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Late Jurassic sponge buildups: environmental interpretation by comparison with microfabrics of modern hardgrounds

By THOMAS C. BRACHERT ¹⁾

ABSTRACT

Siliceous sponge buildups in South Germany are among the typical examples of fossil sedimentary rocks with no modern analogue. According to the microfabrics observed, the fossilization process of the sponges, the early marine diagenesis and the incrustation patterns, the late Jurassic material is similar to Quaternary sponges from the bathyal Mediterranean and to deeper water hardgrounds from the Red Sea. Sponge bioherms within the shallow lagoon of Great Bahama Bank, on the other hand, show no significant similarities with the fossil example. Causes for the death of the benthic organisms are oceanographic in origin (nutrient starvation, oxygen deficiency) and cannot be linked with suffocation by sediment or wave stress as in the Bahamas example. Despite the differences in age and setting, careful examination of microfabrics reveals a close relationship of the Late Jurassic siliceous sponge buildups with modern hardgrounds of the aphotic and dysphotic zone.

ZUSAMMENFASSUNG

Die Kieselschwamm-Bioherme Süddeutschlands gehören zu den klassischen Beispielen sedimentärer Ablagerungen ohne rezentes Vergleichsbeispiel und entsprechend kontrovers ist ihre Deutung. Gemäss Mikrogefügen in Kieselschwammfossilien sind der Fossilisationsprozess, die frühe marine Diagenese, die Inkrustationsfolgen und Verteilungsmuster verschiedener Epizoen und Bohrorganismen bathyalen Schwammkalkvorkommen des Mittelmeeres und tiefermarinen Hartgründen des Roten Meeres sehr ähnlich. Flachmarine Schwamm-Bioherme im Inneren der Grossen Bahamabank zeigen dagegen nahezu keine Übereinstimmungen mit dem fossilen Beispiel, mit dem sie oft verglichen wurden. Gründe für das zeitweilige Absterben der Kieselschwamm-Assoziationen im Mittelmeer und im Oberjura Süddeutschlands sind ozeanischen Ursprungs (Nahrungsverknappung, Sauerstoffverarmung) und können nicht, wie im Falle der Bahamas, mit erhöhten Sedimentationsraten zusammenhängen. Obwohl alle diskutierten Fallbeispiele grundsätzlich verschiedenen, geologischen Situationen entnommen sind, ergibt sich doch durch den Vergleich der Mikrogefüge eine nahe Verwandtschaft des süddeutschen Oberjuras mit den aphotischen bzw. dysphotischen Rezentbeispielen.

Introduction

Because “reefs” were thought to form only in shallow tropical waters, early workers (Roll 1934, Aldinger 1942) compared the setting of siliceous sponge-microbialite bioherms with that of modern coral reefs. During the fifties and sixties the supposed depositional environment shifted into “deep”, “dark” and “dirty” settings (Fritz 1958, Hiller 1964, Gwinner 1976). The late eighties brought back the idea of a shallow-water scenario with siliceous sponge buildups forming on a protected shelf behind a coral reef

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barrier (Brachert 1986, Kott 1989). Some diagenetic features (dissolution of aragonite, cementation, stratiform dolomite and dedolomite) pointed to temporary emergence (Koch & Schorr 1986, Wirsing 1988). Another group of geologists, however, insisted on the idea of a deeper ramp setting in front of shallow-marine carbonate platforms (Gaillard 1983, Gygi & Persoz 1986, 1987, Lang 1989, Brachert 1991 a).

These conflicting interpretations are due to the absence of a true modern analogue. This paper discusses the similarities of two modern carbonate environments with sponges playing a significant role in the benthic community (shallow Bahama Bank, deep Mediterranean Sea) and another one having micritic microbialite crusts and a similar guild structure but no sponges (forereefs of the Red Sea). The localities discussed are described in more detail by Brachert et al. (1987), Brachert (1991), Brachert & Dullo (1990, 1991) (Fig. 1).

Material and methods

This study is based on a dissertation at the Institut für Paläontologie at the Friedrich-Alexander-Universität Erlangen. The investigations were carried out by means of large scale thin-sections (10 × 15 cm), acetate peels and scanning electron microscopy on polished and etched slabs. Carbonate mineralogy was determined by EDX analysis.

The Jurassic material was taken from outcrops of the Fränkische Alb in South Germany (Fig. 1 A). A detailed description of the sections investigated and sample-ID's is given by Brachert (1991). The material from modern hardgrounds of the Mediterranean (Fig. 1 C) was dredged from Vavilov (sample code: 120 DC, water depth – 1375 m) and Ventotene (sample code 95 DC, water depth – 2125 m) seamounts during R.V. SONNE cruise 41 "HYMAS 1" (Brachert et al. 1987). The material from the Red Sea forereefs (Fig. 1 D) was obtained by using the two-man submersible GEO (Brachert & Dullo 1991).

The problem

Late Jurassic siliceous sponge buildups

Siliceous sponge buildups have been reported from long segments of the northern Tethys margin in Europe, where the slope was wide and gentle enough to accumulate large quantities of bank derived carbonate mud (Wilson 1975, Keupp et al. 1990, Brachert 1991 a) (Fig. 1 A). During the Oxfordian and Kimmeridgian, this shelf was situated in a tropical to subtropical regime about 30°N (Smith & Briden 1977). Wide epicontinental areas are characterized by biostromal sponge populations, whereas siliceous sponge bioherms with a high amount of microbial carbonate are found on the distal ramp (Gaillard 1983). In even deeper water pure microbialite mounds occur (Dromart 1988) and planktonic foraminifera within the sediment become more abundant. Sponge buildups are either biostromes of some 100 kms of lateral extension or bioherms ranging in size from decimeters to hundreds of meters with vertical relief from zero to 90 m (Hölder 1952, Gwinner 1958, Brachert 1991 a).

Despite its traditional name, the benthic community is not dominated by sponges but by non-fenestral microbial crusts having an average volume of 50%. They may attain a

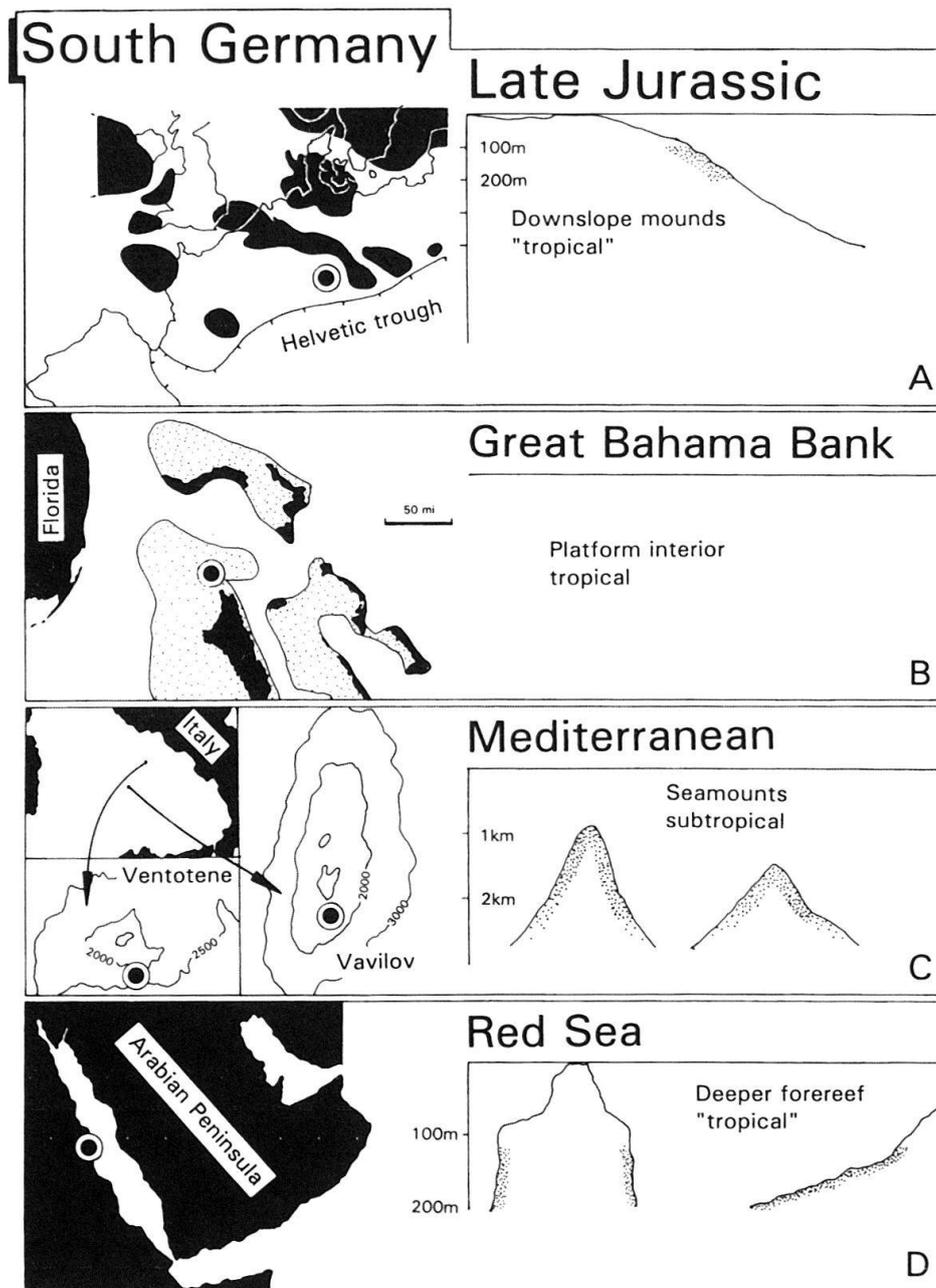


Fig. 1. Localization (circles) and geological setting of sponge buildups and biogenic hardgrounds discussed in the text; dots refer to the bathymetric distribution in vertical sections. A. Paleogeography of the European late Jurassic. Siliceous sponge buildups formed as downslope mounds on a distal ramp. B. Siliceous sponge bioherms form in the interior of Great Bahama Bank. C. Ventotene and Vavilov seamounts in the Mediterranean (Tyrrhenian Sea). D. Deeper foreereefs on the western coast of the central Red Sea (Sudan).

maximum of up to 90% of the rock volume (Lang 1989). These crusts almost exclusively form on the upper surfaces of sponges, whereas the undersides are incrustated by serpulids, brachiopods, molluscs, inozoan sponges, bryozoans and sclerosponges. Only few foraminifers have settled on the surfaces of the crusts. Boring of bivalves and sponges occurs in places but is not an important factor.

Mechanical reworking is unimportant in small bioherms, but large bioherms are surrounded by halos of intraclast/bioclast packstone grading over some tens of meters

distance into bioclast wackestone. Heavy reworking phenomena, however, can be excluded from analysis of bedforms and stratification. Moreover micrite is everywhere, indicating a typical still water environment.

Modern example 1: Bathyal seamounts of the Mediterranean Sea

In a water-depth interval of – 1000 to – 3000 m hardgrounds, which have formed on slopes and plateaus of seamounts (Fig. 1 C), are commonly covered by a fossil benthic community, which consists of either siliceous sponges (Dictyida) or azooxanthellate corals (Cariopyllidae). Both are associated with serpulids, octocorals and foraminifers (Alloué 1987). In places bioherms of meter-size are developed. During submersible dives, Alloué (1987) found that many of the sponges are still in growth position. Reworked sponges, however, are forming more commonly accumulations in unlithified sediment.

According to isotopic analyses bottom water temperatures were 8 °C for the living community (Alloué 1985) of this subtropical marginal sea. Increasing temperatures and a decrease in surface water productivity at the beginning of the Holocene caused the demise of the associations (Zibrowius 1980, Delibrias & Taviani 1985, Alloué 1987).

The sponges: The sponges are cone-shaped individuals of 20–30 cm length and have a maximum diameter of 5–8 cm. Depending on the mode of embedding into the muddy sediment, many of the gastral cavities are lacking any sedimentary infill. Those parts of the sponges that were not covered with pelagic mud are heavily bored, incrustated by serpulids or corals and covered by black ferromanganese crusts (Brachert et al. 1987). Where no coatings are developed, traces of the pore patterns of the sponge surface are preserved (Brachert et al. 1987), which consists of vertical and horizontal lines, similar to the Jurassic genus *Craticularia*.

Preservation: The framework of the spicules is embedded into a mixture of pelagic sediment (micron-sized calcitic bioclasts) including *Emiliana huxleyi* and micritic Mg-calcite cement. Subsequent to the formation of this micrite, the spicules were dissolved and the molds were later filled by ferromanganese oxides or by irregular fringes of bladed Mg-calcite cement (Froget 1976, Brachert et al. 1987). The original spicule fabric, however, is almost totally obscured by subsequent, multiple events of boring, infilling of micrite and reboring. The outline of the individual borings measuring up to several millimeters in diameter is very irregular. Many borings can be very close to each other and are separated by only thin lamellae of lime. The borings commonly follow previous borings leaving irregular relicts of previous micritic or sparitic infilling at their margins. In places, the latter phenomenon results in asymmetric cement linings of cavities (Fig. 2). Truncation of carbonate grains is an exception. In the fossil material, such borings should be difficult to discriminate from burrows.

Modern example 2: Deeper forereefs of the Red Sea

Below a water depth of – 120 m, the deeper forereefs of the Red Sea either show steep cliffs, which are bare of sediment or sand slopes with isolated limestone blocks, which are composed of lithified slope sediment (Fig. 1 D). Ledge-like protrusions have thin sediment caps on the upper surface, whereas the undersides are densely populated



Fig. 2. Multiple borings crosscut through calcified skeleton of mediterranean deep-sea sponge. The latest generation of borings is still open and partially follows an elder bioerosion fabric, which truncates isopachous fringes of cement (water depth – 2125 m), Mediterranean Sea (Ventotene Seamount). Thin-section, SO41 DC95. Scale bar = 1 mm.

by serpulids, corals, bryozoans, bivalves, brachiopods and foraminifers. Lithophags (sponges and bivalves) repeatedly attack the rock from below the overhangs and cause a homogenization of the fabric (Brachert & Dullo 1990, 1991). Below unlithified sediment, the upper surfaces of the ledges are characterized by fossil laminar micrite crusts which probably formed by microbial activity. The crusts show no significant signs of bioerosion. The formation of the crusts could be related to the Early Holocene rise of sea-level (Brachert & Dullo 1990). Siliceous sponges were not observed.

A literature review: Shallow-water Bahama platform

In the north of Andros Island siliceous sponge mounds were found within the grapestone facies belt (Wiedenmayer 1978, 1980) of the platform interior (Fig. 1B). Water depth equals – 3 m to – 13 m. Maximum diameter of the mounds is 10 m and maximum vertical relief is 2 m. The surface of these bioherms is overgrown by green and brown algae, sponges, alcyonarians and corallinaceans. Foraminifera, molluscs and corals are less abundant. The sediment, which is the same as within the surrounding grapestone facies belt, is fixed by incorporation into psammobiotic sponges living still 2 m below the sediment surface and by inorganic cementation caused by water flows produced by sponges. Vertical accretion of the bioherms is mainly caused by storm deposits, which are subsequently fixed by upward growth of endobiotic sponges.

Discussion

Settings: In contrast to the Jurassic sponge buildups, which have formed on a warmwater shelf, the Mediterranean sponge fauna discussed lived in the bathyal realm of this subtropical sea. The Pleistocene associations are found on steep slopes of seamounts or fault scarps and cover a bathymetrical range of more than 2000 m. This is due to low physical gradients in bathyal waters. It is not clear, whether the epicontinental sponge faunas of the Jurassic were restricted to elevations above the surrounding sea floor or whether they were restricted to a certain depth interval of several tens of meters (v. Freyberg 1966) on the deeper shelf. In contrast to the Mediterranean they lived on very gently inclined slopes in front of extensive carbonate platforms, which received significant amounts of micritic particles (type 1 of Wilson 1975). The climate was wet with episodes of less precipitation (Gygi 1986). The Red Sea, in contrast, is a desert enclosed marginal Sea. In shallow water, coral reefs are mainly of the fringing reef type and enclosed back reef areas are small. Foreereef slopes are very steep down to several hundreds of meters of water depth.

The only striking similarity of the sponge bioherms of Great Bahama Bank with the Late Jurassic example is the absence of lithified debris around the bioherm. Major differences, however, are (i) the composition of the benthic association, (ii) the grain-size of the sediments involved, which are silt to sand in the modern example, (iii) the necessity of storm layers for vertical accretion of the bioherms, (iv) the associated facies belts including small-scale sedimentary cycles and (v) the setting within the lagoon of a shallow-marine platform (see Tab. 1).

Microfabrics

Biogenic fabrics: Accelerated by high Holocene bottom water temperatures in the Mediterranean, the opaline spicules were dissolved subsequent to the formation of micrite surrounding the meshwork of the skeleton (Brachert et al. 1987) and prior to burial. For the latter reason the sponges were subject to incrustation and heavy boring activity. Most of the incrusters did not settle directly on the skeleton but on the surface of this micritic wrap (Fig. 3, 4). Early marine dissolution of spicules in the Late Jurassic material is indicated by a pseudomorphic replacement of spicules by marine carbonate cements (Fig. 5), internal sediments, glauconite or pyrite. Borings of bivalves and sponges (*Aka* sp.) within the skeletons indicate that micrite within the spicule meshwork

	Setting	Sponges?	Crusts?	Assoc.	Fabric
Bahamas	Lagoon, shallow	yes	---	different from Jurassic	?
Mediterranean	Basin, slopes and plateaus	yes	Fe/Mn crusts	similar to Jurassic	similar to Jurassic
Red Sea	deeper forereef	---	non fenestral micrite	similar to Jurassic	similar to Jurassic

Table 1: Major characteristics of modern sponge/microbe associations

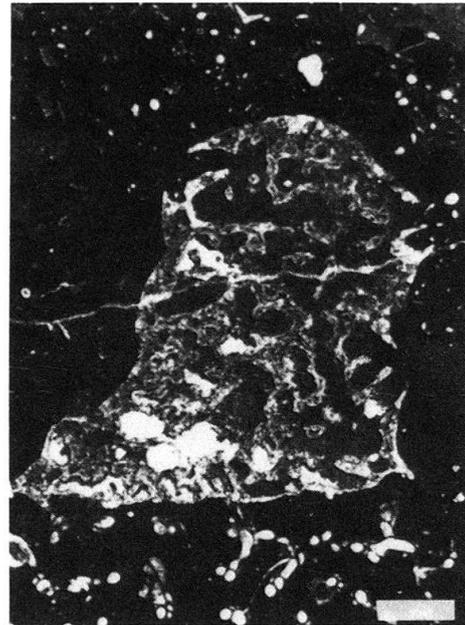
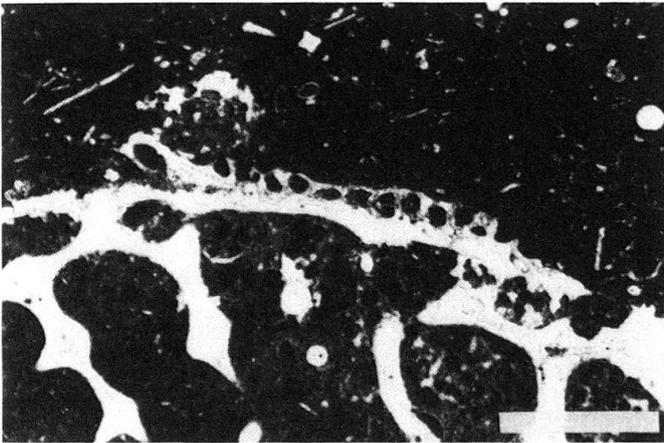


Fig. 3. (left) Incrusting "bryozoan" colony attached to the outer surface of a hexactinose sponge. Thin-section, upper Jurassic, Würgau, Wü. 38. Scale bar = 1 mm.

Fig. 4. (right) Inozoan sponge attached to the surface of a siliceous sponge. The base of the inozoan is even and does not follow the surface of the skeleton. Thin-section, upper Jurassic, Würgau, Wü. 12, scale bar = 1 mm.

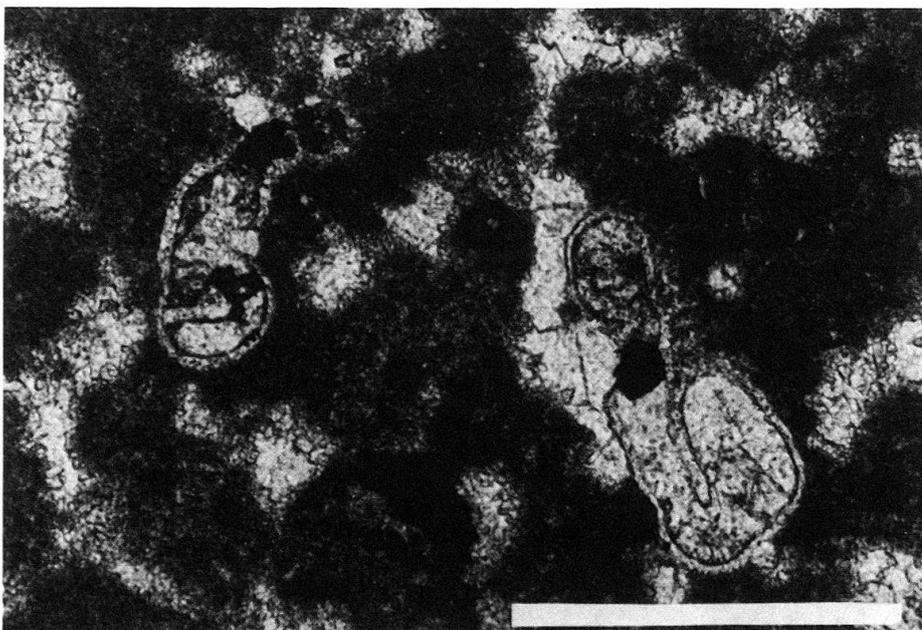


Fig. 5. Detail of siliceous sponge skeleton incrustated by foraminifers (*Thuramina* sp.). The siliceous spicules were replaced by two generations of carbonate cement indicating an early mold stage. Thin-section, upper Jurassic, Ludwag, Lu. 78, scale bar = 0,5 mm.

was lithified and that the sponge itself had no cover of loose sediment. The dissolution of the spicules, however, is only needed for species boring exclusively chemically. The absence of a sediment seal is also indicated by the occurrence of incrusters. In the Jurassic material, the first generation of incrusters is directly attached to the spicules (worm tubes like *Terebella*, the foraminifers *Bullopore*, *Thurammina* (Fig. 5), *Tolypammina* and a nubeculinellid (Fig. 6) inhabiting the pore system of the living sponge or cryptic habitats immediately after its death (Ziegler 1964, Brachert 1986, Fürsich & Werner 1991). Other incrustations (bryozoans or sclerosponges, micrite crusts) clearly settled after the formation of the sponge mummies (Tab. 2). A succession of incrusters belonging to the same genera, which begins with restricted conditions and ends in well aerated sediments was found in lower Toarcian black shales of South Germany (Bruder 1968): *Nubeculinella* (highly restricted), *Bullopore*, serpulids and the bivalve *Placunopsis* (partly restricted) as well as ostreids and bryozoans (well aerated sediments). Although *Nubeculinella* is an omnipresent form, it is cautiously suggested here, that the sequence of incrustation on siliceous sponges have a similar origin. Early diagenetic pseudomorphs of microsparite after gypsum (Fig. 7) surrounding the spicules or occurring within the sediment (Fig. 8) also indicate variations in sea bottom aeration (Schnitker et al. 1980).

The arrangement of microfabrics in ledge rocks from Red Sea forereefs and Jurassic sponges reveals a similar pattern: The ledges commonly have a nucleus which consists of lithified sediment or a biogenic substrate (coralline algae, large bryozoan colonies and corals), that is marginally homogenized by bioerosion. The upper side of this substrate is overgrown by laminar micrite crusts without any borings. On the undersides of the ledges a dense population of sciaphil incrusters and borers is found (Fig. 9).



Fig. 6. Crust of nubeculinellid foraminifers grown like a chimney around exhalant canal of a sponge skeleton. Thin-section, upper Jurassic, Ludwag, Lu. 98, scale bar = 1 mm.

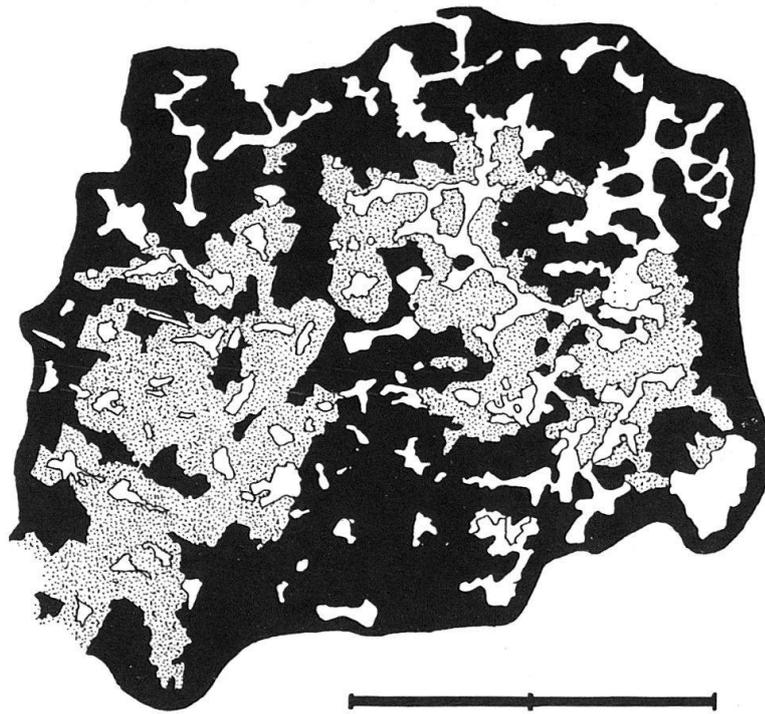


Fig. 7. Micosparitic pseudomorphs after gypsum (dots) have formed around siliceous sponge skeleton (white) before the infilling of micritic matrix (black). The spicules were later replaced by calcite cement. Upper Jurassic, Biburg, F. 1, scale bar = 2 mm.

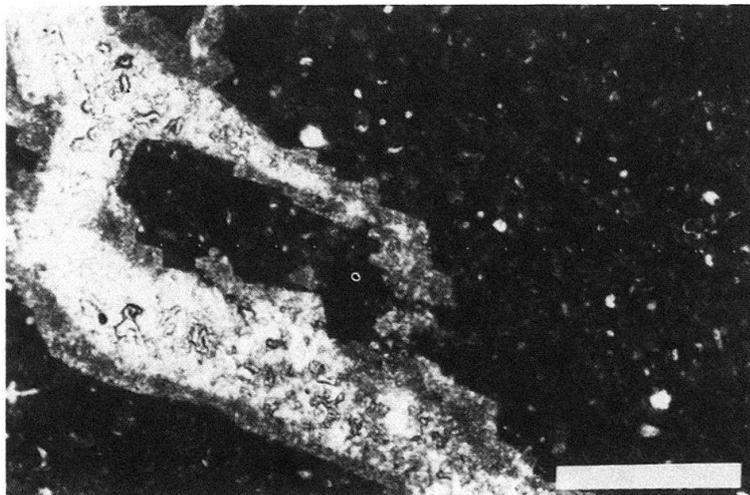


Fig. 8. Pseudomorphs after gypsum. Thin-section, upper Jurassic, Mittersthal, Mi. 26, scale bar = 1 mm.

Crusts: Fritz (1958) and Hiller (1964) believed that the formation of the microbialite crusts and that of the micrite surrounding the sponge skeleton was controlled by bacterial degradation of the sponge softparts. However, except the high Mg-calcitic composition of the Mediterranean sponges, there is no evidence of bacterial cementation. Keupp et al. (1990) pointed out that the small amount of “tissue” also poses volumetrical problems. The absence of bioturbation in between the spicules may have enhanced the cementation

	bryozoans, scleropon- ges, inozoans	laminar micrite crusts	foramini- fers, tube- worms	bivalves	pseudom. after ? gypsum
before mummification	?	?	x	x	x
after mummification	x	x	?	?	

Table 2: Incrustation patterns and diagenetic phenomena of siliceous sponges (Jurassic and modern). ? = not observed

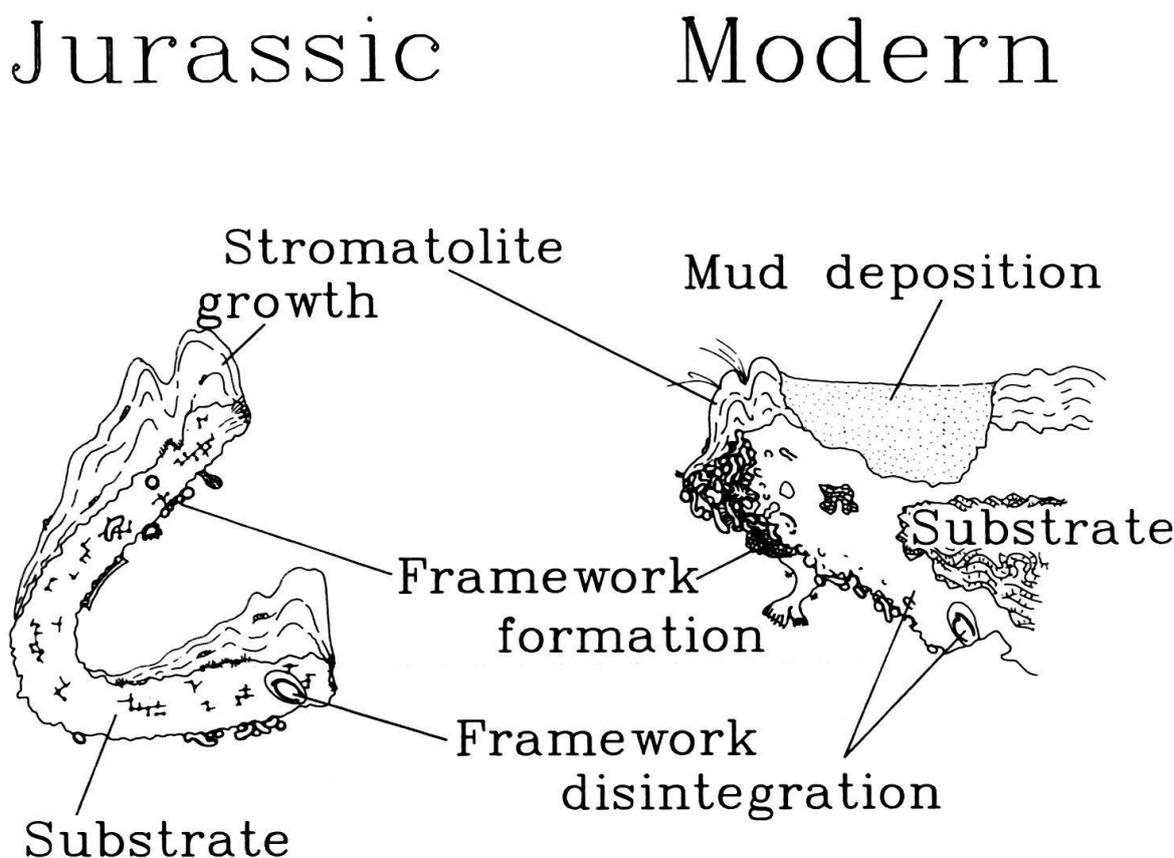


Fig. 9. Schematic drawing of the distribution of incrusters and borers in Jurassic and modern hardgrounds (Red Sea). Microbialites form on upper surfaces, whereas overhangs are incrustated by various negative phototactic live forms. Not to scale.

process. Late Jurassic Schwamm-Mergel (Brachert 1986) showing well cemented, calcified sponges without crusts floating in less cemented marl sediment are another excellent indicator of early marine lithification. Mechanical and chemical compaction occurred mainly at the boundary of sponges and embedding sediment (Brachert 1986, Brachert et al. 1987, Huber 1987).

A comparison of ferromanganese coatings and dendrites being so important in the Mediterranean does not apply, because they have formed a long time after the demise of the sponge population. The bottom water of the Late Jurassic sea was presumably slightly oxygen deficient inhibiting the formation of ferromanganese crusts (Brachert

1991). In contrast to the modern example, in the Jurassic planktonic organisms only play a minor role in sediment accumulation. This is partly due to the young age of this guild: Pteropods had not yet evolved.

Modern laminar micrite crusts in deep waters are only described from the Caribbean (Land & Moore 1980) and the Red Sea (Brachert & Dullo 1990, 1991). The origin of these crusts is probably due to microbial activity by binding and cementing micritic grains. The occurrence of the crusts in waters below that of coralline algal growth as well as their presence within microcavities points towards an independence from the sunlit zone. The same is true for the Late Jurassic material, because crusts occur on upper surfaces of sponges as well as within the interiors of their dark gastral cavities (Gwinner 1976).

Cementation: Only a few thin-sections of Late Jurassic sponge buildups show incomplete marine cementation patterns. These patterns comprise fibrous cements that only occur on roofs of cavities similar to microstalactitic cements of the meteoric zone (Koch & Schorr 1986, Wirsing 1988). However, meniscus cements are absent in interparticle pores and incomplete cementation is restricted to serpulid tubes and possible borings. Often some of serpulid-tubes have typical marine isopachous fringes of cement, whereas others near-by lack any cementation or are incompletely sealed (Fig. 10, 11). Superficially similar features also occur in Mediterranean deep sea sponges (Fig. 2) and in Red Sea ledge rocks (Fig. 12). Brachert & Dullo (1991) ascribed these features to coeval cementation and boring activity in hardgrounds, particularly if later borers follow previous borings (Fig. 2). The same may be true with dwelling of existing pore space by non-fossilized evertebrates.

Causes for demise: The major effect of the global warming at the beginning of the Holocene was a drastic decrease in vertical mixing of the Mediterranean waters and therefore a reduction of surface water productivity, which was further reduced by high runoff of light hyposaline Black Sea waters. The resulting stable stratification of the water column caused stagnation in deep basins (Cita & Podenzani 1980). The demise of the benthic biota on submarine plateaus remaining above the oxygen line was caused by high bottom water temperatures and drastically reduced food supply for suspension

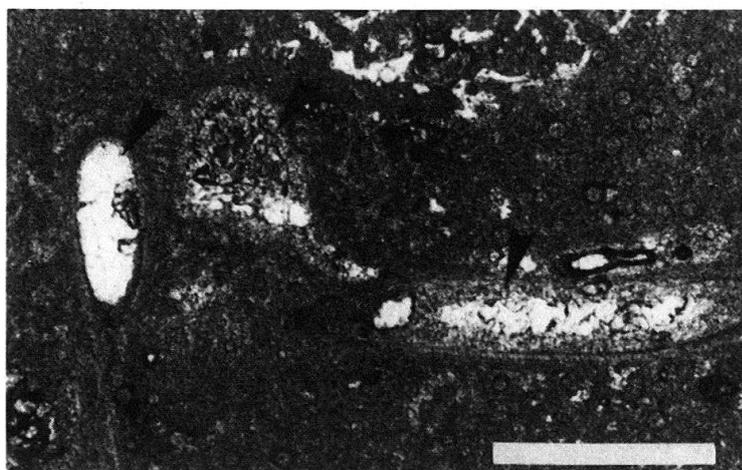


Fig. 10. Inhomogeneous cementation in Late Jurassic boundstone. Marine fibrous cements are not evenly distributed among all serpulid tubes (arrows). Acetate peel, Upper Jurassic, Gräfenberg, G. 19, scale bar = 1 mm.

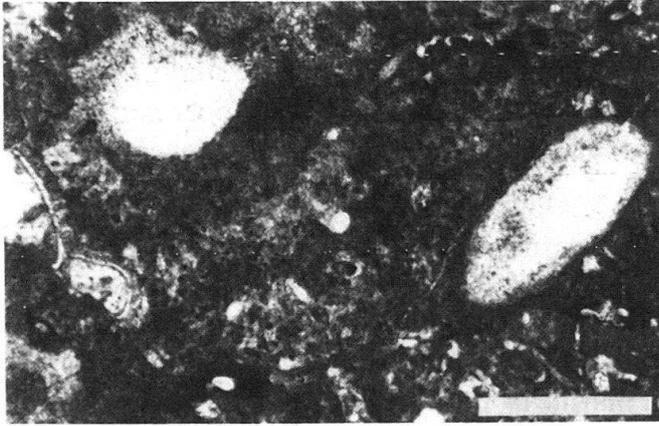


Fig. 11. (left) Agglutinated worm tubes. Early diagenetic fibrous cement only partially fills the pores. Thin-section, upper Jurassic, Konstein, Ko. 70, scale bar = 1 mm.



Fig. 12. (right) Modern Red Sea ledge rock. Cement linings within an irregular boring are laterally discontinuous. Note polar morphology similar to pendant cement (water depth – 200 m), Red Sea, thin-section, GEO 72, scale bar = 1 mm.

feeders (Delibrias & Talwani 1985). For the Late Jurassic Brachert (1991) inferred episodic productivity blooms in surface water and correlating upward excursions of the oxygen line, which also affected some of the sponge buildups.

Conclusions

1. A modern analogue of the late Jurassic siliceous sponge/microbialite association is not known.
2. Three modern examples of similar associations from different geological settings (Great Bahama Bank, Mediterranean Sea, Red Sea) have been compared with the late Jurassic material.
3. Sponge bioherms from the grapestone facies of Great Bahama Bank differ with respect to accompanying organisms and sedimentary regime.
4. The taphonomy of Mediterranean deep sea sponges as well as bioerosion and incrustation patterns of biogenic hardgrounds from the Red Sea are similar to the late Jurassic example.
5. Aphotic and dysphotic examples are different with respect to setting but reveal similar microfabrics. This evidence suggests a deeper water origin for late Jurassic siliceous sponge buildups.

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