MICROBIALLY INDUCED SEDIMENTARY STRUCTURES

Coastal sedimentary systems of moderate climate zones are governed not only by physical dynamics like erosive tidal flushing or reworking by wave action, but also by biotic factors like sediment stabilizing or accumulating by epibenthic bacterial communities. The shallow-marine environments are colonized by benthic microorganisms, amongst those photoautotroph cyanobacteria are an abundant group (ecology: Whitton and Potts, 2000). With the aid of their adhesive and slimy "extracellular polymeric substances" (EPS, see for introduction Decho, 1990), epibenthic species attach to mineral grains, and they can even form thick, tissue-like, organic layers covering extensive areas of the sedimentary surface. Such bacterial "carpets" are termed "microbial mats" (definition of term see Krumbein, 1983; overview also in Gerdes and Krumbein, 1987; Cohen and Rosenberg, 1989; Stal and Caumette, 1994; Stolz, 2000).

Colonizing at the interface between sediment and water, cyanobacteria are able to react to sediment-affecting physical agents in different ways.

Responsive behavior of epibenthic cyanobacteria to physical sedimentary dynamics

During periods of no or low rates of sediment deposition, thick microbial mat layers develop. By growth, they smoothen out or level the original tidal surface morphology, and form flat bedding surfaces (compare Noffke and Krumbein, 1999). In close up on vertical sections through thick mat layers, the growing biomass drags upward mineral grains from the sedimentary substrate. The grains are separated from each other, and become oriented with their long-axes perpendicularly to the loading pressure (microbial grain separation; Noffke *et al.*, 1997).

Slow moving, suspension-rich bottom currents induce a vertical orientation of cyanobacterial filaments that trigger fall-out of sediment by "baffling, trapping, and binding" (Black, 1933). Over time, the sediment agglutinating microbial community grows upward (Gerdes *et al.*, 1991). In vertical section, this produces laminated intrasedimentary patterns.

In depositional areas of higher hydrodynamic energies, only thin microbial mats can grow. They cover surface structures, like ripple marks, without altering the original shape of the relief. Buried depositional surfaces are "imprinted" by the thin, former mat layers (Gerdes *et al.*, 2000, and references therein).

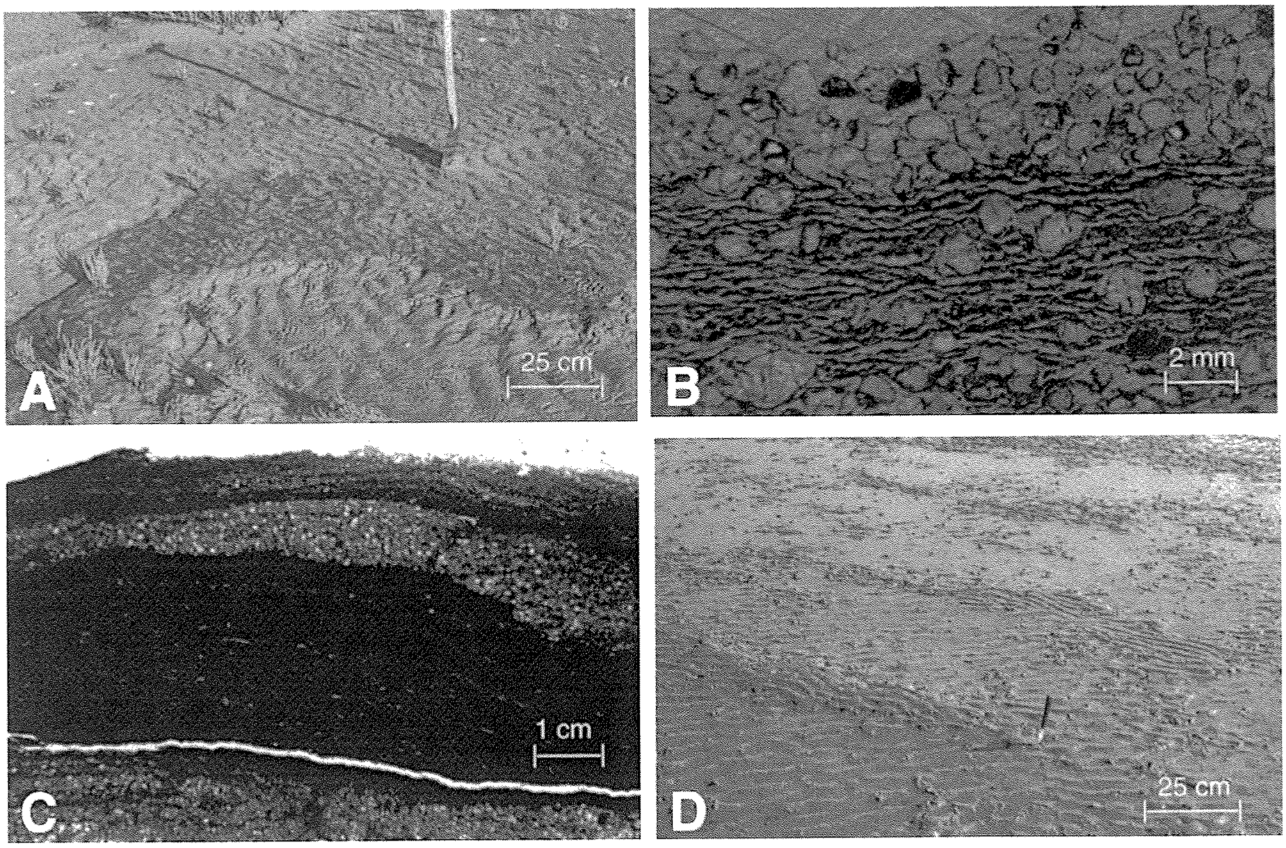

Figure M14 Microbially induced sedimentary structures in physical depositional areas of moderate climate zones—examples. (A) Sedimentary surface smoothened by microbial mat cover; (B) "Oriented grains" within microbial mat layer; thin section; (C) "Biolaminite"; thin section; (D) "Multidirected ripple marks".

Only when subjected to strong bottom currents, mat-secured sedimentary surfaces are eroded, because the dense and coherent microbial mats seal effectively their substrate and increase resistance against erosion. Additionally, cyanobacterial layers prohibit exchange of gas between sediment and water. These effects are known as "biostabilization" (Paterson, 1994; Krumbein *et al.*, 1994; Paterson, 1997; Noffke *et al.*, 2001).

Microbially induced sedimentary structures

The responsive behavior of the mat-constructing microepibenthos generates a great variety of characteristic sedimentary structures. The structures differ significantly from biogene stromatolites we are familiar from chemical lithologies, and mineral precipitation plays no role in their formation.

Flat bedding planes originated by immense mat growth are termed "leveled surfaces" (Noffke, 2000; Noffke *et al.*, 2001), Figure M14(A). In the fossil record, they can be recognized as "wrinkle structures" (Hagadorn and Bottjer, 1997), where they document pauses in sedimentation (Noffke, in press). Characteristically, thin-sections through leveled surfaces reveal "mat layer-bound oriented grains", that is mineral particles floating independently from each other in the organic matrix like a chain of pearls, Figure M14(B). They document former microbial grain separation, and pressure-related orientation (Noffke *et al.*, 1997).

Laminated intrasedimentary pattern caused by baffling, trapping, and binding are well-known as "biolaminites", or, after consolidation, as "planar stromatolites" (discussion of terms by Krumbein, 1983), Figure M14(C).

Typical surface morphologies that are shaped by biostabilization interfering with erosion are "erosional remnants and pockets" (Noffke, 1999; fossil example: MacKenzie, 1968), or "multidirected ripple marks" (Noffke, 1998; fossil counterparts: Pflueger, 1999), Figure M14(D). Internal features are "fenestrae fabrics" (Gerdes *et al.*, 2000). "Sinoidal structures", visible in vertical sections through the sediment, imprint former ripple mark valleys (Gerdes *et al.*, 2000; Noffke *et al.*, 2001; fossil example: Noffke, 2000).

Because the structures are formed syndepositionally by biotic-physical interference, they were grouped as an own category "microbially induced sedimentary structures" into the Classification of Primary Sedimentary Structures (Noffke *et al.*, 2001).

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Cross-references

Algal and Bacterial Carbonate Sediments
Bacteria in Sediments
Bedding and Internal Structures
Biogenic Sedimentary Structures
Surface Forms