Textural and Compositional Variability Across Littoral Segments of Lake Tanganyika: The Effect of Asymmetric Basin Structure on Sedimentation in Large Rift Lakes[1]

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ABSTRACT

Lake Tanganyika, part of the East African rift system, represents one of the most widely cited modern analogs for interpreting ancient rift lakes. To date, few published detailed sedimentologic studies of the modern sediments allow for comparisons to outcrop- and well-bore-scale observations within ancient strata.

Four recurrent structural margin types exist along the alternating half-graben structure of the lake: hinged margins, axial margins, accommodation zone margins, and escarpment margins. The hinged margin consists of a series of structurally controlled benches over which long, continuous tracts of bioclastic lag deposits predominate; clastic sands are limited to moderate-size silty deltas and long, narrow shoreface sands. The axial margin is dominated by a wave-dominated, silt-rich delta system. Accommodation zone margins consist of bioclastic lag deposits atop structural highs, whereas carbonate and clastic mud accumulates farther offshore. Escarpment margins contain small fan-delta deposits alternating along shore with talus deposits; offshore carbonate and clastic mud is present away from active gravity-flow deposition. Total organic carbon (TOC) and pyrolysis data from fine-grained samples subtly reflect the contrasts in margin types, but these values are controlled more directly by water depth.

Although facies are similar among all margin types, their spatial distribution, in particular the degree to which facies tracts trend parallel to shore, best discriminates among the different margin types. These data suggest that unique but predictable associations of reservoir, seal, and source facies exist along each of the different margin types.

INTRODUCTION

Thick lacustrine strata commonly form a significant component of both ancient and modern rift basins. Typically, lacustrine deposits exhibit abrupt vertical and lateral facies changes, producing a complex three-dimensional facies geometry. Both the episodic tectonism of rifts and the climate-induced fluctuations in the water budget of the rift basin control this facies complexity. Nevertheless, differentiating the controls on facies distributions in rift lakes is an important goal because rift lakes not only represent viable economic targets for hydrocarbons and other mineral deposits, but also form long-term repositories of paleoclimatic data for continental regions.

Numerous structural and reflection seismic studies within the East African rift confirm that the rift evolved in an asymmetric fashion (Rosendahl et al., 1986; Ebinger, 1989a; Sander and Rosendahl, 1989). Consequently, recent models developed for sedimentation within rifts incorporate a half-graben

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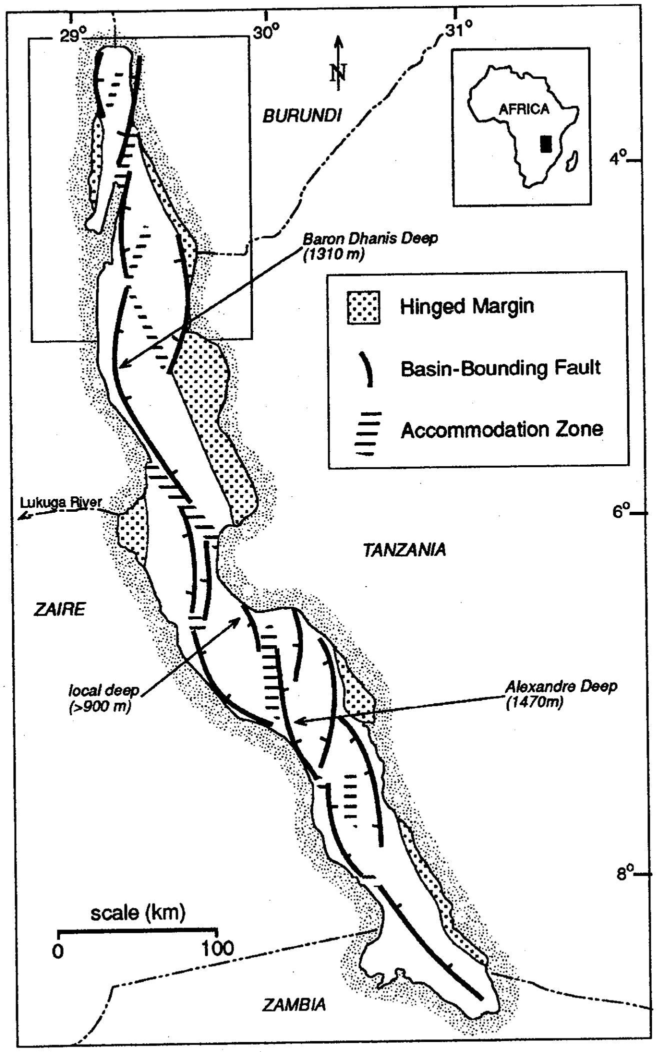

Figure 1—Generalized tectonic map of Lake Tanganyika emphasizing the alternating, half-graben morphology of the basin. Hachures on faults are on side of the downthrown block. The box at the northern end of the lake outlines the study area shown in Figure 3. Structure simplified from Rosendahl et al. (1986), Morley (1988), and Ebinger (1989a).

geometry as one variable that controls deposition (Turner-Peterson and Smoot, 1985; Leeder and Gawthorpe, 1987; Blair and Bilodeau, 1988; Burgess et al., 1988; Gore, 1988; Cohen, 1989, 1990; Lambiase, 1990; Scholz and Rosendahl, 1990; Scholz et al., 1990; Tiercelin et al., 1992). For example, Cohen (1990) developed a tectonic-stratigraphic model for rift lake deposits based on general observations from Lake Tanganyika. Tiercelin et al. (1992) followed with a study that incorporated high-resolution seismic and core data to develop a similar model. Other models have been developed from a combination of several East African lakes and other rift systems to predict basin-fill patterns (Lambiase, 1990; Scholz and Rosendahl, 1990; Scholz et al., 1990; Lambiase and Bosworth, 1994). To date, however, few quantitative sedimentologic studies document the extent of facies differences created by the structural asymmetry within modern rift lakes [exceptions include Cohen et al. (1986), Yuretich (1986), Owen and Crossley (1989), Johnson and Ng'ang'a (1990), and Johnson et al. (1995)].

The goal of this study is to document facies patterns and the distribution of organic matter across specific shallow-water regions of northern Lake Tanganyika, Africa, that represent the typical structural lake margins found within asymmetric East African lake basins. From these data we quantitatively compare and contrast characteristics of sedimentation among different structural margins of the lake to document the variables most sensitive to the half-graben structure of the basin. The results of this study contribute to an improved understanding of the relationship between facies patterns and paleogeography of rift basins by providing data comparable to borehole- or outcrop-based data from ancient rift lake stratigraphic sequences.

BACKGROUND

Regional Tectonic Setting

Lake Tanganyika lies within the western arm of the East African rift system (McConnell, 1972; Ebinger, 1989a). The initiation of rifting and attendant basin formation was probably diachronous throughout the rift and is not well constrained, but may be between 9 and 12 Ma (Cohen et al., 1993), although other workers suggest a significantly older age (16–24 Ma) (Burgess et al., 1988; Tiercelin and Mondeguer, 1991).

A series of half-graben basins, 80–160 km long and 30–80 km wide, comprise the Lake Tanganyika basin. In this geometry, border-fault segments typically face opposite directions along the rift axis (Figure 1) (Rosendahl et al., 1986; Morley, 1988; Ebinger, 1989a; Sander and Rosendahl, 1989). Accommodation zones (transfer zones of Nelson et al., 1992) are structural horsts that trend roughly 45 to 60° from the rift axis and provide for differential subsidence between two adjacent half-grabens (Rosendahl et al., 1986; Ebinger, 1989b; Morley et al., 1990; Nelson et al., 1992). Maximum sedimentary fill within local depocenters of Lake Tanganyika exceeds 6 km (Burgess et al., 1988; Tiercelin and Mondeguer, 1991; Cohen et al., 1993), and elevation along border-fault segments ranges between 1 and 3 km above lake level (Ebinger, 1989a), producing structural relief of at least 7–9 km.

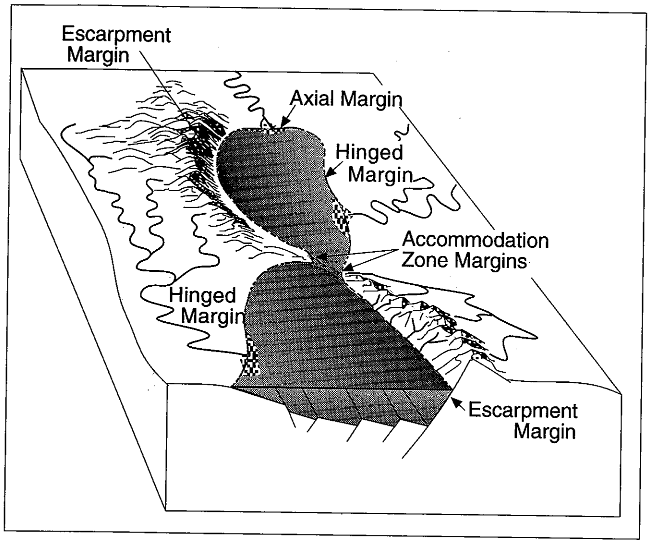

Figure 2—Block diagram illustrating structural margin types present within an alternating half-graben lake basin. These margin types are the focus of this study.

The structural complexity of Lake Tanganyika produces a highly asymmetric and variable basin morphology. Capart (1949) first showed that the three deepest points of Lake Tanganyika lie just offshore and not within the center of the lake (Figure 1). The nature of the shoreline and the littoral zone bathymetry also changes abruptly as the shoreline passes from one structural margin to another. Figure 2 depicts the terminology used in this study for the distinct lake margin types that result from the alternating half-graben morphology: (1) escarpment margins lie adjacent to border faults; (2) hinged margins lie on the lakeshore opposite border faults; (3) accommodation zone margins lie across the complex horst blocks/fault zones that separate half grabens; and (4) axial margins lie where the lake margin trends approximately perpendicular to the rift axis. This terminology varies slightly from that of Tiercelin et al. (1992), but follows closely that of Cohen (1990) and Rosendahl et al. (1986).

Climate and Hydrology

Lake Tanganyika has an area of 33,000 km^2, a maximum depth of 1470 m, and lies within the tropical subhumid belt. Precipitation within the Lake Tanganyika basin ranges from 800 to 1200 mm/yr and falls primarily during two rainy seasons (September–November and February–April). During the remaining months the region is drier and experiences intensified southerly winds. Presently, the lake is hydrologically open (through the Lukuga River, Zaire; Figure 1), although 90% of the water loss occurs through evaporation from the lake surface (Coulter and Spigel, 1991). Influent waters generally form strong underflows upon entering the lake because they are typically cold and highly charged with suspended sediment, especially during the rainy season.

The lake is thermally stratified with permanently anoxic waters below 80–250 m water depth (Hecky and Degens, 1973; Coulter and Spigel, 1991). The thermocline ranges between approximately 50 and 120 m depth. Water temperatures within the mixed, upper waters (epilimnion) range between 24° and 27°C, becoming constant at 23.2° to 23.5°C within the stable, permanently anoxic bottom waters (hypolimnion). The lake waters are fresh (salinity = 0.5‰) and mildly alkaline (pH = 9.15 ±0.05) with a high (~4:1) Mg:Ca ratio (Casanova and Hillaire-Marcel, 1992). The most important source of nutrients for primary productivity is internal recycling within the lake during the dry, windy season; riverine input is minor (Huc et al., 1990).

METHODS

We investigated six study sites (Figure 3): (1) Ruzizi River delta, Burundi (axial margin); (2) Nyanza Lac, Burundi (hinged margin); (3) Magara, Burundi (accommodation zone margin); (4) Cape Banza, Zaire (accommodation zone margin); (5) Bemba, Zaire (escarpment margin); and (6) Kigoma, Tanzania (escarpment margin). Each site represents one of the four margin types and incorporates the entire zone from the shoreline to an offshore distance well into the anoxic zone. Each site ranges in area from 5 to 80 km^2 depending upon the bathymetric gradients and the heterogeneity of depositional subenvironments.

We conducted a bathymetric survey at each site using a single-channel Lowrance X-16 sonar system with an 8° transducer, typically mounted on a small, inflatable boat. Sonar transects provided the data for the bathymetric maps used in this study and allowed us to identify features relevant to the sedimentology of the site (e.g., channels or submerged rocky outcrops).

We collected a total of 320 samples by use of one of three methods: (1) a modified Eckman corer; (2) a "scooper" sampler; and (3) by hand using scuba divers. The sampling scheme at each site was a nonuniform grid that was biased toward regions of transitions between subenvironments. We employed scuba divers for direct observation at each site in depths of less than 40 m for documentation of facies relationships to supplement the laboratory analyses of boat-collected samples.