Kigoma Bay bathymetry, sediment distribution, and acoustic mapping

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Introduction

Echosounding is a method commonly employed for determining the bathymetry of the bottom of water bodies. Acoustic energy transmitted into the lake is reflected back after striking the bottom, and the time it takes for the energy to reflect determines depth. However, all of the energy transmitted is not reflected at the sediment-water interface. Lower frequency waves are capable of deeper penetration into the sediments, returning acoustic data carrying information about the shallow subsurface sediments. A goal of this project was to determine the viability of correlating sedimentary facies data with the acoustic data characteristics of different facies types returned by an echosounder, and, if possible, to create a sedimentary facies distribution map of the study area. Other methods of determining sediment facies composition, such as grab-sampling, are time-consuming and provide very patchy data. Acoustic identification of basic sediment types allows for more rapid and continuous data on sediment type distribution.

Kigoma is located in a three-part bay on Lake Tanganyika (L.T.), a lake that has formed in a trough created by the rifting associated with the East African Rift Zone. The trough where L.T. formed is composed of a series of linked half-graben basins of alternating polarity. The steep-sided escarpments formed by the fault-bounded edge of the basin divert drainage away from the lake, while the ramped basin margins allow large, well-integrated drainage systems to develop (Cohen, 1990). This setting has created depositional environments ranging from river deltas and swamps depositing silts to steep-sided mountains mass wasting into the lake. Kigoma Bay is in a transition zone from a northern steep escarpment area to a southern platform with a broad river delta. The bay is a moderate-energy deposition zone somewhat protected by the jutting headlands that create the embayment.

Paleoclimatological investigations are being conducted using sediments from Kigoma Bay as well as from the Luiche Platform to the south. In addition to creating a bathymetric and sedimentary facies distribution map of Kigoma Bay, an important part of this survey was to provide the rest of the geological research team with the necessary background information, such as bathymetry and morphology, needed to plan sediment sampling transects and to analyze the samples collected. Data obtained from the sediment sampling was subsequently used for sediment/acoustic facies correlation.

Methods

Data was collected at two different sites: in Kigoma Bay and on the Luiche Platform. In Kigoma Bay, data collection was concentrated in the smaller Tafiri embayment. Several transects of continuously recorded bathymetric and acoustic information were taken. GPS points and depth were recorded by hand in a logbook and later entered into ArcView GIS, while acoustic shallow subsurface data was recorded continuously using a Lowrance LCX-17M Echosounder. All transects were east-west oriented in order to be most nearly orthogonal to the depth gradient. Initially, five east-west transects were taken in the Tafiri embayment, extending from the shoreline approximately 3 km into the lake. Two transects to the south and three more to the north were subsequently taken to expand the survey, resulting in a total of ten transects. The first five transects were re-recorded because they were recorded the first time using a different echosounder setting and thus were not consistent in appearance with subsequent recordings, nor did they extend over the shelf break. The re-recorded transects were taken as closely as possible to the first five, except extended over the shelf break. They were similar in appearance.
and character to the other transects, and were used for acoustic facies correlation. Grab-sampling and coring surveys were taken along transects EW3 and EW4. Grab-samples were taken at approximately 10 m depth intervals, starting at 5 m depth and ending around 105 m. The basic sedimentary facies type, GPS location, and acoustic facies (interpreted from echosounder data) were recorded for every grab-sample while in the field, and the samples were taken back to the lab for further analysis by the rest of the Geo team.

The Luiche Platform has previously been mapped bathymetrically and sedimentologically, so the goals of the Luiche Platform survey were slightly different. Rather than taking a grid of data points, only two transects of data were surveyed. Bathymetric and acoustic data were recorded for the two data lines, one of which was located north of the Rusizi River Delta, the other to the south. Both lines extended from shore to approximately 300 m water depth. They were oriented NE-SW in order to be orthogonal to the depth gradient. Grab samples were taken along both the northern and southern transects every 15 m until a depth of 100 m was reached. From there they were taken every 25 m to a depth of 250 m. Data was recorded using the same method for both the Luiche and Tafiri transects and grab-samples. All data were collected using the R/V Echo.

Results

Following data collection, I generated a bathymetric map at 5 m contour intervals of Tafiri Bay and its surroundings (Figure 1) using both the data that I collected and bathymetric data from the 2004 Nyanza Project survey (Wheeler, 2004). The continuous acoustic recordings were used for the interpretation of the morphological features shown in the bathymetry.

*Figure 2. Bathymetric map of Tafiri Bay and the surrounding area. Map also shows platforms and interpreted channel flow for sublacustrine channels.*

The acoustic recordings from the grab samples were then grouped together according to three main acoustic properties: the definition of the lake bottom, the quality of dark to light gradation with depth, and the depth to which the acoustic signal extended (acoustic basement penetration). This resulted in four basic acoustic facies types. A
fifth facies type was added for bedrock outcrops, which were not represented in the grab samples. Table 1 is the key used for assigning each bathymetric point on a transect line a facies classification. An acoustic facies distribution map was made by hand-contouring the point facies classifications.

<table>
<thead>
<tr>
<th>Acoustic Facies Types</th>
<th>Description</th>
<th>Appearance</th>
<th>Grab Samples</th>
<th>Mean Depth</th>
<th>typical Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A or 1</td>
<td>Sharply defined lake bottom Sharply defined short first echo Very deep acoustic basement</td>
<td><img src="image1" alt="Image" /></td>
<td>TB2, TB3, TB4, TB5, TB14, TB15, TB16, TB27, LP1-GB1, LP1-GB2, LP2, LP13, LP14, LP28</td>
<td>16.8m</td>
<td>coarse to med. sand, shell fragments common</td>
</tr>
<tr>
<td>B or 2</td>
<td>Sharply defined lake bottom Pronounced dark to light gradation of first echo Deep acoustic basement</td>
<td><img src="image2" alt="Image" /></td>
<td>TB6, TB17, TB18, TB19, TB20, TB21, TB26, LP15, LP16, LP24, LP25, LP26, LP27</td>
<td>47.0m</td>
<td>fine sands and silts</td>
</tr>
<tr>
<td>C or 3</td>
<td>Indistinct lake bottom Some dark to light gradation of first echo Shallow acoustic basement</td>
<td><img src="image3" alt="Image" /></td>
<td>TB25, TB7, TB8, TB9, TB10, TB11, TB13, TB24, LP11, LP12, LP17,</td>
<td>79.9m</td>
<td>silt</td>
</tr>
<tr>
<td>D or 4</td>
<td>Very indistinct lake bottom No stratification Shallow acoustic basement</td>
<td><img src="image4" alt="Image" /></td>
<td>TB12, TB22, TB23, LP3, LP4, LP5, LP6, LP7, LP8, LP9, LP18, LP20, LP21, LP22, LP23, LP19</td>
<td>139m</td>
<td>mud</td>
</tr>
<tr>
<td>E or 5</td>
<td>Sharply defined lake bottom Often has hyperbolic diffraction Steeply sloping features</td>
<td><img src="image5" alt="Image" /></td>
<td>N/A</td>
<td>N/A</td>
<td>bedrock</td>
</tr>
</tbody>
</table>

Table 1. The acoustic facies recorded for each grab-sample were classed solely according to their acoustic properties. Grab samples from both Tafiri Bay and Luiche Platform were used to create the classification scheme identified in this table.
Figure 3. Acoustic Facies Distribution Map of Tafiri Bay and the surrounding area. A to A’ is the west to east depth transect profiled in figure 4.

Figure 4. A depth profile of west to east transect 3, shown as A to A’ on Figure 3.
Discussion & Conclusion

Tafiri Bay shows great geomorphological variability across its area (see Figure 1). In the southern part the bay slopes for the most part consistently downward, with a steep escarpment from 30 m to 45 m, with a smaller outcrop occurring at 55 m and a large bedrock outcrop at 70 m depth. In the middle part of the bay, directly west of the Tafiri embayment, the downward slope is even, aside from one vertical escarpment from 25 to 45 m depth. In the northern part of the bay that is west of the largest harbor embayment, however, several large features interrupt the slope. Two peaks in the transect with ~20 m of relief, with the shallower point being at 16 m depth, are interpreted as sublacustrine extensions of Nondwa Point, which is directly to the north. West of the peaks there is an east-west symmetrical peak that rises abruptly from 60 m to a depth of only 20 m, then drops just as abruptly down to 85 m. The peak marks the beginning of a large channel which has a maximum depth of 210 m before rising again to 137 m. On the west side of the 137 m topographic high is the shelf break. From south to north the shelf break changes from evenly sloping and rounded, where there is no bedrock outcropping, to extremely steep escarpments with bedrock outcrops preceded by sags or deep channels.

After grouping the grab samples’ acoustic facies according to acoustic properties, other aspects of the grab samples were examined. Table 2 compares the basic sedimentary composition of the grab samples by facies type. There is a clear relationship between grain size and acoustic facies. For facies 1 coarse sand and shells are dominant, for facies 2 fine sand is dominant, for facies 3 silt is dominant, and for facies 4 silty ooze is dominant. Facies 5 has no corresponding grab samples.

<table>
<thead>
<tr>
<th>facies</th>
<th>c. sand/shells</th>
<th>m. sand</th>
<th>f. sand</th>
<th>silt</th>
<th>silty ooze</th>
<th>unsuccessful drop (possibly boulders)</th>
<th>total # of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>71.4%</td>
<td>14.3%</td>
<td></td>
<td></td>
<td>14.3%</td>
<td>7</td>
<td>7</td>
</tr>
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<td>2</td>
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<td>20%</td>
<td>60%</td>
<td></td>
<td></td>
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<td>4</td>
</tr>
<tr>
<td>3</td>
<td>62.5%</td>
<td>37.5%</td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>33.3%</td>
<td>66.7%</td>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Tafiri Bay grab samples grouped into facies by location using the generated sediment facies map.

Acoustic facies changes correlate excellently with large-scale grain size changes. Therefore, instead of being solely an acoustic facies map, Figure 1 is also a sedimentary lithofacies distribution map. Facies 1 consists of coarse-grained sediments, ranging from pebbles, shells and shell fragments to medium sands. Facies 2 ranges from coarse and medium sands to the predominant fine sands. Facies 3 and facies 4 have similar compositions, but in different proportions. The grab samples obtained in the facies 4 area have a higher percentage of flocculent and gelatinous muds and less silty particles. In light of this correlation, acoustic facies can be interpreted in terms of sediment lithofacies.

Sedimentary lithofacies distribution shows relationships with both bay morphology and water depth. In the northern part of the bay, where there is great geomorphological variability (see Figure 1), the sediment distribution deviates from the rest of the bay. Large topographic highs protecting the northern part of the bay may explain why finer sediment sizes are found closer to shore. An anomalous pocket of silts is found in water depths that are typical of silty oozes. The rest of the bay sediments are found on the shallower slope of a nearly 100 m deep sublacustrine channel. However, in the evenly sloping Tafiri embayment, sediment distribution closely follows the bathymetric contours.

Future Work & Recommendations

Acoustic facies mapping using an echosounder is a viable and successful method for continuous and rapid sediment distribution mapping. Acoustic facies showed a definitive relationship with the grain sizes and properties of physical sediment samples obtained from the same locations. Acoustic facies mapping was most successful when measured consistently. When different equipment settings were used on the echosounder, it was impossible to correlated between transects. Additionally, the acoustic facies obtained from the continuous transects showed better relationships between sediment type and acoustic facies than did the acoustic facies recorded while the boat was stopped for sampling.
In order to further verify the relationship between sediment lithofacies and acoustic facies, three predictive samples were taken. The three samples were taken after collecting bathymetric and acoustic transects in Tafiri Bay, and prediction was based upon shipboard acoustic facies observations. The samples were taken with the goal of sampling a different acoustic facies with each test. Despite using only shipboard observations (not analyzing acoustic recordings with the SonarViewer 1.2.2), all three sediment samples matched the predicted lithofacies type.

The continuous and rapid nature of echosounder mapping, especially as compared to the difficulty of obtaining physical samples, has implications for several disciplines. It generates a first-order geological map that gives insight to depositional and geological history of a site. Additionally, paleoclimatologists who use different types of climate proxies for their work have specific site requirements. Preliminary acoustic mapping of an area can provide the information needed for effective site selection. On a smaller scale, acoustic mapping provides data on substrate type that will be useful for biological surveys.

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References