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6. MASSIVE MUDSTONES IN BASIN ANALYSIS AND PALEOCLIMATIC INTERPRETATION OF THE NEWARK SUPERGROUP

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INTRODUCTION

Massive red or gray mudstones make up much of the fine-grained sedimentary rocks of the Newark Supergroup. In fact, the upper third of most sedimentary cycles in the fine-grained facies of most Newark basins is massive mudstone (division 3 of Olsen, 1984). Massive mudstones have not, however, been studied or described nearly as fully as conglomerates, sandstones, and laminated shales. This lack is due primarily to the difficulty in making textural descriptions from weathered outcrop exposures of massive mudstones and to the dearth of published depositional models for them. The widespread distribution and facies associations of massive mudstones in the early Mesozoic basins suggest that they are potentially useful in stratigraphic basin analysis. Furthermore, distinctive characteristics of massive mudstone textures suggest that they may be used for paleoclimatic interpretation, particularly in the context of their surrounding facies.

TYPES OF MASSIVE MUDSTONES

Four major types of massive mudstone texture are proposed for the Newark Supergroup, on the basis of a limited number of observations in most of the exposed early Mesozoic basins. These four types are (1) mudcracked massive mudstone, (2) burrowed massive mudstone, (3) root-disrupted massive mudstone, and (4) sand-patch massive mudstone. Gradations exist between each of the massive mudstone types, so each is treated as an end member with dominant, distinctive fabrics and particular associations with other sedimentary features. The four types of massive mudstone oc-

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cur in a variety of sedimentary sequences of which seven are shown in figure 6.1. These sequences show characteristic associations of the massive mudstone textures with other sedimentary features.

Mudcracked massive mudstone is characterized by abundant small (1–5 cm deep), narrow, jagged cracks, which form a polygonal pattern in plan view. The cracks are filled with sandstone or mudstone (the broader cracks having complex, cross-cutting or stratified fillings) or are partially filled with cements of carbonate minerals or analcime. Mudcracked massive mudstone generally contains different proportions of two fabrics: a breccia fabric and an overlying "crumb" fabric (fig. 6.1, sequence 1). The breccia fabric is defined by polygonal cracks, which separate isolated blocks of mudstone. The mudstone blocks show no evidence of displacement or rotation where they are internally thin-bedded. The "crumb" fabric is composed of millimeter-scale mud clumps and abundant laminoid and ovoid, cement-filled vesicles, which also commonly have thin clay linings. The cracks in the "crumb" fabric are typically narrower and form smaller polygonal patterns than those in the breccia fabric.

Mudcracked massive mudstone typically overlies laminated to thin-bedded, lacustrine mudstone with large polygonal cracks and rare reptile footprints. It is also associated with centimeter-scale siltstone beds, which form concave-upward polygonal curls, and with thin, scour-based, muddy sandstone lenses. Pseudomorphs after a bladed evaporite mineral, possibly gypsum, have been found in a few occurrences of brecciated mudstone (fig. 6.1, sequence 4).

Mudcracked massive mudstone with the breccia fabric is interpreted as lacustrine beds disrupted by desiccation cracks formed by repeated wetting and drying during long periods of nondeposition. The massive mudstone with the "crumb" fabric is believed to be the basin-floor deposit of an aggrading playa mudflat (Smoot and Katz, 1982; Katz, 1983).

Burrowed massive mudstone is dominated by numerous tubes 0.5–1.0 cm in diameter, which are typically randomly oriented, have constant diameters, and are filled with sandstone or mudstone. These tubes are interpreted as burrows. The most distinctive types of tube are *Scoyenia* (Bain and Harvey, 1977), which are characterized by "spreiten" (convex laminae in the burrows, defined by small grain-size changes) and textured outer walls, but other tubes with simple fillings also occur and may be the dominant variety. There is a common minor component of small, often less than 1 mm in diameter, flattened tubes, which bifurcate and taper, associated with this massive mudstone type. These tubes may be lined with tangentially oriented clays, which commonly define the entire tube shape. These branching tubes are interpreted as the casts and molds of rootlets. Large polygonal cracks, 10–20 cm deep, may also be present in these mudstones.

Burrowed massive mudstone is associated with two types of sequences. The most common association is with fine-grained, micaceous sandstone showing climbing-ripple cross-lamination and soft-sediment deformation (load casts, "pseudonodules," and over-steepened ripple cross-laminae) and with laminated shales, which commonly contain abundant conchostracans, ostracodes, and other aquatic fossils (fig. 6.1, sequence 5). Reptile footprints often occur on the bedding planes that are not obscured by burrows, and disarticulated fish fossils and reptile bones occur rarely. The other association is with thick packages of microlaminated mudstone, which grade into wispy thin beds and finally into massive mudstone by a gradual loss of layer definition (fig. 6.1, sequences 6 and 7), apparently owing to bioturbation (Olsen, 1984, p. 521–527). The burrows in the massive mudstones in these sequences lack "spreiten" and are generally smaller than typical *Scoyenia*.

The burrowed massive mudstone probably represents several different depositional environments, including shallow margins of lakes, delta plains, and fluvial floodplain-overbank settings. The most likely burrowers include worms, crayfish-like crustaceans (Olsen, 1980), and insects (beetles?).

Root-disrupted massive mudstone is characterized by abundant downward bifurcating and tapering tubes, ranging in diameter from less than 1 mm to several centimeters. These characteristics are believed to be diagnostic of root casts and molds. The tubes are predominantly oriented perpendicular to bedding, but some are parallel. Large tubes are filled with sandstone and mudstone, whereas smaller tubes are generally lined with clays, which are tangentially oriented, and filled with carbonate mineral cements. Small, spherical nodules of micritic calcite and dolomite are common and are concentrated in the larger tubes or scattered in the surrounding matrix. These nodules are interpreted as caliche concretions. *Scoyenia* burrows and polygonal cracks (5–10 cm deep) may also be present. Remnant patches of laminated mudstone or ripple cross-laminated sandstone are common.

Root-disrupted massive mudstones have two associations: (1) overlying, and laterally equivalent to, burrowed massive mudstone (fig. 6.1, sequences 5 and 6); the contacts are gradational, resulting from an increase of root and carbonate nodule abundances; and

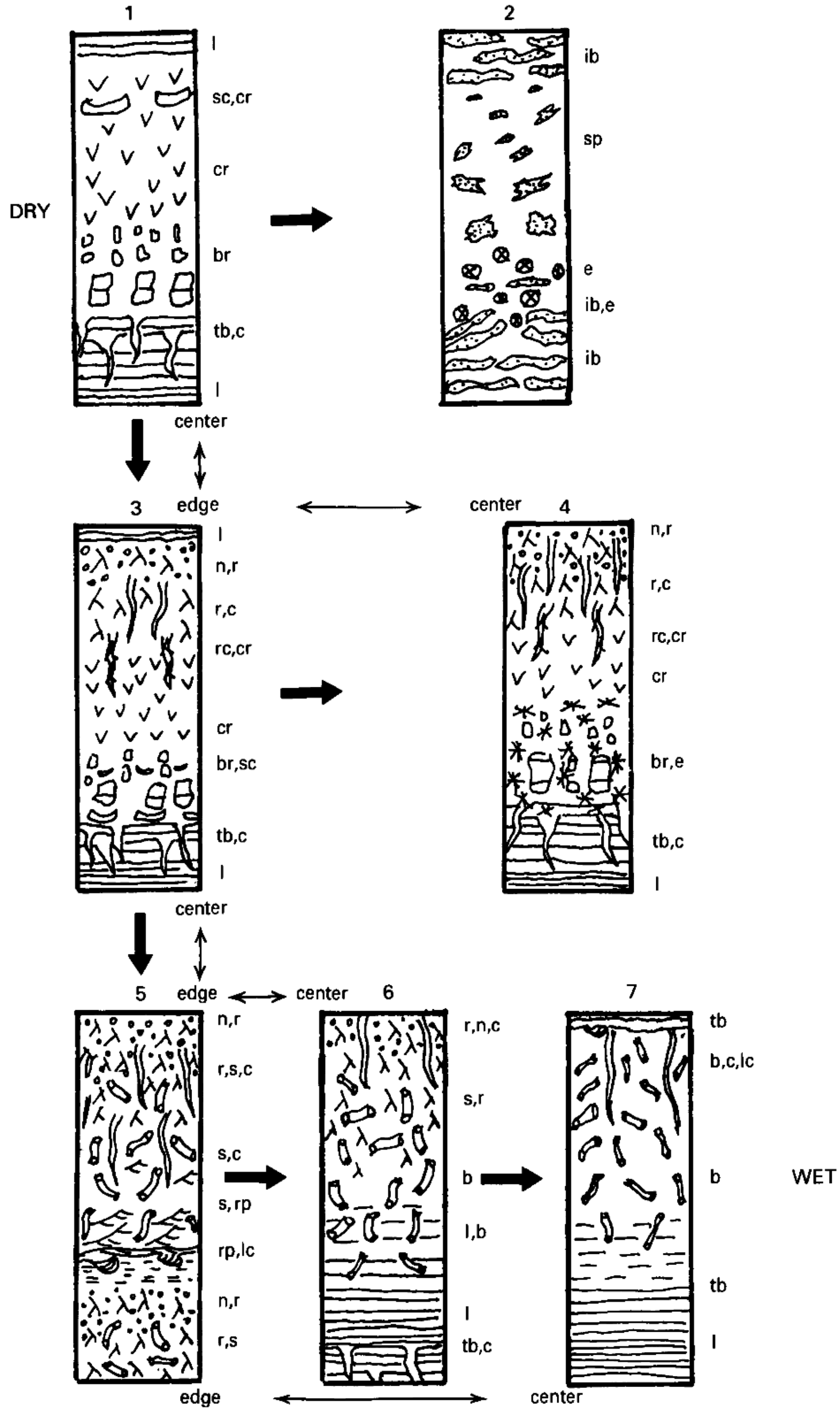

FIGURE 6.1.—Schematic drawing of sedimentary sequences containing massive mudstones. Thick arrows point to relatively wetter depositional environments. The "driest" sequence is at the upper left and the "wettest" is at the lower right. Thinner arrows show possible geographic relationships between sequences within a basin. Thicknesses range from 1–3 m in sequence 2 to as much as 20 m for sequence 5. Symbols: b—burrows, br—breccia fabric, c—cracks, cr—crumb fabric, e—evaporite molds, ib—irregular bedding, l—flat lamination, lc—load casts, n—carbonate nodules, r—root structures, rc—roots within cracks, rp—ripple cross-laminae, s—*Scoyenia*, sc—siltstone curls, sp—sand-patch fabric, tb—thin bedding.

(2) gradationally overlying mudcracked massive mudstone (fig. 6.1, sequences 3 and 4), as shown by tubes that first preferentially follow crack polygons then dominate the mudstone fabric, commonly with an increase in carbonate nodules. In the Newark basin, a number of articulated reptile skeletons were found in massive mudstones that are probably of this type.

The root-disrupted mudstones are interpreted as deposits formed on vegetated floodplains of a basin floor, river overbanks, or the margins of lakes, on which a soil containing caliche was developed.

Sand-patch massive mudstone contains small (1–5 cm long), irregular-shaped pods of sandstone and siltstone with the following diagnostic characteristics: angular margins; internal jagged, mud-filled cracks; internal zones of different grain sizes; and cuspate contacts with the surrounding mudstone. The sand pods may have internal cross-laminae, which are randomly oriented with respect to cross-laminae in adjacent pods.

Sand-patch massive mudstone is associated with eolian sandstone lenses and cross-strata and with mudstone containing evaporite molds and irregular thin beds and lenses of sandstone (fig. 6.1, sequence 2). Hubert and Hyde (1982) interpreted the sand patches as eolian "adhesion ripples." However, the patches strongly resemble fabrics produced by accretional saline mudflats where the sand pods are wind-blown and stream-deposited material trapped in surface irregularities of a subsequently dissolved efflorescent salt crust (Smoot and Castens-Seidel, 1982). No fossils have been found in association with this fabric.

DISCUSSION

Mudcracked massive mudstone and sand-patch massive mudstone are interpreted as deposits formed under relatively arid basin-floor conditions. The "crumb" fabric in mudcracked massive mudstone is believed to represent a playa floor that is inundated by flood water for a few days then totally dry for several years. The breccia fabric probably indicates slightly wetter conditions of formation, since the polygonal cracks in it are wider and deeper than those in the "crumb" fabric. Sand-patch massive mudstones required an evaporitic setting but also needed a shallow, persistent, saline ground-water table to precipitate the salts. This suggests a slightly wetter depositional setting for sand-patch massive mudstone than for mudcracked massive mudstone, or at least for mudstone with the "crumb" fabric.

The burrowed and root-disrupted massive mudstones are interpreted as representing wetter depositional conditions than the mudcracked and sand-patch massive mudstones. The organisms responsible for the burrows in the burrowed massive mudstone probably required water-saturated sediments. The association of this massive mudstone type with low-energy fluvial deposits, soft-sediment deformation structures, lacustrine deposits, and deep, widely spaced mudcracks supports this interpretation. If the abundant tubes in the root-disrupted massive mudstone are properly identified as roots, the environments of their formation must have had enough water to support a vegetative cover. It is difficult to ascertain how much vegetation was growing, or if the growth occurred throughout the accumulation of the massive mudstone, or if the roots are superimposed over another depositional fabric. The common presence of carbonate nodules, which are interpreted as caliche nodules, suggests a dry setting (Gile and others, 1966), at least intermittently. A dry setting is also suggested by the transition upward from mudcracked massive mudstone, at places including evaporite mineral molds (fig. 6.1, sequence 4), to root-disrupted massive mudstone. For these reasons the root-disrupted massive mudstones are believed to indicate generally drier depositional conditions than the burrowed massive mudstones.

The sedimentary sequences containing massive mudstones shown in figure 6.1 are organized from those representing the driest conditions at the top left to those indicating the wettest at the bottom right. A thick accumulation of the "crumb" fabric, as in sequence 1, is believed to indicate drier conditions than the accumulation of the sand-patch fabric in sequence 2. Sequence 1 may represent a greater variation in depositional aridity, however, since the mudcracked massive mudstone grades up from lake deposits, while the sand-patch massive mudstone overlies subaerial deposits. The root-disrupted massive mudstones in sequences 3 and 4 indicate wetter conditions than for sequences 1 and 2. Both overlie mudcracked massive mudstone, suggesting a decrease of aridity in the younger portions. Sequence 4 is interpreted as indicating a wetter depositional setting than sequence 3 because the evaporite crystals in the breccia fabric require a near-surface brine table to precipitate. Sequences 5, 6, and 7 are interpreted as representing progressively wetter settings of formation. Sequence 5 contains fluvial sandstones and common mudcracks and root structures, sequence 6 is mostly lacustrine with mudcracked, root-disrupted massive mudstone at the top, and sequence 7 has only burrowed massive mudstone overlying the lake deposits.

Sand-patch massive mudstone has only been found in the Fundy basin, and mudcracked massive mudstone is apparently more common in the Hartford, Newark, Culpeper, and Danville basins than in the Richmond, Dan River, Durham, Sanford, or Wadesboro basins. In the latter five basins, the burrowed or root-disrupted massive mudstones are apparently the dominant varieties. This general change from "drier" massive mudstone textures in the northern basins to "wetter" massive mudstones in the southern basins supports the hypothesis that the sediments preserved in the exposed Newark basins reflect increasing aridity towards the north, due to the change in paleolatitude (Hubert and others, 1978). One problem with this interpretation is that the burrowed and root-disrupted massive mudstones are present in all of the basins, including the Fundy basin. The distribution of the massive mudstone types may also be influenced or controlled by (1) local environments, such as the margins of shallow lakes on playa floors or desiccated ponds on fluvial flood plains, (2) local climates, such as orographic deserts in a temperate climate belt, and (3) changes in climate over time, such as a wetter Carnian and a drier Norian. Some of the possible coeval lateral relationships of massive mudstone sequences within a basin are shown in figure 6.1. The stratigraphic correlations of Olsen (1984, p. 85, 115–119) in the Newark basin established the lateral equivalence of sequence 3 (center) to sequence 5 (edge), of 4 (center) to 3 (edge), and of 7 (center) to 5 (edge). The other lateral relationships shown in figure 6.1 are suggested by less well constrained correlations in other basins. A change in the depositional conditions from drier to wetter settings within the basins of the Newark Supergroup, as envisioned for some of the massive mudstone sequences, has been suggested by others on the basis of the nature of sedimentary cycles (for instance, Van Houten, 1964; Olsen, 1984) and on fossil pollen and spore assemblages (Cornet, 1977, p. 61–71).

The climatic implications of the massive mudstone textures suggest possible application as constraints for stratigraphic reconstructions. Mudstone cycles dominated by "dry" characteristics (sand-patch or mudcracked massive mudstone textures) may be laterally correlated to sandstones and conglomerates also reflecting dry conditions (such as debris flows and sheet floods); mudstone cycles dominated by "wet" characteristics (burrowed and root-disrupted massive mudstone textures) may be similarly correlated to the sandstones and conglomerates reflecting deposition under sustained higher discharges (such as braided or meandering river deposits with large-scale cross-bedding). More information is needed concerning the lateral variability of massive mudstone fabrics. We also need to determine if subtle differences occur within a specific type of massive mudstone; if so, a more complex breakdown of types or stronger affinities between them may be necessary. Even if massive mudstones ultimately prove to have limited climatic or stratigraphic utility, our understanding of the depositional environments of the Newark Supergroup can be improved by recognition of the differences within massive mudstones.

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