MICROBIALY INDUCED SEDIMENTARY STRUCTURES—A NEW CATEGORY WITHIN THE CLASSIFICATION OF PRIMARY SEDIMENTARY STRUCTURES—DISCUSSION

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INTRODUCTION

Noffke et al. (2001) introduced a new category of primary sedimentary structures that they named “microbially induced sedimentary structures.” Their attempt is laudable and timely, inasmuch as the importance of microbial influences on sedimentary substrates is becoming increasingly recognized.

The authors are perfectly correct in pointing out the requirement for, and validity of, nomenclature for sedimentary structures that result from micro-organic interaction with sediment. Among the sedimentary structures shown in their paper, one group is especially interesting because it is similar to sedimentary structures that carry weighty and beleaguered interpretations. Noffke et al. (2001) refer to this sedimentary structure as organically dimpled surfaces (erosional remnants and pockets; multidirectional/palimpsest ripples), which look very much like runzelmarken, or wrinkle marks. Noffke et al. (2001) differentiate between structures that are induced by microbial leveling (wrinkle structures) and structures that are interpreted to be post-biostabilization, erosional remnants and pockets. “Wrinkle structures” are particularly similar to runzelmarken, in that they have a micro-rippled appearance, millimeter-scale amplitudes, millimeter-scale wavelengths, and rather chaotic orientations. However, Noffke et al.’s (2001) wrinkle marks have a pronounced dimpled appearance and lack sinuous, parallel crests that are common with runzelmarken. Also, Noffke et al.’s suggestion that wrinkled surfaces result from microbial leveling is not consistent with mechanisms previously suggested for the emplacement of runzelmarken. Indeed, the primary physical requirement to develop runzelmarken, which is an elevated cohesiveness of the sediment, has more in common with erosional remnants and pockets that result from biostabilization.

In the recent literature, some authors have linked “wrinkle structures” to microbial stabilization of sediment (Hagadorn and Bottjer 1997; Pflueger 1999). In the case of runzelmarken, the recognition that penecontemporaneous deformation is a fundamental process is well documented (Reineck 1969; Teichert 1970; Allen 1984). So, given their similarity to Noffke et al.’s (2001) biogenically leveled “wrinkle structures,” and their apparent dependence on biostabilized sediment (like “erosional remnants and pockets”) why are runzelmarken not included in the classification of microbially influenced sedimentary structures?

WRINKLE MARKS (RUNZELMARKEN)

Runzelmarken were initially described by Häntzschel and Reineck (1968). Similar ripples, Kinneyia, were described by Martinsson (1965). The initial description, irregular ripple-like features that have low relief, pronounced symmetry, and a chaotic distribution, has led to their unfortunate linkage with adhesion ripples. However, adhesion ripples are sinuous to straight crested antiripplets of sand that have an extremely steep stoss side. Given the accepted descriptions of these sedimentary structures, it is clear that runzelmarken are not synonymous with adhesion ripples.

In Reineck (1969) it was reported that runzelmarken are produced in sand that is semicohesive. Because it was thought that wind shear was primarily responsible for sediment wrinkling, Reineck suggested that runzelmarken indicated intermittent emergence of a substrate. That suggestion has, unfortunately, become dogma. In fact, the acceptance of Reineck’s

original interpretation has led to its being overused as an interpretive tool. Reineck and Singh (1980) recognized that there had to be other ways to produce such wrinkle marks; “. . . likely there is some other mode of origin as well active in flysch sediments.” Unfortunately, this revelation has been mostly lost in the literature.

Conceptually, it is better to think of runzelmarken as the product of sediment cohesiveness and shear stress exerted on the sediment. Reineck (1969) suggests that water is the main agent for sediment cohesion. However, it is well known that microorganisms effectively bind sediment and that they can rapidly transform loose sediment into cohesive sediment. The process of microbially induced binding is summarized by Noffke et al. (2001). With microbial influence, sediment cohesion is increased dramatically in both intertidal and subtidal settings (Noffke 1998).

Just as there are subaqueous means of binding sediment, there are many subaqueous mechanisms that might strain the upper portion of the sediment–water interface. These include: (1) wave orbitals interacting with the bottom sediment; (2) sediment creep down dune, ripple, and foreset surfaces; and (3) shear stress resulting from gentle hydraulic currents. These examples suggest that runzelmarken should be abundant in the rock record and are certainly not strong evidence of intertidal processes.

Indeed, examples of ancient subtidal runzelmarken are common (Fig. 1A, B). Proximal offshore, storm-influenced rocks, such as those reported by Tanoli and Pickerill (1988), Brenchley et al. (1993), and Hagadorn and Bottjer (1997), have runzelmarken in abundance. The runzelmarken generally occur in fine-grained sandstone and are associated with oscillation ripples. Unfortunately, these structures are commonly taken to be intertidal indicators, leading to misinterpretation of the sedimentary succession.

Although Noffke et al. (2001) do not suggest that wrinkle marks should be limited to intertidal occurrences, the realization that runzelmarken could easily occur in subtidal settings evokes three questions. (1) How can one tell intertidal from subtidal runzelmarken? (2) Are all runzelmarken indicative of microbial stabilization of the substrate? (3) What interpretations might be drawn from the observation of runzelmarken in the rock record? Although it is outside the scope of this discussion to thoroughly answer these questions, intuitive answers would include: (1) Using the other sedimentological evidence, such as the presence of rills (Reineck and Singh 1980), nature of the bioturbation (Gingras et al. 1999; Zonneveld et al. 2000), and the overall sedimentary context (Clifton 1982); (2) although Reineck (1969) showed that dampening of muddy sand was enough to make it cohesive if the sediment is sporadically emergent, microbial stabilization may be the cause of all subtidal wrinkle marks; and (3) microbial colonization evidences colonization windows during which bedforms were moribund and thereby is related to sporadic sediment mobilization.

Because runzelmarken appear to represent the effects of sediment creep (shortening) following sediment stabilization, they are not perfectly synonymous with Noffke et al.’s (2001) “structures induced by biostabilization.” Rather, runzelmarken appear to represent both “bedding deformed by penecontemporaneous processes” (after Pettijohn and Potter 1964) and the former. Therefore, runzelmarken cannot be classified within the framework of Noffke et al.’s (2001) proposed scheme. Moreover, Noffke et al.’s (2001) biogenically leveled “wrinkle marks” and microorganically stabilized “erosional pockets and remnants” are probably not just the result of bio-mat leveling, but may be influenced by penecontemporaneous defor-

FIG. 1.—Subtidal runzelmarken from Atlantic Canada. **A)** Wrinkle marks from outcrops of the Cambrian–Lower Ordovician Saint John Group, near Saint John, southern New Brunswick. These strata are interpreted to represent shelfal, storm-reworked deposits (Tanoli and Pickerill 1988). Notice the composition of wrinkles (black arrow) and dimples (white arrow), suggesting that small erosional remnants (due to microbial fixing) are superimposed or adjacent to runzelmarken (due to sediment strain). **B)** A similar surface from the Bell Island Group, Bell Island, Newfoundland, Canada. This has been interpreted to be intertidal, and is virtually indistinguishable from Part A.

mation and thereby hybridized with runzelmarken; the interpretation of such structures should be clarified.

The persistent omission of runzelmarken from sedimentary-structure classification schemes has: (1) diminished their importance as interpretive tools; (2) led to misinterpretation of sedimentary deposits; and (3) failed to recognize the diverse and mostly undocumented effects of microbial stabilization on sedimentary structure. It is apparent that Noffke et al. (2001) fill a void by erecting their classification scheme. However, that scheme should be modified so that sedimentary structures such as runzelmarken are also included.

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