Bathymetric Survey and Structural Models of Kalya Ridge, South Basin, Lake Tanganyika, Tanzania

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Introduction

Lake Tanganyika is the world’s second largest and second deepest lake, containing 18% of the world’s total freshwater. It belongs to the western branch of the East Africa Rift System. It is also one of the oldest lakes, with an estimated age of 9-12 Ma (Cohen, 1993). Although detailed work has been done on the northern end of the lake (See Cohen et al. or Lezzar et al., 1996), the central region has gone largely unexplored. Deep multichannel and high resolution seismic lines were shot in the region southwest of the Mahali Mountains as part of project PROBE (Burgess et al., 1988).

The Moba-Kalya Ridge (Figure 1d) is dominated by high-angle (45°-75°), mostly northwestward-striking normal faults along the western margin, with throws of 100 m or more (Binger, 1989). It is a potentially an ideal location for coring, as paleoclimate fluctuations would be recorded in the deposited sediments. It is important to have a core on a horst, as bottom currents and slope processes on a lake will disturb sediments. Also, the horst will stay below the water surface during lake level low stand events.

The horst is the result of a rift segmentation following the subsidence of convergent polarity half-grabens. It’s defined as “an individual fault-bounded structural element”(Nelson et al., 1992). This region has a relatively low subsidence rate and is located on top of a pre-rift grid of Precambrian faults (Ubendian and Kibarian Trends) (Lenior et al., 1994). East-West extension of the rift valley has created the block structure of the horst. Opposite polarity half-grabens extend from either side of the horst, with accommodation zones in-between.

There is not enough information between the two PROBE lines, however, to determine the geometry of the faults in the Kalya region (Ebinger, 1989).

Methods/Data:

Bathymetric data was collected while on board the M/V Maman Benita. A mobile Echo sounder unit was used to collect water depth, while a Global Positioning System (GPS) unit recorded latitude, longitude, baring and speed. This information was fed into a laptop computer and viewed from a HyperTerminal file. The raw data from the file was later edited to ascertain usable information.

A starting point for the survey was previously determined through evaluation of lines P83.78 and P83.84 (Project PROBE). The point was approximately midway between the two lines and a grid box extended to the southwest in order to cover an area that would contain the Moba-Kalya Horst. Grid transects were 10 km from southwest to northeast and 2 km from north to north-northeast to south-southwest. Ten SW-NE lines were scheduled for this project. Bad weather conditions limited our survey to three SW-NE transects and one NNE-SSW transect.

Data was compared with several models including Burgess et al., 1988, Morley et al. 1988, and Rosendahl et al., 1988. Difficulties were encountered in finding consistent data on the length of lines P83.78 and P83.84. Unavailability of field book records of latitude and longitude coordinates resulted in estimations for location of lines P83.78 and P83.84. One point along line P83.84 was available. Estimates were taken from a straight-line distance between end points on several sources, and an average distance was then attained. Distance was then added to each line to account for the curvature. Depths and distances from the estimated eastern end point (for line P83.78) or from one known point (for line P83.84) were calculated from bathymetric and seismic lines of P83.78 and P83.84 (Rosendahl et al., 1988).
Lines P83.78 and P83.84 have been modified after Rosenthal, Burgess and Wolley.

Figure 1

(c) Line P83.84

(p) Figure 1

(q) Depth (m)

(e) Depth (m)

Figure 1

Line P83.78

Two-way travel time (s)

Two-way travel time (s)
Figure 2
Bathymetric Map of Moba-Kalya Ridge

D.R. Congo  Tanzania

P83.78  LT 00-01
LT 00-02
P83.84

Survey Site

700.00  400.00  300.00
500.00

29.50  29.60  29.70  29.80  29.90  30.00  30.10  30.20
Figure 3

Nyanz2000 Survey Site - Moba-Kalya Ridge
Surfer software was used to create a bathymetric map, which includes the Nyanza2000 survey site as well as data from lines P83.78 and P83.84 (Figure 2). The Nyanza2000 data (Figure 3) was then interpreted in comparison with structural models of the horst and bathymetric check points for the Lake Tanganyika bathymetric map (Rolet et al., 1991).

**Discussion and Interpretation: Nyanza2000 Results**

Data from the bathymetric survey lead to re-interpretations of the Kalya Ridge fault families. Three models have been proposed to explain the findings of the survey (Figures 4, 5, & 6) and have been compared to the Burgess, Morley and Rosendahl models (Figure 7). Rosendahl refers to the Moba-Kalya Horst on line P83.84 as the structure bounded on the west by the West Moba Fault Zone (WMFZ) and by Lufuba 1 Fault (LUF1) to the east. There are several internal faults on the horst, most important of which is LUF2, which created a slope along the western portion of the horst above Block 3 (B3) and a depression between the subsiding Block 1 (B1) and Block 2 (B2). The western slope is ideal for coring because of its elevated position of the horst and increased depth of sediments. The Moba-Kalya Horst is approximately 22 km in length and is vertically offset by 60-100m.

Transect 1 displays a vertical offset, which has been interpreted as the LUF1 fault. The horst can therefore be shown to run NNW at a lesser angle from North than previously proposed by Rosendahl and Morley. In Transect 4, B1 has nearly disappeared and B2 is completely buried. B1 can still be seen in Transect 3, though it appears to be diving down (buried), while B2 is represented by only a slight dome, which suggests a faster, northward subsidence. The structure created by the movements of B1, B2 and B3 reflects a period of adjustment during the formation of Lake Tanganyika. The progression seen in the Nyanza2000 lines is consistent for all three proposed models. The possible structure models are as follows:

**Early rifting phase strike-slip displacement:** A buried ridge (B2/B1) on Line P83.78 probably represents the southern tip of a rift segment, which probably began in the north and propagated southward, ending below line P83.78. A second rift segment, the Moba-Kalya Ridge, represented by B1, B2 and B3 ends below line P83.78 after propagating northward from points on line P83.84. The two rift segments converge in an overlapping fault zone. The WMFZ curves from line P83.84 to Line P83.78, showing that the rift segmentation occurred after rift extension. A variation of the model would propose that WMFZ does not curve but rather depicts an offset between the fault location in Line 83.84 and P83.78. The offset is an artifact of movement along a reactivated pre-rift NE-SW fault during rift extension.

This model is similar to the fault system in the northern basin of Lake Tanganyika. Here, the two major border faults, West Ubwari Fault (WUF) and East Ubwari Fault (EUF), are of opposing polarity, with a horst in-between. The Ubwari horst is buried to the north, with only the Cape Magara Fault (CMF) visible, forming a submarine ridge (Lezzar et al. 1996). The Ubwari Fault could be comparable to the LUF1 and WMFZ faults in the central portion of the lake. Just as the WUF and EUF are buried to the north, thus only visible with seismic surveys (see P83.14 Lezzar et al, 1996), so also are the faults in the site area (WMFZ and LUF1), which are visible on line P83.84 but not bathymetrically.

**Late rifting phase - strike-slip displacement:** This model proposes the formation of the Moba-Kalya horst contemporaneous with reactivated fault movement in a NE-SW direction. Northward propagation of the Moba-Kalya horst between LUF1 and LUF2 dies out north of line P83.78. Formation of the Marangu Half-Graben (HG) occurred at the same time westward of WMFZ due to an EW extension. As extension continued a pre-rift transverse fault below line P83.78 became active and offset the northern tip of the Moba-Kalya horst (labeled “Moba block” on line P83.78, Rosendahl, 1988), as well as the WMFZ and the Mahali mountain chain. This offset varied between 15-20 km.

**Transfer faulting along a pre-rift basement grid:** A grid system of WNW-ESE (U bendian) and NNE-SSW (Kibaran) trending fault families transect the pre-rift basement (Nelson, 1992). Extension in an EW direction created fault propagation in the N-S direction. The pre-rift faulted basement, created areas/zones of fault resistance. Fault propagation continued at points of weakness, products of heterogeneity. No horizontal displacement occurred in this model. LUF1, LUF2 and WMFZ propagated from the north and
Figure 4

Model 1: Early rift phase - strike-slip displacement
Model 2: Late phase rifting - strike-slip displacement

Figure 5
Figure 6

Model 3a & 3b: Transfer faulting along a pre-rift basement grid
south until reaching a pre-rift fault below line P83.78 at which point the fault was transferred to a point of weakness and continued propagation.

**Nyanza2000 results compared to Rosendahl, Morley and Burgess Models**

None of the Nyanza2000 models correspond to models by Rosendahl, Morley or Burgess. There are similarities, but findings from Transects 1, 3 and 4 have lead to modifications of the aforementioned models (Figure 7). Previous models required interpolation between lines P83.78 and P83.84. Transects 1, 3 and 4 can now offer new data within this area. The following differences/modifications occurred:

**Rosendahl** - The pre-rift strike-slip segmentation model proposes that Rosendahl’s Moba block is instead a new structure from the north, while B1 and B2 die out along a NW direction and are not connected to the Moba block. Therefore, LUF1 propagates in a more northerly direction and its location on line P83.78 lies just above the end points of B1 and B2. WMFZ on the Nyanza2000 model correlates to the Rosendahl model. Modification of WMFZ would occur in the pre-rift strike-slip variation of the first Nyanza2000 model. The synrift strike-slip movement model proposes that the Moba block is the tip of a rift segment consisting of subsiding B1 and B2. Offset between the Moba block on line P83.78 and the north-westward propagation of B1 and B2, as suggested in transects 1, 3 and 4, is accounted for by suggesting strike-slip movement along a WSW-ENE pre-rift fault, which also offset the WMFZ. The model of transfer faulting along a pre-rift basement grid suggests that the Moba block is not connected to B1 and B2 and the LUF1, LUF2 and WMFZ were all transferred to points of weakness and not connected as Rosendahl’s model suggests.

In order to have a rough estimate of minimum and maximum ages of sediments deposited on the shoaling site since the Nyanja Event (NE), an estimate was made using the reflection seismic-radiocarbon method (RSRM) of age determination, as used in Cohen *et al.* and Lezzar *et al.* (1996). A sedimentation rate of 0.1 mm/yr was used, based on rates at the Kavala Island Ridge (Scholz *et al.*, in review). Seismic velocity averages and decompaction rates were taken from the Ubwari horst site (Table 1, Lezzar *et al.* 1996). Ages of 13.5 Ma and 5.3 Ma were determined, as shown in Figure 1. Because the horst is jumping northward, and hence being buried deeper, the sediment packages would be expected to thicken to the north, where the sedimentation rates are larger (Ebinger, 1989). However, according to the Rosendahl interpretation, the “Moba block” is actually becoming less sedimented to the north, if the WMFZ is taken as the western boundary and LUF1 as the eastern, and Blocks 1 and 2 are becoming more sedimented. In our proposed models, with the western border WMFZ being shifted further west, and blocks 1 and 2 being buried, the sediment package then thickens to the north.

**Morley** – Morley’s model is similar to Nyanza2000 models. A smaller fault appears to the east of LUF1 on the Morley model (most likely part of the Luenga FZ as deduced from Rosendahl, Rolet and Morley). It can be determined not to be the fault found in transect 1 by the following method: Morley states that vertical offset is greatest toward the center of a fault zone, the vertical offset encountered in transect 1 would place the transect in a middle region of a fault, not at a subsiding end. The second Nyanza2000 model proposes that Morley’s LUF1 propagates more northerly and passes through line 1. It is also interpreted that LUF2 converges with LUF1 below line P83.78, differing from the NE-SW trending of LUF2 in the Morley model. The Morley model connects LUF1 between lines P83.78 and P83.84, but the second Nyanza2000 model suggests the LUF1 point on line P83.78 is instead the southern tip of a separate northern rift segment. The third model, transfer faulting along a pre-rift basement grid, follows similar trends of modification.

**Burgess** – The three proposed models add detail to the simplified Burgess model. A N-S trending fault is located approximately at the location of LUF1 on the Burgess model, in agreement with the Nyanza2000 models. Another border fault correlates to WMFZ and trends in a complimentary direction. Correlation beyond these two faults is not possible due to limited detail of the Burgess model. The three proposed models all suggest that the accommodation zone on the Burgess model should be shifted slightly to the east above line P83.78 and an additional 15-20 km east below line P83.84.
Figure 7

(a) Rosendahl

(b) Morley

(c) Burgess
Conclusions

Bathymetric data has shown that the Moba-Kalya Horst propagates in a northwesterly direction. Consequently, the shoaling site that was previously believed to be located in the Democratic Republic of Congo is now interpreted to be in Tanzania. Sediments found on the high relief of the horst provide an excellent, nearly continuous, record of climatic change. The low sedimentation rate which exists on the horst allow for large periods of time to be analyzed from a short core segment, making this site ideal for paleoclimate and petrology studies. Based on the estimate of sediment ages of 5.6 – 13.5 Ma, a potentially very long history is recorded in these sediments. Coring sites in the deep basin would not be possible due to underwater lake currents and variable sedimentation rates and cores taken on the slope or platform would not provide the continuous record available on the horst, which remained underwater during lowstand periods. Coring sites on B1 and B2 are not possible due to their Precambrian basement composition.

Similar formations to the pre-rift strike-slip segmentation model exist in the northern basin. The Mahali Mountains, Kigoma and Ifume regions all provide evidence of strike-slip movement in comparison to the synrift strike-slip movement model. Comparison with the transfer faulting along a pre-rift basement grid can be seen on a larger scale; the East African rift valley as split into the Kenyan and Western branches.

Future Research

Seismic analysis of the region around lines 1 to 4 is needed to deduce sediment facies. This information will provide the data needed to determine the optimum coring location. Research to date the strike-slip movement of the Mahali Mountains would add to the interpretation of proposed models. An extensive bathymetric survey of the area between line P83.84 and P83.78, as well as the area north of line P83.78, would provide more information for interpretation of proposed models.

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References