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Biolaminites at the Zechstein (Upper Permian) Platy Dolomite (Ca3)-Main Anhydrite (A3) boundary: implications for evolution of an evaporite basin

Biolaminite an der Grenze Plattendolomit (Ca3) – Hauptanhydrit (A3) (Zechstein, O-Perm): Bedeutung für die Evolution eines Evaporit-Beckens

by

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Abstract

Microbial laminations are commonly recorded at the carbonate-sulfate facies transition including the transition from the Zechstein Platy Dolomite to Main Anhydrite (PZ3, Leine) of northern Poland. The Platy Dolomite originated in the sabkha complex environment. It is capped by stromatolites that usually become more and more disordered due to a fast increase of the sulfate content. Upwards, carbonate layers decrease and sulfate layers increase in frequency and thickness. Carbonate layers show characteristic microbialite lamination. These microbialites contain organic laminae that alternate with muddy ones. Organic laminae include frequent microfossils or their remains and products of their direct and indirect activities. Abiogenic laminae and layers consisting of mud contain rare skeletal or nonskeletal grains and mineral precipitates. Microfossils are related to organic laminae and belong to two morphological groups: filamentous and coccoid. The main process controlling microbialite-sulfate alternation is linked with seasonal changes of sea level, rates of evaporation and pumping.

The occurrence of microbial structures typical for extremely shallow environments with rapid changes of salinity at the transition between the carbonates and sulfates indicates a very similar environment of formation of these two mineral phases. The biolaminite layering within the lowermost part of evaporite sequences elsewhere may be useful for environmental interpretation.

Zusammenfassung

Mikrobielle Laminite werden häufig von Karbonat-Sulfat Faziesübergängen beschrieben, so auch an der Grenze zwischen Plattendolomit und Hauptanhydrit im Zechstein (PZ3, Leine) N-Polens. Der Plattendolomit wurde in einem Sabkha Komplex gebildet und wird von Stromatolithen überlagert, die durch rasch zunehmenden Sulfatgehalt gestört werden. Nach oben nehmen die Karbonatlagen an Häufigkeit und Dicke ab, während die Sulfatlagen zunehmen. Die Karbonatlagen zeigen eine typisch mikrobielle Lamination. Diese Mikrobialithe bestehen aus organischen Lagen, die mit schlammigen alternieren. In den organischen Laminae sind Mikrofossilien häufig oder deren Reste bzw. Produkte ihrer direkten oder indirekten Aktivitäten. Die abiogenen Laminae und Lagen bestehen aus Schlamm und sind arm an biogenen und abiogenen Partikeln sowie Mineralfällungen. Die Mikrofossilien der organischen Lagen gehören in 2 morphologische Gruppen: filamentöse und coccoidale. Die Mikrobialit-Sulfat Wechselfolge wurde durch saisonale Schwankungen des Wasserspiegels, sowie der Verdunstungs- und Durchflußraten hervorgerufen.

Das Vorkommen von mikrobiellen Strukturen, typisch für sehr seichte Ablagerungsräume mit schnellen Salinitätsschwankungen, am Übergang zwischen Karbonaten und Sulfaten deutet auf ein sehr ähnliches Bildungsmilieu für beide Mineralphasen hin. Analoge Biolaminationen im untersten Teil von Evaporit-Sequenzen können auch anderswo für die Interpretation des Ablagerungsraumes herangezogen werden.

1. Introduction

Widely correlatable lamination is recorded in evaporite basins both in deep water and subaerial (but ephemerally flooded) environments (KENDALL, 1992), and some of them may be used for precise reconstruction of ancient sedimentary environments in which evaporites were deposited. This applies to microbial laminations that are commonly recorded at the carbonate-sulfate facies transition in which the increase in salinity affected bioge-

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nic activity but not for microbial communities that were very tolerant of increased salinities as indicated by studies of modern evaporitic environments (e.g. ARAKEL, 1980; KUSHNIR, 1981; ORTI CABO et al., 1984; FRIEDMAN & KRUMBEIN, 1985; JAVOR, 1989). Microbial rocks are an essential constituent at the transition from the carbonate to the sulfate facies in the Zechstein (Upper Permian) Platy Dolomite (Ca3)-Main Anhydrite (A3) of northern Poland (GASIEWICZ, 1990; GASIEWICZ et al., 1987). The aim of this paper is characterize this transition. Such a description is lacking for many fossil counterparts of environments in which the Platy Dolomite deposits formed, and, as will be presented further in this paper, the detailed inspection of these rocks may supply important information for deciphering the history of deposition during changes of mineral facies.

2. Material and methods

The studied area is part of the Precambrian Eastern European Platform. The Zechstein sequence consists of a thick (ca. 200 to 250 m) Werra (PZ1) cycle, the thinner (< 50 m) Stassfurt (PZ2) cycle, and the Leine (PZ3) cycle, which in the northern part of the area consists only of the Platy Dolomite carbonates (ca. 1020 m), whereas in the southern part the Platy Dolomite (20-40 m) is overlain by the Main Anhydrite (< 10 m) (Fig. 1).

The area constituted a deep basin that developed during the deposition of Zechstein Limestone (Ca1) when carbonate platforms developed to the west, north, and east. This basin was filled by the Lower Werra Anhydrite (A1d) and Oldest Halite (Na1) deposits (Fig. 1). The Upper Werra Anhydrite (A1g) deposits in the major part of the area indicate that they were formed in very shallow subaqueous to subaerial environments (PERYT, 1991). The deposits of the cycles PZ2 and PZ3 were formed primarily in very shallow subaqueous to subaerial environments (PERYT et al., 1992).

The Platy Dolomite sequence is dominated by various types of microbialites intercalated with allochthonous facies composed of carbonate mudstones, rudstones, and bioclastic, peloidal, and ooidal carbonates (GASIEWICZ, 1985, 1990; GASIEWICZ et al., 1987; GASIEWICZ & PERYT, 1989). The microbialites predominate the facies composition of the inner-platform, peritidal series, while oolites form a thicker complex that developed in the carbonate platform margin zone during deposition of the upper Platy Dolomite.

The Platy Dolomite is capped by the Triassic Buntsandstein deposits in the northern part of carbonate platform and by the Main Anhydrite (A3) in the southern part of carbonate

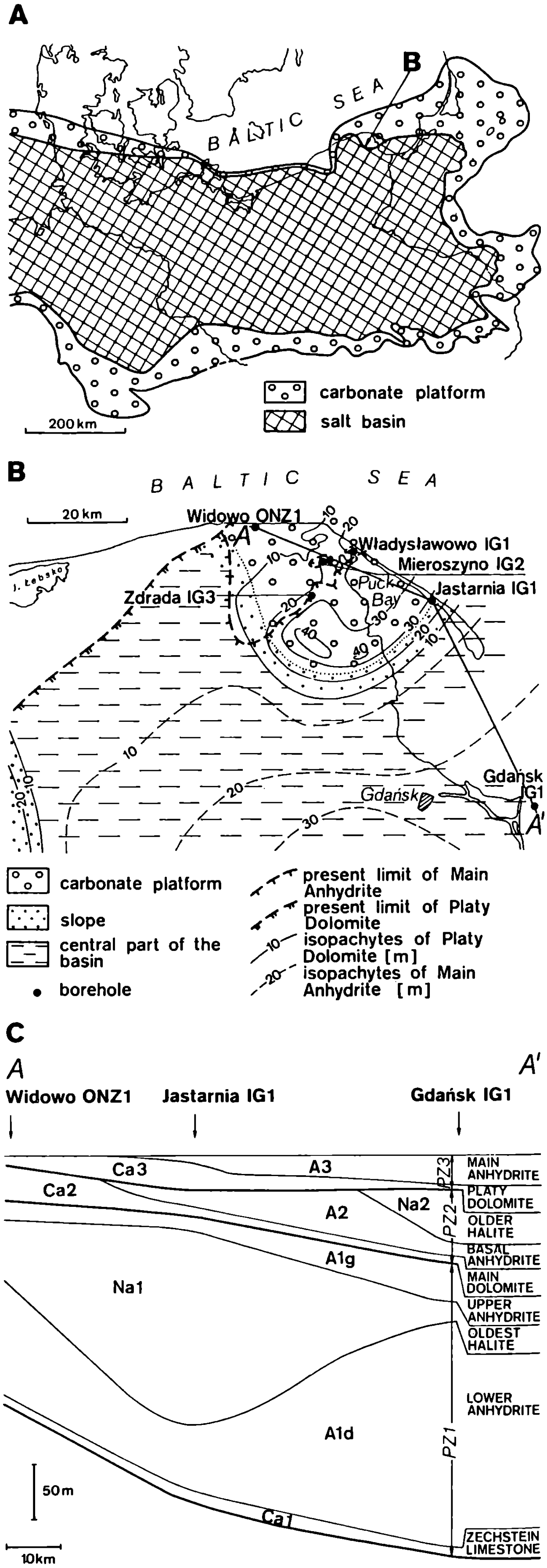

Figure 1: Geological setting. A – The Zechstein 3 basin (after KIERSNOWSKI et al., in press), B – PZ3 of the Puck Bay region (after PERYT et al., 1992), C – Schematic cross-section through Zechstein deposits along the A-A' line shown in A (after PERYT, 1989).

platform as well as basinward. The Main Anhydrite in the latter as well as in the basin zone adjacent to the slope of the carbonate platform is a nodular anhydrite, probably a sabkha facies deposit, and farther basinward is massive anhydrite with pseudomorphs after bottom growth gypsum crystals. The latter indicate shallow subaqueous conditions (PERYT, 1989).

The Platy Dolomite and Main Anhydrite sections have been measured and systematically sampled for petrographical study (ca. 30 samples in 1 meter of core in the upper part of the Platy Dolomite) and SEM study. Samples for SEM were treated with diluted HCl in order to expose microbial remains.

3. Results

In the uppermost part of the Platy Dolomite section stromatolites occur (commonly 0.2 to 0.5 m thick) that usually become more and more disordered higher in the section due to a fast increase of the sulfate content; nevertheless microbial structures can be recognized (Pl. 1, Fig. 1; Pl. 2, Fig. 1). The boundary between the Platy Dolomite and Main Anhydrite is gradational and composed of alternation of carbonate and sulfate layers forming distinct and rather poorly correlatable horizons. They occur in most of the Puck Bay region.

Upward in the Platy Dolomite section the abundance of sulfates increases. The sulfate minerals occur in form of disorderly localized, numerous, often distinct, calcite or anhydrite pseudomorphs after gypsum crystals, and more and more frequent sulfate fenestrae, granules, and nodules (Pl. 3, Figs. 1, 2). This tendency continues in the transitional zone. The increase in frequency of these sulfate minerals results in that they form sulfate laminae and layers. In such layers sulfate minerals initially occur individually, but upwards they exibit more and more expressed tendency to amalgamation forming distinct and relatively uniform layers and beds. Finally the increase of content of sulfate minerals caused typical and thick (around 0.5 to 0.8 m) nodular anhydrite beds. Although the sulfate interlayers are not uniform and contain displaced carbonate mud (mainly dolomite) or darker structureless organic matter, their purity distinctly increases upwards. Carbonate layers show characteristic lamination that exhibits lack of lateral persistence, undulated morpholgy and blurred boundaries of the carbonate layers and their internal lamination, and the presence of fossilized microbial remains. These features differ them from abiogenic laminites often associated with ancient and recent sabkha and deeper water, subaqueous, marine evaporites (e.g. GUNATILAKA & SHEARMAN, 1988). Thus, macro- and microstructure of the lamination demonstrate its organosedimentary origin and allow one to classify them as biogenic structures (or fossilized microbial mats) and therefore as microbialites i.e. organosedimentary deposits that have accreted as a result of a benthic microbial community trapping and binding detrital sediment or forming the locus of mineral precipitation (BURNE & MOORE, 1987).

The stratiform nature of the carbonate, laminated layers allows one to define them additionally as biolaminites. These microbialites contain organic laminae that alternate with muddy ones. They are characterized by a mm-scale layering that is subtle and less regular and rhythmical than that of the upper part of Platy Dolomite.

There are two types of laminae: dark and thinner organic laminae and lighter, thicker, muddy laminae. The latter are commonly so enriched in sulfate fenestrae, granules, and nodules that they in turn form sulfate laminae or layers with some carbonate mud admixture. Organic laminae, usually dolomitized, include frequent microfossils (or structureless remains) and products of their direct and indirect activities. Sometimes they contain occasional fine bioclasts or quartz grains. Abiogenic laminae and layers consisting of calcite and mainly dolomite muds contain rare carbonate grains (bioclasts, peloids or ooids), mineral precipitates, and occasional quartz grains.

Microfossils are related to organic laminae and belong to two morphological groups: filamentous and coccoid (Pl. 1, Figs. 2–4; Pl. 2, Figs. 3 & 4). The latter strongly predominate in the microfossil assemblage. Paleontological data and comparisons with recent analogs allow one to interprete them as remains of cyanobacteria (GASIEWICZ et al., 1987).

4. Discussion and Conclusions

The uppermost Platy Dolomite microbialites originated in the peritidal environment, mainly in the low-energy, intertidal zone of the sabkha system where the rate of the intertidal sedimentation kept pace with the rate of subsidence (GASIEWICZ et al., 1987; GASIEWICZ, 1990). At the same time their textural and structural features indicate considerable fluctuations of both the water chemistry and cover and show a general tendency toward increase of salinity. Sulfate granules and nodules are similar to nodular anhydrite forming today in the tidal-flat complexes of the sabkha environments (e.g. BUTLER et al., 1982) and are interpreted as early diagenetic structures.

The microbialites were deposited in an environment with periodical, shallow water and subaerial exposition of the microbial mats. The internal lamination indicates seasonal changes of drying and wetting of the deposits. Predominance of coccoid microfossils in the fossil microbiota suggests, as in recent microbial mats (e.g. KRUMBEIN et al., 1977; GERDES et al., 1985), an increase of permanency of water cover.

A major control on the development of microbial mats in hypersaline peritidal system of the Platy Dolomite was thus the frequency of wetting by tides or storms and capillary pumping (e.g. KINSMAN & PARK, 1976;

FRIEDMAN & KRUMBEIN, 1985). The main process controlling microbialite-sulfate alternation is linked here with seasonal changes of sea level, evaporation rates, and pumping. These conditions control depositional and biotopic conditions. In summer, evaporation increased and caused the water level to sink, exposing periodically flooded, widespread flats. This caused development of thin microbialite mats that accumulated detrital grains by adhesion. In winter, the evaporative pumping was less efficient, and the flats were flooded and sulfate minerals deposited below the sediment-water interface. Additionally, sulfates minerals precipitated from brines which were progressively more concentrated in the pore spaces due to evaporation. These were destroying the microbial structures.

These findings have important implications. There are problems of facies relations between the basin and platform facies of the Zechstein Leine (Z3) cycle. Some authors consider that the Main Anhydrite in the center of the basin is in part a time equivalent of the Platy Dolomite, which represents the platform facies (e.g. FRICK, 1969; LANGBEIN, 1965, 1973). This idea is questioned by others (see REBELLE, 1986, p. 129, and PAUL, 1991). PAUL (1991, p. 1041) suggested that some carbonate streaks in the lower part of the Main Anhydrite may indicate the transition from chemically precipitated carbonate to sulfate, thus reflecting the increasing salinity of the sea water, whereas REBELLE (1986, p. 129) concluded that it is most unlikely that subaqueous evaporites in the center of the basin and carbonates in the marginal part of the basin could precipitate at the same time and from the same hypersaline water mass.

The deposition of the carbonate members of two first Zechstein cycles was terminated by the fall of sea level and the subaerial exposition of carbonate platforms. There is no evidence yet, however, of such fall during deposition of the third Zechstein cycle. Instead, the occurrence of microbial structures typical of extremely shallow environments with rapid changes of salinity at the transition between the carbonates and sulfates indicates very similar environment of formation of deposits of these two mineral facies. (The lateral carbonate–sulfate transitions were earlier recorded in the PZ2 [= Stassfurt] cycle of SW Poland – PERYT & KASPRZYK, 1992). A possible explanation is the progradation of the sabkha complex with the regression of the Platy Dolomite sea (cf. PAUL, 1991), but this does not exclude the possibility that carbonates in the marginal zone of the basin and sulfates in more central position were deposited at least in part simultaneously. The studied transition indicates that the biolaminite layering within the lowermost part of evaporite sequences can be very useful for environmental interpretation of evaporite sequences.

Acknowledgements

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PLATE 1

Fig. 1. Platy Dolomite-Main Anhydrite transition. Carbonate bed with darker and lighter (middle part) layers containing ubiquitous sulfate granules and nodules (black, dark gray and very light) arranged into distinct layers. These layers are composed of less (in the uppermost and lowermost parts) or more frequent sulfate granules, nodules and contortions that in the middle part may be heavily compacted and elongated, resulting in a change in the stratification from flat and horizontal to slightly dipping and even distinctly bent (in the lowermost part). Sulfate layers are interlayered by carbonate-enriched layers containing better (in the lowermost part) or less well-developed subtle, internal microbialite lamination that often is laterally discontinuous. Initial stage of the contorted layer (light discontinuous and thin diapiric layer) formation is visible in the center of the photograph.

Figs. 2–4. Coccoid microfossils (SEM micrographs). Dark, carbonate laminae contain frequent remains of coccoid microfossils with cast-negatives of former cells or hollow spaces after individual organic forms. They may occur as single forms or may be arranged into colonies. These structures commonly have a microcrystalline replacement structures and sometimes relics of the sheaths of unicellular forms (4) or relics of their aggregates.

PLATE 1

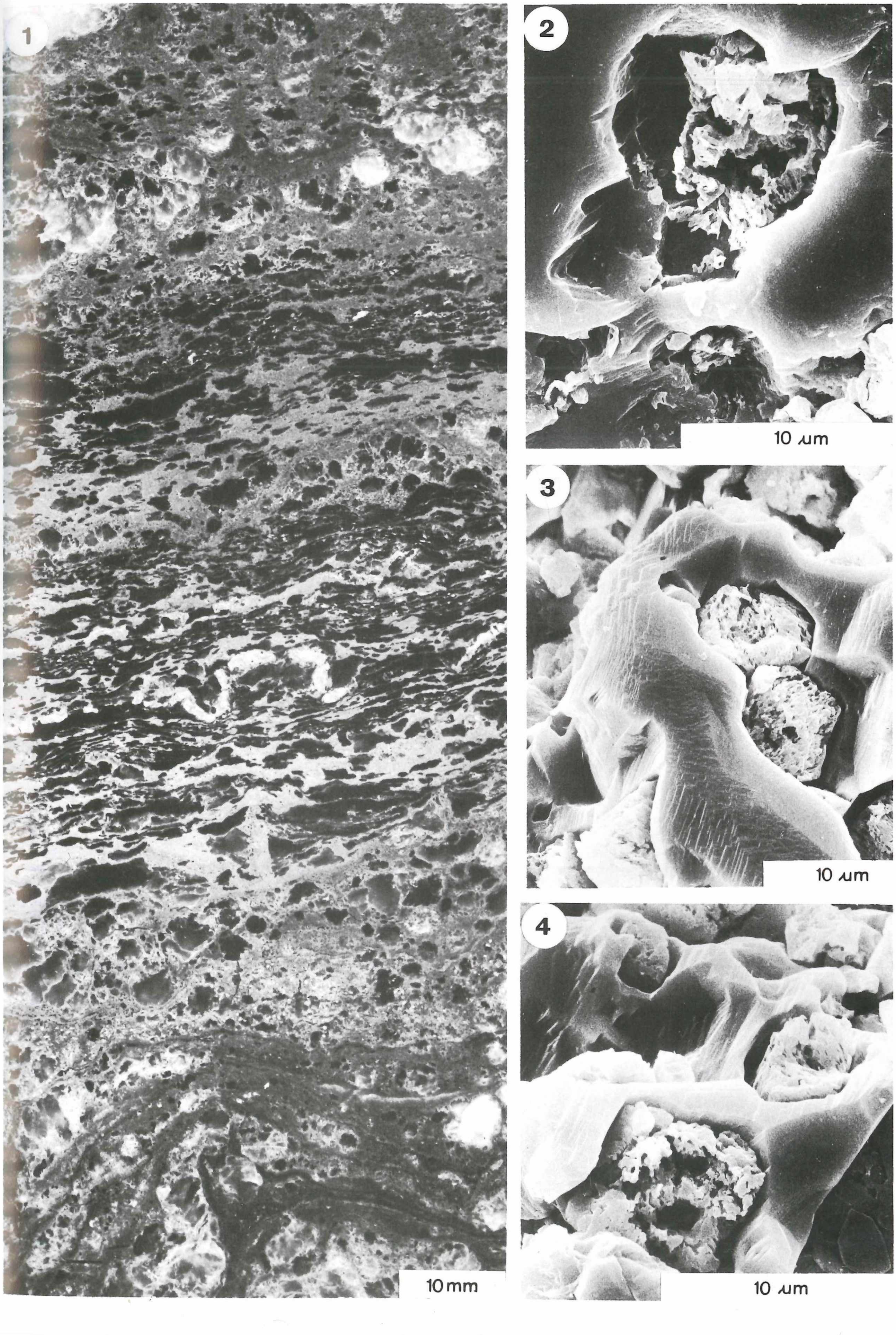

PLATE 2

Fig. 1. Platy Dolomite-Main Anhydrite transition. Carbonate layers of various thickness and composition are slightly inclined and may be enriched or impoverished in sulfates. Distinct lighter (in the middle part) carbonate layer is predominated by a carbonate mud and contain relatively minor, less frequent, and compacted sulfate granules. This layer is limited by distinct erosional surfaces (dark subtle and wavy stylolite-like boundaries). Typical microbialite lamination contains numerous fenestrae. The laminae are commonly diffuse with internal, small scale, wavy undulations and contain single dispersed sulfate granules that sometimes are arranged into poorly developed horizons. Thicker carbonate layer (upper part) contains microbialite lamination which, however, is gradually disturbed by sulfate granules and nodules. As a result, it becomes discontinuous and finally disappears.

Fig. 2. Thin section micrograph. Microbialite layers developed between sulfate granule and nodule levels. Sulfate granules indicate a distinct tendency to coalescence into more homogeneous layers with displacement of carbonate mud fabric in between them. Microbialite layers exhibit internal lamination indicating an alternation of dark (relatively organic rich) and lighter (carbonate mud and pore infilled with anhydrite) layers.

Figs. 3–4. SEM micrographs of remains of filamentous microorganisms rarely preserved in organic laminae. These unbranched forms may be differentiated into thicker forms (often partly degradated) (3) or relatively thin forms (4) often embedded in structureless organic material.

PLATE 2

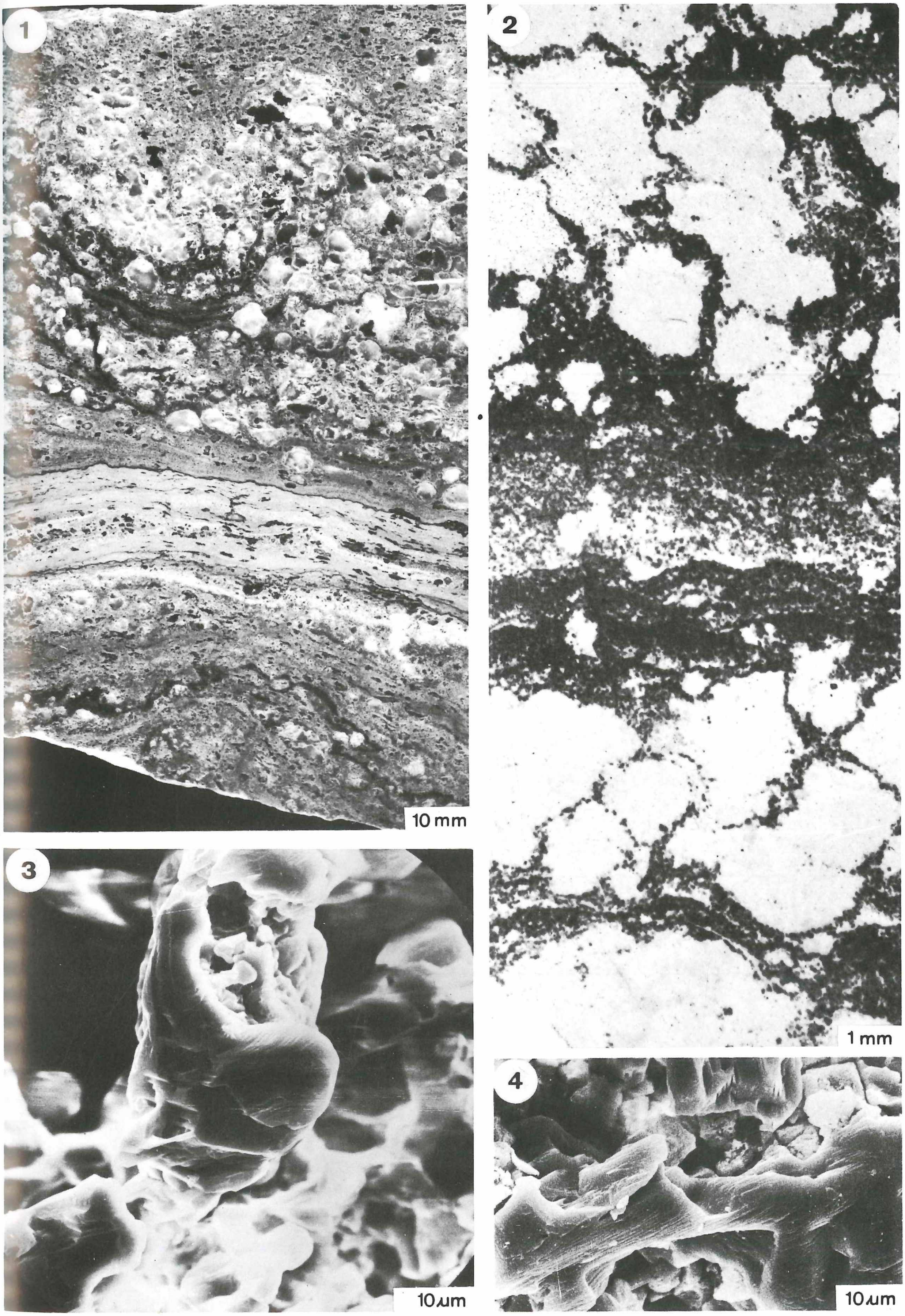

PLATE 3

Platy Dolomite-Main Anhydrite transition.

Fig. 1. Thin section micrograph. Thin and wavy microbialite lamina with distinct alternation of subtle dark organic sublaminae and lighter ones predominated by carbonate mud. Heavily homogenized sulfate–granule layer with extremely low content of carbonate mud occur below the microbialite lamina. Coalescent sulfate granules with relatively high carbonate content in between them occur above the lamina. Darker spots dispersed in the carbonate matrix represent small shreds of unformed organic matter. Locally fine lenticular anhydrite pseudomorphs after gypsum crystals (arrow) are visible in the the carbonate matrix.

Fig. 2. Thin section micrograph. Strongly bent microbialite lamination (lowermost and uppermost parts). The lamination is predominated by distinctly thicker carbonate mud laminae with individual and rare sulfate granules. The organic laminae are subtle, very thin and often deformed by sulfate granules. Thicker carbonate mud-sulfate granule layers are developed between the microbialite layers. Sulfate granules sometimes coalesce into small sulfate nodules. The carbonate matrix is heterogeneous and contains dispersed, oval to elongated, black peloids.

PLATE 3