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A microscopic sedimentary succession of graded sand and microbial mats in modern siliciclastic tidal flats

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Abstract

Microscopic studies of thin sections from modern siliciclastic tidal flat sediments in the southern North Sea demonstrate the significant role of microbial mats in the buildup of sedimentary sequences. This is documented by a unit only a few millimetres thick. It starts at the base with a fine- to medium-grained quartz sand often containing secondary pores ('fenestrae type') merging gradually into finer sediments. The lower siliciclastic part is superposed by an upper organically dominated layer built by microbial mats. Within the organic material, single quartz grains without any contact to each other are oriented with their long axes parallel to the bedding planes. Each siliciclastic part in the lower section of the unit indicates the initial deposition of coarser grains in a stronger flow regime followed by gradually decreasing flow velocities. Each microbial mat in the upper part essentially represents a period of low sedimentation rate. During its growth, grains still settle down onto the mat and become bound in the organic matrix. The orientation of these grains with their long axes parallel to the bedding plane points to an energetically suitable position to gravity achieved by the friction reduction of the soft organic matter. Repeated depositional events followed by low-rate deposition cause the buildup of various units. There is no visible reworking of the former surfaces, since the microbial mats prevent erosion during periods of increased flow. The buildup is characteristic of siliciclastic sediments repeatedly occupied, stabilized, and fixed by microbial films or mats.

Keywords: microbial mats; microscopic sedimentary succession; siliciclastic; graded sand; particle orientation; biostabilization

1. Introduction

Bedding, perhaps the most widely used term in describing a sedimentary sequence, includes the process of deposition, e.g., fall-out of suspended material from water, and a period of non-deposition or abrupt change in depositional conditions. The latter is characterized by bedding planes that separate a single bed from adjoining beds (Reineck and Singh, 1986). Distinction between beds depends upon recognition of bedding surfaces (Reineck and Singh, 1986). In the postdepositional phase, bedding planes are subject to a great variety of processes. They may be physically contoured by ice or salt crusts (Reineck et al., 1995), or biologically con-

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toured due to the stabilization potential of microphytobenthic populations (Krumbein et al., 1994). In particular sedimentary surfaces of higher-lying tidal flats are often stabilized by the prolific growth of coherent surface films and mats produced by benthic cyanobacteria and diatoms.

Within more or less homogeneous-looking deposits, e.g. sedimentary sequences built by quartz sand, the distinction between individual units may not be easily detected. In this case, microbial mat formation on bedding planes may support the separation of sedimentary units (Gerdes et al., 1991). However, since preservation of the soft organic material may be poor in siliciclastic environments, it is worthwhile to look also for indirect indices of postsedimentary biological impact on originally physically dominated sedimentary structures.

This paper represents results of microscopic studies on thin sections prepared from modern tidal flat sediments of Mellum Island (southern North Sea). The studies revealed a characteristic microscopic unit that reflects the unique character of sediments occupied, stabilized, and fixed by microbial films or mats.

2. Study area and methods

Mellum Island belongs to the type of high-lying sandbank islands situated in the southern North Sea (Gerdes et al., 1985; Fig. 1). The climate is moderately humid. Low pressures, westerly winds, and high rainfall are typical. The mean tidal range is 2.90 m, and the mean spring tidal range is 3.50 m. A scattered dune/salt-marsh complex protects extended back-barrier tidal flats composed of fine- to medium-grained quartz sand. In the upper intertidal

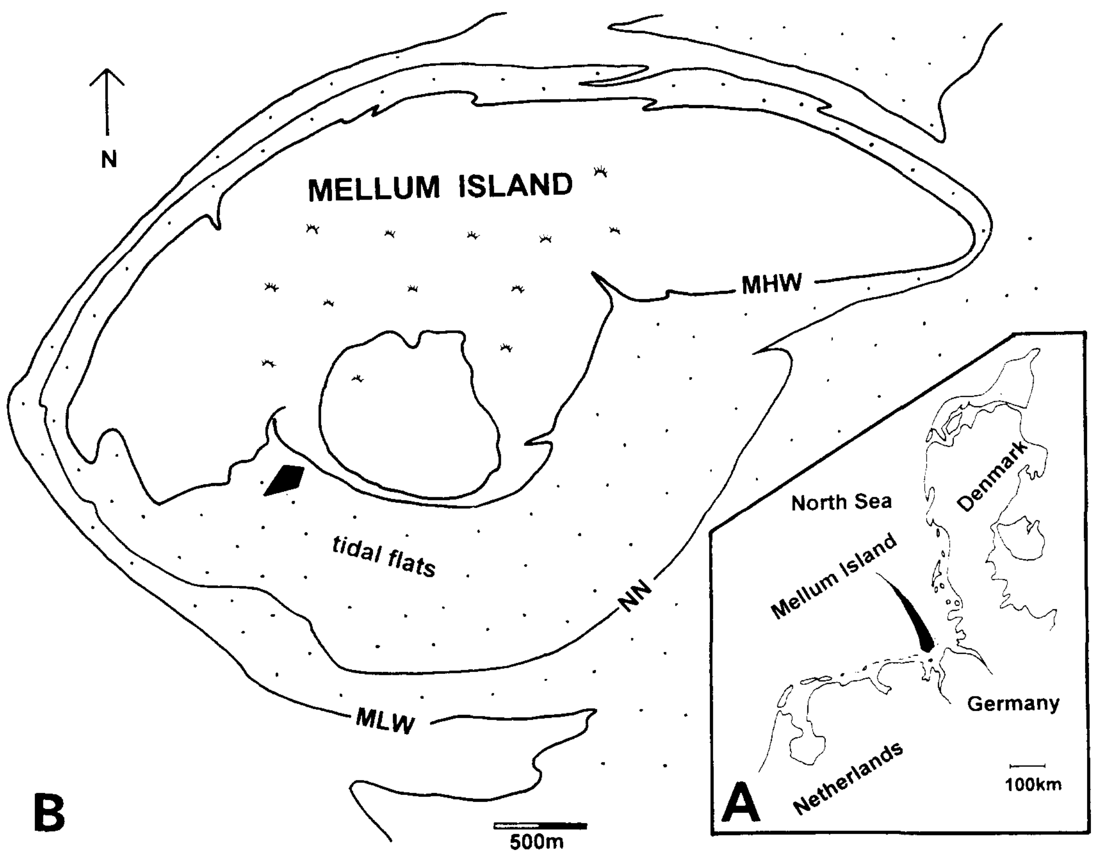

Fig. 1. (A) Location map of the southern North Sea and Mellum Island. (B) Mellum Island with an elevated centre covered by a salt-marsh/dune complex, and extended back-barrier tidal flats. Arrow indicates study site.

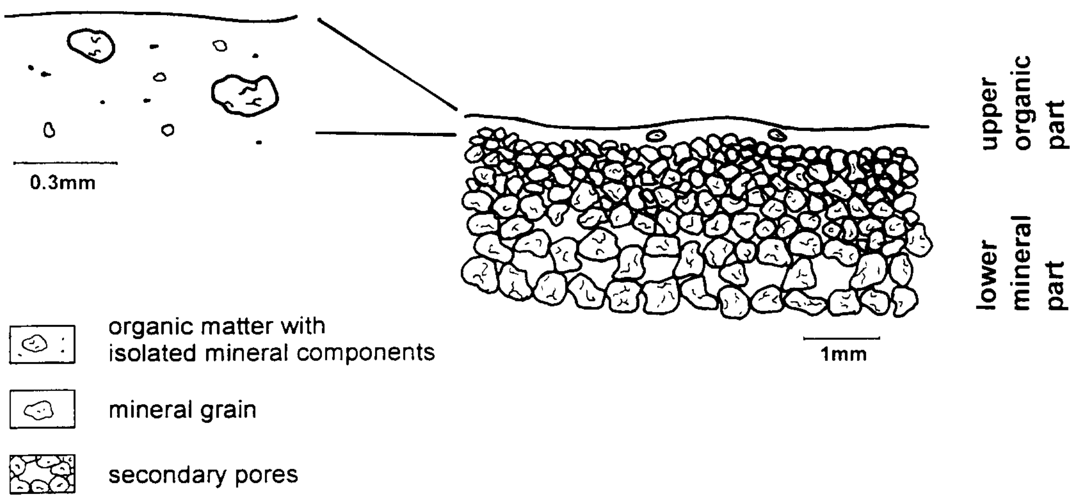

Fig. 2. Schematic presentation of a microscopic sedimentary unit seen in thin sections. Upper part: isolated mineral compounds (both sand-sized and silt-sized quartz grains) 'float' in the organic matrix (not drawn in detail) produced by a microbial mat. Lower part: grain-supported fabrics of quartz sand, grading upwards into finer-grained sand. At the base secondary pores.

and lower supratidal zone of the tidal flats, microbial mats are developed effectively stabilizing the sedimentary surfaces (Krumbein et al., 1994). The main constituents of the mats are cyanobacteria with the dominant species *Microcoleus chthonoplastes*. A diverse community also comprising benthic diatoms, purple sulphur bacteria and a wealth of other bacterial groups is present (Gerdes et al., 1985).

Undisturbed samples of mat-covered sediments were taken, fixed and hardened with epoxy resins (ARALDIT F and hardener) for thin sections (Reineck, 1970). Thin sections were prepared perpendicular to the sedimentary surface. The morphometry of the grains was determined layer-wise under a light microscope. The orientation of the grains and their visible long axes were measured and the values transferred into a circular chart.

3. Description of the unit

Microscopic investigations of thin sections revealed the repeated appearance of a characteristic microscopic sedimentary unit a few millimetres thick (Figs. 2 and 3(1)). Upwards from the base to the top, mineral grains of medium to fine sand grade into fine sand. In the lowest part of the unit, often hollow cavities of about 0.3 mm diameter on average occur. Towards the top, the unit is completed by an upper part enriched in microbial biomass. Within this upper organic layer, two different appearances can be observed.

(1) Single quartz grains without any contact seem to float in the scummy organic matrix (Fig. 3(2)). Grain sizes are similar to those of the mineral base. In contrast to the grains occurring in the mineral-supported unit below, however, the mat-embedded grains predominantly are arranged with their long axes parallel to the sedimentary surface (Fig. 4).

(2) The organic layer also is enriched with various silt-sized quartz grains (Fig. 3(3)) that are lacking in the lower-lying part.

The whole succession reaches an average thickness of 1.5 to 4 mm. It can be vertically repeated several times indicating the type of concordant bedding (Fig. 5A).

4. Interpretation

The lower siliciclastic part of the unit indicates the initial deposition of coarser grains from suspension in a relatively higher flow regime. In response to a following phase of decreasing flow velocities, the grain size decreases gradually to fine sand sizes. The origin of grading in intertidal flats has been attributed to deposition in the last phase of heavy floods (Reineck and Singh, 1986). Such situations are typical

of the study area where spring tides often are accompanied by stronger winds and even storms, also leaving behind evenly laminated sand as the most prominent primary sedimentary structure (Reineck and Gerdes, 1996). After the hydrological energy has approached to zero, microphytobenthos colonizes the freshly sedimented layers, initially forming biofilms that after longer periods of non- or low-rate deposition reach a mat-like condensation of organic matter. Each microbial mat essentially represents a plane of low-rate deposition. During its development, grains still fall down on the mat and become glued together by the microbial slime. Shinn (1983) describes this process as 'trapping'. The mat gradually incorporates the grains as it grows upward, a feature termed 'binding' (Dunham, 1962). The orientation of these grains with their long axes parallel to the bedding plane points to an energetically suitable position to gravity made possible by the friction reduction of the soft organic matter. In contrast to this, particles in the grain-supported part do not show the predominant orientation with their long axes parallel to the bedding plane, since the compact fabric may not allow for their arrangement according to gravity.

The origin of silt-sized quartz sand within the mats may be attributed to the last phase of fall-out from the flood. Another explanation is related, however, to the characteristic behaviour of the mat-forming filamentous cyanobacterium *Microcoleus chthonoplastes* to erect filamentous tufts perpendicular to the mat surface into the supernatant fluid. These function as bafflers that may trap silt-sized grains even during periods of moving water.

The hollow cavities in the lower siliciclastic part of the unit are induced by gas enrichment. The gas originates from the decay of buried mat material and is trapped by the coherent mats that cover the sediment. The intrasedimentary gas pressure increases in the course of time causing secondary pores in the siliciclastic part, a feature named 'sponge sand structure' (Noffke et al., 1996).

Fig. 3. (1) Microbially modified stratum in tidal sediment. The lower siliciclastic part is graded. In its lowest part, a sponge sand structure can be observed. The organic layer tops the stratum. (2) Oriented quartz grains in a microbial mat layer. (3) Silt-sized mineral compounds fixed by microbial mat.

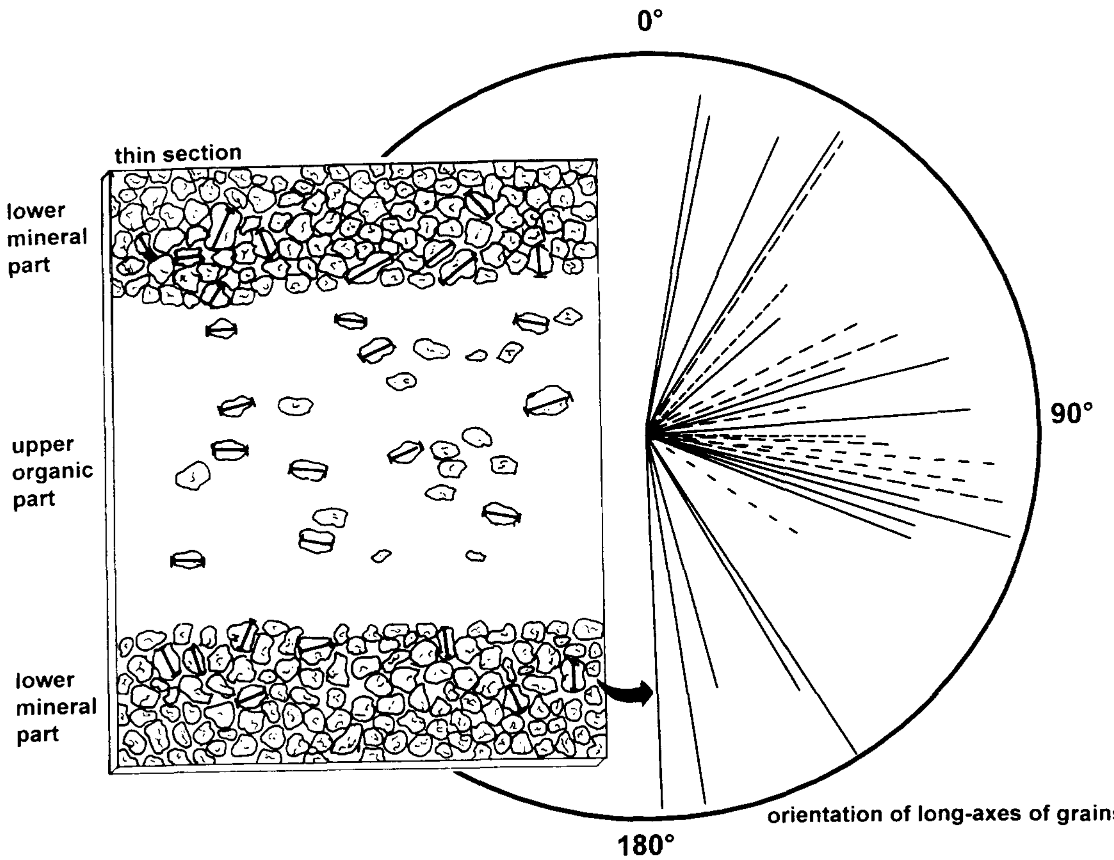

Fig. 4. Schematic presentation of the orientation of quartz grains seen in thin sections. Left drawing: top and base indicate the orientation of grains in the mineral layers; intermediate part indicates orientation of grains in microbial mat layers. Right drawing: measurements of the orientation of visible long axes of grains transferred into a circular chart. Stippled lines indicate orientations of grains in mat layers.

Repeated depositional events followed by low-rate deposition cause the buildup of various units. There is no reworking of the former surface visible, since the microbial mats prevent erosion during periods of increased flow. The organic layer functions as a separating matrix between two units and supports the preservation of sedimentary surfaces. If the surfaces were not colonized by microbes, the sedimentary units would be amalgamated (Fig. 5B).

5. Conclusion

The microscopic unit reflects the unique character of sediments occupied, stabilized and fixed by microbial films or mats. Microbial influences include trapping and binding, biostabilization, and the friction-reducing behaviour of the organic matrix. Microbial mats also increase the critical shear stress value required to re-suspend deposited grains. A typical indication of the presence of microbial mats is the specific geometric arrangement of quartz grains within the organic material. Sediment stabilization by microbial mats may support surface preservation after burial presumably resulting in bedding planes in consolidated rocks. Additionally, these structures represent a complementary feature to physical effects leading to the preservation of surfaces. In fossil material, successions like these may provide hints to the former presence of microbial mats. Such organic layers may have a low preservation potential in ancient rocks, but their significance cannot be overlooked.

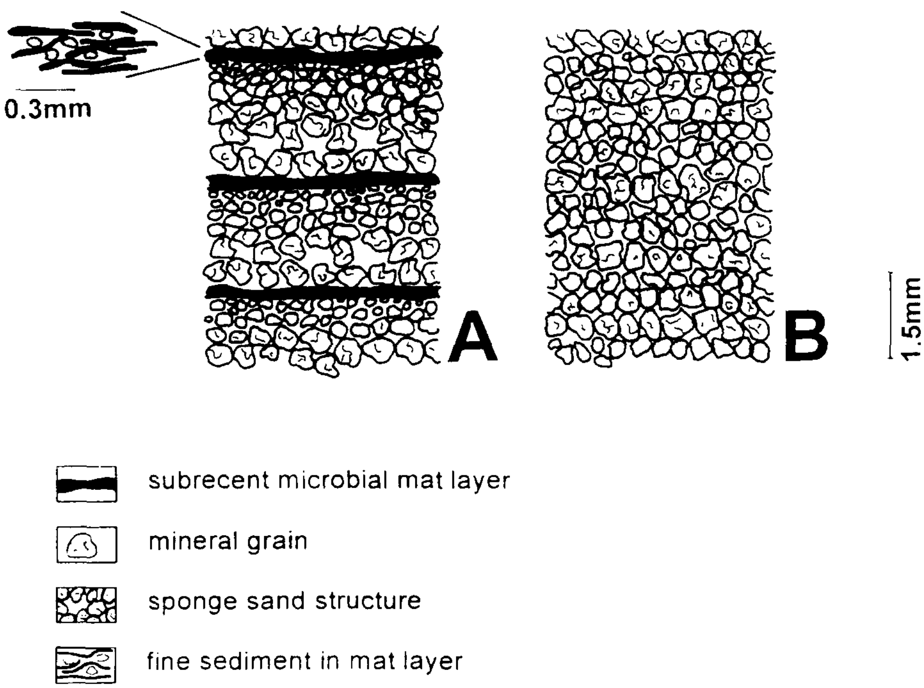

Fig. 5. (A) Idealized succession of three units. Bedding planes are imprinted by subrecent mats separating the units. The mats developed after hydrodynamic energy caused by stronger floods approaching zero. Indicated at left: close-up of mat-supported material bound by the former active mat. Indicated in the lower siliciclastic part of each unit: secondary pores causing 'sponge sand' (see text). (B) Idealized presentation of an amalgamated tidal flat sequence. Environments lacking microbial stabilization of bedding surfaces may cause erosion of former deposited sediments during short-term dynamic events. This may give rise to amalgamated units.

Acknowledgements

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