

## 7. CONSTRAINTS ON THE FORMATION OF LACUSTRINE MICROLAMINATED SEDIMENTS

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Microlaminated sediments have very thin (less than 1 mm), usually laterally continuous laminae. Many ancient examples, including those of the lower Mesozoic Newark Supergroup and the Eocene Green River Formation, are relatively rich in organic matter (total organic carbon greater than 1 weight percent) and contain complete fossil fish and other delicate organisms.

The main controls on the distribution of microlaminated sediments are bottom energy conditions and bioturbation. Microlaminated sediments can retain their structure in high-energy conditions only if they are bound by microbial communities. The microbial communities can be dominated by blue-green algae or by sulfur-oxidizing bacteria such as *Beggiatoa*. Such microbial mats exist today only where grazing organisms are limited by such factors as high salinity or toxic waters. Modern algal mats typically form in very shallow water where they are commonly desiccated. Fish have not been found preserved under these conditions. However, fish can be preserved on deeper water lake bottoms, where sulfur-oxidizing microbial mats flourish in microenvironments devoid of bottom feeders.

Microlaminated sediments not bound by microbial mats can form only in water where there is no bottom turbulence (that is, below wave base). The depth at which microlaminated sediments can form is controlled by the surface area of a lake and the modal wind velocity (Manspeizer and Olsen, 1981; Olsen, 1984). A lake must be relatively deep compared to its surface area for this type of microlaminated sediment to form. In strongly density-stratified lakes, wave propagation can be impeded, causing wave base to be shallower than in unstratified lakes.

The third factor controlling the distribution of microlaminated units is protection from bioturbation. Bioturbators today are limited by primary productivity levels in the lakes. Microlaminated sediments form today at two ends of the productivity spectrum (fig. 7.1). Very low productivity excludes macroscopic bioturbators, as in Lake Brienz, Switzerland; sediments in such

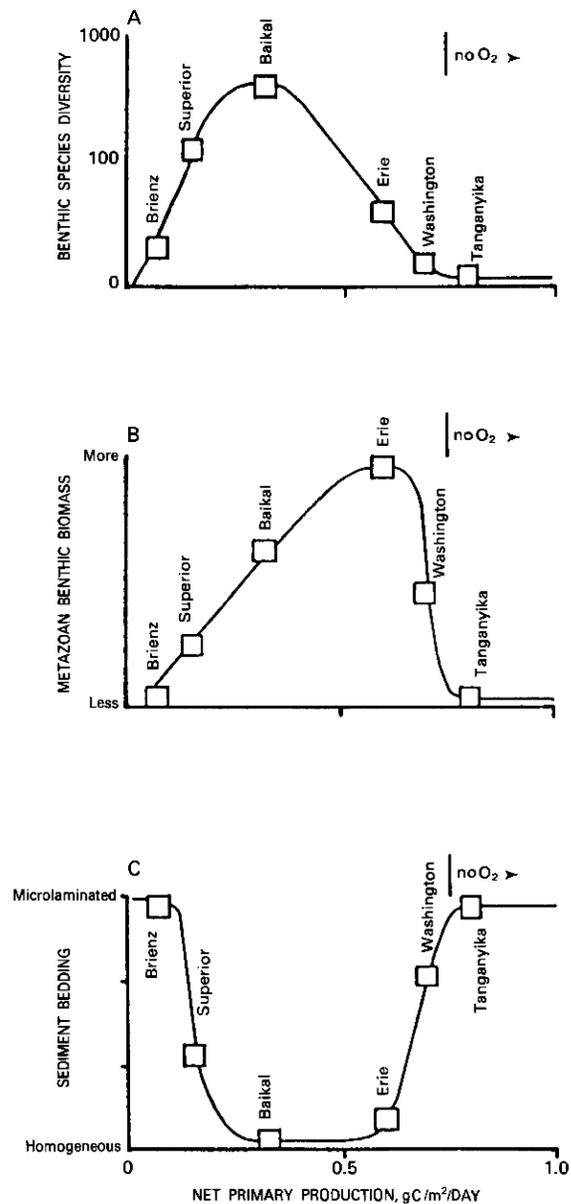


FIGURE 7.1.—Theoretical relationships between primary production and properties of the benthos of lakes. If benthic bioturbators needed higher oxygen levels in the past than they need now to survive, these curves would all be narrowed, shifted to the left, and probably made more symmetrical. (A) Relationship between primary production and benthic species richness in modern deep lakes. (B) Relationship between primary production and metazoan benthic biomass in modern lakes. (C) Relationship between primary production and sediment lamination development in modern lakes.

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lakes contain little organic carbon. In other lakes, there is so much primary production that oxygen taken up by consumers exceeds oxygen supply, as in Lake Tanganyika. In a given lake, benthic species diversity first increases with increased productivity, then drops as the tolerances of bioturbators to low oxygen are reached, ultimately dropping to zero. Metazoan benthic biomass, and hence the degree of bioturbation, also first increases with productivity and lowered oxygen levels, continues to rise or levels off where benthic diversity is very low, and then decreases dramatically as oxygen levels drop off to zero. The oxygen tolerances of bioturbators limit them to the region between the two productivity extremes (fig. 7.1). Therefore, the distribution of non-microbial-mat microlaminated sediments is, in part, limited by the tolerances of the range of bioturbators available to colonize the lakes.

The history of major groups of bioturbating organisms is thus critical to the understanding of the paleoecological meaning of microlaminated beds. In the early Precambrian, there was no bioturbation and all sediments deposited below wave base could be microlaminated. Sometime between then and now, the modern groups of bioturbators became important. Tubificid worms, ostracodes, and fly larvae are the most important modern lacustrine bioturbators; their oldest known occurrences are unknown, Ordovician, and Late Triassic (late Carnian), respectively. I hypothesize that, through the Phanerozoic, sediments of increasingly lower oxygen levels were colonized by bioturbators. Examination of broad suites of sediments of different ages supports this hypothesis: as the sediments get

younger, bioturbation becomes more important (and water turbulence proportionally less important) in limiting the distribution of microlaminated sediments. Therefore, simply extrapolating from modern conditions that limit bioturbation may lead to erroneous estimates of the frequency of ancient lakes with anoxic bottom waters.

Similarly, the distribution of modern microbial mats depends both on the range of grazers available and on their tolerances to high salinity and low oxygen or toxic water. In the Precambrian, we can imagine a continuum from shallow-water, blue-green microbial mats, formed under high-energy conditions, to deeper water microbial mats, and, ultimately, to unbound microlaminated sediments below wave base. The range of conditions under which microbial mats were formed may have been much wider then, simply because of differences in predation pressure.

## REFERENCES

- Manspeizer, Warren, and Olsen, P.E., 1981, Rift basins of the passive margin; tectonics, organic-rich lacustrine sediments, basin analysis, in Hobbs, G.W., III, ed., *Field guide to the geology of the Paleozoic, Mesozoic, and Tertiary rocks of New Jersey and the central Hudson Valley*, New York: Petroleum Exploration Society of New York, p. 25-105.
- Olsen, P.E., 1984, Periodicity of lake-level cycles in the Late Triassic Lockatong Formation of the Newark Basin (Newark Supergroup, New Jersey and Pennsylvania), in Berger, Andre, Imbrie, John, Hays, James, Kukla, George, and Saltzman, Barry, eds., *Milankovitch and climate*, NATO Symposium: D. Reidel, Dordrecht, Part 1, p. 129-146.