sulzgrabenkopf und Durlachkopf in den Chiemgauer Alpen.- unpubl. diploma thesis., 1-37, 22 figs., Univ. Bremen, Bremen

HUDSON, J. D. (1982): Pyrite in ammonite-bearing shales from the Jurassic of England and Germany.- Sedimentology, **29**, 639-667, 26 figs., Amsterdam

JACOBSHAGEN, V. (1965): Die Allgäu-Schichten (Jura-Fleckenmergel) zwischen Wettersteingebirge und Rhein.- Jb. Geol. Bundesanstalt, **108**, 1-114, Wien

JENKYNS, H.C. (1972): Pelagic oolites from Tethyan Jurassic.- J. Geol., **80**, 21-33, 8 figs., Chicago

KÄLIN, O. & TRÜMPY, D.M. (1977): Sedimentation and Paleotektonik in den westlichen Südalpen: Zur triasisch-liasischen Geschichte des Monte-Nudo-Beckens.- Eclog. geol. Helv., **70**, 295-350, 5 figs., 11 pls., Basel

KEENE, J.B. (1983): Chalcedonic quartz and occurence of quartzine (length-slow chalcedony) in pelagic sediments.- Sedimentology, **30**, 449-454, 2 figs., Amsterdam

LACKSCHEWITZ, K.S. (1987): Die Geologie des Rechenbergs und des Rehwaldkopfes in den Nördlichen Kalkalpen.- unpubl. diploma thesis., 1-121, 50 figs., 5 pls., Univ. Kiel, Kiel

LAUBSCHER, H.P. & BERNOULLI, D. (1982): Deformation and history of the Alps. In: HSÜ, K.J. (ed.), Mountain building processes.- 169-180, London (Academic Press)

LEMOINE, M. & TRÜMPY, R. (1987): Pre-oceanic rifting in the Alps. - Tectonophys., **133**, 305-320, Amsterdam

MONTADERT, L., ROBERTS, D.G., DECHARPAL, O. & GUENNOC, P. (1979a): Rifting and subsidence of the northern continental margin of the Bay of Biscay.- In: MONTADERT, L., & ROBERTS, D.G. (eds.): Int. Rep. DSDP, **48**, 1025-1060, Washington

MONTADERT, L., DECHARPAL, O., ROBERTS, D., GUENNOC, P. & SIBUET, J.-C. (1979b): Northeast Atlantic passive continental margins: Rifting and subsidence processes.- In: TALWANI, M., HAY, W. & RYAN, W.B.F. (eds.): Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvirinment, Maurice Ewing Ser., **3**, 154-186, Washington

MONTENAT, C., BUROLLET, P., JARRIGE, J.J., OTT D'ESTEVOU & PURSER, B.H. (1986): La succession des phénomènes tectoniques et sédimentaires néogène, es sur les marges du Rift de Suez et de la Mer Rouge nord-occidentale.- Compt. Rend. Acad. Sci.

Paris, sér. II, 213-218, Paris
MULLINS, H.T. (1983): Modern carbonate slopes and basins of the Bahamas.- Soc. Econ. Paleont. Mineral. Short Course 12, 4-1 - 4-138, 75 figs., Tulsa
RUHLAND, G. (1987): Geologie, Stratigraphie und Tektonik des Hochbajuvarikums im Bereich der Rötelmoosalm (Nördliche Kalk- alpen).- unpubl. diploma thesis, 1-39, 14 figs., Univ. Bremen, Bremen
SCHÄFER, P. (1979): Fazielle Entwicklung und palökologische Zonierung zweier obertriadischer Riffstrukturen in den Nördlichen Kalkalpen („Oberrhät"-Riff-Kalke, Salzburg).- Facies, **1**, 3-245, 46 figs., 21 pls., Erlangen
SCHLAGER, W. & SCHLAGER, M. (1974): Clastic sediments associated with radiolarites (Tauglboden-Schichten, Upper Jurassic, Eastern Alps).- Sedimentology, **20**, 65-89, Amsterdam
SCHOLLE, P.A., ARTHUR, M.A. & EKDALE, A.A. (1983): Pelagic.- In: SCHOLLE, P.A., BEBOUT, D.G. & MOORE, C.H. (eds.): Carbonat deposition environments.- Mem. Am. Ass. Petrol. Geol., **33**, 132-171, 115 figs., Tulsa
SCHOTT, M. (1984): Mikrofaziell, multivariate Analyse einer rhätoliassischen Karbonatplattform in den Nördlichen Kalkalpen. - Facies, **9**, 22 figs., 6 pls., Erlangen
STEIGER, T. & WURM, D. (1980): Faziesmuster oberjurassischer Plattform-Karbonate (Plassen-Kalke, Nördliche Kalkalpen, Steierisches Salzkammergut, Österreich).- Facies, **2**, 241-284, 8 figs., 6 pls., Erlangen
SUHR, J. (1989): Die Geologie zwischen Hochgern und Mehrentaler Wand in den Nördlichen Kalkalpen unter besonderer Berücksichtigung der Mikrofazies in den jurassischen Gesteinen.- unpubl. diploma thesis, 1-140, 42 figs, 9 pls., Univ. Kiel, Kiel
THOMSEN, E. & VORREN, T.O. (1984): Pyritization of tubes and burrows from late Pleistocene continental shelf sediments of North Norway.- Sedimentology, **31**, 481-492, 6 figs., Amsterdam
WEISSERT, H. (1979): Die Paläozeanographie der südwestlichen Tethys in der Unterkreide.- Mitt. geol. Inst ETH und Univ. Zürich, **226**, 174p., Zürich

Manuscript received December 20, 1990
Revised manuscript accepted March 4, 1991

Plate 1 Jurassic carbonate series of the Chiemgau Alps (Bavaria). Lias and Dogger basin and swell facies

Fig. 1. Sponge spicule-bearing limestone (Liassic Spiculite facies). x 25

Fig. 2. Echinoderm-grainstone with syntaxial cement overgrowths. Some echinoderm fragments are bored (Liassic Hierlatz limestone). x 25

Fig. 3. Framboidal pyrite with clusters of small isometrix crystals indicating authigenic formation in association with early diagenetic decay of organic matter (Lias basin marly limestone); SEM. Bar is 10µm.

Fig. 4. Echinoderm-rich wackestone with typical benthic foraminiferal assemblage (e.g. *Astacolus* sp.). These biomicrites reveals frequent iron/manganese coated borings (Lias Adnet limestone). x 25

Fig. 5. Sponge spicule filled by chalcedony with a sheal of length-fast fibres. The botryoidal form with radiation sphere bundles indicates initial precipitation of Opal- CT which later converted to chalcedony. (Lias Spiculite facies). x 90

Fig. 6. Typical turbidite bed, about 6cm thick, with sharp contact at the base, graded central section with mudclasts of up to 4mm size and horizontal lamination on top (Lias basin marly limestone). Bar is 1cm.

Fig. 7. Basin marly limestones with well-developed deposit- feeding burrows of *Zoophycos-Chondrites-Planolites* ichnofacies (Lias basin marly limestone). Bar is 1cm.

Fig. 8. Bioturbation activity in a sponge spicule-bearing limestone is indicated by well-developed burrows with darker infills. (Dogger siliceous limestone). x 25

Fig. 9. Intraformationally reworked red nodular limestone with a differential fossil content and colour in intraclasts and matrices (Dogger red nodular limestone). Horizontal section; Bar is 1cm.

Fig. 10. Enrichment of filaments of *Bositra* type (Dogger siliceous limestone). x 25

Fig. 11. Intraformational reworking of echinoderm wackestone/packstone with typical deformation of semilithified intraclasts (Dogger echinoderm-rich limestone). Bar is 1cm.

Plate 1

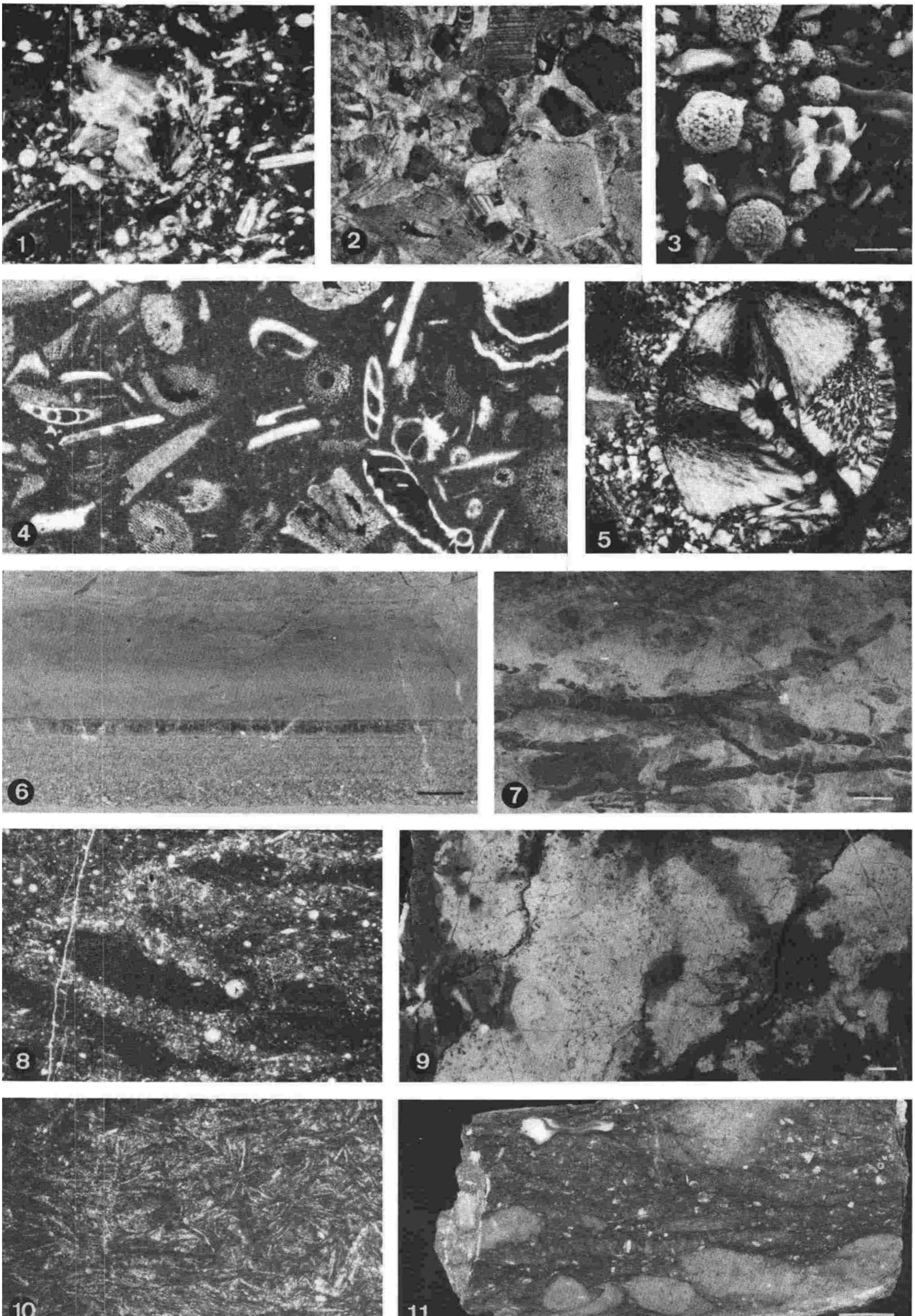


Plate 2 Jurassic carbonate series of the Chiemgau Alps (Bavaria). Dogger and Malm basin and swell facies

Fig. 1. Packstone with abundant sponge spicules (Dogger siliceous limestone). x 25

Fig. 2. Filament-rich and pseudopeloid-bearing packstone including P*rotopeneroblis striata* Weynschenk (lower part of Malmian red nodular limestone). x 25

Fig. 3. Echinoderm packstone with abundant crinoid fragments (Dogger echinoderm-rich limestone). x 25

Fig. 4. Pseudopeloid packstone with Protoglobigerina in the nucleus of the ooids indicating an open marine environment (Malmian red nodular limestone). x 25

Fig. 5. Pseudopeloid packstone. Echinoderm and filament fragments often form the nucleus of the pseudopeloids (Malmian red nodular limestone). x 25

Fig. 6. Radial structure of ooids within a partially micritized pseudopeloid (Malmian red nodular imestone); SEM. Bar is 40µm.

Fig. 7. Pelagic nannofossil remains in the nucleus of a completely micritized pseudopeloid (Malmian red nodular limestone); SEM. Bar is 20µm.

Fig. 8. Section through a juvenile ammonite which had been completely filled with pseudopeloids (Malmian red nodular limestone). x 25

Fig. 9. Intraformationally reworked pseudopeloid facies;Intraclasts (pseudopeloid packstones) embedded in a pseudopeloid grainstone (Malmian red nodular limestone). x 25

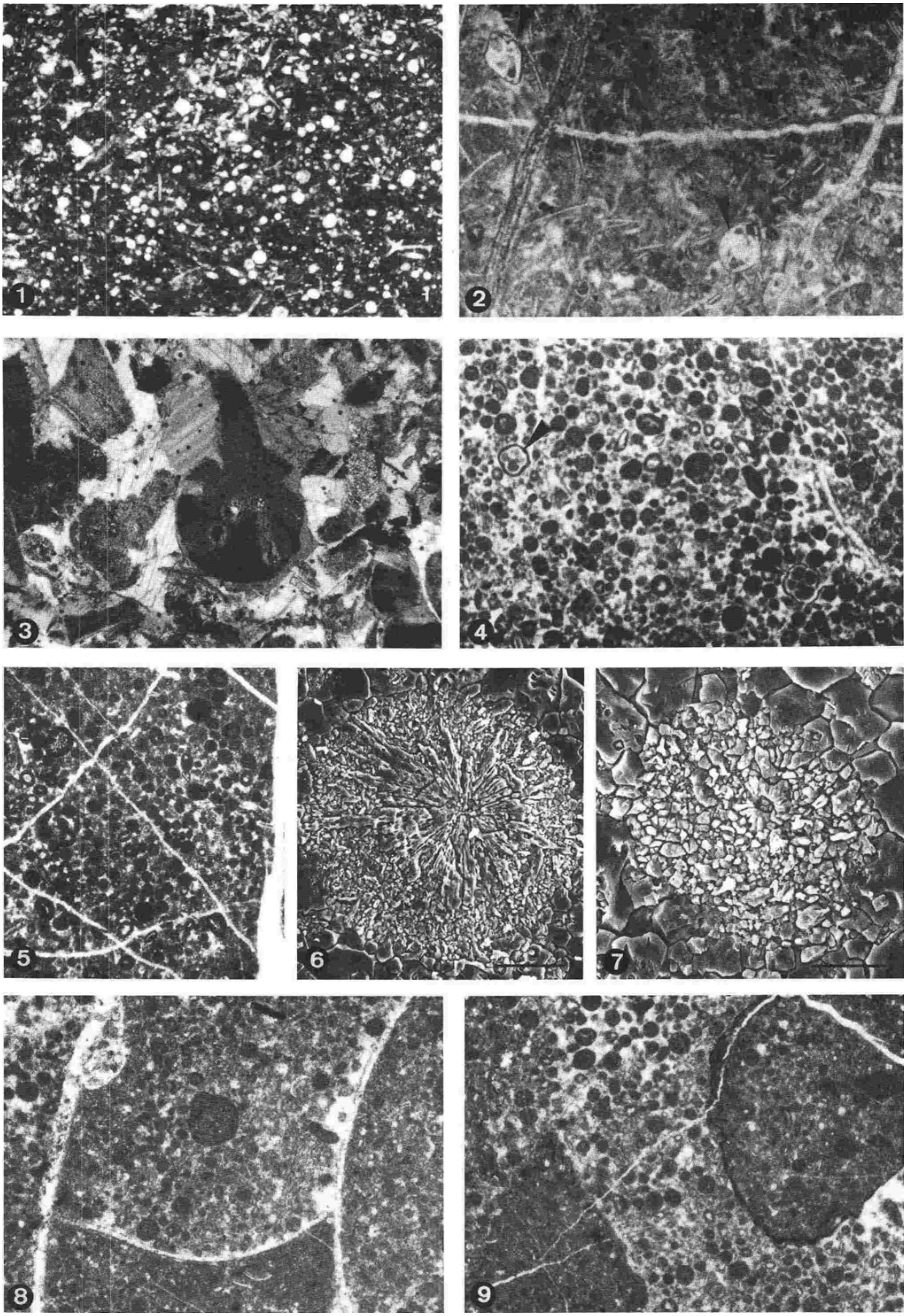


Plate 3 Jurassic carbonate series of the Chiemgau Alps (Bavaria). Malmian swell and basin facies

Fig. 1. Pseudopeloid grain flow incised into calpionellid facies.This reflects resedimentation phenomena and downslope mass movements (red nodular limestone). Bar is 1cm.

Fig. 2. Small scale pseudopeloid grain flow repititions, some of he with weakly developed inverse gradation (red nodular limestone). x 25

Fig. 3. Polished slab of intraformational conglomerate with ight-coloured intraclasts (red nodular limestone in calpionellid facies). Bar is 1cm.

Fig. 4. Thin section of the intraformational conglomerate shown in Fig. 3 with a lower density of calpionellids in the intraclasts. Furthermore, dispersed radiolarian tests occur only in the intraclasts (red nodular limestone). x 25

Fig. 5. *Saccocoma* wackestone showing fragments of *Saccocoma alpina* Lombard (red nodular limestone). x 25

Fig. 6. Protoglobigerina packstone with admixture of echinoderm-debris and some bivalve fragments (red nodular limestone). x25

Fig. 7. Radiolarian-rich packstone limestone with well preserved radiolarian tests. (radiolarite sequence). x 25

Fig. 8. Jurassic coccolith (undetermined species) in the fine-grained matrix of radiolarian-bearing limestone (radiolarite sequence); SEM. Bar is 2µm.

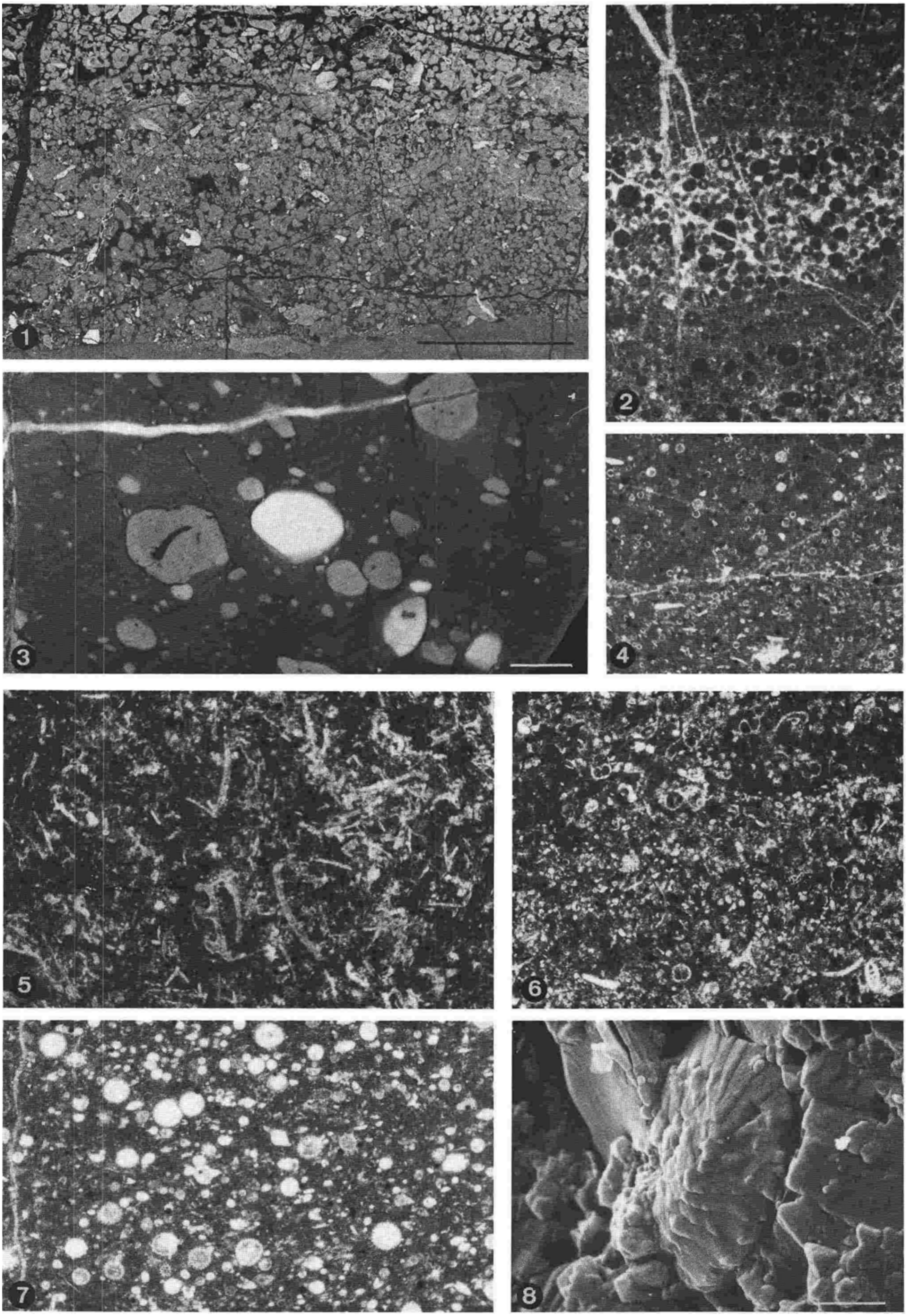

1
2
3
4
5
6
7
8

Plate 4 — Jurassic carbonate series of the Chiemgau Alps (Bavaria). Radiolarian assemblages in the Radiolarite sequence (Malm) of the Rechenberg syncline (Fig. 1-8) and Burgau-Alm syncline (Fig. 9-18)

Bar for all figures: 100µm

The faunal assemblage of Figs.1-8 corresponds to the time-stratigraphic unit Callovian to Tithonian.

Fig. 1. *Tetratrabs gratiosa = zealis* BAUMGARTNER

Fig. 2. *Angulobracchia purisimaensis* (PESSAGNO)

Fig. 3. *Emiluvia antiqua* (RÜST)

Fig. 4. *Acanthocircus* sp.

Fig. 5. *Triactoma blakei* (PESSAGNO)

Fig. 6. *Emiluvia sedecimporata elegans ?* (WISNIOWSKI)

Fig. 7. *Podobursa triacantha* (FISCHLI)

Fig. 8. *Dibolachras chandrika* KOCHER

The faunal assemblage of Figs.9-18 corresponds to the time-stratigraphic unit Callovian to Berriasian.

Fig. 9. *Archaedictyomitra apiaria* (RÜST)

Fig. 10. *Parvicingula boesii* (PARONA) (right side)

Fig. 11. *Parvicingula cosmoconica ?* (FOREMAN)

Fig. 12. *Tritrabs exotica* (PESSAGNO)

Fig. 13. *Hsuum* sp.

Fig. 14. *Praeconocaryomma magnimamma* (RÜST)

Fig. 15. *Emiluvia orea* BAUMGARTNER (lower part of the photo)

Fig. 16. *Triactoma tithonianum* RÜST

Fig. 17. *Thanarla* sp.

Fig. 18. *Podocapsa amphitreptera* FOREMAN

Plate 4