CHAPTER 9

Sedimentary Structures: Textures and Depositional Settings of Shales from the Lower Belt Supergroup, Mid-Proterozoic, Montana, U.S.A.

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Introduction

The Belt Supergroup of the northwestern United States is a thick (20 km) shale-dominated sequence that accumulated in an epicontinental basin between 1450 and 850 Ma (Harrison, 1972; Stewart, 1976). In this chapter shales from the lower portion of the Belt Supergroup are examined and interpreted with respect to potential depositional environment. Shale samples were collected in the eastern portion of the basin from the Newland Formation, and in the central and western portion of the basin from its lateral equivalent, the Prichard Formation (Fig. 9.1).

Shales of the Newland Formation have been studied in considerable detail (Schieber, 1985, 1986, 1989), and six major shale fades types can be distinguished. The overall depositional setting for these shales was probably a shallow, low-energy shelf. Shales of the Prichard Formation were deposited in a deeper portion of the basin, and differ in a number of sedimentary features from those of the Newland Formation. These differences may be used to distinguish between shallow and deep water shales in general. Shales of the Newland Formation are unmetamorphosed (Maxwell and Hower, 1967) except in contact aureolas around plutons. In contrast, shales of the Prichard and Aldridge Formation have commonly undergone greenschist facies metamorphism (Cressman, 1984).

Shales of the Newland Formation

Striped Shale Facies (NS-1)

The characteristic striped appearance of this shale facies is caused by the interlayering of carbonaceous silty shale, dolomitic clayey shale, siltstone, and lithoclast beds (Schieber, 1986). Textural features are shown in Figure 9.2 and summarized in Figure 9.3. Siltstone beds commonly form graded silt/mud couplets with overlying beds of dolomitic clayey shale (Fig. 9.2). These couplets show parallel lamination, cross-lamination, and graded rhythmites in the lower silty portion.

Interpretation

Beds of hummocky cross-stratified sandstones (Harms et al., 1982) occur interbedded with the striped shales, indicating occasional sediment deposition by storms. Interstratified carbonate units contain various indicators of relatively shallow water, such as wave and current ripples, flat pebble conglomerates, and cryptalgal laminites. Irregular wavy-crinkly laminae (Fig. 9.2) and mechanical strength during soft sediment deformation suggest a microbial mat origin for carbonaceous silty shale beds (discussed in depth by Schieber, 1986). The silt/mud couplets strongly resemble modern storm deposits (Aigner and Reineck, 1982) of muddy shelf seas. Their abundance and their association with less abundant thicker storm sand deposits suggests that they were deposited by more frequent but relatively weak storms. The intimate interlayering of silt/mud couplets and beds of carbonaceous silty shale indicates episodic interruption of microbial mat accumulation by storm sedimentation. Because of the absence of any signs of emergence in these shales, and because of the abundant indicators of storm sedimentation, these shales probably accumulated between fairweather and (average) storm wave base.

Carbonaceous Swirl Shale Facies (NS-2)

These shales consist primarily of a clay-dolomite matrix with scattered quartz silt, micas, and carbonaceous flakes (Fig. 9.4).

Figure 9.1. Location map. Stipple pattern shows present day outline of the Belt basin. Newland shale samples were collected from the eastern extension of the basin, Prichard and Aldridge shale samples were collected from the central, western, and northwestern portion of the basin. The pair of solid lines indicates the approximate position of the east-west slice shown in Figure 9.3.

Bedding planes are irregular and nonparallel, and poor alignment of clays and mica flakes (Fig. 9.4) and crumbled and rolled up carbonaceous flakes are conspicuous (Fig. 9.3). Continuous carbonaceous films and thin laminae of carbonaceous silty shale (identical to those described from facies NS-1) are also found.

Interpretation

These shales are interbedded with fine crystalline dolostones that show a variety of features, such as wavy-crinkly lamination, shrinkage cracks, erosion surfaces, scour and fill structures, ripples, and edgewise conglomerates, that are commonly thought to indicate deposition in restricted shallow shelf lagoons (Wilson, 1975). In analogy to facies NS-1, the carbonaceous films and laminae are interpreted as fossil microbial mats. Crumbled and rolled up carbonaceous flakes are probably due to erosion and redeposition of these thin microbial mat deposits. Because of the absence of signs of emergence, these shales were probably deposited in fairly shallow water, between fairweather and weak storm wave base. Microbial mats colonized the surface in calm periods and were eroded during storms. After storms, with decreasing wave agitation, rapid flocculation from moving water led to irregularly bedded muds with homogeneously mixed and random texture, and with variably deformed microbial mat fragments (carbonaceous flakes).

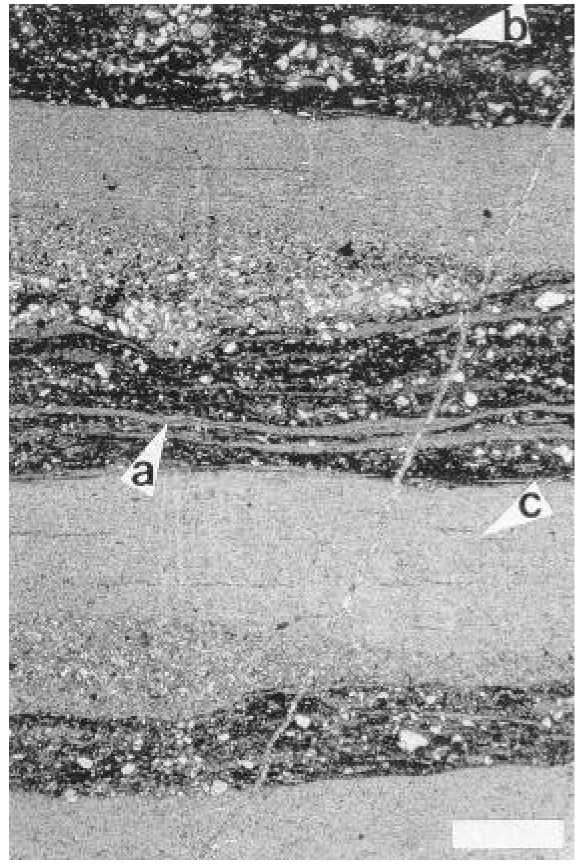


Figure 9.2. Photomicrograph of striped shale. Several beds of carbonaceous silty shale alternate with graded silt/mud couplets. Carbonaceous shale beds consist of wavy-crinkly carbonaceous laminae, alternating with drapes of dolomitic clayey shale (arrow a), and tiny silt-rich lenses (arrow b). These beds have been interpreted as microbial mat deposits. Note carbonaceous flakes in dolomitic clayey shale beds (arrow c). Scale bar is 500 Um.

Carbonaceous Streak Shale Fades (NS-3)

These shales are characterized by silt and carbonaceous flakes (parallel to bedding) that are randomly distributed in a clay-dolomite matrix (Fig. 9.5). Individual beds of this shale type are thick (up to 10 cm), parallel, and lack sedimentary structures. Beds of hummocky cross-stratified coarse sandstone are interbedded with these shales. No signs of erosion and sediment reworking are found except at the base of interbedded hummocky cross-stratified sandstone beds.

Interpretation

Lack of sorting in shale beds suggests rapid sedimentation from suspension (Potter et al., 1980) and absence of reworking. Massive bedding implies deposition from successive prolonged pulses of continuous sedimentation. The presence of hummocky cross-stratified

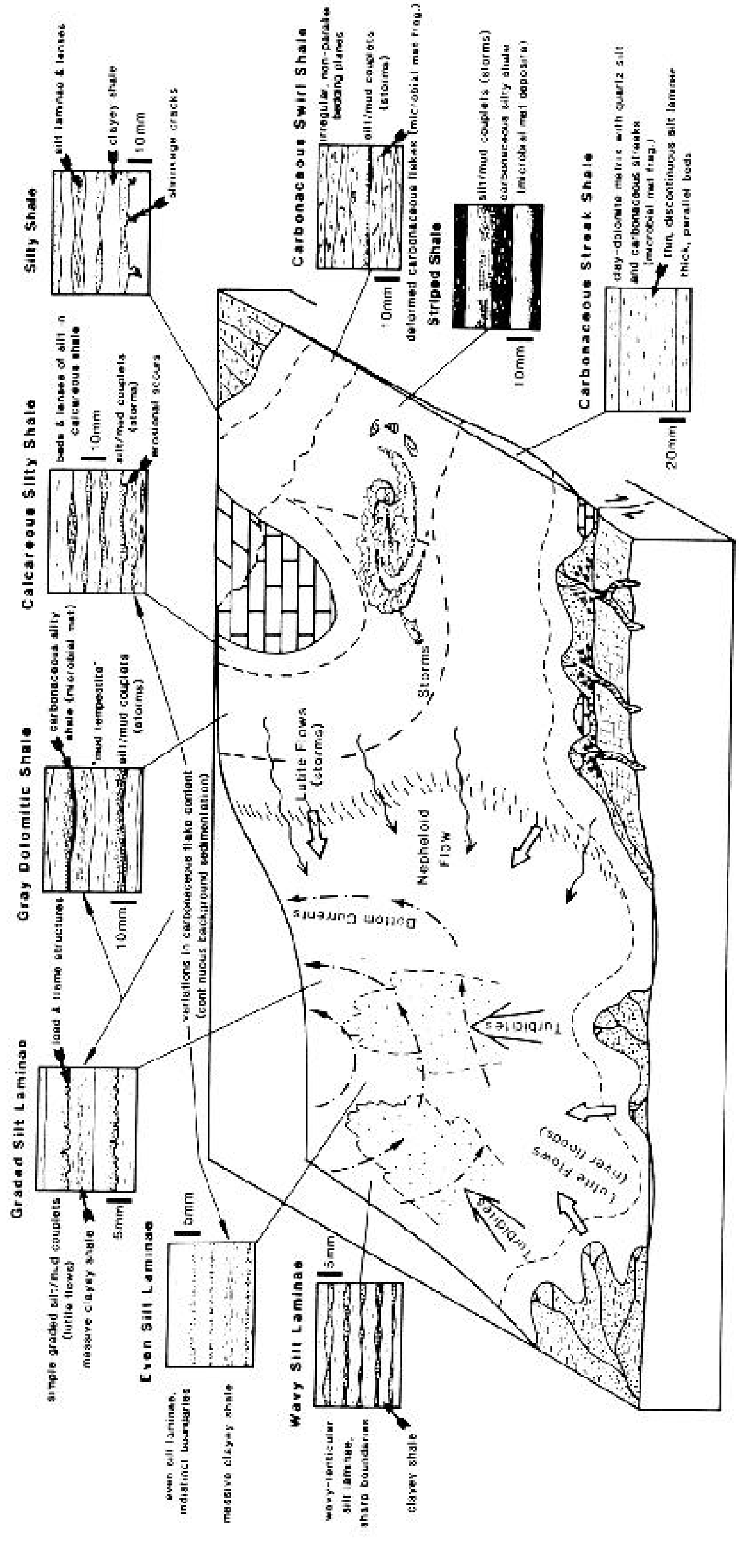


Figure 9.3. Hypothetical east-west slice (viewing north) through the southern portion of the Belt Basin during deposition of Newland (east) and Prichard Formation (central and west). The diagram summarizes major features of shale types, and the author's view of shale fades associations, sediment sources, and sedimentary processes.

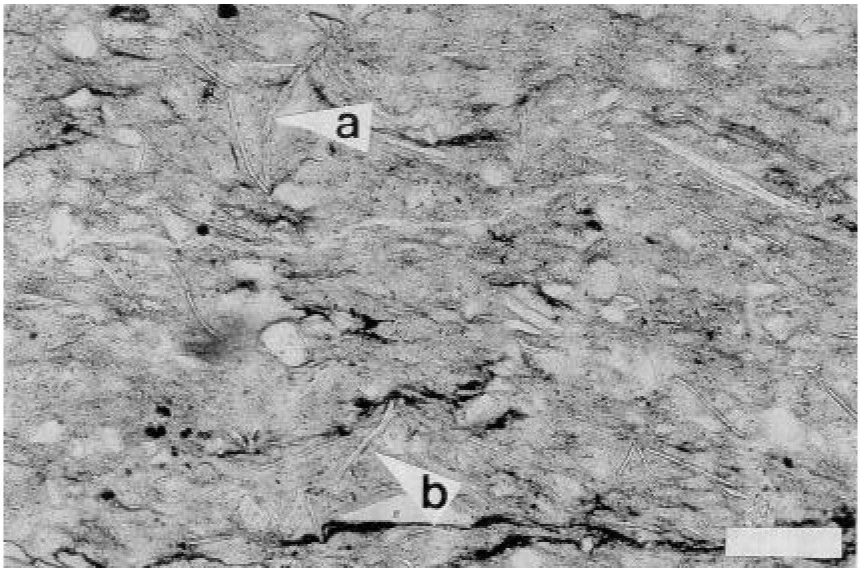


Figure 9.4. Photomicrograph of carbonaceous swirl shale with randomly oriented mica flakes. A fair number of mica flakes are in near vertical position and may show deformation due to compaction (arrows a and b). Scale bar is 100 gm.

sandstone beds and the absence of silt/mud couplets indicates that only very strong storms were able to touch the sea bed (see interpretation of facies NS-1). Thus deposition was probably below average storm wave base. Scattered silt grains in this facies suggest an eolian component to sedimentation. Carbonaceous flakes in this facies are of the same appearance as in NS-1 and NS-2 and are considered microbial mat fragments that were swept in from shallower areas.

Gray Dolomitic Shale Facies (NS-4)

This facies consists of interbedded dolomitic clayey shale (dominant), siltstone, and carbonaceous silty shale. These lithologies are of the same appearance as in facies NS-1 with respect to textures, sedimentary features, and composition. They differ only in their relative abundances. Silt/mud couplets as observed in facies NS-1 are common, and are analogously interpreted as storm deposits. Carbonaceous silty shale beds on the other hand are much less abundant and very thin (1 mm or less). In analogy to NS-1 a microbial mat interpretation is applied to the carbonaceous beds. The paucity and thinness of these deposits may indicate inhibition of mat growth, possibly because of a continuous background sedimentation component that diminished light penetration of the water column. The similarity of this facies to NS-1 with respect to the silt/mud couplets suggests that deposition occurred offshore between fairweather and (average) storm wave base.

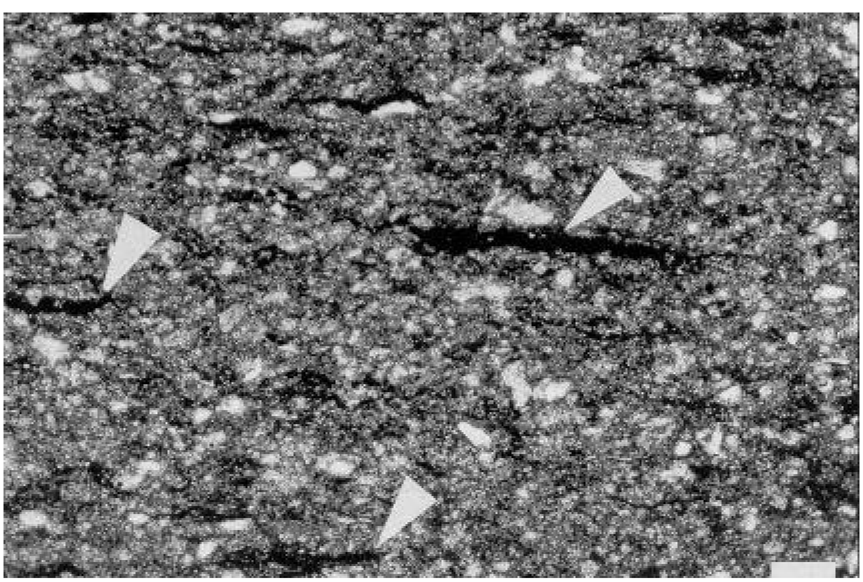
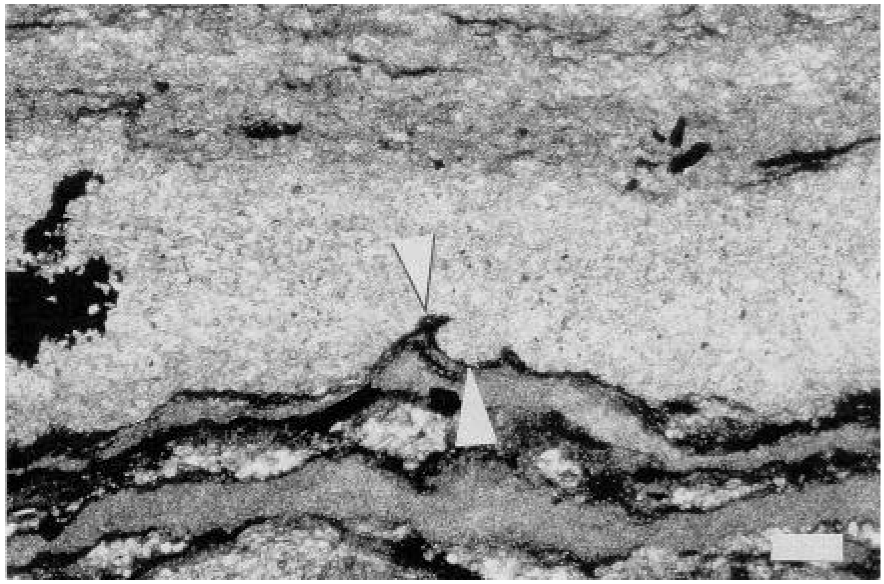


Figure 9.5. Photomicrograph of carbonaceous streak shale. Carbonaceous flakes (arrows) float in a matrix of clay, fine crystalline dolomite, and silt. Alignment of carbonaceous fragments indicates bedding plane orientation. Scale bar is 100 wm.

Figure 9.6. Photomicrograph of ML - I (Prichard Formation) showing simple graded silt/mud couplet with load and flame structures at base (arrow). Scale bar is 200 gm.



Calcareous Silty Shale Fades (NS-5)

These shales consist of clayey shale with variable amounts of dolomite, calcite, quartz silt, and carbonaceous flakes. Silt occurs as thin laminae, lensy-wavy beds, and trains and lenses of cross-laminated ripples. Silt layers commonly have sharp upper and lower boundaries, and may show erosional scours at the base (Fig. 9.3). Silt/mud couplets, as described from fades NS-1, also occur, but are not prominent.

Interpretation

Carbonates and sandstones that are interbedded with these shales show evidence of wave reworking and episodic strong currents, such as ripples with form-discordant internal structure, cross-stratal offshoots, symmetrical ripples with spillover aprons, imbricated flat pebble conglomerates, planar crossbedding, and erosive channels. The common occurrence of erosional features in these shales indicates that their deposition took place in shallower water than that of NS-1 and NS-4.

Silty Shale Facies (NS-6)

These shales consist mainly of alternating laminae of siltstone and clayey shale, with interbedded packages of siltstone and sandstone. Silt laminae are usually wavy or consist of individual silt lenses, and have sharp boundaries with laminae of clayey shale (Fig. 9.3). Sedimentary features of siltstone intervals are cross-lamination, wavy and lenticular bedding, mudcracks, clay galls, load-casts, and erosional rills. Sandstone packages contain conglomerate beds, wave ripples, and erosive channels.

Interpretation

Sedimentary features in associated sandstones and siltstones indicate deposition in fairly shallow water. Intermittent exposure is indicated by mudcracks. These shales probably accumulated on nearshore mudflats and in shallow offshore environments.

Depositional Setting

Storm deposits, growth and erosion of benthic microbial mats, wave reworking, erosional channels, mudcracks, and mudclasts all indicate that shales of the Newland Formation accumulated in all likelihood in a shallow, low-energy shelf to shoreline setting. Examination of sedimentary features in interbedded carbonates and sandstones leads to the same conclusion (Schieber, 1985).

Comparison with Shales from the Prichard Formation

The Prichard Formation is characterized in many places by interbeds of thin to medium fine sandstone beds. On the basis of sedimentary features (flute casts, grading, climbing ripples, rip-up clasts etc.), these sandstone beds are commonly interpreted as turbidites (Cressman, 1984). No evidence of wave reworking and exposure is found in the bulk of the Prichard Formation. Even though because of metamorphic overprint the shales of the Prichard Formation are more correctly characterized as argillites, the terms shale, clay, and silt are used here to describe these rocks, primarily for the sake of more direct comparison with shales of the Newland Formation. Distinction of shale facies types in the Newland Formation is relatively easy and is accomplished by

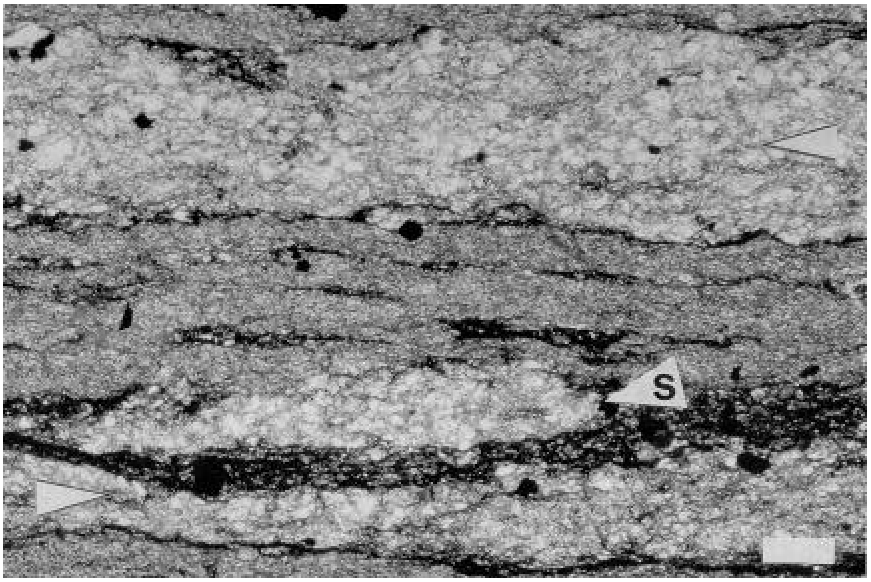


Figure 9.7. Photomicrograph of ML -2 (Prichard Formation) showing wavy-lenticular silt laminae with sharp boundaries (arrows), and single silt lens (arrow labeled S). Scale bar is 200 gm.

using macroscopic features visible in hand specimens. In contrast, sedimentary features and lithological differences in shales of the Prichard Formation are much more subtle. Microscopic examination of shale samples from the Prichard Formation shows that samples can be grouped in terms of a small number of "microlithologies" (ML). Four common types are graded silt/mud couplets (ML-1), alternating wavylenticular silt and clay laminae (ML-2), massive clay beds (ML-3), and continuous silt laminae (ML-4).

The graded silt/mud couplets (1-5 nun thick) of ML-1 have a layer of fine to medium siltstone at the base (internally graded), and are in gradational contact with an overlying layer of clayey shale (Fig. 9.6). The silt layers commonly show load and flame structures at their base (Fig. 9.6). Silt/mud couplets in the Prichard Formation (ML-1) differ from those of the Newland Formation by the absence of cross-lamination, parallel lamination, and graded rhythmites, an indication that wave action and currents did not influence silt/mud couplet deposition in the Prichard Formation. Thus it appears that the silt/mud couplets of the Prichard Formation were deposited in deeper water than the silt/mud couplets of the Newland Formation. The complete absence of features that have been observed in muddy turbidites (Stow and Shanmugam, 1980) and storm layers (Aigner and Reineck, 1982), may indicate that these silt/mud couplets are the result

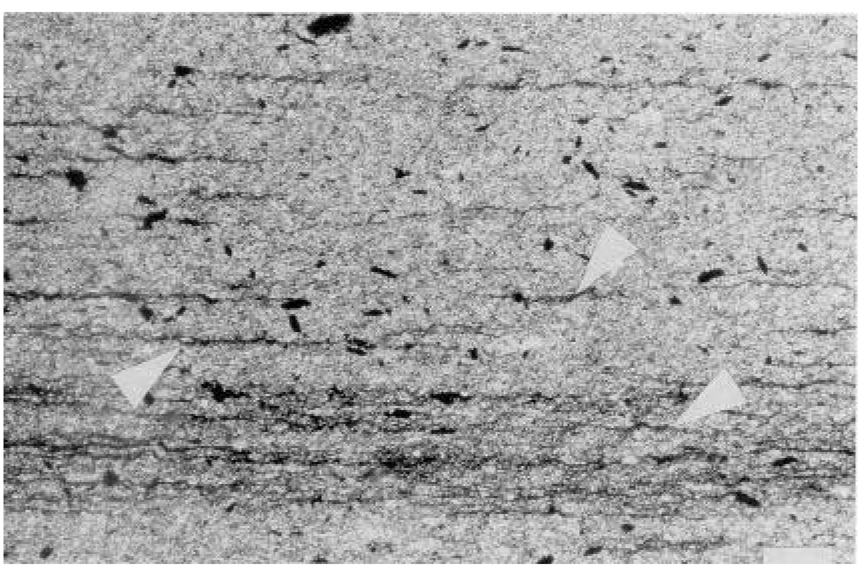
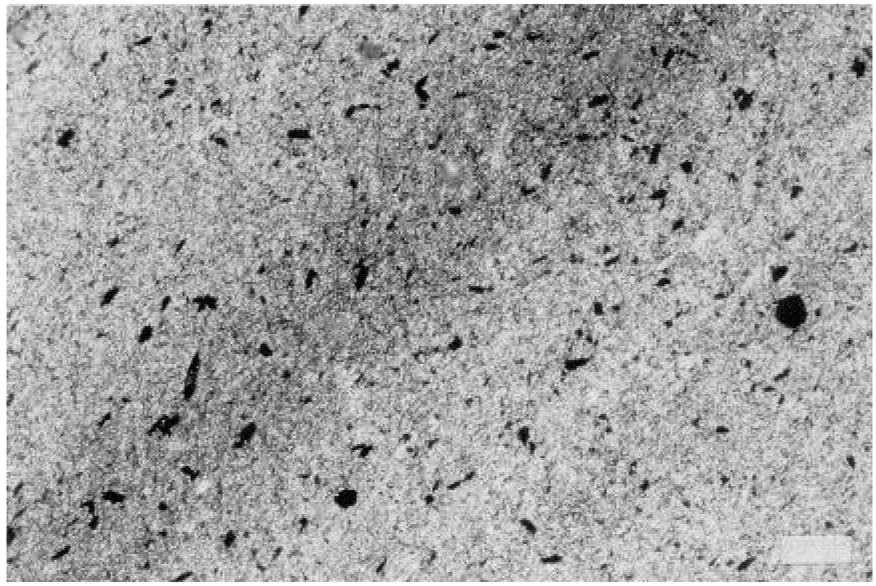


Figure 9.8. Photomicrograph of ML -3 (Prichard Formation) showing massive clayey shale bed with gradual variation in the amount of carbonaceous flakes (arrows). These gradual variations are interpreted to indicate fluctuations in sediment supply during background sedimentation. Scale bar is 200 Um.

Figure 9.9. Photomicrograph of ML-3 (Prichard Formation) showing gradual variations in clay content within massive clayey shale beds. Clay-rich laminae are darker in color. Variations are interpreted as fluctuations in background sedimentation. Scale bar is 200 wm.



of short lived lutite flows, possibly due to storms on the shelf or to river floods (McCave, 1972).

ML-2 consists of wavy-lenticular laminae of coarse silt to fine sand with sharp upper and lower boundaries, alternating with laminae of clayey shale (laminae 0.3-2 mm thick). The latter contain streaks of carbonaceous material. The silt laminae contain small amounts of detrital mica, and in places it is apparent that they consist of tiny silt lenses "overriding" each other (Fig. 9.7). These silt lenses may represent tiny starved ripples migrating over a mud surface. The sharp upper boundaries and the wavy appearance of the silt laminae suggest that these silt laminae did not simply settle out of suspension in stagnant water, but rather that currents transported silt over the seabed in bedload. Because silt requires current velocities only on the order of a few ten centimeters per second for bedload transport (Harms et al. 1982), and because silt laminae alternate with laminae of clayey shale, ML-2 is interpreted to be the product of episodic sediment reworking by weak bottom currents.

ML-3 consists of massive layers (up to 10 mm thick) of more or less homogeneous clayey shale and may represent pelagic background sedimentation. Subtle and gradual variations in the content of carbonaceous flakes and clay in these beds (Figs. 9.8 and 9.9) indicate continuous background sedimentation with slight variations in the supply of sedimentary components (Schieber, 1989). Within massive

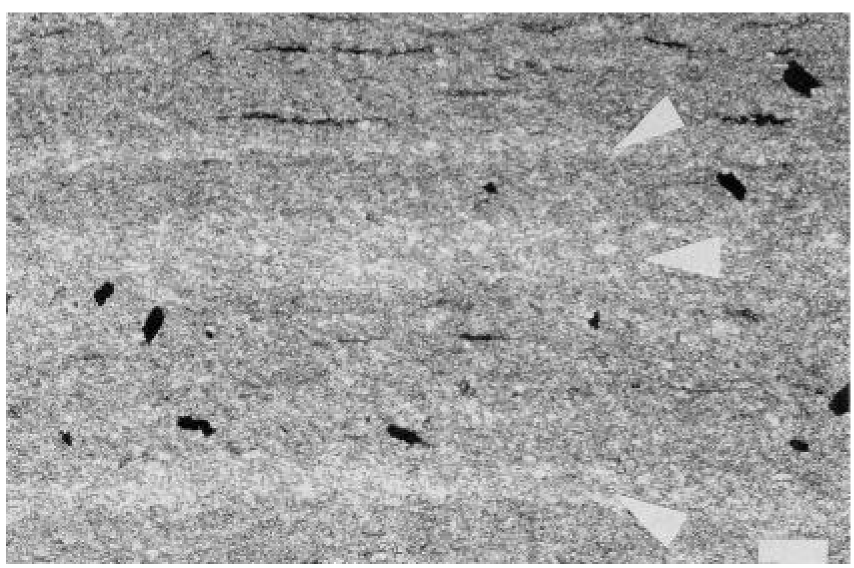


Figure 9.10. Photomicrograph of ML-4 (Prichard Formation) showing even silt laminae (arrows) with indistinct upper and lower boundaries in ML-3. Scale bar is 200 gm.

beds of ML-3, continuous even laminae of fine to medium silt (0.25-1 mm thick) with indistinct upper and lower boundaries (ML-4) are found (Fig. 9.10). These occur singly or as bundles of closely (0.2-1 mm) spaced laminae, and are perhaps due to gradually shifting sediment supply by nepheloid flows (Moore, 1969). This kind of silt laminae was not observed in shales of the Newland Formation.

Even silt laminae that bear similarity to ML-4 were described by Huebschman (1973) from the upper portion of the Prichard and Aldridge Formations (the Aldridge Formation is the correlative of the Prichard Formation in Canada). These silt laminae were described as being 1-20 mm thick, and individual laminae were correlated from outcrop to outcrop over a distance of more than 200 km. The wide areal distribution as well as the even and continuous appearance of these silt laminae led Huebschman (1973) to the conclusion that these silt bands were deposited in quiet water (below storm wave base), and that the silt was transported across the basin by dust storms.

Conclusion

Sedimentary features in Newland and Prichard Formations show that shale facies can be interpreted in terms of depositional setting, and that shales of the Newland Formation were deposited in shallow water. The absence of certain features in shales of the Prichard Formation, such as microbial mat deposits and cross-lamination in silt/mud couplets, points toward deposition in a deep basin, and sediment supply by nepheloid flows and reworking by bottom currents are suggested by indistinctly bounded and sharply bounded silt laminae, respectively. Possible eolian sediment input is indicated by scattered silt in "deep" water shale facies of the Newland Formation, and by even silt laminae of large areal extent in the Prichard Formation. Small scale sedimentary features are still readily recognizable in shales that have undergone low-grade metamorphism. Thus, an approach to shale sedimentology as shown here can be applied also to metamorphosed shale sequences.

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