Structure, pattern of distribution and paleobathymetry of Late Jurassic microbialites (stromatolites and oncoids) in northern Switzerland

Autor(en): **Gygi, Reinhart A.**

Objekttyp: **Article**

Zeitschrift: **Eclogae Geologicae Helvetiae**

Band (Jahr): **85 (1992)**

Heft 3: **Symposium on Swiss Molasse Basin**

PDF erstellt am: **21.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-167057

Nutzungsbedingungen

Die ETH-Bibliothek ist Anbieterin der digitalisierten Zeitschriften. Sie besitzt keine Urheberrechte an den Inhalten der Zeitschriften. Die Rechte liegen in der Regel bei den Herausgebern.
Die auf der Plattform e-periodica veröffentlichten Dokumente stehen für nicht-kommerzielle Zwecke in Lehre und Forschung sowie für die private Nutzung frei zur Verfügung. Einzelne Dateien oder Ausdrucke aus diesem Angebot können zusammen mit diesen Nutzungsbedingungen und den korrekten Herkunftsbezeichnungen weitergegeben werden.
Das Veröffentlichen von Bildern in Print- und Online-Publikationen ist nur mit vorheriger Genehmigung der Rechteinhaber erlaubt. Die systematische Speicherung von Teilen des elektronischen Angebots auf anderen Servern bedarf ebenfalls des schriftlichen Einverständnisses der Rechteinhaber.

Haftungsausschluss

Alle Angaben erfolgen ohne Gewähr für Vollständigkeit oder Richtigkeit. Es wird keine Haftung übernommen für Schäden durch die Verwendung von Informationen aus diesem Online-Angebot oder durch das Fehlen von Informationen. Dies gilt auch für Inhalte Dritter, die über dieses Angebot zugänglich sind.

Ein Dienst der *ETH-Bibliothek*
ETH Zürich, Rämistrasse 101, 8092 Zürich, Schweiz, www.library.ethz.ch

http://www.e-periodica.ch

Eclogae geol. Helv. 85/3: 799–824 (1992)

0012-9402/92/030799-26 $1.50 + 0.20/0
Birkhäuser Verlag, Basel

Structure, pattern of distribution and paleobathymetry of Late Jurassic microbialites (stromatolites and oncoids) in northern Switzerland

By REINHART A. GYGI [1]

ABSTRACT

Microbialites of the Oxfordian/early Kimmeridgian in northern Switzerland occur from the upper intertidal zone to the bottom of an epicontinental sea in the Swabian-Rhodanian realm north of the Tethys. Oxfordian deposition began when the epicontinental basin was between 80 and 100 m deep. In the first half of Oxfordian time, basinal sedimentation rates varied between very slow and zero. A warm climate fluctuating between moderately humid and semiarid controlled the rate at which siliciclastic sediments were supplied from land in the north. The siliciclastics were mixed with carbonates that were produced mainly on Bahamian-type platforms in the marginal part of the epicontinental basin. The resulting sediments grade from clay-dominated mud to very pure carbonates. The shallowing-upward depositional sequences which prograded into the basin from the northwest were complicated by eustatic sea level changes. Carbonate platforms with coral bioherms at the seaward edge and with a wide belt of ooid sand bars landward of the bioherms developed from the Middle Oxfordian on.

Deep-water (between 100 and 150 m) microbialites of the initial starved basin stage are represented either by calcareous crusts forming spherical oncoids up to 4 centimeters across, or by undulating envelopes around indurated, exhumed internal molds of large ammonites. Both types include glauconite pellets. When the sedimentation rate approached zero, millimeter-thick crinkled or mammillate crusts of chamosite/limonite with a shining surface formed on very widespread hardgrounds, at a water depth ranging from 80 to 100 m. Most of the sponges in the sponge biostromes and bioherms of the basin are covered by microbial crusts on their upper surfaces. Oncoids impregnated with glauconite grew to sizes of between a few millimeters and 2 centimeters; they grew in lime mud seaward of the margins of successive carbonate platforms, at a depth of 30 to 50 m. Widespread deposits of mostly mud-supported oncolite formed in more or less restricted lagoons, landward of the belt of ooid sand bars and coral bioherms at the platform margin. The stratiform microbialites of the peritidal zone have flat or wavy laminae with or without fenestrae. Some of them are prism-cracked to a depth of as much as 60 centimeters.

ZUSAMMENFASSUNG

Mikrobialithen des Oxfordian und des frühen Kimmeridgian in der Nordschweiz kommen vom oberen Gezeitenbereich bis zum Grund eines Epikontinentalmeeres im schwäbisch-rhodanischen Faziesgebiet nördlich der Tethys vor. In der ersten Hälfte der Oxford-Zeit schwankte die Sedimentationsgeschwindigkeit im Becken zwischen sehr langsam und Null. Ein warmes, zwischen gemässigt feucht und semiarid pendelndes Klima bedingte den Umfang, in dem siliziklastisches Sediment von einem Land im Norden geliefert wurde. Das siliziklastische, vor allem tonige Material mischte sich mit Karbonaten, welche vor allem auf Bahama-ähnlichen Plattformen im Randbereich des epikontinentalen Beckens entstanden. Die resultierenden Sedimente reichen von tonigem Schlamm bis zu sehr reinen Karbonaten. Die regressiven Sequenzen, welche von Nordwesten her ins Becken progradierten, wurden von eustatischen Meeresspiegelschwankungen beeinflusst. Karbonatplattformen mit Korallenbiohermen am beckenwärtigen Rand und mit einem breiten Gürtel von Oolithsandbänken auf der proximalen Seite der Bioherme entwickelten sich vom mittleren Oxfordian an.

---

[1] Museum of Natural History, Augustinergasse 2, CH-4001 Basel, Switzerland

In 100 bis 150 m tiefem Wasser gebildete Mikrobialithen des ersten Stadiums mit sehr geringer Sedimentation im Becken sind einerseits kalkige Krusten, welche kugelige Onkoide mit einem Durchmesser von bis zu 4 cm bilden, oder wellig-bucklige Schalen um exhumierte, frühdiagenetisch gebildete, grosse Ammonitensteinkerne. Diese Mikrobialithen schliessen Glaukonitkörner ein. Wenn die Sedimentationsgeschwindigkeit gegen Null ging, entstanden ausgedehnte Hartgründe mit millimeterdicken, buckligen Krusten von Chamosit und Limonit mit einer glänzenden Oberfläche, bei einer Wassertiefe zwischen 80 und 100 m. Die meisten Schwämme der Biostrome und Bioherme im Becken und am Abhang sind auf der Oberseite von mikrobiellen Krusten bedeckt. Onkoide mit Glaukonitimprägnationen wuchsen bis zu Grössen zwischen einigen Millimetern und zwei Zentimetern; solche Onkoide bildeten sich auf Kalkschlamm in einer Wassertiefe von 30 bis 50 m am oberen Abhang von aufeinander folgenden Karbonatplattformen. Zum Teil sehr ausgedehnte Ablagerungen von Onkolith mit vorwiegend schlammiger Grundmasse entstanden in teilweise abgeschlossenen Lagunen, auf der proximalen Seite des Gürtels von Oolithsand und Korallenbiohermen am Rand der Karbonatplattform. Die schichtförmigen Mikrobialithen des Gezeitenbereichs haben flache oder wellige Laminae mit oder ohne Fenestrae. Einige von ihnen sind von Prismenrissen mit einer Tiefe von bis zu 60 cm durchsetzt.

1. Introduction

The study area lies between the Ardenno-Rhenan Massif to the N-NW that was emergent in Late Jurassic time and the submerged Aar Massif to the S-SE (Figs. 1 and 2). The described transect concerns the central and eastern part of the Jura mountain chain, north of the Alps. Correlations in this transect were controversial for a long time. These by Gressly (1838–41) were improved by Oppel (1857, p. 626) on the evidence of ammonites. Oppel demonstrated that the thick marl-clays of the first depositional sequence of the Oxfordian (see Fig. 3 of this paper) were time-equivalent with a thin iron oolite (now Schellenbrücke Bed) at the base of the Oxfordian in the distal part of the basin. Rollier (1888) pointed out that the "Rauracien", a carbonate platform of Bahamian type (now St-Ursanne Formation, SUF in Fig. 3) was older than the micritic limestones with ammonites in the basin (Rollier's "Séquanien," now Villigen Formation, VIL in Fig. 3). Bolliger & Burri (1967) concluded that the bulk of the Wildegg Formation in the basin was time-equivalent with the Natica Member in the proximal shallow-water realm (NAT in Fig. 3).

Gygi & Persoz (1986) reevaluated these controversial correlations with an integrated approach based on detailed new lithostratigraphic work, mineral stratigraphy and ammonite biostratigraphy. They gave a correlation chart and divided the sediments into depositional sequences. Gygi (1986) correlated these sequences with the global sequences as defined by Vail et al. (1984) and evaluated the paleobathymetry of the Oxfordian sediments by different, independent methods. This scheme is used to calibrate the bathymetry of the microbialites described in this paper.

A locality map is not given for the following reason: After the publication of a photograph of an outcrop with prism cracks (given here as Fig. 5) by Gygi & Persoz (1986), the outcrop has been destroyed by someone taking samples. Information on the location of outcrops may be obtained by writing to the author.

2. Sedimentological setting

Sedimentation in the area studied began in an epicontinental basin northwest of the Tethys ocean. The water depth at the beginning of the Oxfordian was between 80 m in the proximal and 100 m in the distal part of the basin. The basement was characterized

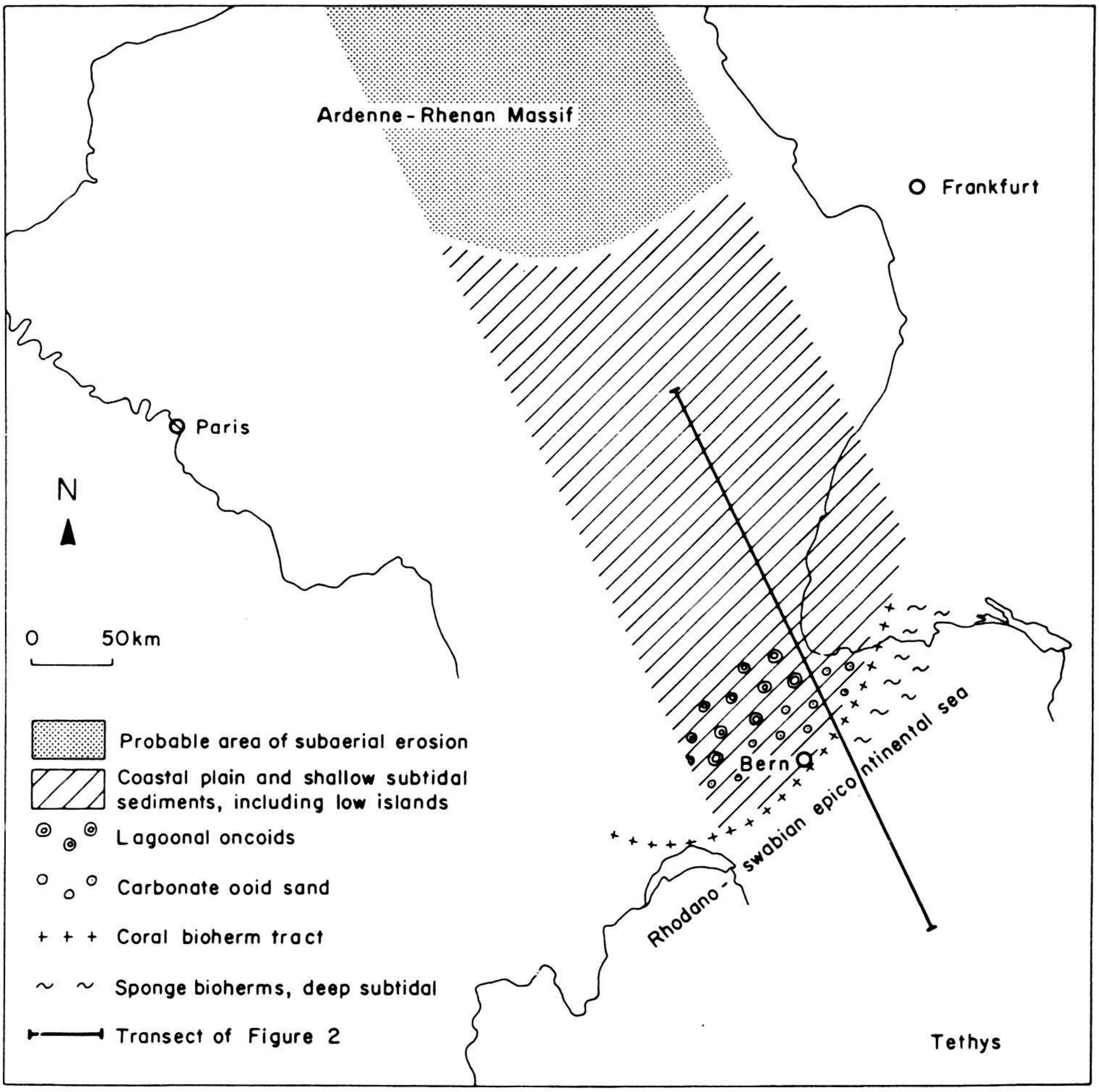


Fig. 1. Paleogeographic map of central Europe in the Late Oxfordian (early Bimammatum Subchron). The bank of Oxfordian shallow-water sediments in northern Switzerland (now part of the folded Jura Mountains) was probably contiguous to the land of the Ardenne-Rhenan Massif, as indicated by a large dinosaur that was found in the lowermost Reuchenette Formation of northern Switzerland (see Gygi & Persoz 1986). The position of the coastline is not indicated for reasons given in the text. The Tethys sensu lato (now: Alps) includes the southern passive margin of Europe from the ultrahelvetic facies belt to the deep south penninic basin with oceanic basement (see Trümpy 1980, p. 31). After Dreyfuss (1954), Ziegler (1982), Gygi & Persoz (1987).

by an equable, regional subsidence that was strongly influenced by the load of sediments (Gygi 1986, Fig. 3). Terrigenous sediments were supplied from the Ardenne-Rhenan Massif to the north-northwest. They were mixed with carbonates that were mostly produced locally on successive carbonate platforms. The progradational pattern of the Middle Jurassic argillaceous/carbonate Burgundy platform (Purser 1979), as well as that of the early Oxfordian prodelta marl-clay, suggests that part of the terrigenous sediment came from the area that is now the British Isles.

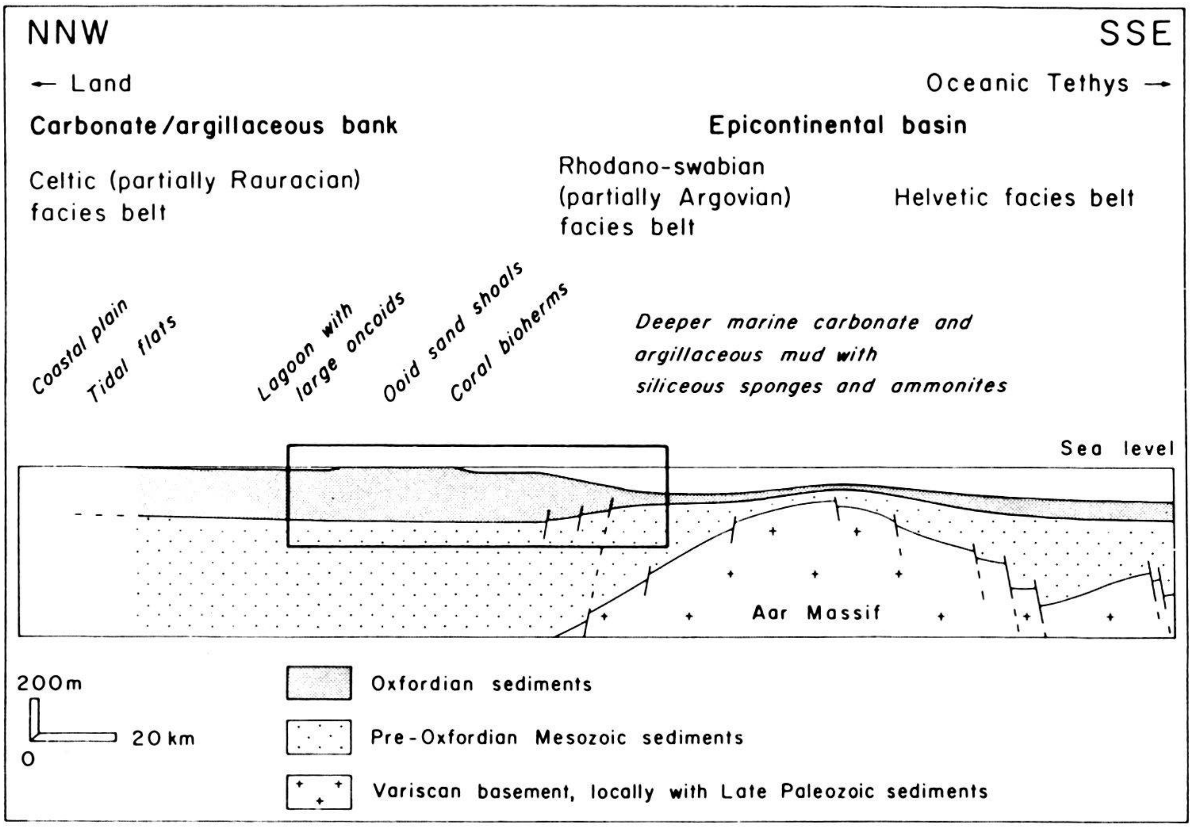


Fig. 2. Schematic cross-section through the epicontinental sea north of the Tethys in the late middle Oxfordian (Bimammatum Chron). By this time, much of the epicontinental basin was filled up with terrigenous sediment and carbonates that prograded from land to the south-southeast. Post-variscan rifts in the igneous and metamorphic basement that are filled with thick Permo-Carboniferous siliciclastics are not shown. After Vonderschmitt (1942), Trümpy (1980), Gygi & Persoz (1986), Kugler (1987), Vollmayr & Wendt (1987). Inset enlarged in Fig. 3.

2.1 Lithostratigraphy

2.1.1 Sequence 1

Sedimentation of the Oxfordian began with a thin iron-oolitic marl-clay with carbonate nodules in the distal part (Gygi & Marchand 1982, Fig. 2). Above follows the thick, homogenous blue-grey marl-clay of the Renggeri Member with ammonites preserved as casts of iron sulfide (REN in Fig. 3). The next unit is a marl-clay with abundant sponge spicules that are preserved in bands of rounded carbonate nodules. This is the Terrain à Chailles Member (TAC in Fig. 3). The Liesberg Member (LIE in Fig. 3) resembles the Terrain à Chailles Member in that it is also a marl-clay with carbonate nodules, but the nodules of the Liesberg Member are more abundant and have an irregular shape. The Liesberg Member contains a profusion of dish-shaped and lenticular colonies of hermatypic corals. On top of this follow the sediments of a widespread carbonate platform with oncoids and ooids and with coral bioherms at the margin. In the platform interior there was an open marine lagoon with coral patch reefs. This is the St-Ursanne Formation (SUF in Fig. 3) with very pure carbonates.

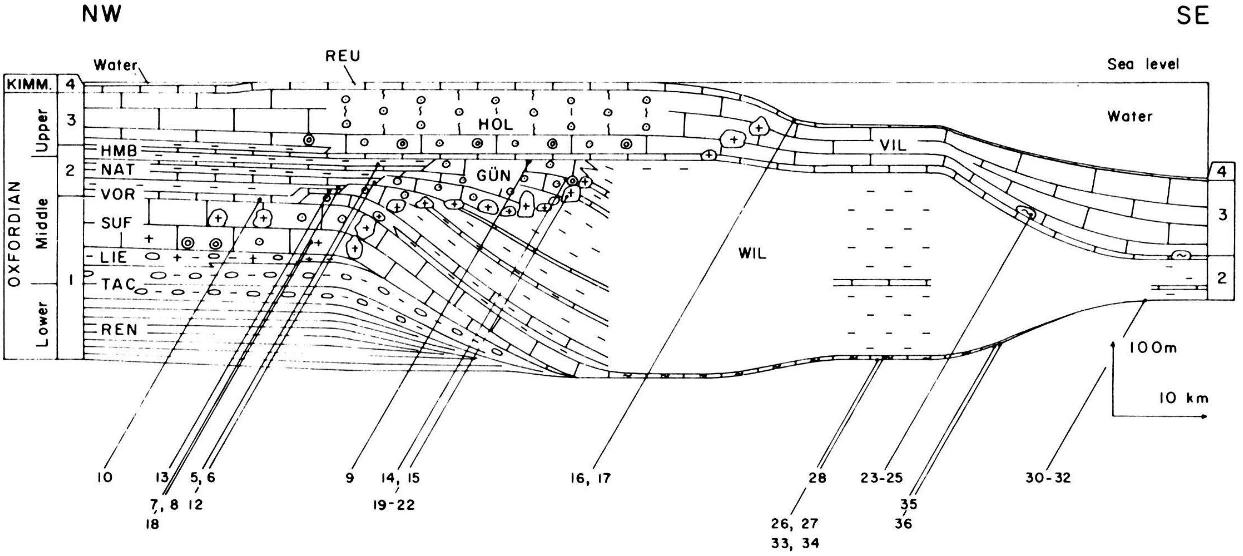


Fig. 3. Synthesized section of Oxfordian and earliest Kimmeridgian sediments of northern Switzerland. The numbers below are those of the figures of microbialites. They indicate the position of the figured microbialites within the section. The numbers on the sides of the section relate to depositional sequences. For more detail, see Gygi & Persoz (1986, Pl. 1) and Gygi (1986, Fig. 3).

The Renggeri Member and the lower part of the Terrain à Chailles Member become very thin in the distal direction and grade into an iron oolite (Schellenbrücke Bed), then into a glauconitic marl-clay (Glaukonitsandmergel, see Gygi 1981, Fig. 4). The upper part of the Terrain à Chailles Member, the Liesberg Member, and the St-Ursanne Formation grade laterally into the thin Birmenstorf Member (BIR in Gygi & Persoz 1986, Pl. 1), an alternation of marl and limestone with siliceous sponges and ammonites. No progradation occurred during deposition of sequence 1.

2.1.2 Sequence 2

The onset of siliciclastic-dominated sedimentation initiated sequence 2. This sequence is difficult to separate from sequence 1 near the platform margin where the carbonate platform continued to grow in spite of an increasing supply of siliciclastic sediment from the land. The oldest sediment of sequence 2 on the platform is the Vorbourg Member (VOR in Fig. 3), a peritidal micritic limestone with prism cracks, oncolites and stromatolites (see Figs. 10 and 13). On the slope thick, prograding clinoforms of argillaceous and carbonate mud of the Wildegg Formation (WIL) were deposited. The narrow carbonate platform of the Günsberg Member (GÜN in Fig. 3) prograded over the clinoforms of the Wildegg Formation. The mixed siliciclastic-carbonate Natica Member (NAT) was sedimented on the peritidal inner platform. This member contains numerous stromatolites (Figs. 7, 11, and 12). The pure carbonate end-member of sequence 2 on the platform is the Hauptmumienbank Member (HMB in Fig. 3) which is essentially an oncolite (not indicated in Fig. 3; see Gygi & Persoz 1986, Pl. 1 A). Sequence 2 is a thick shallowing-upward cycle in the basin with coral bioherms in the carbonate end-member (Fig. 3).

2.1.3 Sequence 3

Sequence 3 begins on the platform with the thin Humeralis marl that grades laterally into a red-brown oolite. In this sequence, the carbonate platfom became much wider than that of the Günsberg Member because the siliciclastic sediment supply from the land greatly diminished. Oncolites are common in the lower part of sequence 3 on the platform. The oncoids may grow to the size of several centimeters. They are embedded in an oolitic groundmass.

2.1.4 Sequence 4

Sequence 4 is made up of pure limestone on the platform and of marly limestone in the basin. The delineation from sequence 3 is easy because of the change in colour and lithology. The upper part of sequence 3 is a massive, almost pure white oolite (upper part of Holzflue Member of the Balsthal Formation, HOL in Fig. 3). The base of the Reuchenette Formation (REU in Fig. 3) is in most places a grey micritic, well-bedded limestone. The change to a darker colour is linked with a marked increase in the content of smectites, chlorite, and mixed-layered clay minerals (Gygi & Persoz 1986, Fig. 9). The lowermost Reuchenette Formation becomes glauconitic towards the basin and grades into the Baden Member with ammonites and siliceous sponges (Gygi & Persoz 1986). This transitional facies contains glauconitic oncoids (Figs. 16

and 17). Their position in the rock succession is indicated in Fig. 3 or, in more detail, in Gygi & Persoz (1986, Pl. 1 B).

2.2 *Facies analysis*

Detailed facies analysis yielded some substantial information on the water depths, mainly of the deep subtidal realm. The facies analysis of the described transect was given mainly by Gygi (1969, 1981, 1986) and by Gygi & Persoz (1986, 1987). Facies indicative of climate can also be recognized (Gygi, 1986).

Sedimentation of sequence 1 began with a thin bed of iron oolitic marl-clay which contains a macrofauna dominated by ammonites. Gygi (1981) concluded that iron oolites of this type are formed at the toe of argillaceous prodelta mud banks at a depth of at least several tens of meters (see Gygi 1981, Fig. 4). Then the basin was gradually filled up with argillaceous mud. The Terrain à Chailles Member contains a mixed macrofauna of mainly bivalves with some ammonites which is indicative of an intermediate depth (Gygi 1986, Fig. 6 B). On top of this submarine mud bank the carbonate platform of the St-Ursanne Formation developed with carbonate oolite and coral bioherms indicating very shallow water. In the time-equivalent slope sediment, the Pichoux limestone, the macrofauna is composed of ammonites and bivalves indicating an intermediate water depth, as in the Terrain à Chailles Member. The thin basinal equivalent of the St-Ursanne Formation, the Birmenstorf Member, is an alternation of marl and limestone beds with a macrofauna that is dominated by siliceous sponges and ammonites.

Sequence 2 on the platform is peritidal with facies ranging from the shallow subtidal zone with sea urchins and brachiopods to terrestrial horizons with thin bands of coal and characean gyrogonites. More distally, sequence 2 is a shallowing-upward sequence with mainly ammonites in the lower Wildegg Formation that indicate relatively deep water. In the Günsberg Member carbonate oolites and coral bioherms indicate very shallow water. An oncolite from an open marine lagoon with hermatypic corals of the Günsberg Member is depicted in Figs. 14 and 15, and a microbialite from a tidal flat of the Günsberg Member in Fig. 9. The Hauptmumienbank at the top of sequence 2 is a very widespread oncolite from a partially restricted lagoon. It can be followed over a distance of at least 100 km along the depositional strike (Gygi & Persoz 1986, p. 400). The Hauptmumienbank Member grades laterally in the distal direction into the carbonate oolite of the Steinebach Member (Gygi & Persoz 1986, Pl. 1 A). Coral bioherms occur at the platform margin near Olten. Beyond the bioherms are thick-bedded micritic limestones with an almost pure bivalve macrofauna, the Geissberg Member of the lower Villigen Formation. This is indicative of the shallow subdital zone (Gygi 1986, Fig. 6 B). On the slope and on the basin floor, this member contains ammonites and bioherms of siliceous sponges. Sequence 3 on the platform was a vast oolite sand shoal with an admixture of oncoids in the lower part. In the basin it consists of well-bedded micritic lime mudstones with a macrofauna of mostly ammonites. The change of the macrofauna in the lateral transition from the platform to the basin of sequence 4 was documented by Gygi (1986, Fig. 6) with large samples.

The vertical and lateral facies transitions are complicated by sea level changes that were demonstrated to be eustatic by Gygi (1986). For instance, sea level changes of a few meters caused the coastline to shift by a proven minimum distance of several tens of kilometers in the peritidal part of sequence 2. Consequently, there are problems in the detailed correlation between sections. The coastline is not indicated in Fig. 1 because of such correlation problems and because of the erosion of sediments above the Vosges horst. The southern extension of the Ardenne-Rhenan land reached the described transect at least twice, first during the deposition of the Natica Member when horizons with lignite, rootlets, characean gyrogonites and black pebbles above planed erosion surfaces were formed, and second during deposition of the lowermost Reuchenette Formation, when the large terrestrial dinosaur *Cetiosauriscus greppini* (Von Huene) reached Moutier, 35 km southwest of Basel.

2.3 Paleobathymetry

Facies analysis provides reliable evidence of terrestrial, intertidal and shallow subtidal environments. Detailed paleobathymetric evidence of deeper subtidal environments is as a rule not available. But there are exceptions. Gygi (1981) made a detailed study of the iron oolite of the Schellenbrücke Bed in northern Switzerland. He concluded from sedimentologic, mineralogic and taphonomic evidence that the bed was formed in an open marine environment at a depth of between 80 and 100 m. The rich, ammonite-dominated macrofaunal assemblage of the bed confirmed this conclusion as the assemblage is interpreted following the fundamental work by B. Ziegler (1967). Based on his arguments, Gygi (1986) assumed that the initial water depth was ca 80 m in northwestern Switzerland at the beginning of the Oxfordian. The basin was entirely filled with sediments by the end of the Transversarium Chron in the middle Oxfordian as indicated by sedimentary structures and fossils in the lowermost Vorbourg Member (Gygi & Persoz 1986).

From this it can be calculated that the basement subsided under the load of sediment by two thirds of the compacted thickness (Gygi 1986, p. 472). This is in agreement with the value obtained by P. A. Ziegler (1982, p. 106). With this value, Gygi (1986, p. 472) calculated that the relative rise of sea level in northern Switzerland was

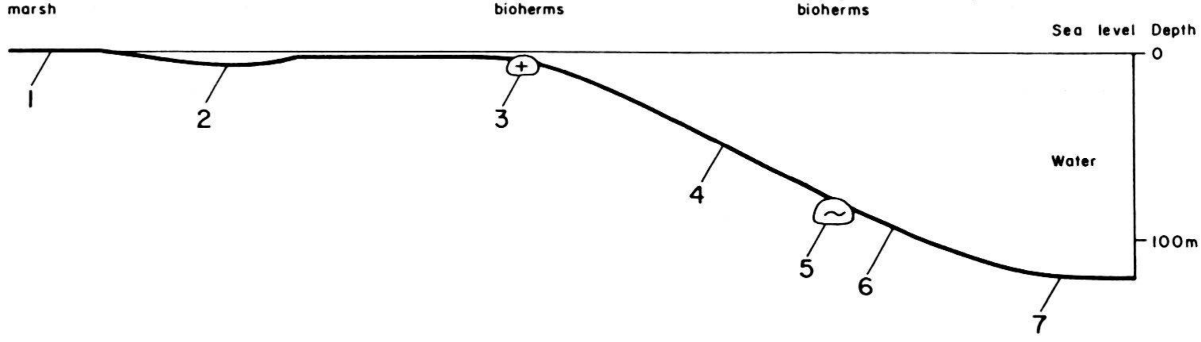


Fig. 4. Synthetic cross-section showing the bathymetric position of the figured microbialites. 1) Stratiform microbialites ot the upper intertidal zone and of the inshore algal marsh: Figures 5 through 13. 2) Oncoids from an open marine lagoon: Figures 14 and 15. 3) Erect microbialites from coral bioherms: Figures 18 through 22. 4) Oncoids of the upper slope: Figures 16 and 17. 5) Microbialites from bioherms of siliceous sponges: Figures 24 and 25. 6) Ferriferous microbialites: Figures 26 through 31. 7) Microbialites of the basin floor: Figures 32 through 36.

about 100 m during the whole of Oxfordian time. Thus it was possible to establish the bathymetric profile between the platform and the basin floor at the beginning of the Kimmeridgian. The paleobathymetric position of several rich macrofaunal assemblages of the early Kimmeridgian could be evaluated by this procedure (Gygi 1986, Fig. 6). In the present paper, the paleobathymetric estimates of the deeper subtidal zone will be made by comparison with the composition of these macrofaunal assemblages and with the sedimentological and taphonomic evidence produced by Gygi et al. 1979, p. 944–946.

3. Structure and microstructure of microbialites

The microbialites will be described here following the transect given in Fig. 4. The numbers of the microbialite photographs are indicated below the cross-section of Fig. 3.

3.1 Peritidal microbialites

3.1.1 Prism-cracked microbial laminites from the algal marsh

The bed illustrated in Fig. 5 is 25 cm thick. The prism cracks reach from the surface of the bed vertically down to the base. The mud prisms are as much as 40 cm across. The internal layering is mostly laminated. The thickness of the laminae ranges from 0.5 to 3 mm. The thickness varies laterally because the thinner laminae are wavy and often pinch out. There are few fenestrae and some fine sheet cracks. Rootlets are very fine and impregnated with limonite. Three centimeters below the surface of the bed is a 1 cm thick horizon with angular and rounded mud clasts up to 7 mm across (polished surface Gy 4830). The upper 3 cm of the bed are bioturbated except the uppermost few millimeters (sample Gy 4831). The bed is part of a micritic mud-cracked unit that is 3.65 m thick. The lowermost bed is 60 cm thick. In this bed the prism cracks reach also from the surface down to the base.

The isolated mud prism shown in Fig. 6 is 22 cm across and 20 cm thick. The mud cracks intersect the whole thickness of the bed. The internal layering is entirely laminated. The thickness of the micritic laminae is from 0.3 to 3 mm. In the lower part, the laminae are finely crenulated and in the upper part undulating, almost flat. There are lenses of fine-grained carbonate sand with angular detrital quartz with a grain size of as much as 45 microns (thin section Gy 6731). Fenestral pores are few and small. This prism is from the same unit as the bed illustrated in Fig. 5. The mud-cracked unit is the upper intertidal end-member of a shallowing-upward sequence with ammonitiferous marl below and coral bioherms in the upper part. The unit grades laterally, over a distance of a few kilometers, into a black pebble conglomerate with nerineid gastropods (section RG 406 near Vermes JU, polished surface Gy 4735 as figured by Gygi & Persoz 1986, Fig. 5).

The microbialitic part of the bed depicted in Fig. 7 is up to 15 cm thick. Two generations of prism cracks reach from the surface a few centimeters down. The first generation cracks are twisted. Some of them are intersected by the straight vertical cracks of the second generation. The mud prisms are from 5 to 12 cm across. Sheet cracks as much as 7 cm long and 7 mm thick are filled with dark, silty sediment. The fenestrae in the bed are small and uncommon except in the lowermost two centimeters of the bed (polished surface Gy 4455). The internal layering of the bed is wavy laminated. The laminae are between 100 microns and 5 mm thick. Micritic laminae alternate with silty ones that contain about 10% detrital, angular quartz with a grain size of 30 microns at most (Fig. 8).

The microbialite of Fig. 9 is disrupted by two generations of dewatering cracks. The laminae are dissected by dewatering and truncated by erosion at the upper right of the figure. At the upper left pebbles with partly visible lamination can be observed. This microbialite belongs to the upper part of sequence 2. In the lower part of the sequence are the ammonite-bearing marl of the Wildegg Formation, and in the upper part coral bioherms and calcareous oolite (see Fig. 3).

The mud-cracked microbialite illustrated in Fig. 10 begins above a base that is partly laminated. The layer above is massive micrite with domal stromatolites. Fenestral pores (bird's eyes) occur in the dome on the right hand side. The vaguely laminated domes resemble to some extent the microbial mat of *Schizothrix calcicola* as figured by Monty (1967, Pl. 16-3). The sediment above the domes is micritic with numerous fenestrae (loferite). On top of it is a wavy laminite. This microbialite is directly above the top of the shallowing upward sequence 1 with ammonite-bearing marl-clay at the base and coral bioherms followed by calcareous oolite at the top.

3.1.2 Coarsely crinkled microbialites

The upper surface of a coarsely crinkled microbialite is depicted in Fig. 12. The axes of corrugation are twisted and branching. The height of the corrugations is as much as 7 mm. The lamination of the microbialites is best visible on weathered surfaces. The laminae are between 0.5 and 2 mm thick. Only 1 cm below the upper (photographed) surface, the laminae are only slightly undulating, almost flat. In a thin section of this part tiny sheet cracks are visible (Fig. 11).

A similar, wavy laminated microbialite is illustrated in Fig. 13. The corrugations are up to 5 mm high in the lower part of the microbialite. In the upper part the laminae are almost flat. The numerous dark blotches on the polished surface are probably rootlets.

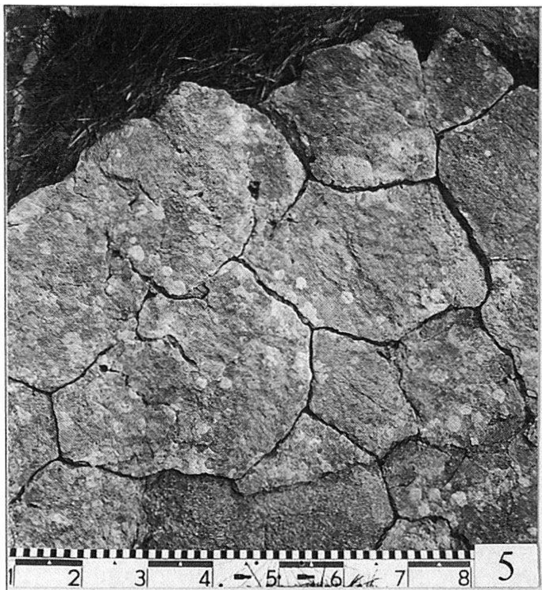
Fig. 5. Prism-cracked bedding plane of the upper Natica Member (NAT in Fig. 3), probably from inshore algal marsh. Section RG 417 at Crémines BE, bed no 42. Scale is in decimeters.

Fig. 6. Isolated prism with margins upwarped by dewatering. Same unit as in Fig. 5, section RG 414 at Grandval BE, bed no 21, sample Gy 4795. Scale bar is 2 cm.

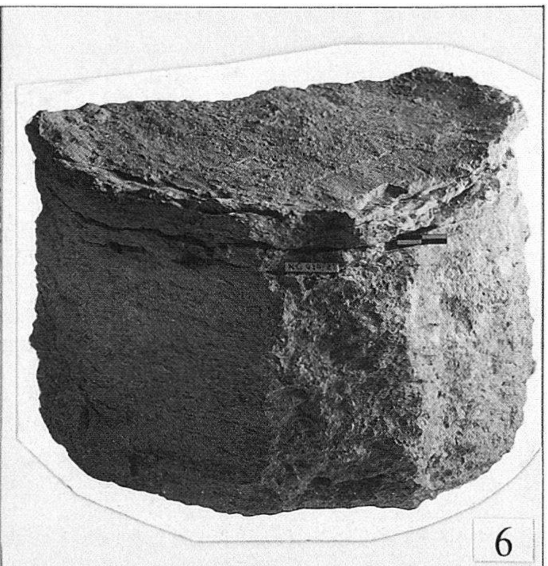
Fig. 7. Stratiform, laminated microbialite with dewatering cracks descending from the surface. Polished slab Gy 4454, lowermost Natica Member (NAT in Fig. 3), section RG 317 at Saulcy JU, bed no 52. Scale bar is 1 cm.

Fig. 8. Laminae of micrite and calcisiltite. Thin section Gy 6410 (positive print) of microbialite depicted in Fig. 7. Scale bar is 1 mm.

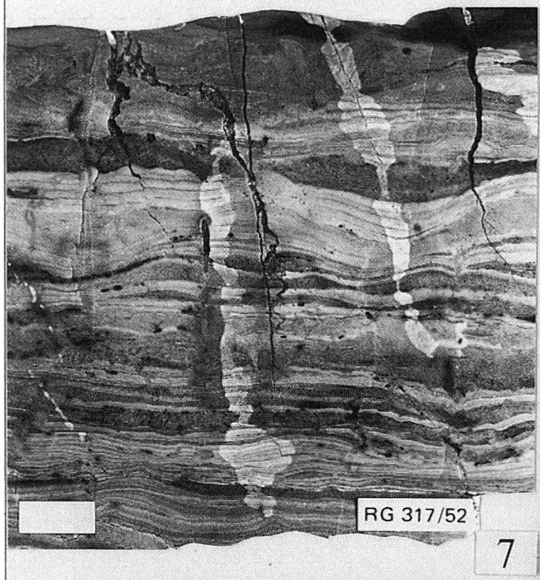
Fig. 9. Partly laminated, crinkled and cracked microbialite. Small tidal channel with some rounded mud pebbles at upper left. Polished slab Gy 4875, upper Günsberg Member (GÜN in Fig. 3), section RG 419 at Seehof BE, bed no 74b. Scale bar is 1 cm.



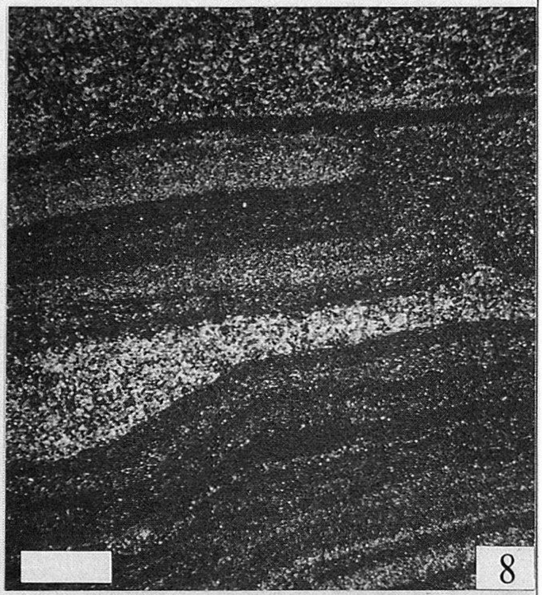
5



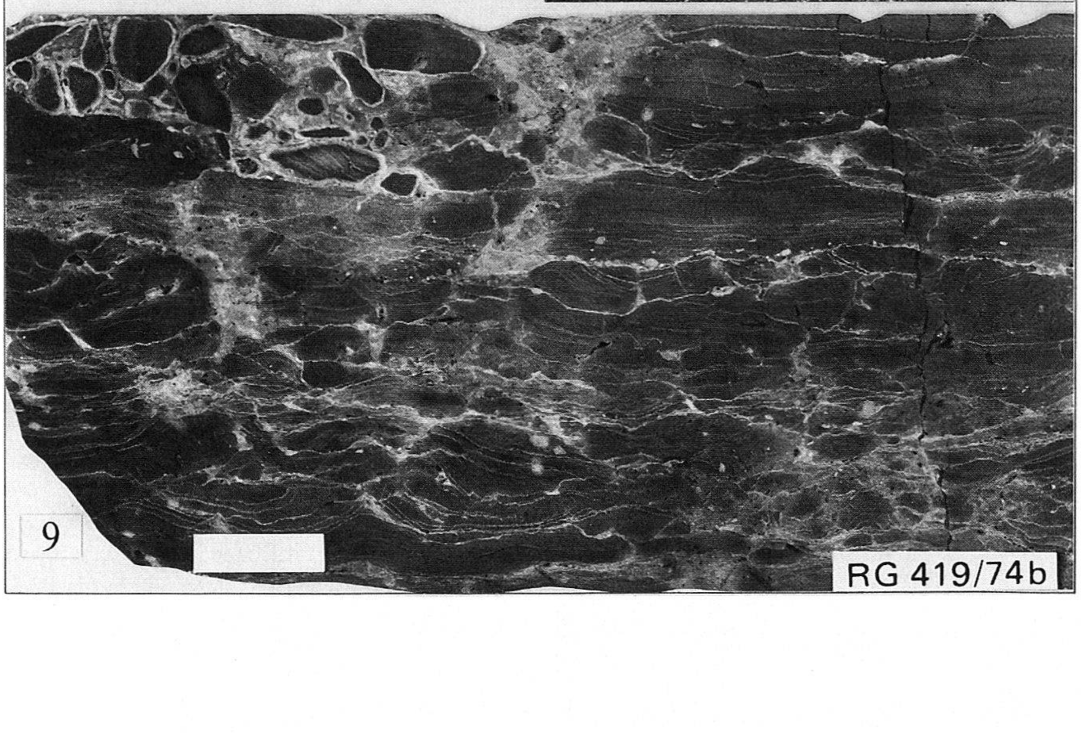
6



7



8



9

3.2 Oncoids from an open marine lagoon

The oncoids depicted in Fig. 14 are from the 4.5 m thick Green Oncolite Bed of the Günsberg Member. The groundmass is a biopelmicrite (thin section Gy 7242). Two meters above the base of the bed, the oncoids amount to 40 to 50% per volume of the rock. Small oncoids are well rounded. Large oncoids have a rounded, concentric laminated core which is coated by columnar microstromatolites. They may be asymmetric. The cores of the oncoids are mostly bioclasts of hermatypic corals (Fig. 15) or of ostreid bivalves. In the crusts, cloudy micrite occurs with readily visible traces of microbial filaments (Fig. 15 on the right). In the same bed isolated colonies of branching and massive corals in life position are found.

3.3 Microbialites from coral bioherms

One well-exposed coral bioherm of the Günsberg Member in sequence 2 (see Fig. 3) is found in the quarry of La Charuque near Péry BE (Fig. 19). The bioherm has an ill-defined internal bedding. It had a slight relief over the lateral alternation of limestone and marl (Fig. 19). The groundmass of the bioherm is biopelmicrite. Most coral colonies are massive, but there are some branching forms. The microbialites completely encrust essentially massive coral colonies. They form microcolumnar structures (Fig. 20) that may grow upward, sideways, or downward. Empty microbial tubes 30 to 70 microns in diameter occur in the crusts (Figs. 21 and 22).

A part of another bioherm with microbialites from the St-Ursanne Formation in sequence 1 (Fig. 3) is depicted in Fig. 18. The bioherm is small and contains massive corals of the genus *Microsolena* (see Fig. 18, lower right). Branching stromatolites growing from the coral surface are embedded in a groundmass of spiculitic biomicrite (thin sections Gy 6093 and 6094). Many of the stromatolite columns have an indistinct convex lamination. The laminae are between 1 and 2 millimeters thick.

3.4 Oncoids from the slope

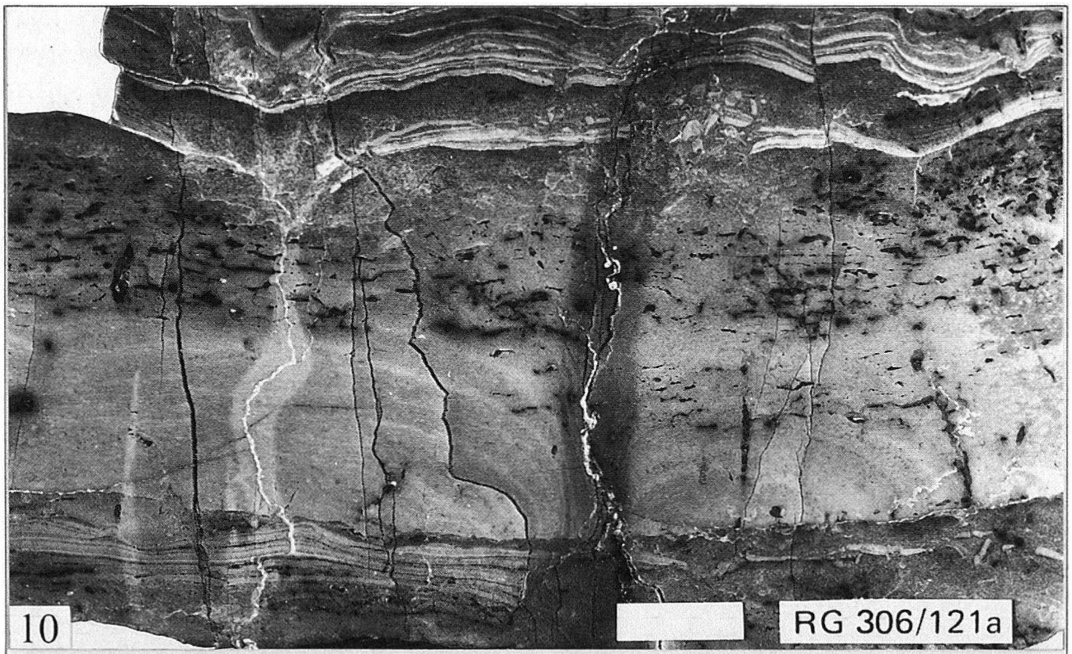
The oncoids from the slope (4 on Fig. 4) are centimeter-sized and lie in a spiculitic biomicrite. Their cores, generally bioclasts, are surrounded by a non-laminated cortex;

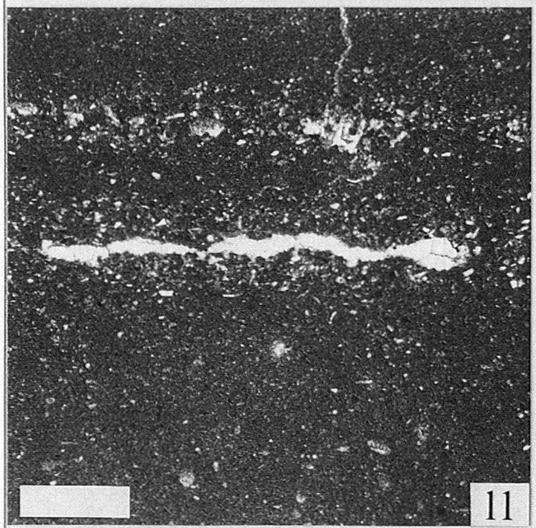
Fig. 10. Domal stromatolite growing on laminated base. Loferite with dark fenestrae in the middle part, followed by a wavy laminated microbialite at the top. Thin subvertical dewatering cracks. Upper intertidal zone. Polished slab Gy 4558, Vorbourg Member, section RG 306 at Liesberg BE, bed no 121a. Scale bar is 1 cm.

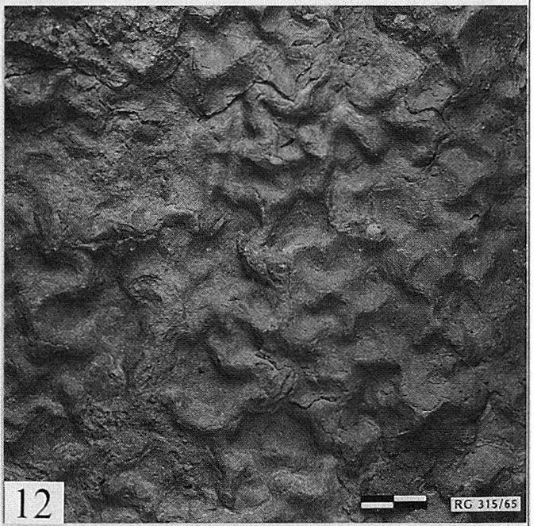
Fig. 11. Graded microbialite with sheet crack and small subvertical dewatering crack. Thin section Gy 5585 (positive print), lower Natica Member, section RG 315 at Sornetan BE, bed no 65. Scale bar is 500 microns. Detail from microbialite depicted in Fig. 12.

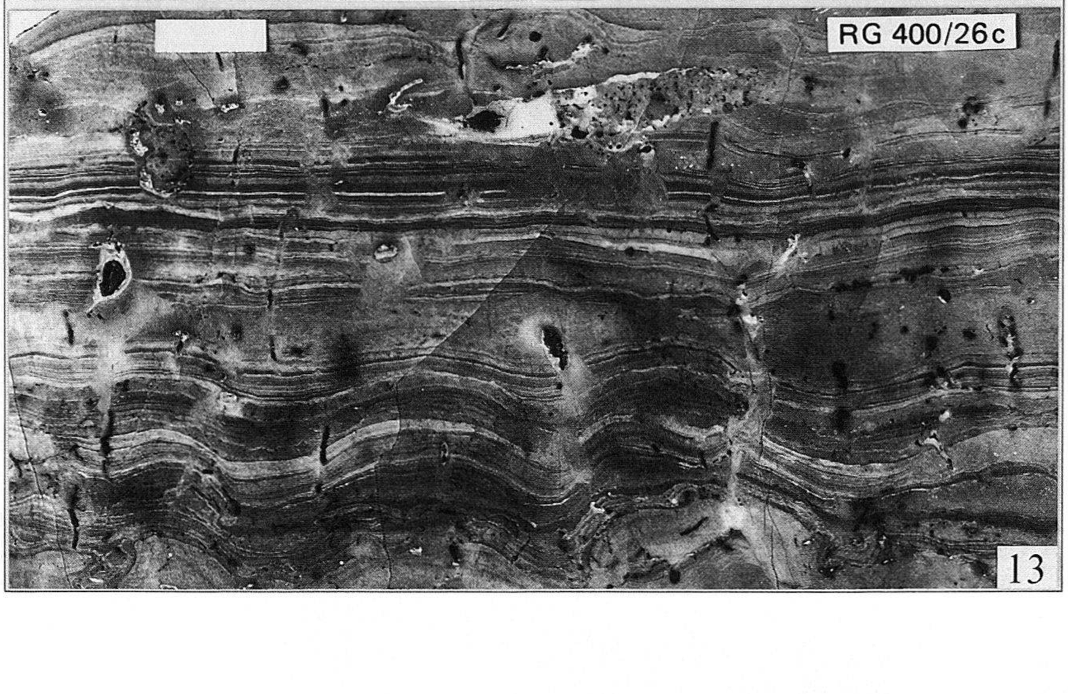
Fig. 12. Crinkled microbialite of the upper intertidal zone. Bedding plane, sample Gy 4928, lower Natica Member, section RG 315 at Sornetan BE, bed no 65. Scale bar is 2 cm.

Fig. 13. Wavy (base) and flat laminated (top) microbialite. Dark blotches and filaments are probably rootlets. Polished slab Gy 4621, Vorbourg Member, section RG 400 at Corban JU, bed no 26c. Scale bar is 1 cm.


10
RG 306/121a


11


12
RG 315/65


RG 400/26c
13

the latter is made of a cloudy bioclastic micrite infilling the spaces between a frame of carbonate tubes of the worm *Cycloserpula* (Fig. 17). Fine-grained glauconite impregnates the surficial part of the oncoids (Fig. 16) which may be locally disrupted by shrinkage cracks. Many of the larger bioclasts found in the cortex have been bored and the borings partly filled with glauconite. These oncoids are from the early Kimmeridgian transition beds between the lowermost Reuchenette Formation and the lower Baden Member. They resemble the millimeter-sized glauconitic oncoids in the late Oxfordian Crenularis Member underneath which have been described and figured in Gygi (1969, Pl. 5, Fig. 21).

3.5 Microbialites from sponge bioherms

The sponge bioherms of the late Oxfordian Villigen Formation in northern Switzerland are not well-known. One of these is illustrated in Fig. 23.

Tuberoids (Fig. 24) are small micritic nodules of differing size with an irregular shape. They were named by Fritz (1958, p. 77). Unlike typical oncoids, tuberoids do not normally have any concentric lamination. The tuberoid illustrated in Fig. 24 has a lobate contour and an ahermatypic solitary coral as a core. The micrite of the tuberoid is cloudy and includes many milky-white nodules of sessile nubeculariid foraminifers (*Vinelloidea*). In the lower left corner of the tuberoid is a part of a siliceous sponge with a calcitized skeleton (see arrow in the photograph). The boundary of the sponge part within the tuberoid is transitional.

The toppled siliceous sponge (*Sporadopyle* sp.?) of Fig. 25 has a well visible calcitized skeleton. The microbialitic crust on top of the sponge is not laminated. The crust consists of cloudy, inhomogenous micrite with aggregates of sessile foraminifers (light blotches on the upper left). The micrite of the crusts in this sponge bioherm is indistinguishable from the micrite within sponge skeletons or within tuberoids.

3.6 Stromatolites associated with oolitic ironstones

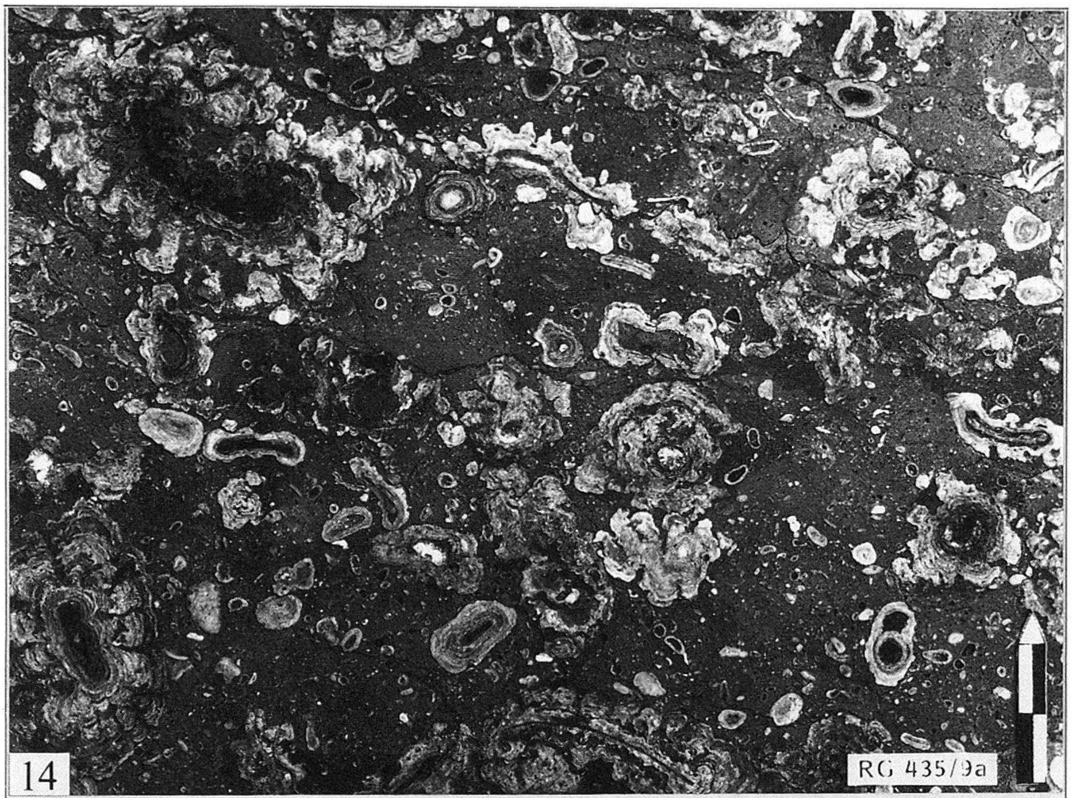
The middle Bathonian iron oolitic bed of Fig. 28 is about 8 cm thick. It consists of a ferriferous, biomicritic groundmass containing numerous bivalves, mainly ostreids.

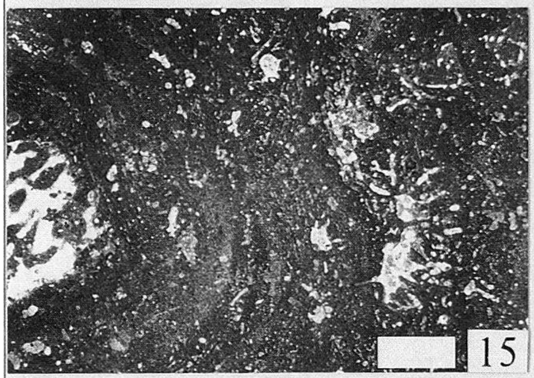
Fig. 14. Lobate oncoids in a biomicritic groundmass. Polished surface perpendicular to the bedding, sample Gy 5059, Green Oncolite Bed (Grüne Mumienbank) with hermatypic corals of the Günsberg Member, section RG 435 at Péry BE, bed no 9a. Scale bar is 2 cm.

Fig. 15. Central part of a lobate oncoid from the unit depicted in Fig. 14, same locality. Coral bioclast in the core at left, microbial filaments at right. Thin section Gy 7242 (positive print), Péry BE. Scale bar is 1 mm.

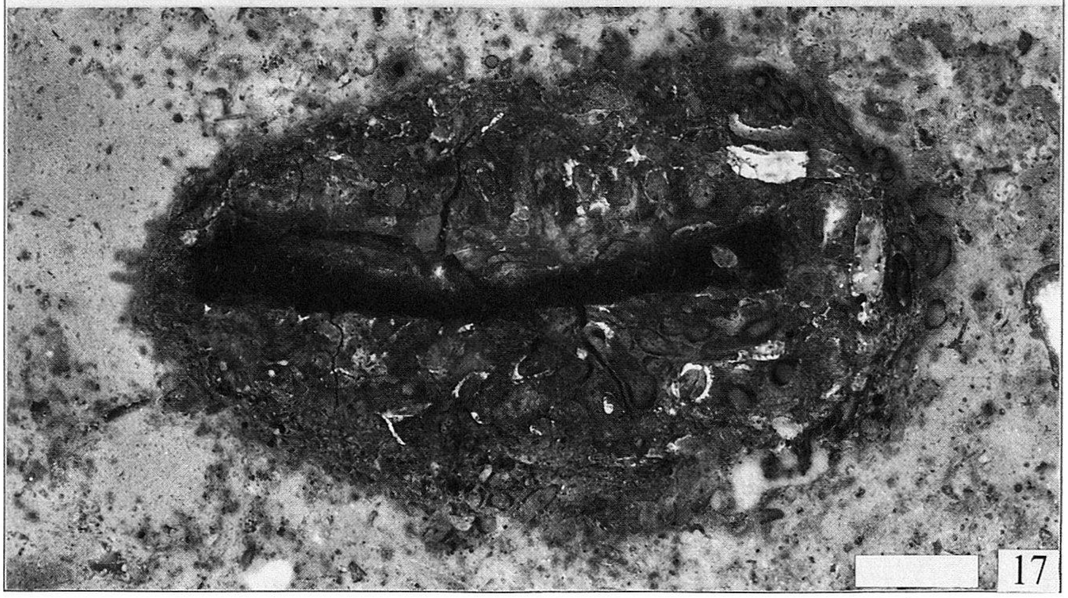
Fig. 16. Surficial part of oncoid from the same unit and locality as depicted in Fig. 17. Gastropod bioclast with algal borings about 10 microns thick. The boreholes are filled with glauconite (dark grey). Thin section Gy 7367, scale bar is 100 microns.

Fig. 17. Oncoid in biomicritic, spiculitic groundmass with ammonites. The core is an algally bored bivalve bioclast encrusted with *Cycloserpula*. The matrix within the oncoid is impregnated with glauconite mainly near the surface. Water depth: between 40 and 50 m. Polished slab Gy 498, lower Baden Member, lowermost Kimmeridgian, section RG 28 at Schönenwerd SO, bed no 47. Scale bar is 2 mm.


14


15


16


17

The essentially chamositic iron ooids are concentrated in the uppermost part of the bed. Locally, the bed forms subhorizontal overhangs from which green, tuberculate accretions of chamosite grow downwards (endostromatolites sensu Monty, 1982). The upper surface of the bed is covered by a similar grey-green crust that may be thicker than 1 cm in places (Fig. 28, infill at the upper left). The upper surface of the crust is glossy and mammillate (cf. Fig. 30). The age of the uppermost part of the crust near Veltheim is probably early Oxfordian to judge from an ammonite found near the neighbouring village of Holderbank in a lens just below the crust (Gygi & Marchand 1982, p. 523). In cross-section, such crusts are finely laminated (top of Fig. 28) and may contain millimeter-size laminated domes (Fig. 29). The cross-section of one of these dome-like structures is visible in Fig. 28 (arrow on top of photograph). The laminae of such domes consist of calcareous micrite, phosphorite and goethite. Fungal filaments and capsules can be found within the laminae (Figs. 26 and 27).

The thin bed with ammonites illustrated in Fig. 28 is above a calcarenite with inclined bedding (Spatkalk Member) of early Bathonian age without ammonites. The thin bed of Fig. 28 with a rich macrofauna of the middle Bathonian is a transgressive sediment that was deposited in the deeper subtidal zone. The upper part of the crust on top of the bed was formed in Oxfordian time at a depth approaching 100 m (Gygi 1981, Gygi & Marchand 1982).

Substantially larger columnar stromatolites (Fig. 31) have been found near Dangstetten, southernmost Germany, where they form a bed about 5 cm thick. The bed is delineated below and above by a shining film of goethite. The groundmass is ferriferous biomicrite with abundant bioclasts of echinoderms. There are few goethitic iron oooids and some glauconite pellets with an oxidized surface. The lower part of the columns is not laminated and includes numerous small, angular or rounded lithoclasts. The upper part of the columns is laminated with wavy to finely crinkled laminae. Ammonites are common in the lower part of the bed. The bed has an early Oxfordian age like the crust of Figs. 28 and 29.

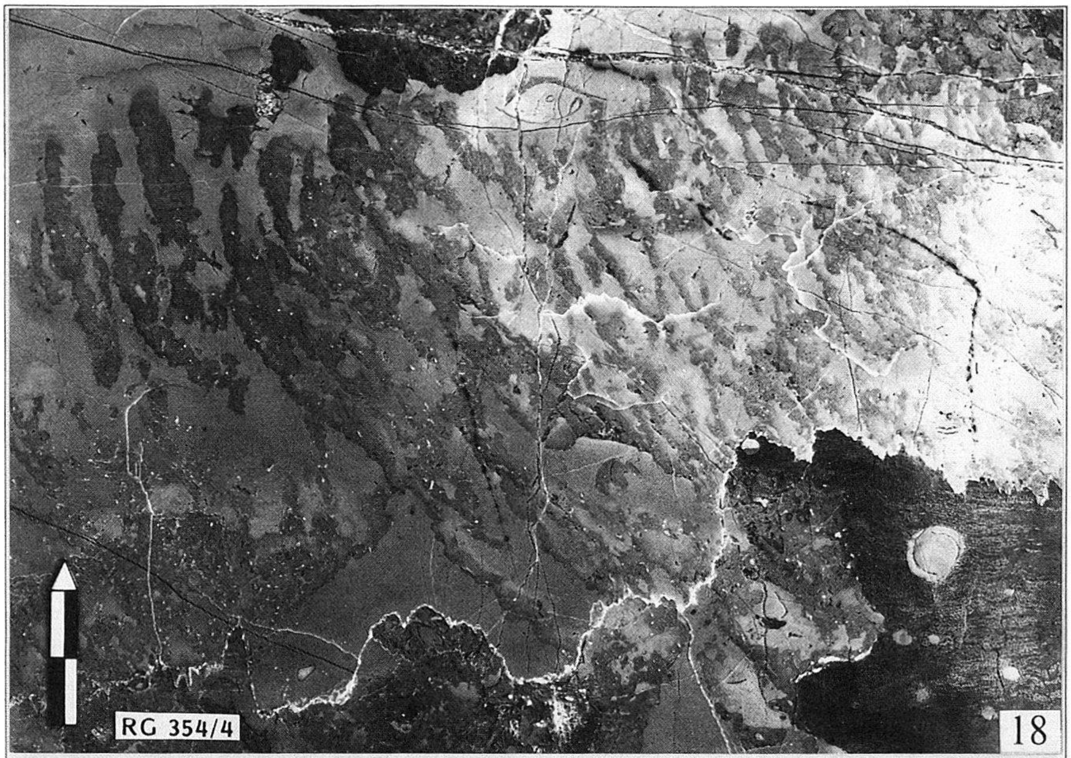
Fig. 18. Columnar microbialites on hermatypic corals bounded by stylolite. Polished slab Gy 4120 from coral bioherm in the St-Ursanne Formation (SUF in Fig. 3), section RG 354 at Bassecourt JU, bed no 4. Scale bar is 2 cm.

Fig. 19. Coral bioherm (left) with ill-defined internal bedding. The bedded sediment to the right of the bioherm is an alternation of silty, marly limestone and marl. The height of the picture is about 7 m. Günsberg Member, section RG 307 in the quarry of La Charuque at Péry BE, bed no 160.

Fig. 20. Hermatypic colonial coral from biohem depicted in Fig. 19 with columnar microbialite at the upper surface, covered by biomicrite. Thin section Gy 7363 (positive print), section RG 307 at Péry BE, bed no 160c. Scale bar is 2 mm.

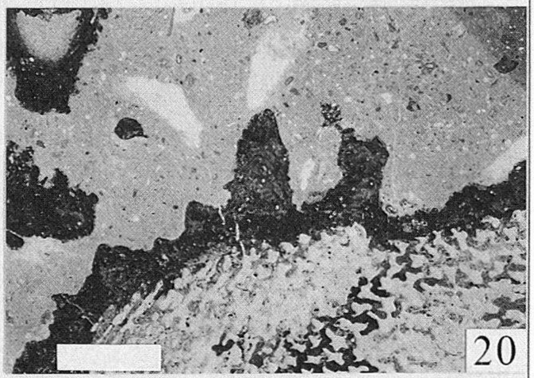
Fig. 21. Detail from microbialite depicted in Fig. 20 with empty tubes of presumed algal origin. Scanning electron microscope, scale bar is 100 microns.

Fig. 22. Enlarged empty algal tube. Scanning electron microscope, scale bar is 10 microns.

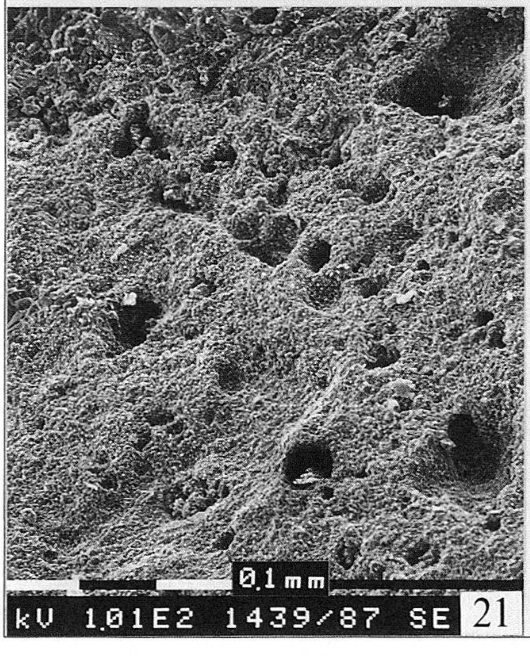


18

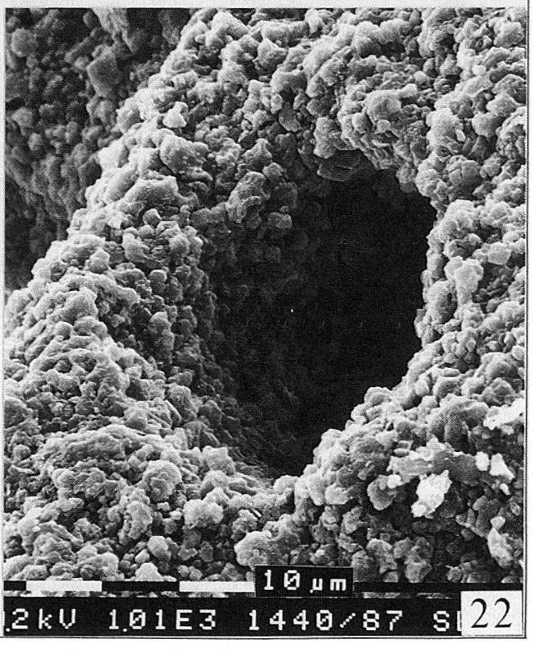
19



20



21



22

3.7 Crusts and oncoids of the basin floor (depth over 100 m)

3.7.1 Crusts on siliceous sponges

Dish-shaped siliceous sponges (*Discophyma* sp.) are less than 1 cm thick, but such specimens can grow to a diameter of 70 cm. There are irregular cavities in the sponges that are partly filled with geopetal mud and silt (Fig. 33). The sponges may be encrusted by microbial accretions such as illustrated in Fig. 32. These accretions grow on the upper surface of the sponges and may reach a thickness of up to 15 mm. Such crusts are not laminated. They consist of dark micrite with abundant light patches of microspar that give the crust a spongy appearance (Fig. 33). Arenaceous foraminifers are found within the crusts. The groundmass around the sponge is a spiculitic biomicrite with common glauconite pellets and tuberoids of various sizes. Dark tuberoids are found directly below the sponge. Ammonites are fairly abundant in the bed. They are the dominant group in the macrofauna except the siliceous sponges.

3.7.2 Oncoids of the ammonite facies

The oncoid illustrated in Fig. 35 is from the Mumienkalk Bed of the middle Oxfordian. There is a small eccentric lithoclast as a core. The oncoid is almost spherical. The crusts are distinctly laminated. They include abundant glauconite pellets. There are shrinkage cracks in the central part of the oncoid. Such small subspherical oncoids are exceptional in the ammonite facies.

The oncoids of the basin floor are normally larger and have an ammonite or an ammonite fragment as a core. The crust on the underside of the oncoids is laminated. At the upper side of the oncoid, the crust is indistinctly laminated (Fig. 34). The crust includes glauconite pellets. Towards the upper oncoid surface, the crust becomes increasingly ferriferous. There are shrinkage cracks in the ferriferous part of the crust. The filling of the ammonite in the core has a geopetal structure. This indicates that the ammonite was overturned at least twice during its fossilization.

Fig. 23. Sponge bioherm within the Crenularis Member of the Villigen Formation. The bedded micritic limestones of the Wangen Member above are flat lying. Scale bar is 1 m. Section RG 70 at Mellikon AG.

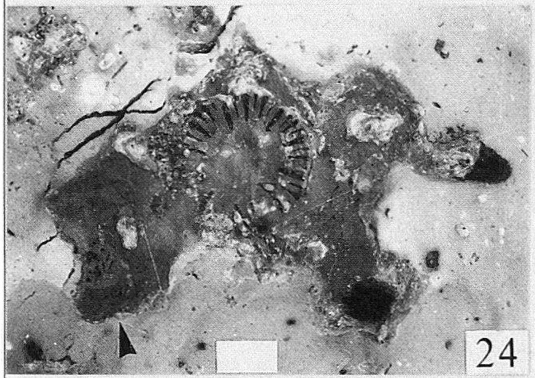
Fig. 24. Tuberoid with solitary ahermatypic coral encrusted with microbialite and nubeculariid foraminifers (light blotches), from sponge bioherm depicted near the scale bar in Fig. 23. Water depth: about 80 m. Section RG 70 at Mellikon AG, bed no 17, polished slab Gy 1460. Scale bar is 1 mm.

Fig. 25. Siliceous sponge *Sporadopyle* sp. with microbialitic crust and encrusting foraminifers (*Vinelloidea*) at upper side. From the same polished slab as depicted in Fig. 24. Scale bar is 2 mm.

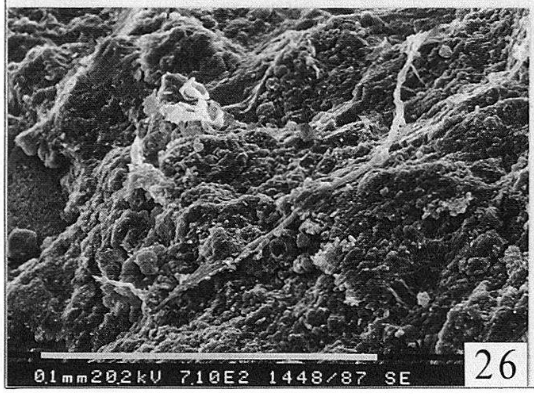
Fig. 26. Calcareous/ferruginous microbialite with goethitic filament of probably fungal origin. Scanning electron microscope, scale bar is 100 microns. Detail from Fig. 29. Section RG 226 at Veltheim AG, bed no 28, uppermost part.

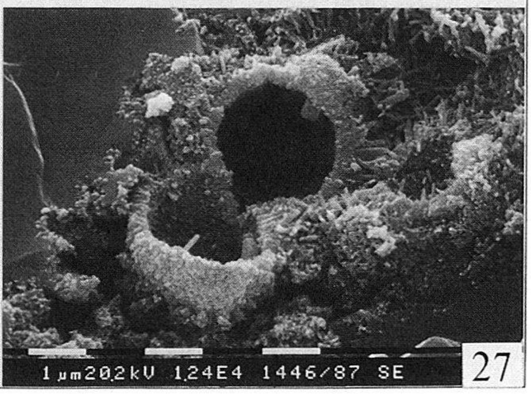
Fig. 27. Two empty goethitic capsules in acicular goethite. Large calcite crystal at left. Detail from microbialite depicted in Fig. 26. Scanning electron microscope, scale bar is 1 micron.


23


24


25


26


27

Another oncoid with an ammonite in the core is depicted in Fig. 36. The geopetal sediments in two chambers of the ammonite phragmocone are upside down. They prove that the ammonite has been overturned at least once during its fossilization. A second-stage geopetal sediment in the chamber on the right is in a normal position. The oncolitic crust is indistinctly laminated. Glauconite pellets (black dots) are abundant. The crust is asymmetrical: on the lower side it is unaltered, while on the upper side of the oncoid, the crust is corroded and impregnated with limonite from the upper surface.

4. Discussion

1) The majority o the figured microbial laminites with prism cracks have a variable abundance of fenestral pores (bird's eyes, see Fig. 10). This indicates that the microbialites were formed on a tidal flat (Shinn 1968) with a high exposure index (Ginsburg et al. 1977). The great depth of some of the prism cracks (Fig. 6) also indicates a high exposure index, but caution must be taken with this conclusion, because deep prism cracks may also form in intertidal lime mud that is regularly flooded (see Hardie & Garrett 1977, Fig. 28). A high exposure index is probable for the microbialite of Fig. 6 because abundant characean gyrogonites were found 0.45 m below the bed. The dome-like stromatolites of Fig. 10 resemble modern "pincushions" of *Scytonema* in cross-section as figured by Hardie & Garrett (1977, Fig. 18) that grow at the edge of a pond. The prism-cracked microbialites figured in this paper were formed by dewatering during exposure. They cannot be compared with the polygonal algal mats described from the middle intertidal zone of the Persian Gulf by Kendall & Skipwith (1968, Fig. 5). They rather resemble the mud-cracked algal mats from the high algal marsh zone of western Andros Island in the Bahamas as figured by Hardie & Garrett (1977, Fig. 17), or the polygonal prims cracks in the upper intertidal zone of Hamelin Pool, Western Australia (see Logan et al. 1974, Fig. 9 A).

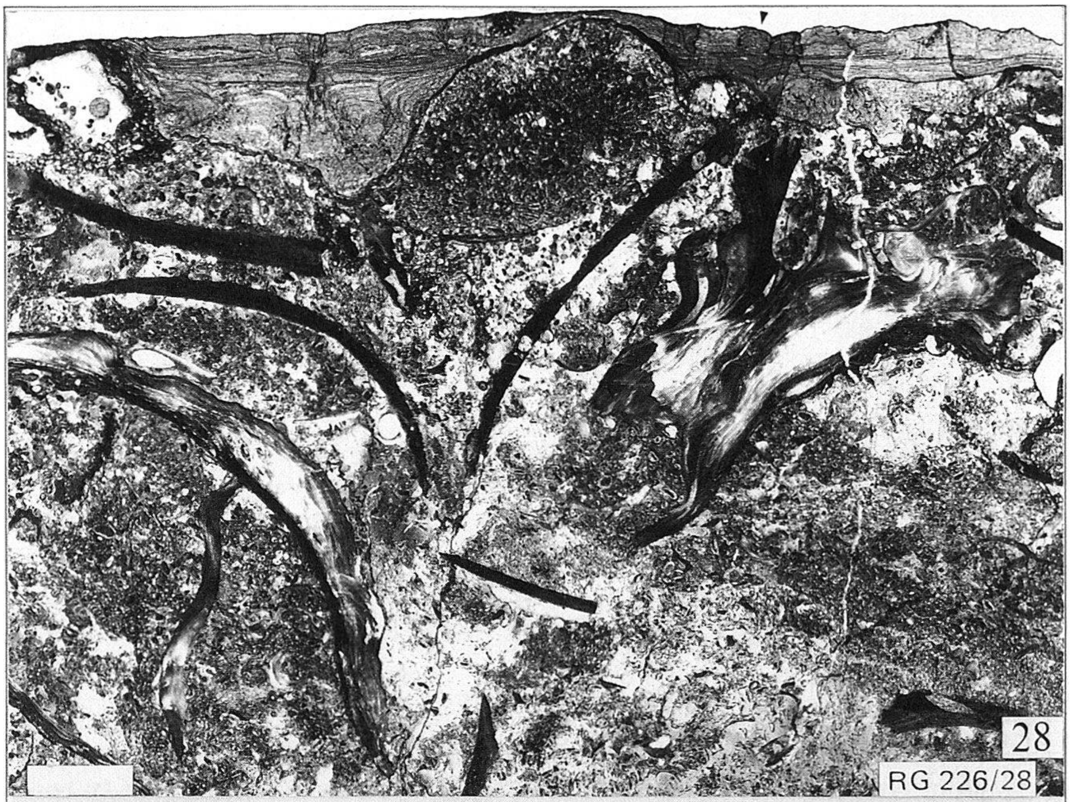
The coarsely crinkled microbial laminite of Fig. 12 has a good resemblance with the crinkled algal mat from the upper intertidal zone of the Persian Gulf in Kendall & Skipwith (1968, Fig. 2 F and 5).

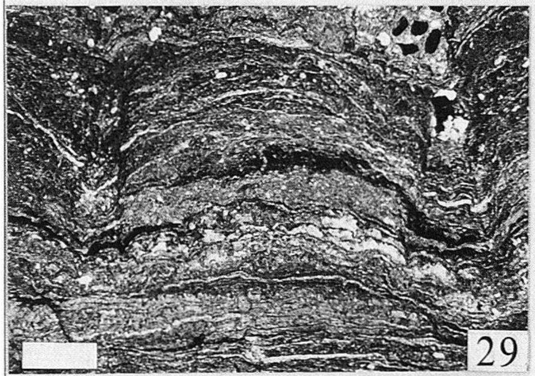
Fig. 28. Iron oolitic biomicrite of the middle Bathonian with large ostreid bivalves covered by a calcareous/phosphatic/goethitic microbialite. Small arrow points to dome as depicted in Fig. 29. These domes are probably of Oxfordian age (see text). Polished slab Gy 3099, section RG 226 at Veltheim AG, bed no 28 (middle Bathonian). Scale bar is 1 cm.

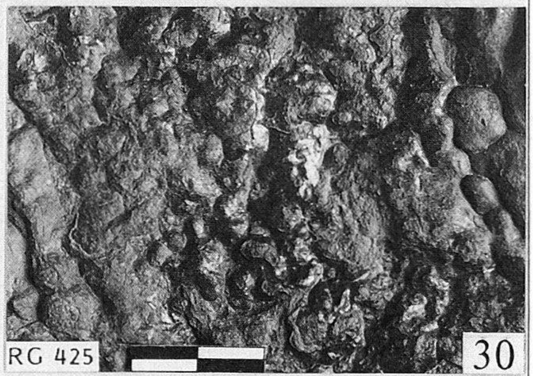
Fig. 29. Microbialitic dome with mixed layers of calcareous micrite (homogenous grey), phosphorite (patchy grey), and goethite (dark). Thin section Gy 7352 (positive print), section RG 226 at Veltheim AG, bed no 28, uppermost part, probably time-equivalent to the Schellenbrücke Bed, early Oxfordian. Scale bar is 500 microns.

Fig. 30. Glossy upper surface of a mammillate microbialite of calcareous micrite and goethite. Water depth: approaching 100 m. Sample Gy 4920, locality RG 425 at Zurzach AG, Schellenbrücke Bed, early Oxfordian. Scale bar is 2 cm.

Fig. 31. Domal iron oolithic microbialite with bioclasts and lithoclasts. Water depth: around 90 m. Polished surface of sample Gy 1666, section RG 73 at Dangstetten, Germany, bed no 3 (Schellenbrücke Bed). Scale bar is 1 cm.


28


29


30


31

2) Oncoids like the ones depicted in Fig. 14 do not exist in the modern marine environment (Monty 1974, p. 612). They were lithified already at the state of growth, because many of these oncoids are bored by the bivalve *Lithodomus* sp. (Gygi 1969, Pl. 10, Fig. 37). They grew in an unrestricted lagoon with normal salinity, because they are associated with hermatypic coral colonies. The larger oncoids were probably overturned or rolled only at irregular intervals during storms. Accordingly, they grew asymmetrically.

3) The columnar and microcolumnar microbialites of coral bioherms grew in a somewhat protected environment. They constitute only a few percent by volume of the bioherms. The Oxfordian coral bioherms of platform margins cannot be compared with modern counterparts. They have mostly a muddy matrix and a low density of coral growth. As far as we know, the bioherms are always isolated and did not coalesce into a barrier reef. The bioherms probably grew in the shallow subtidal zone. They had never a great relief above the neighbouring sea floor.

4) The oncoids of the upper slope were lithified during growth like the lagoonal oncoids. They formed by microbial intergrowth with serpulid worms on a soft bottom of carbonate mud. They were rolled probably only during storms, because the depth of formation was several tens of meters (Fig. 4). It is possible that they were seldom overturned because there are no distinct discontinuities in the crust.

5) The tuberoids within and beside sponge bioherms must have been overturned from time to time because the tuberoid of Fig. 24 occurs with bivalve shells that may be encrusted on both sides (Gygi 1969, Pl. 6, Fig. 23). A paleodepth of ca 80 m is concluded for the sponge bioherms of Mellikon (Fig. 23) from the composition of the associated ammonite fauna, according to the scheme in Gygi (1986, Fig. 6A).

6) The ferriferous stromatolites of the Schellenbrücke Bed range from a thickness of several centimeters (Figs. 30 and 31) to a few millimeters (Figs. 28 and 29). Gygi (1981,

---

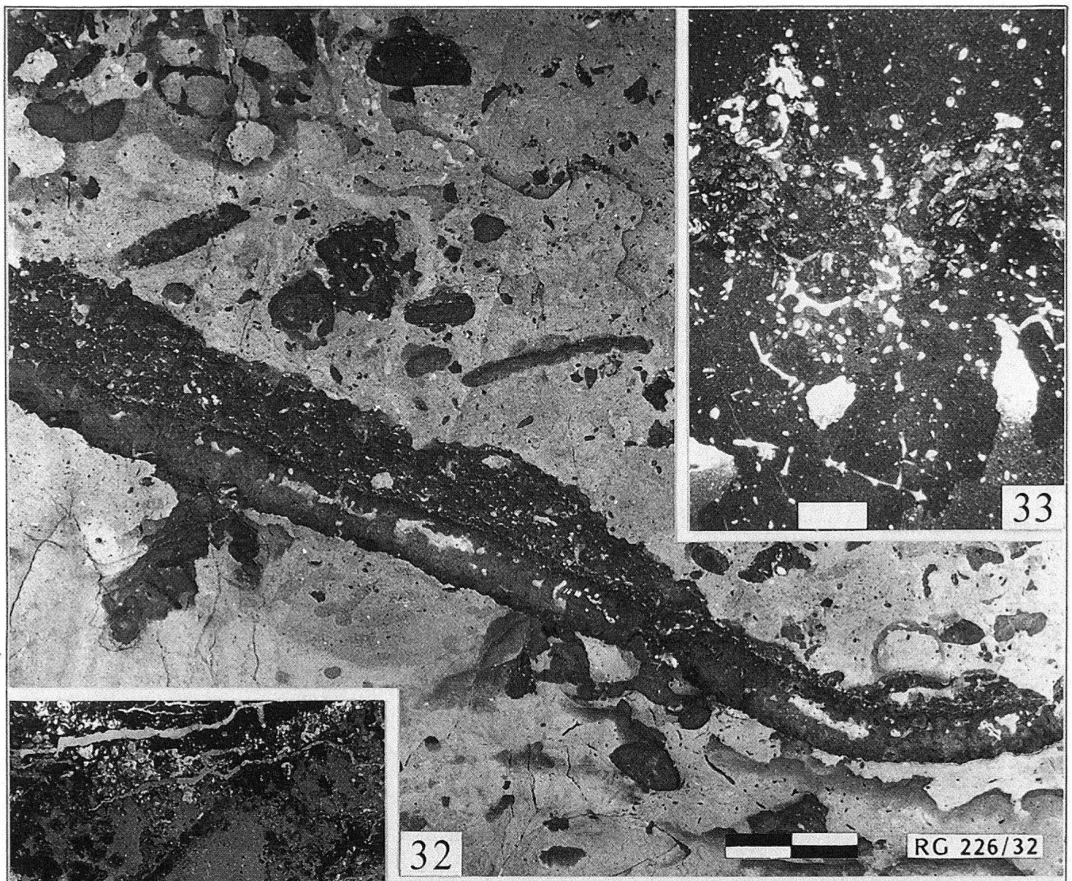
Fig. 32. Dish-shaped siliceous sponge (*Discophyma* sp.) less than 1 cm thick with light cavities and with dark, granular microbialitic crust at the upper surface. The matrix is glauconitic biomicrite with tuberoids of varying size. Water depth: more than 120 m. Polished slab Gy 3101 from the Birmenstorf Member, middle Oxfordian, section RG 226 at Veltheim AG, bed no 32. Scale bar is 2 cm.

Fig. 33. Siliceous sponge *Discophyma* sp. below with cavities filled with coarsening upward sediment, domal microbialitic crust in the middle, and biomicritic matrix above. Detail from the sample Gy 3101 depicted in Fig. 32, thin section Gy 7098 (positive print). Scale bar is 1 mm.

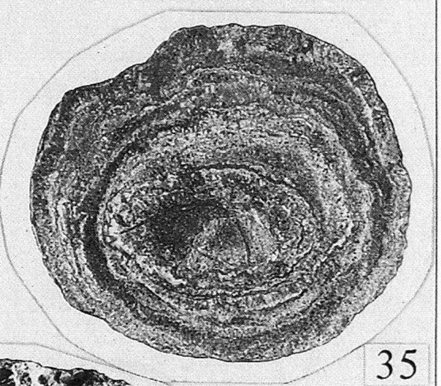
Fig. 34. Cross-cut ammonite *Ochetoceras canaliculatum* (Von Buch) with geopetal filling in the large chamber on the left. The ammonite is enveloped in glauconitic (dark spots) and ferriferous crusts (dark blotches). There are shrinkage cracks in the ferriferous crusts. Thin section Gy 7349 (positive print), from section RG 212 at Siblingen SH, bed no 8 (Mumienkalk Bed, middle Oxfordian). The height of the picture is 3 cm.

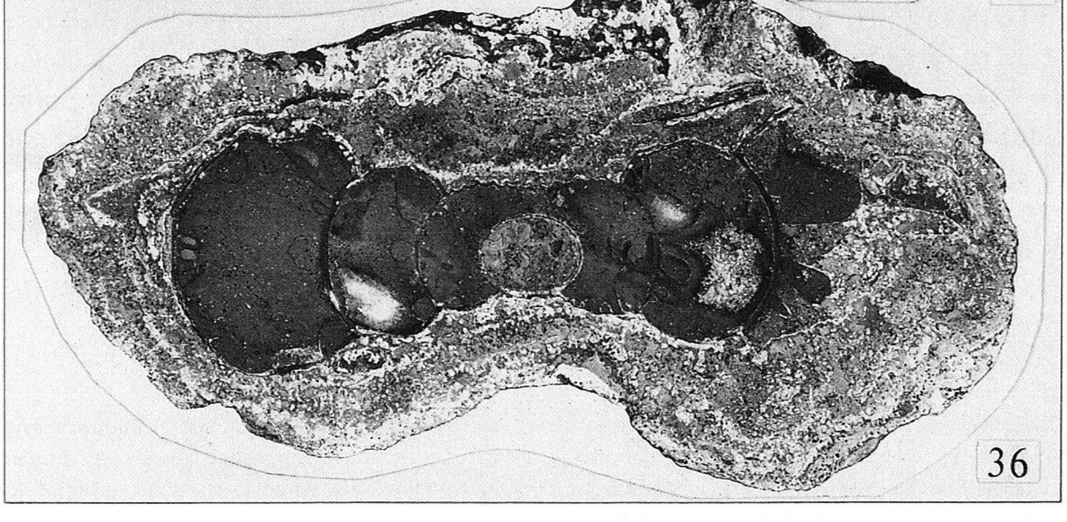
Fig. 35. Polished surface of deep-water oncoid Gy 7448 cut near the centre. Fine dark spots are glauconite. Water depth: more than 120 m. From section RG 207 at Siblingen SH, bed no 16a (Mumienkalk Bed). The long diameter of the oncoid is 3.2 cm.

Fig. 36. Cross-cut ammonite (perisphinctid) with oncolitic crust Gy 7449. Two oblique geopetal chamber fillings indicate that the ammonite cast is upside down. Water depth: more than 120 m. From section RG 212 at Siblingen SH, bed no 7 (Mumienmergel Bed, middle Oxfordian). The diameter of the oncoid is 7.3 cm.


33
32
RG 226/32


34


35


36

p. 245) concluded on several, independent lines of evidence that the depth of deposition of the Schellenbrücke Bed was between 80 and 100 m. The crust on the upper surface of the bed most probably represents an oceanic hardground that formed slowly during a period of basin starvation. These ferriferous and partly glauconitic microbialites can be compared with the ones described by Szulczewski (1968) from the Jurassic of Poland. The polish microbialites are also associated with a rich ammonite fauna, condensed sedimentation and with hiatuses.

7) The microbialites of the Mumienmergel Bed and the Mumienkalk Bed (Figs. 35 and 36) are the most difficult to interpret. The small, near-spherical oncoids with laminated, concentric crusts must have been overturned rather frequently, probably during violent storms. The matrix of argillaceous and carbonate mud indicates that the water above the sediment was normally quiet. The macrofauna is evidence that the water was at least 120 m deep (Gygi et al. 1979, Tab. 12, and Gygi 1986, Fig. 6). The largest oncoids with ammonites in the core have a diameter of as much as 30 cm (Gygi et al. 1979, p. 943). The internal sediments within the larger ammonites indicate that the ammonites were first embedded in lime mud, fossilized, and then winnowed clear of sediment. They were overturned only a few times as far as can be concluded from the internal sediments (see above). The oncolithic crusts on larger ammonites are not concentric. This is evidence that they are not diagenetic concretions. A problem with such large oncoids is how they could be overturned in deep, quiet water. The taphonomy of the Mumienkalk Bed was described and discussed at length by Gygi et al. (1979).

5. Conclusions

The described microbialites are from the following environments (see Fig. 4):

1) Tidal flat
2) Open marine lagoon
3) Coral bioherm
4) Upper slope
5) Deepwater sponge bioherm
6) Deepwater oolitic ironstone
7) Basin floor

The conclusions about the above environments are the result of 30 years of research on the Late Jurassic of northern Switzerland. They are based on the combined evidence of facies analysis, the distribution of macrofossil assemblages, ammonite taxonomy and stratigraphy, taphonomy, sedimentology of fossil and recent sediments, refined correlation, the geometry of sediments and calculations of compaction and subsidence. There is no room here to repeat the conclusions of the pertinent earlier papers that are given in the references.

Acknowledgments

The fieldwork used in this study was mainly funded by the Swiss National Science Foundation grants no 2.211.69 and no. 2.165-0.78. The majority of the thin sections and of the polished slabs were prepared by K. Müller. The photographs with the scanning electron microscope were made in the laboratory of R. Guggenheim. The photograph no 23 is by S. Dahint (the rest are by the author). S. Gygi typed the manuscript. C. Monty and R. Riding critically read the manuscript and made helpful suggestions. The writer wishes to thank the foundation and the persons mentioned above for their support.

REFERENCES

BOLLIGER, W. & BURRI, P. 1967: Versuch einer Zeitkorrelation zwischen Plattformcarbonaten und tiefermarinen Sedimenten mit Hilfe von Quarz-Feldspat-Schüttungen (mittlerer Malm des Schweizer Jura). Eclogae geol. Helv. 60, 491–507.

DREYFUSS, M. 1954: Le Jura dans les mers du Jurassique supérieur. Essay sur la sédimentation et la paléogéographie dans leur rapport avec les déformations. Mém. Soc. géol. France N.S. 33, 1–62.

FRITZ, G. K. 1958: Schwammstotzen, Tuberolithe und Schuttbreccien im Weissen Jura der Schwäbischen Alb. Arb. geol.-paläont. Inst. T.H. Stuttgart N.F. 13, 1–118.

GINSBURG, R. N., HARDIE, L. A., BRICKER, O. P., GARRETT, P. & WANLESS, H. R. 1977: Exposure index: a quantitative approach to defining position within the tidal zone. In: Sedimentation on the Modern carbonate tidal flats of northwest Andros Island, Bahamas (Ed. by HARDIE, L. A.). Johns Hopkins Univ. Stud. Geol. 22, 7–11.

GRESSLY, A. 1838–41: Observations géologiques sur le Jura soleurois. Denkschr. schweiz. Ges. Natw. 2, 4, 5.

GYGI, R. A. 1969: Zur Stratigraphie der Oxford-Stufe (oberes Jura-System) der Nordschweiz und des süddeutschen Grenzgebietes. Beitr. geol. Karte Schweiz N.F. 136.

– 1981: Oolitic iron formations: marine or not marine? Eclogae geol. Helv. 74, 233–254.

– 1986: Eustatic sea level changes of the Oxfordian (Late Jurassic) and their effect documented in sediments and fossil assemblages of an epicontinental sea. Eclogae geol. Helv. 79, 455–491.

GYGI, R. A. & MARCHAND, D. 1982: Les Cardioceratinae (Ammonoidea) du Callovien terminal et de l'Oxfordien inférieur et moyen (Jurassique) de la Suisse septentrionale: Stratigraphie, paléoécologie, taxonomie préliminaire. Geobios 15, 517–571.

GYGI, R. A. & PERSOZ, F. 1986: Mineralostratigraphy, litho- and biostratigraphy combined in correlation of the Oxfordian (Late Jurassic) formations of the Swiss Jura range. Eclogae geol. Helv. 79, 385–454.

– 1987: The epicontinental sea of Swabia (southern Germany) in the late Jurassic – factors controlling sedimentation. N. Jb. Geol. Paläont. Abh. 176, 49–65.

GYGI, R. A., SADATI, S.-M. & ZEISS, A. 1979: Neue Funde von *Paraspidoceras* (Ammonoidea) aus dem Oberen Jura von Mitteleuropa – Taxonomie, Ökologie, Stratigraphie. Eclogae geol. Helv. 72, 897–952.

HARDIE, L. A. & GARRETT, P. 1977: General environmental setting. In: Sedimentation on the modern carbonate tidal flats of northwest Andros Island, Bahamas (Ed. by HARDIE, L. A.). Johns Hopkins Univ. Stud. Geol. 22, 12–49.

KENDALL, C. G. S. C. & SKIPWITH, P. A. 1968: Recent agal mats of a Persian Gulf lagoon. J. sediment. Petrol. 38, 1040–1058.

KUGLER, C. 1987: Die Wildegg-Formation im Ostjura und die Schilt-Formation im östlichen Helvetikum; ein Vergleich. Mitt. geol. Inst. ETH Univ. Zürich N.F. 259.

LOGAN, B. W., HOFFMANN, P. & GEBELEIN, C. D. 1974: Algal mats, cryptalgal fabrics, and structures, Hamelin Pool, Western Australia. Amer. Assoc. Petroleum Geol. Mem. 22, 140–194.

MONTY, C. L. V. 1967: Distribution and structure of Recent stromatolitic algal mats, eastern Andros Island, Bahamas. Ann. Soc. Géol. Belgique 90/3, 55–100.

– 1974: Precambrian background and Phanerozoic history of stromatolitic communities, an overview. Ann. Soc. géol. Belgique 96, 1973, 585–624.

– 1982: Cavity or fissure dwelling stromatolites (endostromatolites) from Belgian Devonian mud mounds (extended abstract). Ann. Soc. géol. Belgique 105, 343–344.

OPPEL, A. 1856–58: Die Juraformation Englands, Frankreichs und des südwestlichen Deutschlands. Jh. württemb. natw. Ver. 12–14, 1–857.

PURSER, B. H. 1979: Middle Jurassic sedimentation on the Burgundy platform. Publ. spéc. Assoc. Sédiment. franç. 1, 75–97.

ROLLIER, L. 1888: Étude stratigraphique sur le Jura bernois. Les faciès du Malm jurassien. Eclogae geol. Helv. 1, 3–88.

SHINN, E. A. 1968: Practical significance of birdseye structures in carbonate rocks. J. sediment. Petrol. 38, 215–223.

SZULCZEWSKI, M. 1968: Stromatolity jurajskie w Polsce. Acta geol. polonica 18, 1–99.

TRÜMPY, R. 1980: Geology of Switzerland. A guide-book, part A: An outline of the geology of Switzerland. Wepf, Basel.

VAIL, P. R., HARDENBOL, J. & TODD, R. G. 1984: Jurassic unconformities, chronostratigraphy, and sea-level changes from seismic stratigraphy and biostratigraphy. Mem. amer. Assoc. Petroleum Geol. 36, 129–144.

VOLLMAYR, R. & WENDT, A. 1987: Die Erdgasbohrung Entlebuch 1, ein Tiefenaufschluss am Alpennordrand. Bull. Ver. schweiz. Petroleum-Geol. u. -Ing. 53/125, 67–79.

VONDERSCHMITT, L. 1942: Die geologischen Ergebnisse der Bohrung Hirtzbach bei Altkirch (Ober-Elsass). Eclogae geol. Helv. 35, 67–99.

ZIEGLER, B. 1967: Ammoniten-Ökologie am Beispiel des Oberjura. Geol. Rdsch. 56, 439–464.

ZIEGLER, P. A. 1982: Geological atlas of western and central Europe. Shell int. Petroleum Maatsch., Amsterdam.

Manuscript received 5 February 1992
Revision accepted 23 August 1992