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Tectonic, Climatic, and Biological Modulation of Lake Sediments in the Newark Supergroup

The basic controls on lakes, lacustrine ecosystems, and the sediments they produce are their tectonic, climatic, and biological milieus, all of which change on various time scales. Here, I outline some of the dynamic aspects of these controls, using as examples the early Mesozoic half-graben rift sequences of the Newark Supergroup of eastern North America.

The balance between supplied sediment and basin growth determines the maximum possible depth and area of the lake basin. mass balance models show that if the tectonic subsidence rate is slow enough or rate of sediment supply is high enough, a basin will initially fill with fluvial sediment with excess sediment and water leaving the basin. As the basin continues to subside, the same sediment volume will spread over an increasingly larger surface. At some point, the volume of sediment will just fill the basin; thereafter, there will be a deficit between sediment supply and subsidence, and a lake basin will form. Sedimentation rate will then show an hyperbolic decrease through time, and the depth of the lake basin will correspondingly increase. After a brief period of exponential increase in maximum lake depth, it will slowly and hyperbolically decrease through time. The often cited tripartite divisions of the Triassic age Newark sequences can be quantitatively explained by this model.

Increasing subsidence rate should increase basin asymmetry and temporarily decrease depositional and lake surface area, thus increasing sedimentation rate and maximum lake depth. An hyperbolic decrease in sedimentation rate and maximum lake depth would follow. Accordingly, an earliest Jurassic increase in subsidence rate due to an increase in extension rate led to the stratigraphic pattern seen in northern Newark basins, as well as the extrusion of voluminous lava flows. Additional non-linear processes were also in operation, but the often cited relationship between fault movement and sedimentation is probably grossly overemphasized. Only under special conditions could there be a linear correlation between tectonic rates and anything happening in the lake. This model shows why the largest volumes of Newark organic-rich deposits are either close to the base of Triassic age lacustrine sequences or in the Jurassic age portions.

In the Newark Supergroup, Milankovitch-type climate changes appear to have been the cause of the permeating transgressive-regressive lacustrine sequences called Van Houten cycles. Based on Fourier analysis of dozens of sections from several basins, Van Houten cycles appear to have been under the control of the precession cycle of about 21,000 years. Clusters of Van Houten cycles make up larger cycles under the control of the obliquity cycle of 41,000 years and the eccentricity cycle of about 100,000, 400,000 and 2,000,000 years.

In the Newark, Gettysburg, and Culpeper basins, the "best developed" Van Houten cycles record very large changes in depth: from no lake, to very deep (> 100 m) lake, and back. The lakes seem to have dried out completely every 21,000 years. In contrast, in the Richmond, Taylorsville, and perhaps the Sanford basins, the fluctuations were more muted. Such differences could have resulted from differences in climate or they could reflect basin catchments—perhaps major rivers fed the latter basins while bypassing the former.

Primary production, consumption, and bioturbation were under the control of lake depth, and hence responded to the lake depth cycles. The amount of organic material that accumulates in sediments is a function of ecosystem efficiency which is highest in shallow water and lowest in deep water. Newark Supergroup black, microlaminated units were produced only by the deepest, probably chemically stratified lakes, with depressed ecosystem efficiency and no or very little bioturbation. In contrast, the shallow water, high ecosystem efficiency lakes produced mostly massive red or gray mudstones with little or no preserved organic material, even though they probably had higher primary productivity. The fluctuations in carbon content characterizing Van Houten cycles show that lacustrine ecosystems were in constant flux, and no single modern lake can possible serve as an analog to a long section of Newark sediments.

Changes in lacustrine ecosystems depend not only on short term external forcing, but also long term evolution of organisms. We can be certain that Newark Supergroup lakes were different from modern lakes in primary production, because fresh water diatoms had not yet evolved, different in their zooplankton communities because pea-sized clam-shrimp not flea-sized Cladocera were dominant in the plankton, and different in their bioturbation because chironomid flies had not yet evolved. Thus, the principal links in the food chain were qualitatively different from modern lakes, and the responses of the lake ecosystems to external forcing were probably different as well. The Phanerozoic history of lakes was characterized by increasing diversity and abundance of low-oxygen tolerant bioturbators, decreasing average size of zooplankton, and increasing dominance of armored phytoplankton.

Both the highly unstable nature of lakes and the long term changes in the composition of lacustrine communities are profound limits to our use of modern lakes as analogs of fossil systems. These limits can be overcome by careful comparison of lake systems over time and by rigorous understanding of specific physical and biological processes. Otherwise, our use of simple analogy condemns us to the weaving of untestable yarns of extremely limited use.

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