Microbial Carbonate Crusts -
a Key to the Environmental Analysis of Fossil Spongiolites ?

Helmut **Keupp**, Berlin, Angela **Jenisch**, Hamburg, Regina **Herrmann**, Fritz **Neuweiler**
and Joachim **Reitner**, Berlin

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BIOGENE SEDIMENTATION

Riff-Evolution
und
Kreide-Sedimentation

SUMMARY

Morphological and geochemical comparisons between modern cryptic microbialites from Lizard Island/Great Barrier Reef and fossil counterparts in the Upper Jurassic (Southern Germany, Dobrogea/Romania) and late Lower Cretaceous (Aptian/Albian from Cantabria/Spain) spongiolitic environments show that there are common factors controlling the crust formations mostly independent of light despite of diverging (paleo-) oceanographic positions as well as relationships of competitors. Factors such as increased alkalinity, oligotrophy, and reduced allochthonous deposition are of major importance. Thrombolitic microbialites are interpreted as biologically induced and therefore calcified in isotopic equilibrium with the surrounding sea water. Corresponding with shallowing upward cycles, microbial mats which produce stromatolitic peloidal crusts become more important. Different biomarkers are introduced for the first time extracted and analyzed from spongiolitic limestones of Lower Kimmeridgian age from Southern Germany.

1 INTRODUCTION

Throughout the earth's history, spongiolitic limestones (sensu GEYER, 1962) are characterized by two features, the more or less rich occurrence of siliceous sponges (hexactinellids and lithistid demosponges) preserved partly or entirely and presumed microbialitic carbonates (="microbialites" sensu BURNE & MOORE 1987). This facies is often dominated by partly thrombolitic, partly peloidal stromatolitic crusts. KEUPP et al. (1990: 155) pointed out concerning the synopsis of actual often contradictory discussed knowledges of processes controlling the formation of Late Jurassic spongiolites: "Studies on the formation of sil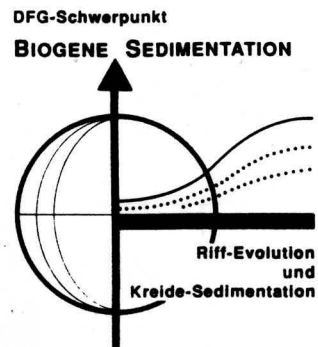iceous sponge buildups is, to a great extent, an interdisciplinary approach and hence must be undertaken by carbonate sedimentologists, biochemists and palaeontologists. Clarification of existing hypothetical models for the fossilization of siliceous sponges and elucidation of carbonate crust formation play a key role in this approach." We take up this proposal with an attempt to explain essential controlling factors of the fossil spongiolitic facies on the base of comparisons between morphological, geochemical, biogeochemical, and biological data of both modern carbonate crusts which are built under more or less known cryptic conditions, and their similar Jurassic and Cretaceous counterparts. This contribution compares Recent and fossil carbonate crusts to point out corresponding and diverging environmental factors, respectively.

REITNER (1993) describes and interprets modern cryptic microbialites which were collected from coral reef caves; they appear to be very similar to both Recent deeper water crusts described by BRACHERT & DULLO (1991) and some fossil crusts from different spongiolitic limestones.

In conclusion of the above-mentioned descriptions of modern cryptic microbialitic crusts from Lizard Island, Great Barrier Reef, the following factors controlling their growth can be deduced:

1. The modern crusts are restricted to cryptic, dysphotic to aphotic environments controlled by the competition with coralline red algae.

2. The crusts form only on places where the detrital supply is reduced, or where only few detrital components are able to remain on the bottom due to exposed or steep slope position. The establishment of the very slowly growing carbonate crusts seems not be possible on places characterized by higher sedimentation rates due to rapid burial effects.

Addresses: Prof. Dr. H. Keupp, R. Herrmann, F. Neuweiler, Doz. Dr. J. Reitner, Institut für Paläontologie, Freie Universität Berlin, Malteserstr. 74-100, Haus D, D-12249 Berlin; Fax: Germany-030-77622070; Dr. A. Jenisch, Institut für Biogeochemie und Meereschemie, Universität Hamburg, Bundesstraße 55, D-20146 Hamburg
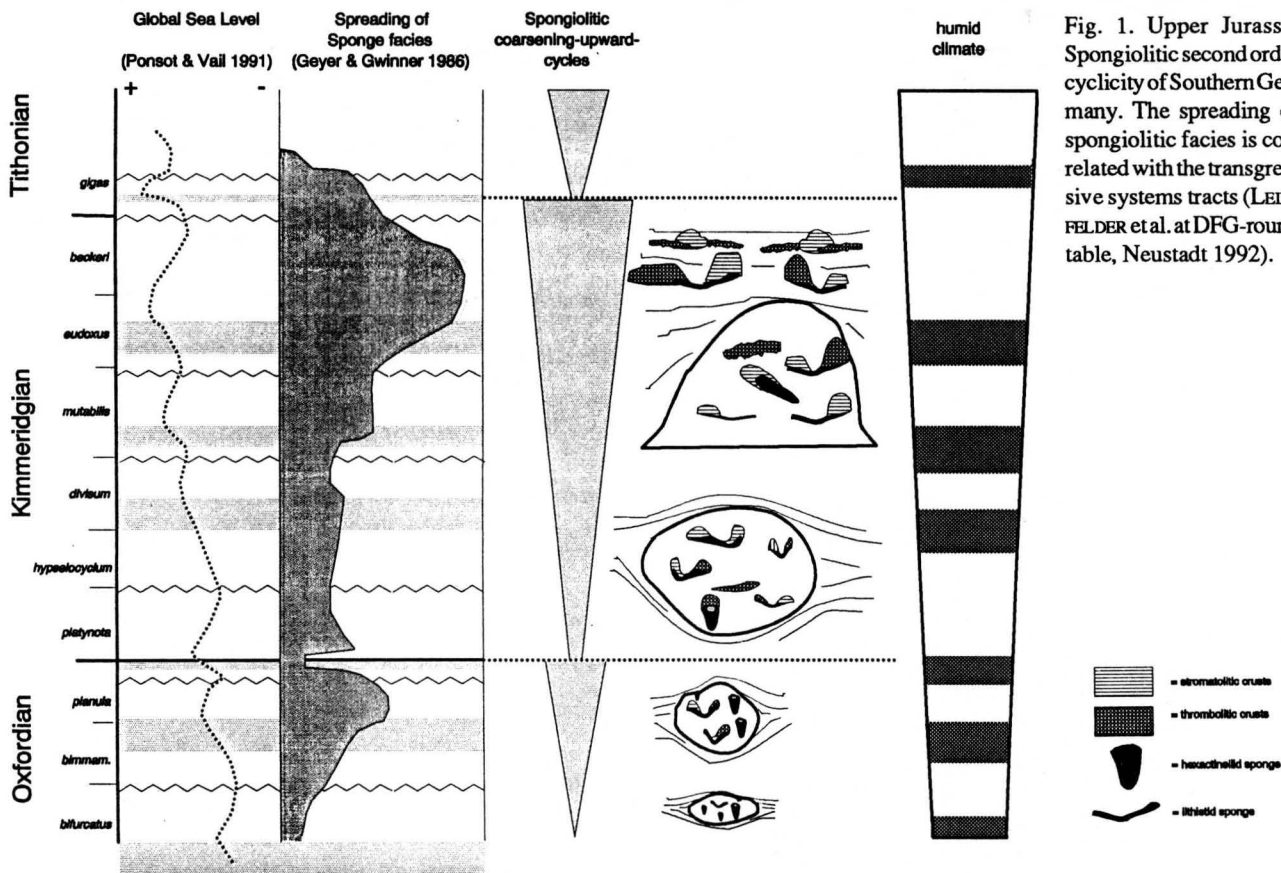
Fig. 1. Upper Jurassic Spongiolitic second order cyclicity of Southern Germany. The spreading of spongiolitic facies is correlated with the transgressive systems tracts (LEINFELDER et al. at DFG-round table, Neustadt 1992).

3. The described modern crusts from St. Croix and Lizard Island are restricted to islands on which crystalline rocks are exposed. Therefore, influences of weathering and, possibly, also of freshwater which increases the alkalinity of the sea water, seem to play an important role in crust formation.

4. The very slow carbonate accumulation, which is altering with both leaching activities including incrustations by Fe/Mn-bacteria and boring activities of various organisms, results from different processes:

* Trapping of sediment particles by microbial films.

* Microbialite formation occurs only uncommonly by calcification of microbes under direct metabolic control. Therefore, the stable isotopes (δ^{13}C) of the microbialites which are in equilibrium with the surrounding sea water, do not contain an appreciable amount of metabolic ^{13}C (cf. WEFER & BERGER 1991). Metabolic processes, neighter microbial photosynthesis nor respiration seem to play an important role in carbonate cementation.

* "Biologically-induced" (LOWENSTAM 1981) micritic cementation of organic sheets, partly under anaerobic conditions.

* Incrustation by foraminifers, coralline sponges, serpulids, bryozoans, brachiopods, and other organisms.

2 CARBONATE CRUSTS OF LATE JURASSIC SPONGIOLITES

Many former studies of Late Jurassic spongiolites, particularly from Southern Germany, deal with the detailed description and classification of microbial crusts (e.g. FRITZ 1958, HUMMEL 1960, HILLER 1964, WAGENPLAST 1972, NITZOPOULOS 1974, GWINNER 1976, FLÜGEL & STEIGER 1981, GAILLARD 1983, LANG 1989, KOTT 1989). These authors agree that "microbial"- or "algal"-crusts principally are of non-skeletal type containing various amounts of encrusting organisms. The so called "filamentous algal crusts" sensu FLÜGEL & STEIGER (1981) represent misinterpreted structureless micritic microbialites including bundles of dermal spicules of lithistide demosponges (Pl. 9/2).

In Southern Germany, the Late Jurassic sponge facies is subject to a more or less distinct cyclic development (KEUPP et al. 1990):

A) The development of two larger scale (each 4-5 million years) shallowing upward cyles during Oxfordian and Kimmeridgian time (Fig. 1), -and possibly a third one in the Lower Tithonian- apparently contradicts the global transgressive sea level trend (VAIL et al. 1977). However, the progressive shallowing can be explained by overcompensation by relatively high carbonate productions of both the small subsidence rate of the platform at the passive margin of the Tethyan Ocean and the falling sea level. The first cycle starts with smaller spongiolitic bodies of Middle Oxfordian age (Pl. 9/1) which are embedded in marly limestones. The facies is characterized by both a dominance of hexactinellid sponges including Tremadictyon radicatum (QUENSTEDT) the only described Upper Jurassic species which could anchor itself in soft sediment (MÜLLER 1991) and a small amount of - mostly aphanostromatic - carbonate crusts. In the earliest Upper Oxfordian spongiolites, the bioherms become larger and the amount of carbonate crusts including
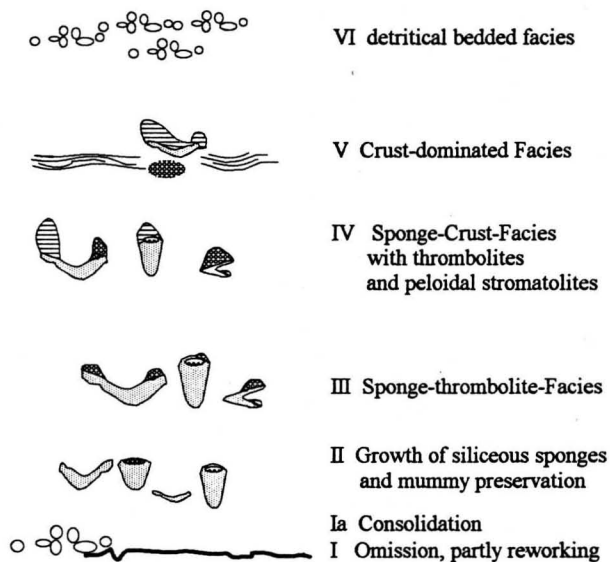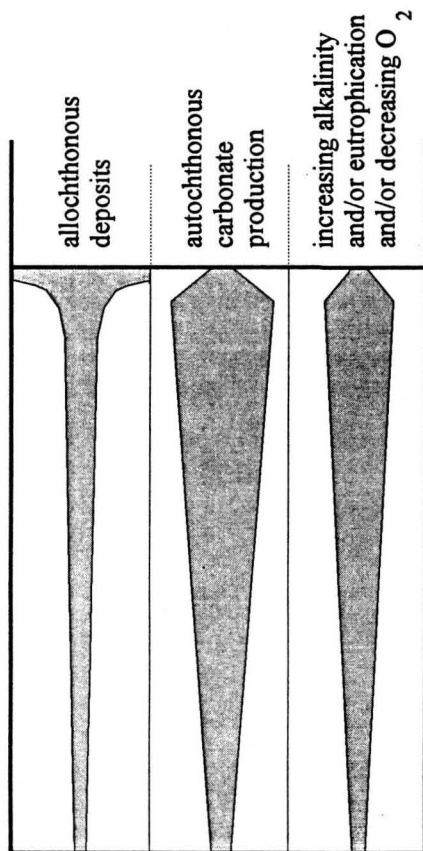
Fig. 2. Main factors controlling the small scale spongiolitic cycles which can be developed in the dimension of each Upper Jurassic spongiolitic bank.

steadly more stromatolitic peloidal structures increases (cf. LANG 1989). Above the *platynota*-marls of earliest Kimmeridgian age the second cycle starts: most of the buildups are now dominated by lithistid demosponges. All siliceous sponges reported from these buildups need solid substrates for settling. In the stratigraphical lower spongiolites only poor carbonate crusts exist. Above the middle part of Lower Kimmeridgian strata (Malm gamma 2), thrombolitic crusts become important (Pl. 9/4). In the Middle and Late Kimmeridgian, thrombolitic and also stromatolitic crusts often dominate the biohermal and biostromal spongiolites (cf. KOTT 1989, MEYER 1975, SCHORR & KOCH 1985). The associated sediments contain still more high energy structures (resedimentation, grainstones, and ooids (cf. MEYER 1975, WIRSING & KOCH 1986, POMONI-PAPAIOANNOU et al. 1989).

B) Small scale cycles are reported from mounds and thick-bedded autochthonous limestones ("Treuchtlinger Marmor") by SCHORR & KOCH (1985), MEDER (1989), LANG (1989), KOTT (1989), REHFELD-KIEFER (1992), and others. These cycles are interpreted by LANG (1989) and KOTT (1989) to be orbitally forced (Milancovitch-cycles). The following generalized sequence can be deduced (Fig. 2):

Following an omission phase connected with a consolidation of the bottom, siliceous sponges grow probably very slowly under oligotrophic conditions. Several modern

hexactinellids and lithistid demospongiae are extreme K-strategists: their optimal adaption to poor living conditions enabled their survival, reproduction and competition with other organisms in a dynamic equilibrium near the minimal capacity. Therefore, they propagate mostly by sexual reproductions and are probably temporarely living without any active particle feeding, but together with endosymbiontic chemoautotrophic bacteria. Corresponding with the reproductive fitnesss of K-strategists, we can find in Jurassic spongiolites mostly single sponge individuals originated by sexual reproduction and grew due to settlement of a single larva, while asexual budding only very rarely occurs.
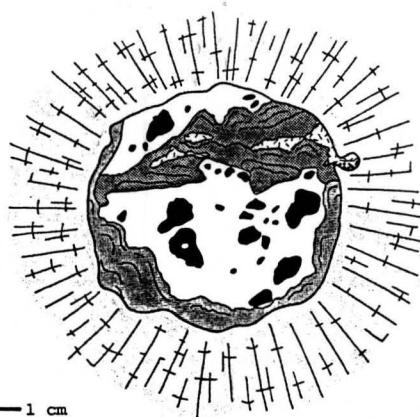
Fig. 3. Two generations of dense (=aphanic) peloidal microbialitic crusts have grown under dysphotic conditions inside a spongocoel of a toppled siliceous sponge. Their growth conditions have been interrupted by temporary infilling with detrical sediment (floatstones); Oxfordian, Dobrogea/Romania
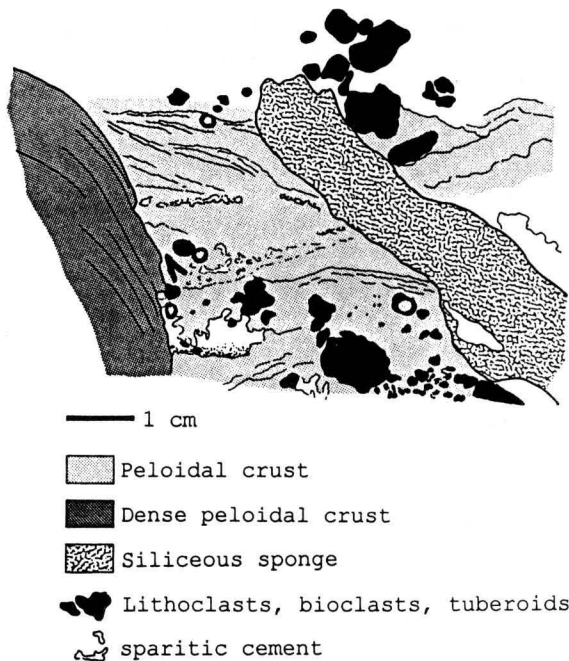
Fig. 4. The primary position of peloidal microbialites from Dobrogea (Oxfordian) below a preexistent lithistid siliceous sponge let presume dysphotic growth conditions (cf. Pl. 9/5).

The second phase is characterized by sponge-carbonate crust assemblages. The mostly aphanostromatic, often thrombolitic crusts contain different encrusting organisms as well as biodetrital components (Pl. 9/3). These crusts resemble a hardground characterized by concomitant incrustation and boring activities. The upper part of a spongiolitic body is often characterized by a decreasing amount of benthic organisms and an increasing importance of a more or less pure microbialitic facies including both thrombolitic and stromatolitic crusts.

2.1 Morphology of Upper Jurassic Microbialites

All the modified types of autochthonous carbonate products and their numerous transitional morphotypes connected with the Late Jurassic siliceous sponge facies, instructively figured in GAILLARD (1983: p. 133, fig.57), can be reduced to 3 basic types:

1. Micritic to peloidal mummies preserving the morphology and internal structures of siliceous sponges. Their formation took place under anoxic conditions (see chapter 2.2)

2. Thrombolitic and dendritic crusts rich in both detrital components and encrusting organisms, particularly foraminifers (including the enigmatic organism-community *Tubiphytes morronensis*), polychaete worms (serpulids and *Terebella*), cyclostomate bryozoans, coralline sponges (*Neuropora*, minchinellid Calcarea). In general, no distinct internal laminations occur, but we often find brownish coloured iron-rich films penetrating the crusts irregularly. Their calcification is characterized by a slow growth rate. It seems to be restricted to the sediment/surface boundary. Some of these thrombolitic microbialites are characterized by repeated alternations of carbonate accumulation and removal by leaching (?) and boring organisms (e.g. *Aka*: REITNER & KEUPP 1991, lithophagous pelecypods). GYGI (1992: Fig. 18) reported very similar columnar microbialites from Late Jurassic coral bioherms, which permit to draw a parallel between modern coral facies occurences as described by REITNER and ZANKL (this volume) and the Jurassic sponge facies.

3. Stromatolitic laminar to domal peloidal crusts become more and more important within the higher parts of shallowing upward cycles of Late Jurassic spongiolites (Pl. 9/5-7). On polished slabs these appear milky. Except numer-

Fig. 5. Generalized drawing of specific components of biomarkers extracted and analyzed from differnt Kimmeridgian spongiolitic limestones of Southern Germany and their affinity to discrete organisms.
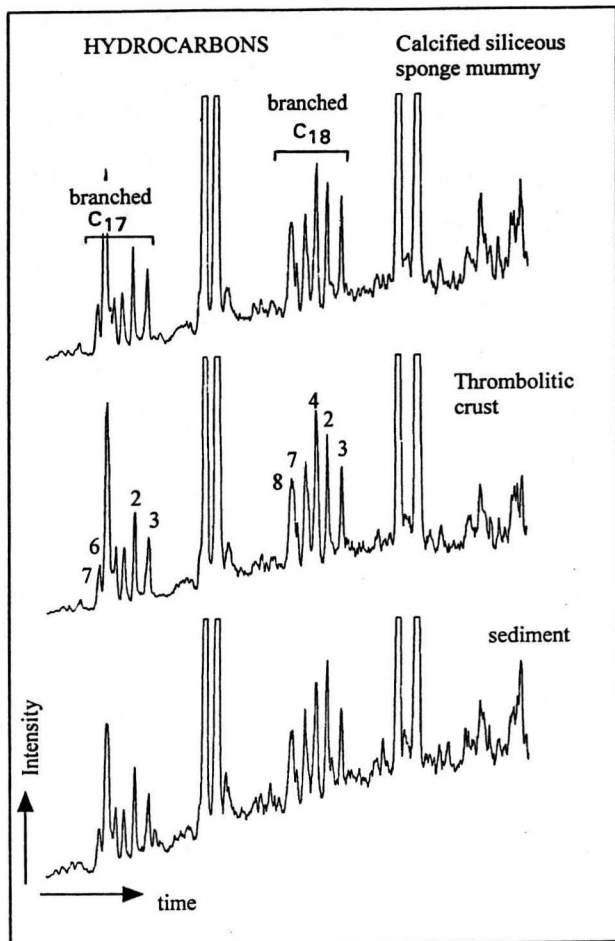
Fig. 6. Section of gas chromatographic spectra of hydrocarbons showing the alcanes C_{17} and C_{18} characterizing particularly their origin from cyanobacterians. The corresponding graphs of different analyzed spongiolitic facies elements (1. calcified lithistid sponge from Middle Kimmeridgian, SW Treuchtlingen/Franconia; 2. thrombolitic crusts from Lower Kimmeridgian, Core B 110 near Geislingen/Swabia; 3. detritic sediment from a Late Kimmeridgian bioherm near Gosbach/Swabia) prove the homogenous distribution of organic material and does not allow to classify the biomarkers with a distinct facies element.

ous peloids, which are presumed to be of in situ origin, only a small content of biodetritus can be observed. Encrusting and boring organisms can be found only rarely. Each lamina is characterized by a dense micritic coating at its surface and a more or less loose arrangement of peloids below it varying in size. The latter are fixed by (micro-)sparry calcite cements. The lamination is normally not disturbed or reworked. Therefore, we assume that the mat calcification is related to self burial processes including the autochthonous formation of peloids below the micobial mat comunity analogous to the Recent anaerobic origin of peloids as described by REITNER (this volume).

Apart from the sponge mummies, the other basic types of Upper Jurassic microbialites, particularly the thrombolites, resemble morphologically the aphotic crusts of Lizard Island and St.Croix, respectively. In addition to this morphological congruence, the following further common features can be observed:

* The crusts favour obviously exposed positions. Due to this observation, photic growth conditions have been postulated (cf. WAGENPLAST 1972: 30; GAILLARD 1983: p.126). However, the exposed positions are not only characterized by optimal light conditions, but also by absence or at least a reduced rate of sediment deposition.

* All the desribed types of microbialites inside the spongocoel of toppled sponges as well as below large platy sponges (Figs. 3-4, Pl. 9/5; GAILLARD, 1983: Fig. 12, p. 125) can be found. Their growth seems to proceed under at least dysphotic conditions. Therefore, we can presume a facultative aphotic growth potential of the described mirobialites.

With the intention to find hints of the possible primary crusts producers which are not documented by skeletal or filamental relics, we used biogeochemical and stable isotopic methods, in addition to the description of thin sections.

2.2 Biogeochemistry

Spongiolitic samples of different localities and different stratigraphical positions of the Swabian and the Franconian
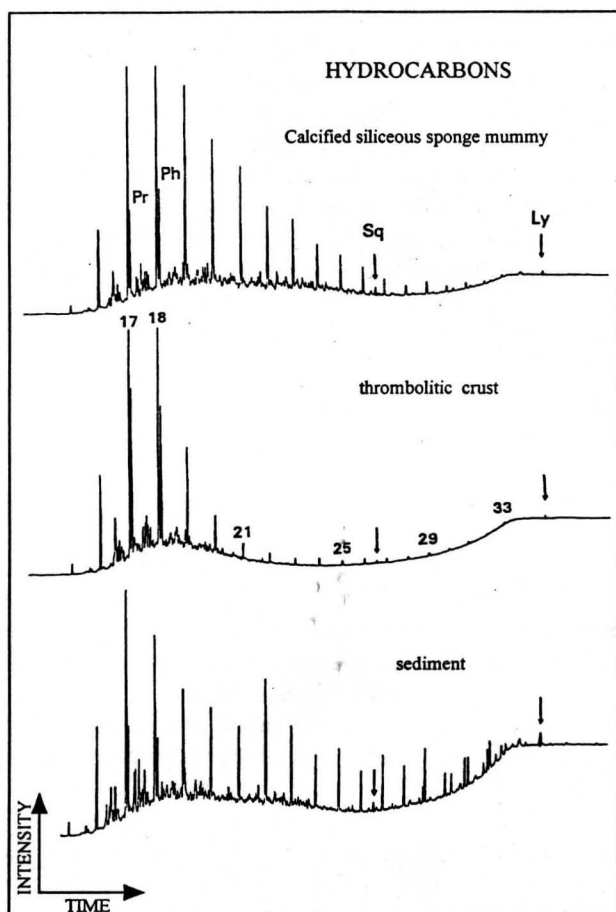

Fig. 7. Complete gas chromatographic spectra of hydrocarbons of the same samples as represented in Fig. 6. The pristane (Pr) and phytane (Ph) relationships of sponge mummy give hints for anoxic conditions, while the chlorophyll of both other facies types (microbialite crust and detrital sediment) seem to be altered under more oxic conditions. The biomarkers squalane (Sq) and lycopane (Ly) are derived from anoxic archebacterians (arrows).
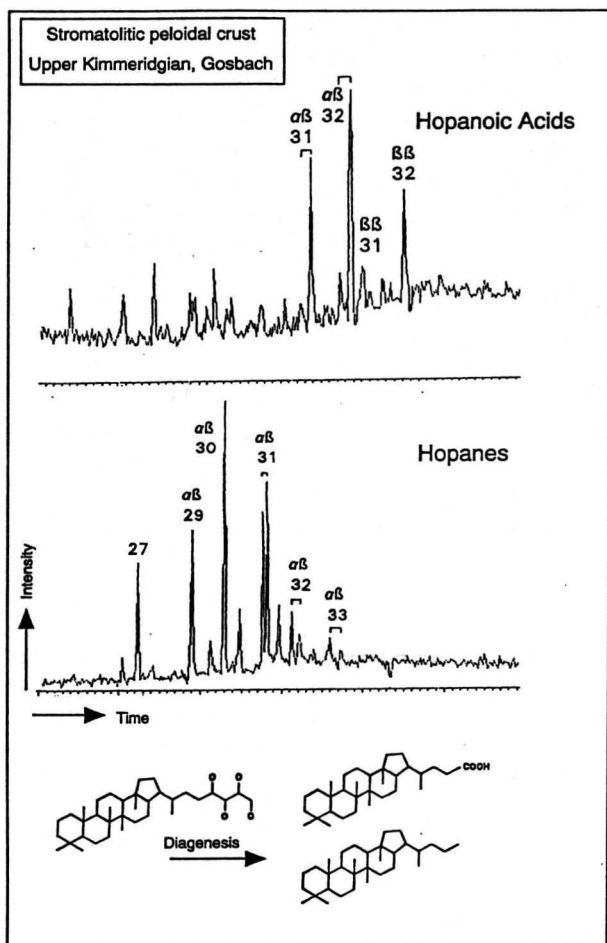
Fig. 8. Mass spectrometric analyses of hopanoids from an LateKimmeridgian stromatolithic peloidal crust of the Gosbach bioherm (Swabia). The hopanoic acids have been analyzed from the fraction of acids, the hopanes from the fraction of hydrocarbons. All the different series of hopanoic acids and of hopanes derived from the same bacteriohopantetrol during diagenetic processes (oxidation/hydrogenation).

Alb have been analyzed by methods of gas chromatography and mass spectrometry. In spite of some methodical problems during the sample extraction (particularly for sugar analysis) caused by the little C_{org} content of the pure limestones, characteristic biomarkers have been found (Fig. 5).

Unfortunately, the spectrum of biomarkers within the different types of samples analyzed from the spongiolitic facies (sponge-mummies, thrombolitic carbonate crusts, dedrital sediment), particularly of the hydrocarbons, seems to be more or less identical (Figs. 6-7). Therefore, we suggest that the distribution of biomarkers may be rather the result of detrital mechanisms than a original *in situ* signal. Due to this homogenization, differentiated interpretations seem to be questionable because we cannot establish specific markers to distinct facies elements. Moreover, the long chain alcanes n-C_{25} to n-C_{33} which can be traced back probably to eucaryotic higher plants, support the existence of detritic C_{org} influx.

Being aware of the fact that a correlation of the biomarkers with a distinct sediment feature might not be reliable, as described above, the following interpretations seem to be possible:

The different pentacyclic hydrocarbons (hopanes: Fig. 8), diagenetically derived from the Bacteriohopantetrol, mark the influence of non-differentiable eubacterians, which were active during or after deposition of organic material, while the n-alkanes C_{17} and C_{18} (Fig. 6), occurring in most of the samples, are quite typical for cyanobacterians. The hydrocarbons pristane and phytane can be presumed to have originated from chlorophyll (phytol), while pristane derives under oxic conditions and phytane under anoxic conditions. These isoprenoids give hints for photosynthetic activities, but we cannot determine their origin from neither cyanobacterians nor detrital land plants. On the other hand, different phytane/pristane-relationships prove probably anoxic conditions of the sponge mummies and more oxic conditions for both the thrombolitic crusts and the sediment (Fig. 7). Also, the hydrocarbons squalane and lycopane seem to prove anoxic archebacterian activities within crusts and sediment. In conclusion, there is evidence of activity of different anaerobic and aerobic bacterians including cyanobacterians (cf. LANG 1989). However, their participation in carbonate precipitation, particularly in the formation of thrombolitic and laminated crusts, can not be judged on account of the results of the used biochemical methods unfortunately.

2.3 Stable Isotopes

Measurements of stable isotopes (^{18}C and ^{13}C) have been performed on different spongiolitic facies of a Kimmeridgian core drilled near Geislingen/Swabian Alb (borehole 120) and of an outcrop of Oxfordian spongiolitic

Core Geislingen 120 (Kimmeridgian spongiolites)

x   Microbial crusts

●   Sediment

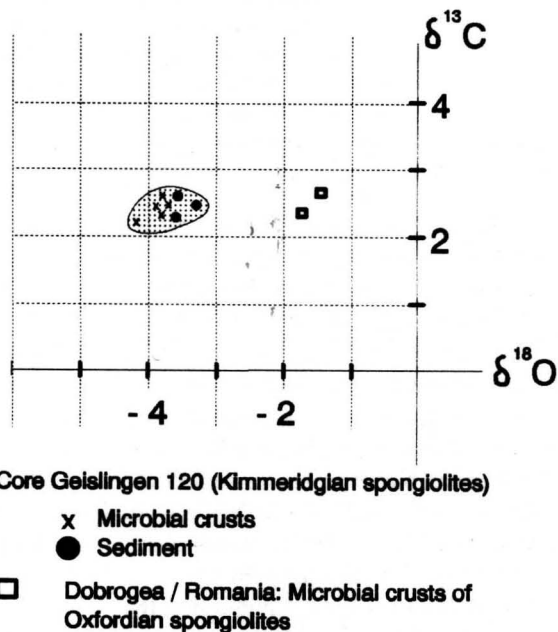□   Dobrogea / Romania: Microbial crusts of Oxfordian spongiolites

Fig. 9. Uncorrected values of $\delta^{13}C$ and $\delta^{18}O$ measurements of primary calcitic Late Jurassic microbialites and of detrital sediment: Kimmeridgian of Geislingen/Swabia (core B 120) and Oxfordian of Dobrogea/Romania.
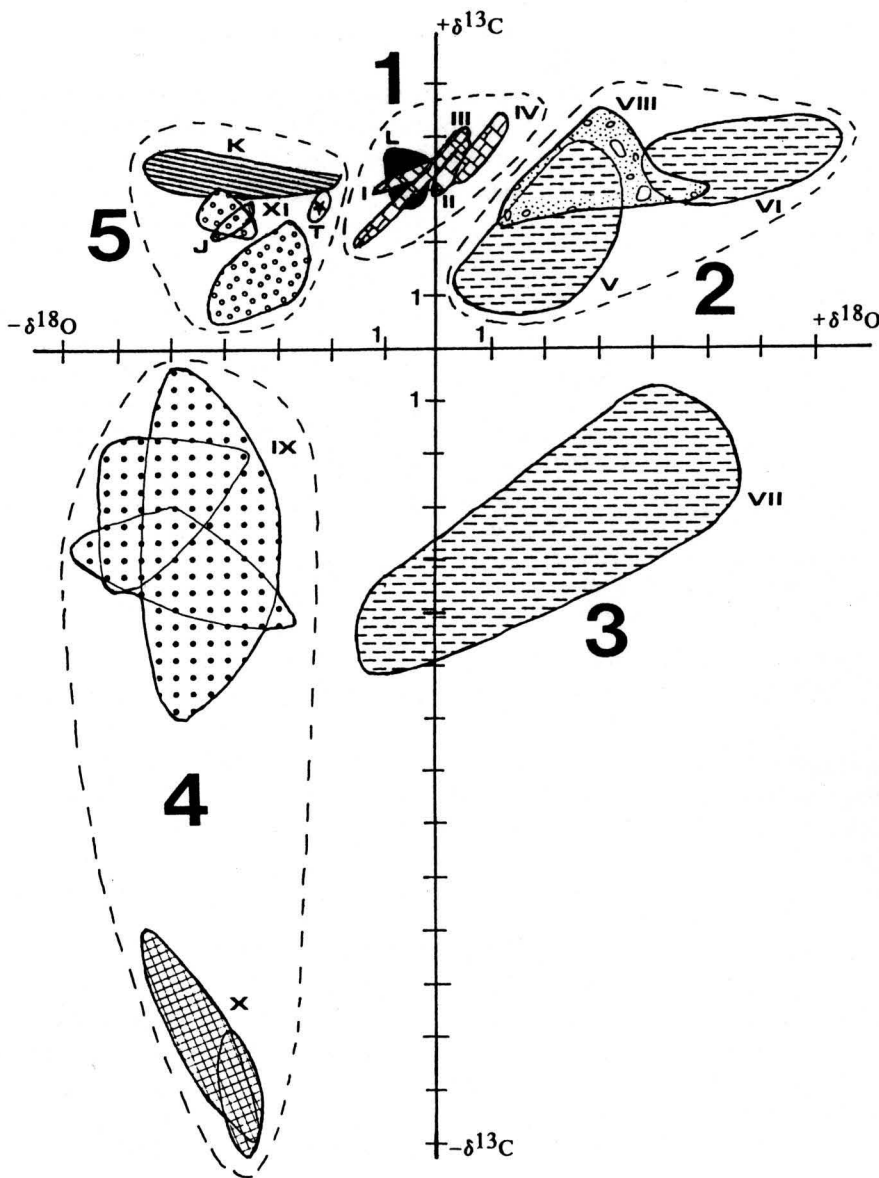
Fig. 10. The comparative overview of isotope ratios from different modern and fossil primary calcitic mirobialites (Upper Jurassic to Recent) shows the following pattern (values uncorrected):

Group 1: Distribution of stable isotopes in modern cavity-dwelling marine microbialites:
I: Mg-calcite of non-lithified mud, Belize (MacIntyre 1984)
II: Mg-calcite of micobialite, Belize (MacIntyre 1984)
III: Mg-calcite cements (microbialite, Jamaica: MacIntyre & Marshall 1988, Land & Goreau 1970)
IV: Microbialite, Belize Reef (James & Ginsburg 1979)
L: Cryptic microbialites from Lizard Island (Reitner 1993)

Group 2: Crusts of the Red Sea and of fresh water environments:
V: Deeper water calcitic crusts calcified in equilibrium with Red Sea water (Stoffers & Botz 1990)
VI: The high positive $\delta^{18}O$ values of this field result from aragonitic crust mineralogy (Stoffers & Botz 1990).
VIII: Fresh water lake (Sleaford Mere, Fellmongery) calcitic microbialites (Burne & Moore 1987)

Group 3: Deep water crusts from the Red Sea which consist of diagenetic dolomite and siderite. The light $\delta^{13}C$ values are probably linked with anaerobic sulfate reduction within the sediment:
VII: Carbonate crust "group III" (Stoffers & Botz 1990)

Group 4: Microbialites with portions of photosynthetic fractionation pattern characterized by partly light $\delta^{13}C$ values:

IX: Middle Jurassic algal limestones from Scotland (Andrews 1986)
X: Middle Jurassic algal limestones from Loch Bay/Scotland (Andrews 1986).

Group 5: Various fossil microbialites without recognizable photosynthetic organisms. This group is depleted in ^{18}O, a typical pattern for meteoric diagenetic influences (also seen in group 4). The $\delta^{13}C$ patterns fit more ore less with the modern ones of group 1:
J: Upper Jurassic microbialites from core B 120, Geislingen/Swabia (cf. Text-Fig. 9)
K: Albian microbialites from Northern Spain (Neuweiler, this volume)
T: Carnian microbialites from Cassian Cipit boulders (Northern Italy)
XI: Late Jurassic microbialites from Southern Germany (Wirsing 1988).

limestones of Dobrogea/Romania: thrombolites, calcified lithisthid demospongians, sediment surrounding the microbialites, and sediment inside an ammonite test. They all show a narrow range of $\delta^{13}C$ and a spatial variation concerning $\delta^{18}O$ (Fig. 9). Our data from the Kimmeridgian of Geislingen (Fig. 10: J), particularly of the $\delta^{13}C$, correspond with the published data by Wirsing (1988). The primary calcite precipitation seems to have happened more or less in equilibrium with the sea water analogous to modern microbialites from Lizard Island. We do not have evidence for a considerable fractionation in connection with the lithification of the entire sediment. However, "biological calcification is essentially a disequilibrium process, due to its use of CO_2 as an important raw material..." (McConnaughey 1989). Typically, carbonate precipitation produced by photosynthetic activities is much faster than anorganic calcification from the same water. Therefore, we should expect a lighter ^{13}C composition due to kinetic isotope effects. A substantial equilibration occurs when the calcification is very slow, or initiated through extracellular catalysis of CO_2 reactions (McConnaughey 1989, Wefer & Berger 1991).

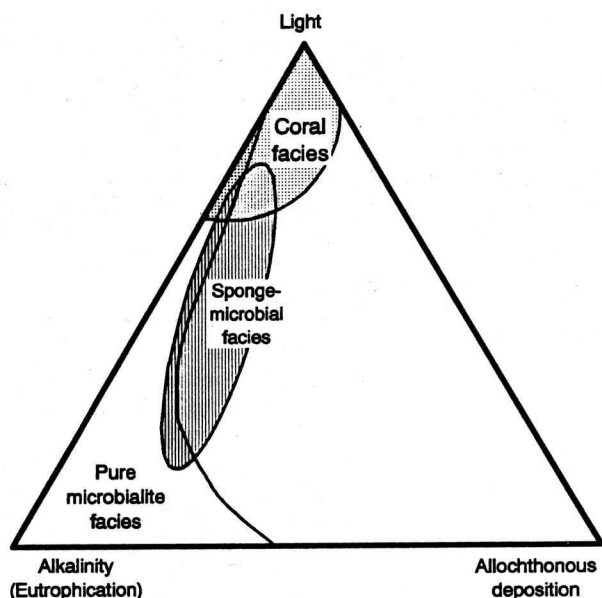The isotopic data of Upper Jurassic spongiolites prove

Fig. 11. Main factors controlling the Late Jurassic spongiolitic facies in comparison with both the coral facies and the pure microbialite facies at this period.

2.4 Environmental Interpretation

The comparison of described Jurassic microbialit features and growth conditions of similar modern cryptic, mainly cavity dwelling carbonate crusts allow to claim the following processes controlling the Jurassic sponge facies:

A. Paleogeographic configuration and its consequences for water chemistry and nutriation:

During the Kimmeridgian, the time of the maximal distribution of spongiolitic facies, the position of the pelagic, weakly inclined ramp along the wide passive northern shelf of the Tethys Ocean, far from slope conditioned upwelling systems, produces principally oligotrophic circumstances for spongiolite formation (KEUPP et al. 1990).

The supposed carbonate precipitation of the slowly growing aphanostromatic microbialites, which is only biogenetically induced by organic macromolecules (proteins, polysaccharids) and/or biofilms, is in equilibrium with the surrounding sea water, whereas the process could only be induced provided that the alkalinity of the water masses during Upper Jurassic increased. This may be induced

(1) by the epicontinental carbonate platform model after KEMPE (1990), which obtained the alkalinity from a water exchange with an anaerobic basin connected with the opening of the Atlantic Ocean,

(2) by freshwater influences (cf. NEUWEILER, 1993). However, the second model is improbable because of the large distribution of the spongiolitic facies, its position far from the coast, and its association with a normal marine fauna.

B. Global sea level development and its
   a) sedimentologic consequences
   b) climatic consequences

The successive expansion of the spongiolitic facies in Southern Germany follows exactly the transgressive systems tracts of the global sea level chart (PONSOT & VAIL

similar cementation processes within a closed pore water system as described by NEUWEILER (1993) from the Albian mounds. Both early lithification of microbial crusts and the dominating micritic sediment characterized by only low permeability are favourable for the preservation of almost primary isotopic sea water composition, also during burial cementation (compare the inverted "J" model of LOHMANN (1988) and discussion by NEUWEILER (this volume)). According to investigations of samples of spongiolitic Late Jurassic limestones from both cores and outcrops, later exchanges of carbon isotopes between pore and/or clevage water masses by meteoric influences are also excluded by WIRSING (1988:281).

Plate 9   Microbialites of various Late Jurassic spongiolites

Fig. 1.   Polished section through a small spongiolitic buildup (45 x 30 cm) from Late Oxfordian marls of Streitberg/ Northern Frankenalb (coll. T. Steiger, Munich). Microbialites are restricted to formation of calcareous sponge mummies and few thrombolitic crusts only. Scale bar = 10 cm.

Fig. 2.   Lithistid sponge surrounded with a thrombolitic microbialite crust incorporating bundles of dermal scleres. Similar structures were formerly described as "filamentous algal crusts" (FLÜGEL & STEIGER 1981) or "Algal Problematicum LADWEIN 1976" (BRACHERT 1986). Middle Kimmeridgian, (Treuchtlinger Marmor), Treuchtlingen /Southern Frankenalb. Scale bar = 1 mm.

Fig. 3.   Mummy of a hexactinellid sponge encrusted with aphanic thrombolite which includes tubes of polychaete worms (arrows) and biodetritus. Late Oxfordian, Urspring/Northern Frankenalb. Scale bar = 1 mm.

Fig. 4.   Dendroid thrombolites growing on a lithistid sponge. Middle Kimmeridgian (Malm Delta), Kaider/Northern Frankenalb); scale bar = 1 mm.

Fig. 5.   Densely laminated stromatolitic hemispheroid constructed of peloids which are presumed to be of in situ origin. It grew below a overturned platy lithistid sponge under dysphotic conditions upon a thrombolitic aggregate rich in *Tubiphytes morronensis* (arrow). Biostromal spongiolite of Middle Kimmeridgian age. Quarry of the Treuchtlinger Marmorwerke south-west of Treuchtlingen/ Southern Frankenalb. Scale bar = 1 mm.

Figs. 6.-7.   Peloidal stromatolitic microbialites from Oxfordian of Dobrogea/Romania. The various density of laminations result from different growth rates of the microbial mats. Scale bar = 1 mm.

Plate 9
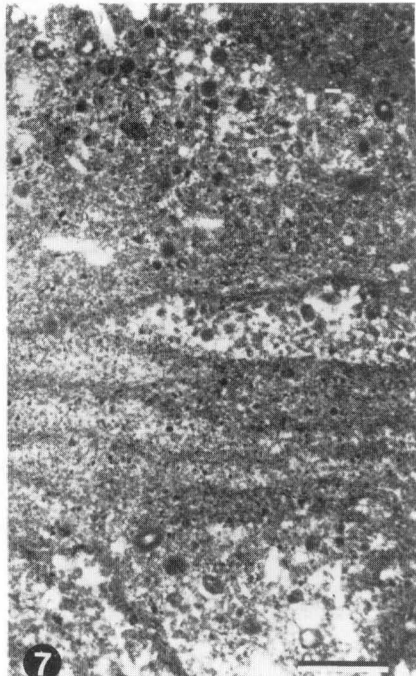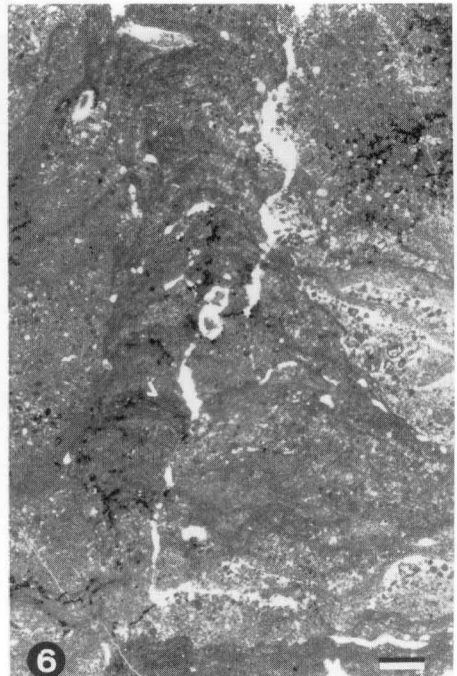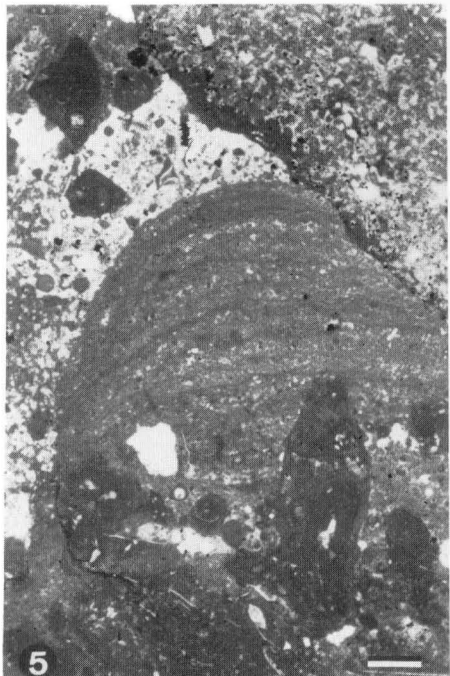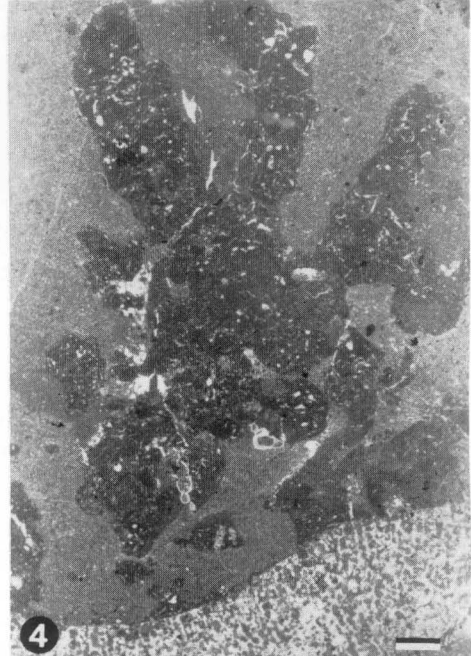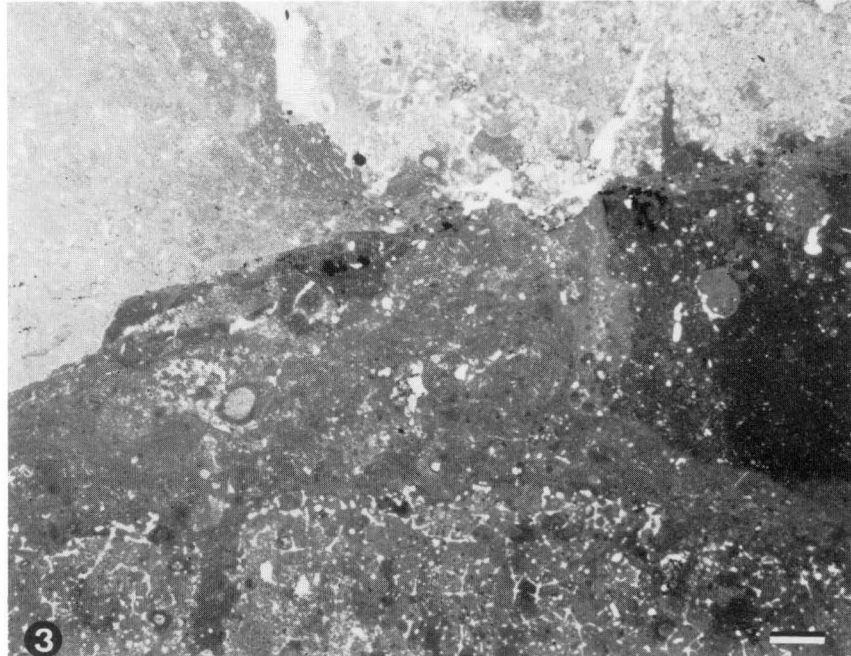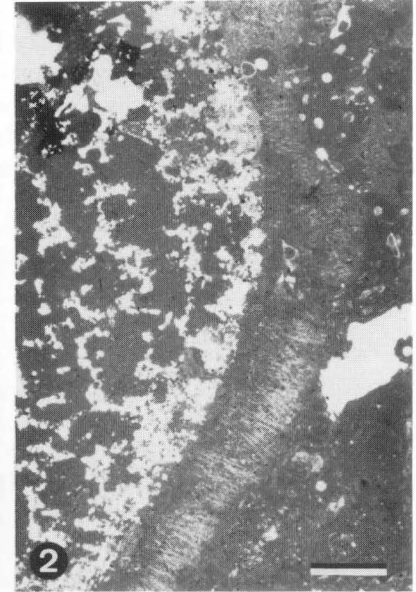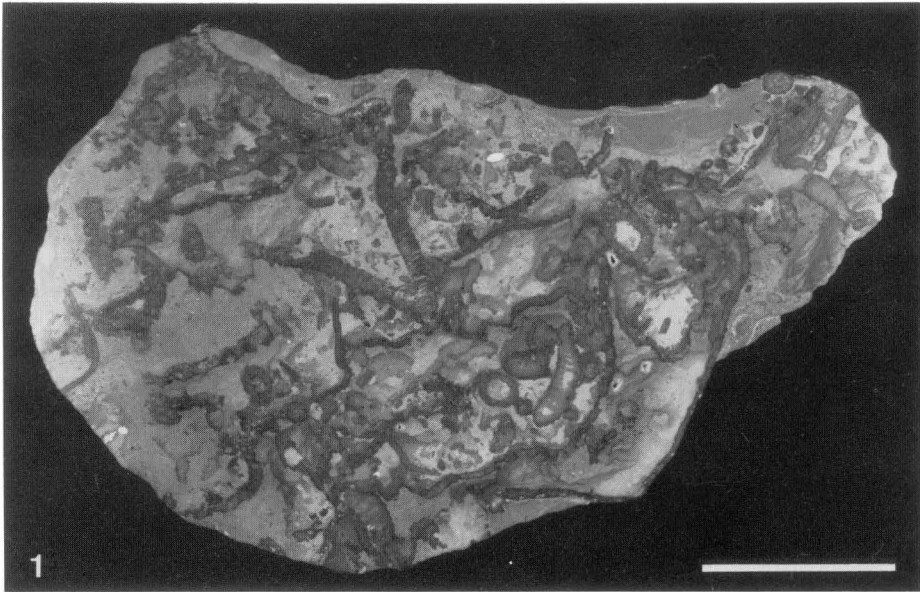
1991) as pointed out by Leinfelder, Krautter & Werner (1992; Fig. 1). The obviously reduced allochthonous sedimentation, which is pobably the main factor to establish both the slowly growing siliceous sponges and the aphanostromatic thrombolites, may be caused by the receding shoreline. The sponge facies progrades during the Upper Jurassic from deeper slope positions (cf. Gygi & Persoz 1986, 1987) to the shallowing platform successively with each transgressive thrust and reaches its maximum regional distribution during the Middle and Late Kimmeridgian (Gwinner 1976).

According to Leinfelder et al. (1992), the climatic consequences of the sea level development may be responsible for the 4-5 million year sequences. Humid climate and reduced water circulation during the highstands possibly produce an eutrophication of the surface water and a decreasing ventilation of the bottom water. Subsequently, the oligotrophic benthic fauna disappear, and the more or less pure microbialitic facies could be explained. It is dominated by stromatolitic peloidal structures, which are presumed to have grown more rapidly without remarkable participation of other benthic organisms situated predominantly at the upper part of the cycle. The obviously small-scaled, congru-

ent orbital-forced facies sequences indicate a similar mode of changing in climate conditions.

C. Bathymetry, particularly its consequences of light penetration:

The modern microbialitic crusts as described by Reitner (1993) and Zankl (1993) seem to be restricted to cavities and other dysphotic habitats owing to the competition with the much more rapidly growing coralline red algae. However, photic influences were without remarkable effects on crust formation during the Jurassic below the maximum depth of hermatypic corals (about 50-60 m), due to the still missing corallinaceans. Based on the fact that both facies, the spongiolites and the coral reefs, claim - except the light - nearly the same environmental conditions (oligotrophy, mostly solid substrates, normal marine salinity), we suppose that the sponge facies was generally situated deeper than the coral facies analogous to the Upper Jurassic sections of Portugal described by Leinfelder (1992). Therefore, the transition from sponge to coral facies in Southern Germany is described in different vertical shallowing upward sections only (Bausch 1963, Aldinger 1968, Gwinner 1976, Meyer 1977, 1978; Meyer & Schmidt-Kaler 1983). However we

Plate 10   Comparative representation of similar mirobialites through time: Late Jurassic (left column), Albian (Cantabria/N Spain, middle column) and Recent (Lizard Island, right column):

Figs. 1 -3.   Microbialites with common columar thrombolitic features exhibiting irregular to missing laminations and many included allochems:

Fig. 1.   Oxfordian (Dobrogea/Romania); scale bar = 1 mm.

Fig. 2.   Late Albian (buildup from La Sia, Northern Spain); scale bar = 5 mm.

Fig. 3.   Modern reef cave from Lizard Island; scale bar = 1 mm.

Figs. 4.-6.   Facies contacts of microbialites of different ages:

Fig. 4.   Middle Kimmeridgian biostromal limestone of Petersbuch near Eichstätt/Southern Frankenalb: A badly preserved lithistid sponge (L) is overgrown by thrombolitic microbialites including a minchinellid calcareous sponge (M) and "Tubiphytes" (T). The remaining pore space of the thrombolitic crust is infilled with stromatolitic peloidal crusts (S). Scale bar = 1 mm.

Fig.5.   Dense (=aphanic) micritic/fenestral microbialite containing some specimens of the encrusting foraminifer Placopsilina (P) overgrow a lithistid sponge (L) inside a small cave. Wider spaced sediment binding laminae originated from the main hemispheroidal microbialite structure (arrow) demonstrate increasing sediment influx into the remaining space.Middle Albian from Andarrosa/Northern Spain; scale bar = 5 mm.

Fig. 6.   Characteristic facies succession of a Recent reef cave microbialite from Lizard Island. Its base is characterized by coralgal structures. The scleractinians are represented by Leptoseris types, the coralline algae by Lithophyllum, Neogoniolithon and Peyssonnelia. The succession is formed by aphanic microbialites including biodetritital material and encrusting foraminifera, serpulids, bryozoans, coralline sponges and brachiopodes. It is interrupted by mineralized films of Fe-Mn bacterians. The remaining pore space is filled up with Ca-binding organic mucus (M) in which detritus is bound. Scale bar = 5 mm.

Figs. 7.-9.   The thrombolitic microbialites of all the described occurences are characterized by poorly laminated structures that consist of micrite associated with detrital grains and various encrusting organisms:

Fig. 7.   Oxfordian microbialite from Dobrogea/Romania encrusting a siliceous lithistid sponge (L) with enclosed serpulids (S) and foraminifers (F). The dark, limonitic laminae probably correspond with the mineralized films of Fe/Mn bacterians (compare Pl. 10/9). Scale bar = 1 mm

Fig. 8.   Detail of the Middle Albian microbialite of Fig.5 with alternating encrustations of Placopsilina and polychaete worms. Scale bar = 1 mm.

Fig. 9.   Pillar-like microbialite covered by a film of Fe/Mn bacterians from Lizard Island. It shows the integrated characteristic serpulid-foraminifer assemblages. Scale bar = 1 mm.

Plate 10
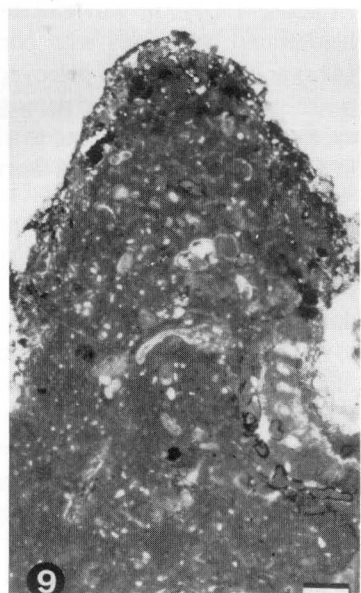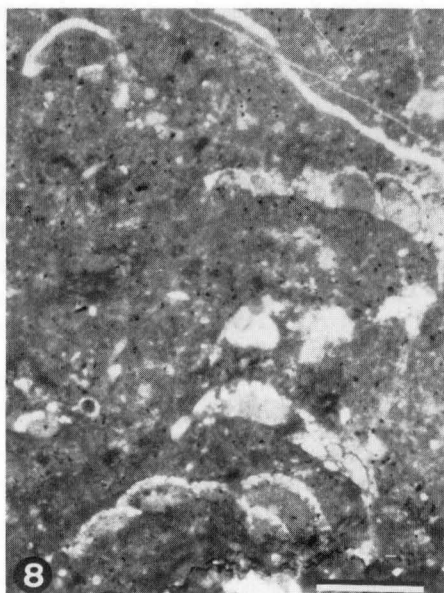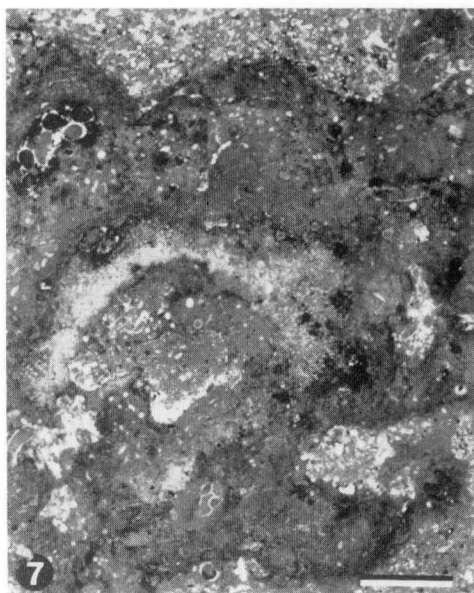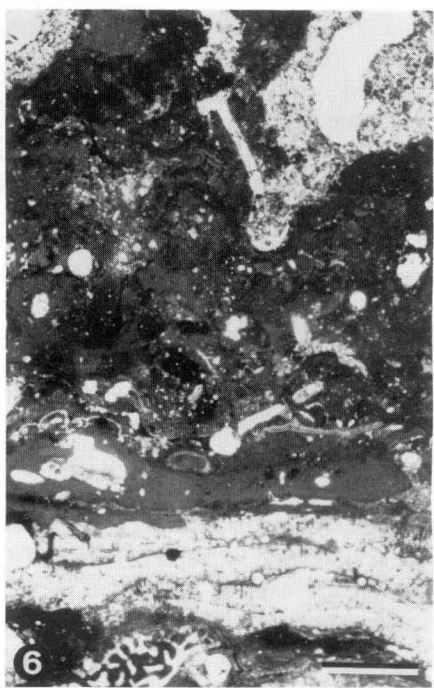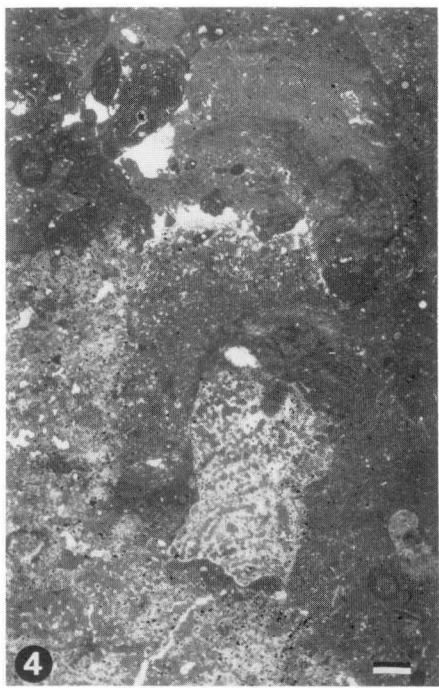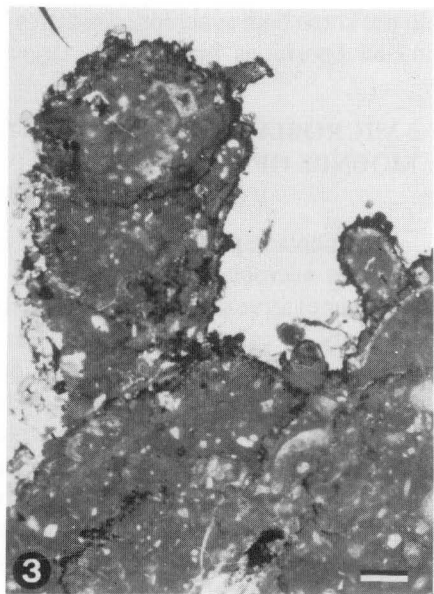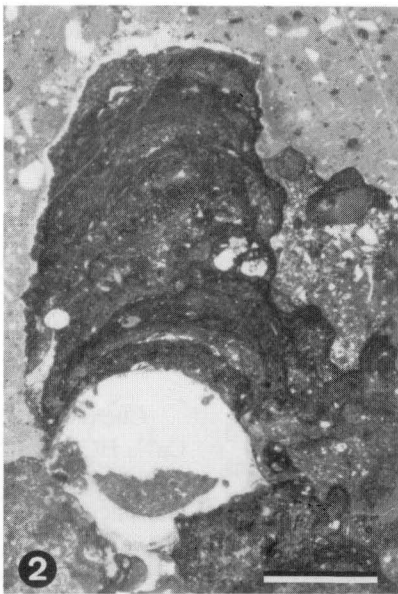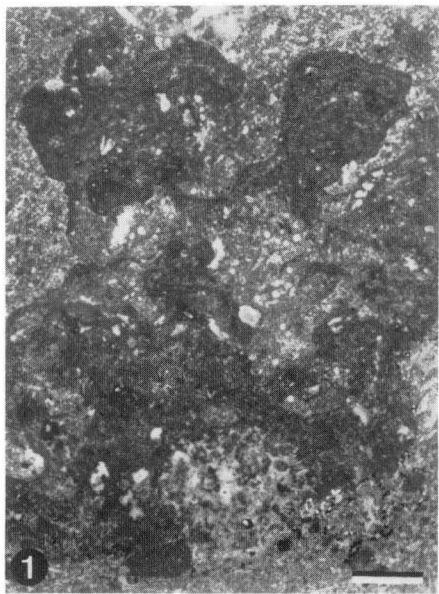
do not know both synchronous facies immediately linked in lateral positions, but only over larger distances.

3 MICROBIALITES OF ALBIAN SPONGIOLITIC MOUNDS OF THE VASCOCANTABRIAN BASIN (NORTHERN SPAIN)

Sedimentary, paleontological and geochemical features of Albian microbialites from northern Spain (NEUWEILER, this volume) serve as an additional example in the comparative study of calcareous microbialites. Despite of some individual characteristics (basin type, paleogeographic setting and phylogenetic trends of involved organisms), micro- and macroscopic structures of microbialites and related deposits are partly very similar to spongiolitic limestones from the Upper Jurassic and cryptic microbialites of modern age. The common quality of microbialites is well expressed by microbialitic microstructures, stable isotope geochemistry and special chemical environment.

3.1 Microbialite microstructures

Some types of microbialite microstructures described by NEUWEILER (this volume) can be transferred to their possible Jurassic counterparts in the following manner:

3.1.1 Dense (=aphanic) micritic/fenestral microbialites forming laterally linked hemispheroids and vertically stacked hemispheroids most probably correspond to thrombolitic and dendritic crusts as described above. Variations of microstructure is caused by different rates of sediment supply. Microbialites of this type are potentially stromatolitic, defined by the rate of allogenic particle flux. Calcification occurs in situ and is related to the biofilm/water interface. Dense micritic/fenestral microbialites are the main contributors to microbialite reef development, situated at mid to lower slope environments of marginal platform areas. Their distribution extends below the photic zone. In contrast, some other Late Albian mounds of Northern Spain seem to be formed similarly to modern environments by a coralgal frame which is penetrated and overgrown by microbialites (REITNER 1987). In situ calcified microbialites induced hardground conditions with boring activities of sponges (Aka) and lithophagous pelecypods. The principal associated organisms are lithistid demosponges, coralline sponges, encrusting foraminifera, and to a minor extent polychaetes, bryozoans, terebratulid, and thecidean brachiopods.

3.1.2 Dense micritic/peloidal microbialites revealing low amplitude laterally linked hemispheroids or subplanar orientated growth forms correspond to stromatolitic laminar or domal peloidal crusts of the Jurassic. Calcification is related to self burial processes in conjunction with decaying organic matter. Microbialites of this type are restricted to shallow marine conditions with a bathymetric range comparable with the photic zone. They occasionally bind coarse bioclastic debris related to buildup developments in small intraplatform basins or occur as relatively pure peloidal bindstones covering microbialite reefs.

3.2 Geochemistry of microbialites

Geochemical results obtained from microprobe analyses (Mg-content) and stable isotope geochemistry (δ^{13}C, δ^{18}O) indicate a primary high Mg-calcite mineralogy of microbial carbonates and precipitation in isotopic equilibrium with corresponding inorganically precipitated marine calcites. Therefore, major metabolic effects and influences of ^{12}C enriched organic carbon derived from autotrophic microorganisms are regarded as negligable.

3.3 Environmental Interpretation

Chemical considerations, i.e. the increased supply of Ca^{2+}, HCO_3^-, alkalimetal and sulfate ions into the marine realm are discussed as the primary control on episodes of in situ calcifying microbial mats (NEUWEILER 1993). This supply is controlled by the fluviatile influx of weathering products (in connection with the terrestrical Utrillas facies), diapir derived brines and paleokarst developments. In addition to increased alkalinity, possible effects of toxic $[Ca^{2+}]$ comprise the increased release of Ca^{2+}-affine organic films, favouring self burial effects of peloidal microbialites.

4 CONCLUSION

Similar morphological features and geochemical data including stable isotope geochemistry prove some corresponding controlling mechanisms of Recent cryptic microbialites and fossil microbialites associated with spongiolitic limestones of Jurassic and Cretaceous age. However, historical facts, particularly phylogenetic reasons and different geological settings, cause essential modifications of the actualistic principle (Fig. 12).

Common features:
* All calcareous crusts considered here grew under essentially oligotrophic conditions of normal marine salinities.
* They contain corresponding sessile assemblages.
* Their calcification is possibly controlled by phases of increased alkalinity.
* They needed more or less well consolidated substrates.
* Particularly the thrombolitic and dense micritic microbialites represent slowly growing primary Mg-calcite precipitates induced by organic macromolecules and/or biofilms and are, therefore, independent of light and potentially aphotic to dysphotic.
* Reduced allochthonous sedimentation (controlled by sea level changes or regional tectonic factors).
* Peloidal calcitic grains associated frequently with the spongiolitic facies are interpreted to be mostly produced in situ under anoxic conditions by self burial processes below the surface of microbial mats.

Diverging features:
* Paleogeographic and tectonic positions
* In modern crusts light plays an important role, favouring the competition with corallinaceans. However, corallinaceans are lacking or of minor importance, respectively, in fossil communities of Jurassic and Lower Cretaceous age. Photic
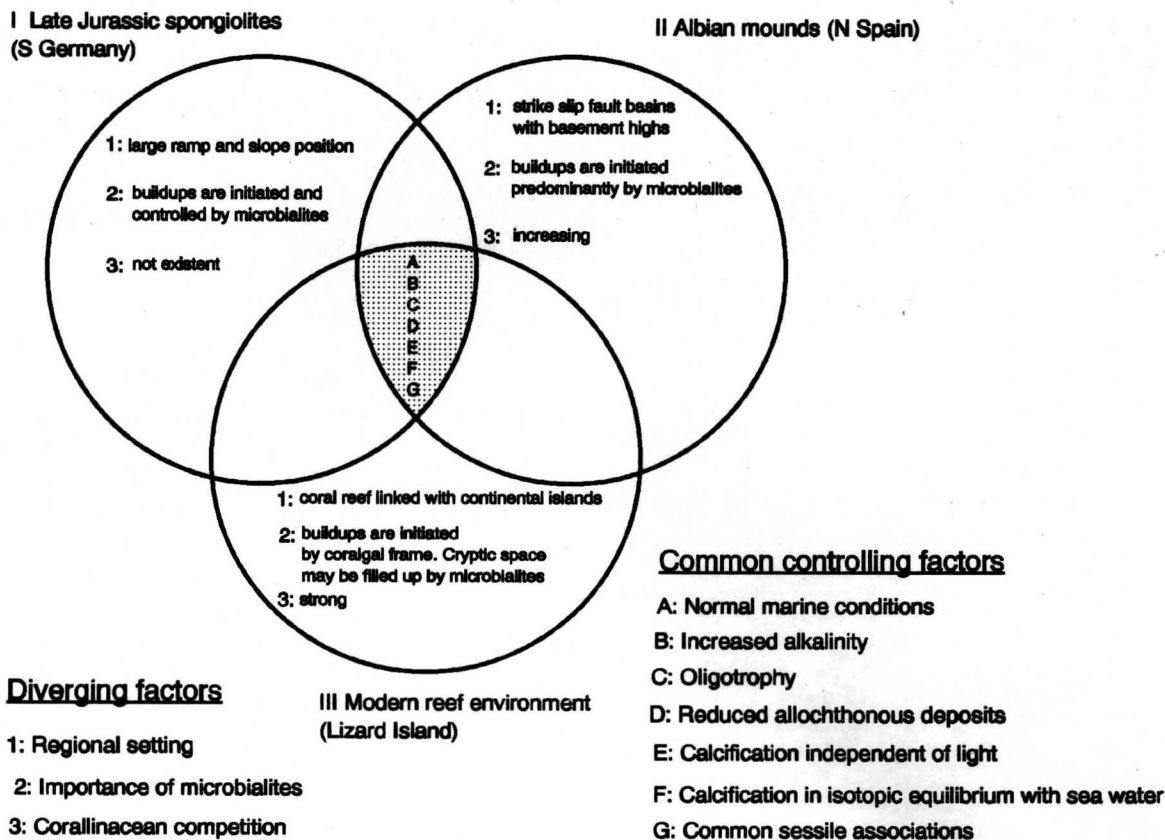
I Late Jurassic spongiolites (S Germany)

1: large ramp and slope position

2: buildups are initiated and controlled by microbialites

3: not existent

II Albian mounds (N Spain)

1: strike slip fault basins with basement highs

2: buildups are initiated predominantly by microbialites

3: increasing

1: coral reef linked with continental islands

2: buildups are initiated by coralgal frame. Cryptic space may be filled up by microbialites

3: strong

Common controlling factors

A: Normal marine conditions
B: Increased alkalinity
C: Oligotrophy
D: Reduced allochthonous deposits
E: Calcification independent of light
F: Calcification in isotopic equilibrium with sea water
G: Common sessile associations

Diverging factors

1: Regional setting
2: Importance of microbialites
3: Corallinacean competition

III Modern reef environment (Lizard Island)

Fig. 12. Comparative synopsis of factors controlling microbialite formations of three selected occurences through time (Late Jurassic, Albian, Recent).

conditions for analogous Mesozoic microbialites, particularly of Jurassic age, became a significant controlling factor, however, limited to water depths above 60-50 m, where hermatypic corals replaced the sponge facies. Below this critical boundary, the microbialites could grow extensively provided that the sedimentation rate was low and the carbonate saturation sufficient due to increased alkalinity.

* In contrast to the known Late Albian and particularly modern counterparts, in which the buildups are initiated by coralgal frames, the similar Upper Jurassic and Albian microbialites described by NEUWEILER (1993) construct and often initially control the buildups.

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