D

DEPOSITIONAL FABRIC OF MUDSTONES

Definition

The fabric of a rock is the total of all textural and structural features (Whitten and Brooks, 1972). Texture is defined as the relationship between the particles that form a rock, and structure has to do with discontinuities and major inhomogeneities. Both are intrinsic properties of the rock that serve as guides to its origins (Pettijohn and Potter, 1964), as well as providing a basic rationale for the study of mudstone fabrics.

Studying mudstone fabrics

The structural dimension of mudstone fabrics (discontinuities and major inhomogeneities) is best examined in hand specimens (preferably cut and polished surfaces) and in petrographic thin sections (Figure D8). For hand specimens, one starts with visual inspection, followed by closer examination under a binocular microscope. This approach is suitable to study features in the millimeter range, such as small-scale sedimentary structures. Petrographic thin sections should initially be examined at low magnification (binocular microscope). Further study by petrographic microscope at higher magnification can reveal additional details (e.g., nature of lamina contacts), as well as providing information on mineral composition.

For the investigation of the textural dimension of mudstone fabrics (relations between particles) high magnifications are required to see individual grains and their contact relations. The scanning electron microscope is the tool of choice here (Trewin, 1988), operating in either secondary (SEM) or backscattered (BSE) mode (Figure D9). Observation in SEM mode is popular because sample preparation is easy (a freshly broken surface will suffice), but BSE imaging has gained popularity because it provides compositional information in addition to much clearer contact relations. The main drawback of the BSE mode is the need for a polished surface.

Fabric elements

From a sedimentologist's perspective, small-scale sedimentary structures tend to be the most informative fabric elements. Inconspicuous or even invisible in outcrop (they range in size from a few centimeter to less than a millimeter), they can nonetheless reveal a wealth of information about depositional conditions and history of a mudstone. When studied in polished slabs and petrographic thin sections, even seemingly drab shales can show a large range and variability of sedimentary features (Figure D10). If density contrasts are sufficient, small-scale sedimentary features may also be enhanced through X-radiography.

Laminae are the most typically observed sedimentary feature in shales, and exhibit a large range in thickness and

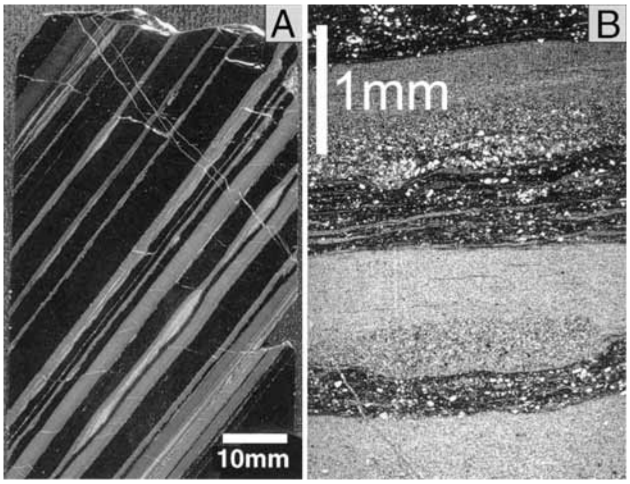

Figure D8 (A) example of hand specimen with alternating carbonaceous layers (black) and silt/clay couplets (light). Note lenticular and cross-laminated silt layer. (B) thin section of same shale as in A. Note graded silt/clay couplets (storm layers), and wavy crinkly laminae in carbonaceous layers (microbial mat deposit; Schieber, 1986).

lamination styles (even, discontinuous, lenticular, wrinkled, etc.), which can represent quiet settling, sculpting of the sediment surface by bottom currents, and growth of microbial mats respectively (Schieber, 1986). Internal lamina features include: (a) grading; (b) random clay orientation; (c) preferred clay orientation; (d) sharp basal contacts; and (e) sharp top contacts. They may be interpreted as indicative of: (a) event-sedimentation (e.g., floods, storms, turbidites); (b) flocculation or sediment trapping by microbial mats; (c) settling from dilute suspension; (d) current flow and erosion prior to deposition; and (e) current flow and erosion/reworking after deposition (Schieber, 1990). Silt laminae are usually the most easily observed lamina type in shales because of their somewhat larger grain size. They also imply somewhat more energetic conditions, and may, for example, indicate deposition by density currents (grading, fading ripples), storm reworking and transport (graded rhythmites), wave winnowing (fine even laminae with scoured bases), and bottom currents (silt layers with sharp bottom and top). Gradual compositional changes between clay and silt dominated laminae are another commonly observed feature, and are suggestive of continuous (although slow) deposition, possibly from deltaic sediment plumes and shifting nepheloid flows.

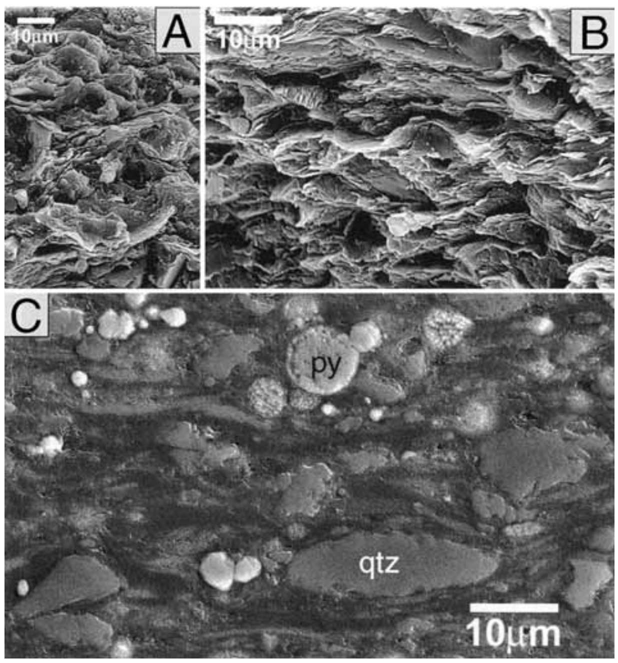

Figure D9 (A) SEM picture of bioturbated mudstone fabric; (B) SEM picture of laminated mudstone; (C) BSE picture of carbonaceous shale. Minerals with high molecular weight (py = pyrite) appear brighter than those of lower molecular weight (qtz = quartz). Gray streaks consist of clay minerals, dark-black streaks are kerogen. Note horizontal alignment of sediment grains, clay streaks, and kerogen stringers.

Other small scale sedimentary features that can be observed in shales are mudcracks, load casts, flame structures, bioturbation, graded rhythmites (Reineck and Singh, 1980), fossil concentrations and lags, cross-lamination, and loop structures (Cole and Picard, 1975), all of which carry information about conditions of sedimentation. Shales may also reveal clay-filled mud cracks, brecciation due to desiccation, and sands or conglomerates that consist entirely of shale particles (Schieber *et al*., 1998). Because in the latter features the fills in cracks and between shale particles consist of the same components as the cracked substrate or the shale particles, there is little compositional contrast to reveal them on broken surfaces in outcrop. Polished slabs or petrographic thin sections are typically required to detect shale-filled cracks and shale sands and conglomerates. The latter, for example, can form as a result of soil erosion (pedogenic particles; Rust and Nanson, 1989), erosion of cracked mud crusts, on submarine scouring of mud substrates by strong currents.

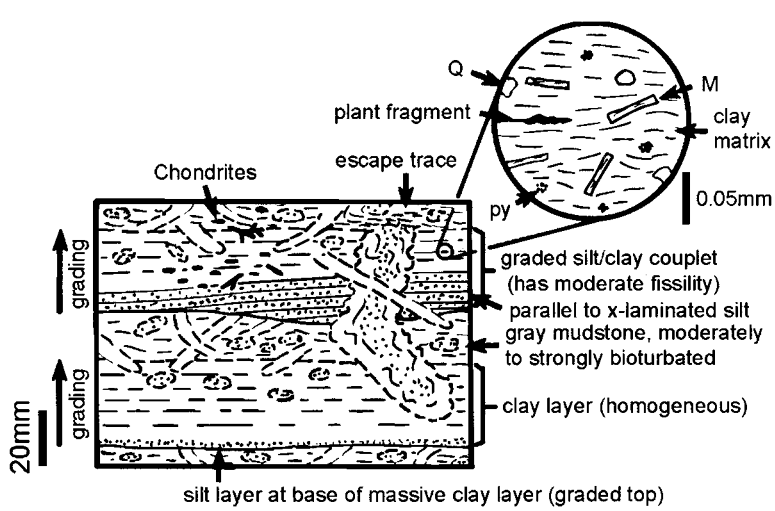

Figure D10 Line drawing that summarizes features observed in a mudstone from the Late Devonian Sonyea Group in New York (Schieber, 1999b). M = mica; Q = quartz; py = pyrite.

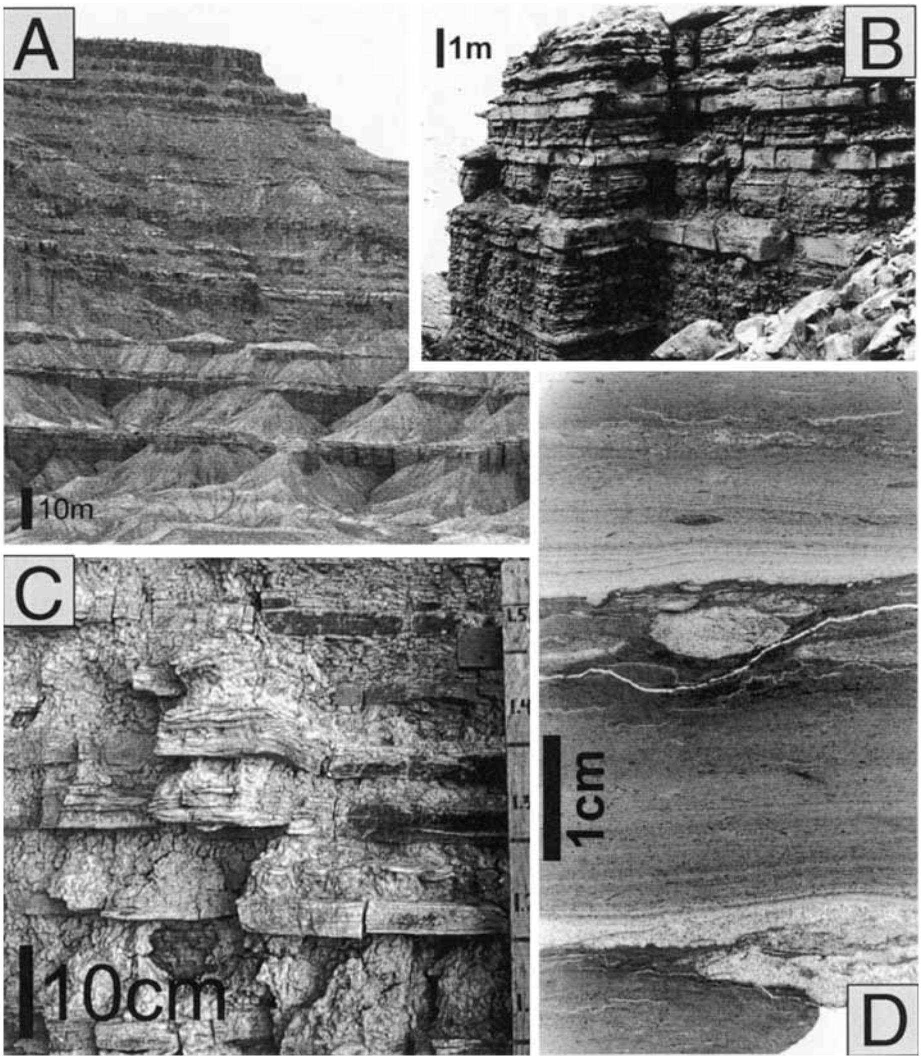

Figure D11 The "self-similar" nature of sediments. Magnification jumps by a factor of 10–20 between successive photos. (A) shale packages alternate with sandstone-rich units (Blackhawk Fm., Cretaceous, Utah); (B) sandstone-rich units from A consist of alternating sandy ledges and shaley intervals; (C) shaley intervals from B show softer shale alternate with centimeter-thick sandstone/siltstone beds; (D) thin section of soft interval from C shows graded siltstone layers and variably bioturbated mudstone. The resistant beds are storm deposits throughout (from HCS beds in B, to distal tempestites in D).

Biologic agents may produce microbial laminae and protection of mud surfaces from erosion (Schieber, 1986; O'Brien and Slatt, 1990), or may manifest themselves as bioturbation and destruction of primary fabrics. In many instances, however, sufficient primary features survive bioturbation, and observation of bioturbation features can thus provide additional information about substrate firmness, event deposits (escape traces), and rates of deposition. Fecal pellets and pelletal fabrics are another by-product of organic activity, and they are probably more abundant in mudstones and shales than commonly recognized (Potter *et al*., 1980; Cuomo and Rhoads, 1987). They are indicators of organic activity, and are best seen in thin section, where they typically differ from the shale matrix with respect to texture, color, and organic content. They may range in size from 0.2 mm to 2 mm and are generally of elliptical outline. Compaction tends to flatten the pellets to varying degrees, and if matrix and pellets are similar in composition and composed of particles of similar grain size, their identification can be challenging. The composition of fecal pellets can give clues on whether they were produced by benthic or planktonic organisms. Investigation of modern environments suggests that potential microbial colonization of mud surfaces has to be taken into account when studying ancient mudstones. Although difficult, recognition of microbial laminae is possible, and can lead to substantially different interpretations of mudstone environments (Schieber, 1999a).

Notwithstanding the usefulness of small-scale sedimentary structures, the study of particle relationships (texture) also constitutes an important avenue of inquiry. This aspect of shale fabrics, studied by electron microscope, is frequently referred to in the literature as *microfabric* (O'Brien and Slatt, 1990). Microfabric features of mudstones record the combined impact of processes active during transport, deposition, and burial at the scale of individual grains and grain aggregations. The *Argillaceous Rock Atlas* by O'Brien and Slatt (1990) contains case examples from a variety of sedimentary environments (as well as many references) and illustrates mudstone fabrics with SEM photos and photomicrographs.

Experimental work has shown that microfabrics can for example be related to depositional processes, such as flocculation and single-grain sedimentation (Mattiat, 1969; O'Brien and Slatt, 1990). The book *Microstructure of Fine-Grained Sediments* (Bennett *et al*., 1991) contains a series of papers that employ microfabric analysis in the study of modern muds. A major drawback with the application of modern microfabrics to the interpretation of depositional conditions is the fact that muds undergo serious compaction and diagenetic changes on the way to becoming rocks. To determine from an SEM study which fabrics are secondary and which features are reflective of original depositional fabrics is difficult and requires considerable experience. In many instances the successful interpretation of microfabrics hinges on the availability of other information, such as small-scale sedimentary features, paleogeographic setting, and paleoecological information (e.g., O'Brien *et al*., 1994). Nonetheless, a comparison of modern and fossil examples suggests that under favorable circumstances, fabrics produced by flocculation, settling of dispersed clays, bioturbation, agglutination on microbial mats, deposition of biosediment aggregates ("marine snow"), compaction, and fecal pellets can still be recognized and differentiated (Bennett *et al*., 1991).

Fabric and environment

The broader significance of mudstone fabrics relates to the observation that sedimentary rocks and sedimentary successions have an inherent fractal quality (Mandelbrot, 1983). For example, large-scale stratification features can be repeated at different scales within individual stratigraphic packages, in the details of bedding, and even in the minutiae of lamination (Figure D11). Figure D11 illustrates that at increasingly higher levels of magnification, the basic theme of alternating soft and resistant intervals remains unchanged. Likewise, and regardless of scale, scoured bases, cross-stratification, and grading characterize resistant intervals, and bioturbation is more intense in soft intervals. This "self-similarity" from one magnification level to the next is at the heart of fractal geometry (Mandelbrot, 1983), and in our example (Figure D11) it reflects the overall conditions under which the succession accumulated. In that context we may even be tempted to speculate whether the information that can be extracted from fabric elements of a thin section or hand specimen (Figure D11(D)), will lead us to conclusions that are comparable to those derived from the study of an entire outcrop as shown in Figure D11(B). Studies of shale fabrics from rocks ranging in age from Proterozoic to the Tertiary have positively shown that shale fabrics do reflect the conditions of the broader sedimentary setting (Schieber, 1986, 1989, 1990; O'Brien and Slatt, 1990; Schieber *et al*., 1998). Comparing what can be learned about depositional conditions in a mudstone-rich sedimentary succession from paleoecological observations and the study of interbedded sandstones, with the information derived from a detailed study of shale fabrics, shows that shale fabrics can provide a more concise account of depositional conditions than the other two approaches (Schieber, 1999b).

Summary

Mudstone fabrics are the cumulative record of the history of transport, deposition, and burial of muddy sediments. Their final "look" depends upon the interplay between a whole range of physical, biological, and chemical processes. As such, successful studies of mudstone fabrics require the integration of all available paleontologic (body and trace fossils), sedimentologic, and petrographic observations. If done thoroughly, the information derived from a sample of mudstone (fabric study of hand specimen and thin section) can accurately portray depositional conditions and environments of the interval from which it was collected. If there is a choice between studying an entire outcrop of more resistant interbedded lithologies (e.g., sandstone), and the careful study of a mudstone sample from the same locality, the information derived from mudstone fabrics may well be superior.

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Cross-references

Algal and Bacterial Carbonate Sediments
Black Shales
Dessication Structures (Mud Cracks, etc.)
Flocculation
Mudrocks
Physical Structures
X-Radiography