Results of 1992 Seismic Reflection Experiment in Lake Baikal

PAGES 465, 469-470


Lake Baikal, at more than 600 km long and 1632 m deep, covers the central third of the Baikal Rift (Figure 1). It is the world's most voluminous lake, containing 20% of the world's surficial freshwater, and it is probably also the oldest lake, at >15 Ma. The Lake Baikal Rift occupies the boundary between the Precambrian Siberian craton and several microplates of south-central Asia [Zonenshain and Savostin, 1981] (Figure 1). Topics of current geoscience research in Lake Baikal include the nature and history of extension and subsidence in the region, deep lithospheric structure, the paleoclimate record of central Asia, and the history of sedimentation and water level fluctuation in the lake. Another topic of recent debate is whether the rift formed actively via mantle doming [Logatchev and Florensov, 1978], or passively as a result of distant plate interactions [e.g., Tapponnier and Molnar, 1979].

In August and September 1992, a joint Russian-U.S. team conducted an extensive multichannel seismic reflection (MCS) survey in Lake Baikal focusing on two structurally elevated regions of the Lake Baikal Rift. The Baikal Rift system of southern Siberia is often cited as one of the best examples of an active continental rift system. The data collected reveal considerable information on the extensional tectonics of the upper crust in the region and on the effects of tectonism on sedimentation during the accumulation of the rift's thick syn-rift fill. Primary objectives of the collaborative studies are to develop a detailed sequence stratigraphic framework and to augment and support paleoclimate studies and deep drilling efforts now underway in the lake [e.g., Lake Baikal Paleoclimate Project Members, 1992]. Here we present selected lines from the 2200 km of multichannel seismic reflection data acquired during the 1992 field program and highlight our initial results.

Recent Seismic-Reflection Investigations

Prior to 1989, the Lake Baikal Rift was examined through analog single-channel reflection studies of the upper sedimentary section [e.g., Nikolayev et al., 1985], analog Deep Sounding Seismic profiles, and refraction and seismicity studies [e.g., Krylov et al., 1981], and thermal, gravity, and magnetic studies [e.g., Zorin et al., 1989]. In 1989, the southern branch of the Shirshov Institute of Oceanology conducted a major field program, collecting more than 1500 km of...
of 6- and 12-fold multichannel seismic data, which were then jointly processed by U.S. Geological Survey and Russian scientists in 1990 and 1991 (Table 1). This survey, which consisted of sixteen widely spaced dip lines and a single strike line, revealed information on rift-wide structural and stratigraphic trends and provided images of the syn-rift depositional sequences down to the crystalline basement in many localities. The joint U.S. Russian interpretive effort of the 1989 data revealed that the three bathymetric basins of the lake are each underlain by separate sedimentary depocenters, and that a fourth small, thick sedimentary basin is present along the western edge of the Selenga Delta [Hutchinson et al., 1992a]. The resolution of the 1989 data was inadequate to permit a detailed analysis of the seismic sequence stratigraphy, but three acousto-stratigraphic units could be discerned based on relative differences in acoustic character and the stratigraphic extent of fault groups that internally deformed the basins. Each of these units has been tentatively correlated with a recognized phase of rift development [e.g., Logatchev and Florenzov, 1978]. The limited resolution of the 1989 data indicated that a broad-band seismic source and a longer-offset receiving array were required to adequately image details of the syn-rift structure and stratigraphy within the basin fill, particularly in the deeper parts of the basins [Hutchinson et al., 1992b].

The more comprehensive multichannel seismic survey was conducted in August and September 1992 with financial support from the U.S. Geological Survey, U.S. National Science Foundation, and the Russian Academy of Sciences. Details of the acquisition program are presented in Table 1.

**Initial Results**

The 1992 field program focused on two areas, the Selenga Delta and the Academician Ridge (Figure 1), whereas the previous MCS survey collected widely spaced regional lines along the length of the lake. We concentrated limited time and resources on these two areas of greatest complexity because they represent major tectonic boundaries most likely to reveal information about key rifting processes and critical events in the rift's history. Each is a region of transitional tectonics connecting two of the asymmetric basins that comprise the Lake Baikal rift (Figure 1); both are basement high of the type commonly referred to as accommodation zone or transfer zones [e.g., Rosendahl, 1987].

The 1992 MCS and wide-angle data provide considerable velocity information and indicate that an even thicker pile of syn-rift sediment may underlie Lake Baikal than had been estimated from the 1989 MCS data. In the north end of the Central basin, crystalline basement is observed at depths of 5-6 s on Line 92-44 (Figure 2). Interval velocities derived from stacking velocities and other refraction data were used to estimate sediment thicknesses, which on this profile reach a maximum of about 5 km. Maximum accumulations of sediment >8 km are found on Line 92-10A in the small basin west of the Selenga Delta (Figure 3) and may exceed 10 km in other parts of the Selenga Delta area and in the Central basin. Unlike the earlier MCS data, the 1992 data contain numerous continuous reflections throughout the syn-rift section.

The overall geometry observed on the 1992 data is that of a series of deeply sub-sided half-grabens or tilted full-grabens. The primary boundary faults in each basin are on the northwestern shore, and thus the syn-rift strata typically dip to the west or northwest. The geometry of the North basin stands in sharp contrast to that of the Central and South basins, however. The North basin is less subsided (that is, basement is at a maximum of about 2.6 s subbottom on the 1992 data), has a thinner syn-rift fill, and may not have been active during all of the rifting phases recognized in the Central and South basins. The main basin boundary faults within these basins have relatively steep dips, generally >65° (see Figure 2, Line 92-44); thus, the basin geometries may be incompatible with simple orthogonal extension [Etheridge et al., 1988]. These geometries and results of earlier modeling analyses [Balla et al., 1991] suggest that oblique extension has dominated much of the evolution of the Lake Baikal Rift. This is corroborated by analysis of seismicity in the northeast part of the rift [Doser, 1991].

**Selenga Delta**

The Selenga River is the largest source of freshwater and sediment to Lake Baikal, and its delta is the one of the most prominent features of the shoreline (Figure 1). Information from the upper 1 s of MCS data and from high-resolution seismic surveys (S. M. Colman, personal communication, 1993) indicates that relatively little material is deposited off the central delta front; rather, most riverine sediment is channeled through fault-controlled canyons into the basins to the northeast and southwest sides of the delta. This is manifested on the MCS data as regions of pronounced surficial channeling and slumping (Figure 3). In general, the thick deposits forming the delta are well imaged in the MCS data and clearly show intra-basinal faults, unconformities, stratal relationships, and strong basement reflections. Locally, the quality of the deeper seismic data diminishes in regions of the deeply incised channels and downslope from the channelized area, where there is mass wasting and turbidity current activity.

Data from the 1989 program indicated that the bathymetric saddle in front of the Selenga Delta is a result of a pronounced basement high between the South and Central basins, rather than deltaic accumulation [Hutchinson et al., 1992a]. The 1989 data imaged the delta along a strike line; the de-
Table 1. Acquisition Parameters

<table>
<thead>
<tr>
<th>1989 Survey</th>
<th>1992 Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seismic Source</strong></td>
<td>Tuned array of 10 Sleeve guns, total volume = 1665 l (27.31 litres). Fired on time. Two 60 litre guns for wide-angle lines.</td>
</tr>
<tr>
<td><strong>Hydrophone Streamer</strong></td>
<td>2400 m long active section, 2870 m total offset, 25 m groups, 96 channel, dynamic streamer control system</td>
</tr>
<tr>
<td>** Acquisition System**</td>
<td>Russian Institute of Oceanology system</td>
</tr>
<tr>
<td><strong>Data Coverage</strong></td>
<td>2200 km total MCS coverage; 24-Fold, except on selected Selenga delta lines which were 12-Fold. Profiles concentrated near accommodation zones.</td>
</tr>
<tr>
<td><strong>Navigation</strong></td>
<td>Radar, Dead Reckoning</td>
</tr>
<tr>
<td><strong>Quality Control</strong></td>
<td>Demux and record section display on MASSCOMP computers using SIOSEIS software</td>
</tr>
<tr>
<td><strong>Wide-Angle Data</strong></td>
<td>Four wide-angle reflection lines using a maximum of six USGS Ocean Bottom Seismometers</td>
</tr>
<tr>
<td><strong>Magnetometer</strong></td>
<td>Towed magnetometer</td>
</tr>
<tr>
<td><strong>Participating Institutions in Field Program</strong></td>
<td>Southern Branch, Shirshov Institute of Oceanology (Gelendzhik, Russia); Institute of Limnology (Irkutsk, Russia); USGS - Branch of Atlantic Marine Geology (Woods Hole, Mass.); Duke University (Beaufort, N.C.)</td>
</tr>
</tbody>
</table>

*Kitgord et al., 1993; Nichols et al., 1992; Ten Brink et al., 1993*

**Academician Ridge**

Academician Ridge is a major physiographic and tectonic feature of the Baikal Rift that separates the Central and North basins of Lake Baikal (Figure 1). In part a submerged extension of Ol'khon Island, it also separates a zone of concentrated oblique extension and deep subsidence in the Central basin from a region of more limited subsidence and possibly more diffuse extension across the lake's North basin and the Barguzin basin to the east (Figure 1). Profiles across the Academician Ridge and into the basins on either side show a much thicker sedimentary section on the Central basin side of ridge. The sedimentary section in the Central basin has been severely deformed by a series of intraslabal faults (Figure 2).

Subsidence patterns and boundary fault activity in the Central basin have changed markedly over time. For instance, the lowermost sediments tend to thicken to the northwest, whereas most of the upper section thickens toward the southeast. Yet the very upper 100-200 ms of sediment appear to thicken again to the northwest. These alternating depocenters indicate that subsidence and extension have not remained concentrated along the main border fault in this basin but instead have shifted from one side of the basin to the other. Onshore studies in the Ol'khon region of the border fault identified a similar shift in deformation to the northwest during the most recent rifting phase. Based on similarity of acoustic character alone, the MCS data suggest that the thickest section of young sediments is in the North basin, and thus most recent subsidence is focused on the northwestern side of that basin. However, recent seismicity tends to be concentrated on the southeastern side of the Central basin (Doser, 1991).

Several pronounced unconformities are recognized in the profile on top of Academician Ridge (Figures 2 and 5), and the lower sequences thin considerably toward the center of the North basin. The depositional sequences bounded by those unconformities have variable thicknesses and distributed depocenters on top of the ridge. This distribution and the complicated fault pattern (Figure 5) reflect the complex history of relative uplift of this large basement high. These unconformities and depositional sequences define at least three depositional phases in the Central basin but only two phases in the North basin. Figure 5 shows some of the details of this anomalous sediment accumulation as well as the significant improvement in seismic resolution in the 1992 data compared to the earlier survey.

**Discussion**

In February 1989, a drilling barge operated by the Russian deep drilling program NEDRA was frozen into the ice about 6 km offshore from the Buguldeika delta (Figure 1). Using Advanced Piston Corer technology adapted from the Ocean Drilling Program, the Baikal Drilling Project completed two 100 m boreholes and recovered nearly 175 m of core as of late March 1993. This is the site of the first of several drill holes that will be used to reconstruct the paleoclimatoge of central Asia during the late Cenozoic (Lake Baikal Paleoclimate Project Members, 1992). The site chosen is within 1 km of the north-east side of Line 92-16 (Figure 4). Both MCS and high-resolution seismic records (S. M. Colman, personal communication, 1993) show a laterally homogeneous section of high-amplitude, continuous reflections in...
conclusion

the Lake Baikal part of the Baikal Rift is composed of three asymmetric basins (South, Central, North) that all have their respective basin-bounding faults on the northern side of the rift, and a smaller basin (Selenga) that may be an arm of the South basin. The three major basins are separated by two basement highs commonly referred to as accommodation zones or transfer zones. The basement high underlying the Selenga Delta is a complex amalgamation of faulted basement blocks. Initial interpretations suggest that the syn-rift fill in the basins may be as much as 10 km thick in some localities. The North basin is less deeply subsided, contains a thinner sediment fill, and is probably younger than the Central and South basins. The cross-sectional geometry of the North basin shows the most resemblance to a typical half-graben. The data indicate that all three basins have been modified by oblique-slip tectonics, although extension directions may have varied considerably during the rift's development. Several well-developed unconformities, defined by both erosional surfaces and onlap surfaces, are seen in several localities and at various stratigraphic levels within the sedimentary section. The acoustic stratigraphy is further complicated by a BSR in many areas where water depths exceed 700 m. Detailed structural and seismic-stratigraphic sequence analyses tied to "ground-truth" studies of drill core material and outcropping lacustrine sediments may reveal to what extent the observed unconformities formed as a result of tectonic activity, and also how sedimentation patterns have varied due to past climatic variations.

Acknowledgments

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References

Doser, D. I., Faulting within the eastern Baikal rift as characterized by earthquake studies, Tectonophysics, 196, 109, 1991.
NSF to Receive 10% Funding Increase

PAGE 465

Work is almost complete on the fiscal year 1994 funding bill for the National Science Foundation. On October 1, Conference Committee Chairs Louis Stokes (D-Ohio) and Barbara Mikulski (D-Md.) and their colleagues completed work on the final version of HR2491, the VA, HUD, Independent Agencies Appropriations Bill. The House and Senate will soon give their final approval to the conference report for HR2491, after which it will lack only the president’s signature. NSF’s overall budget increase of 10%, raising total funding to $3,005.3 million, is the highest increase among all departments and agencies. Last year’s increase in NSF funding was 6.3%.

Funding for research and related activities will increase 7% to $1,986 million, a compromise between the 10% House increase and the 4% Senate figure. Last year’s bill cut research funding. Education and human resources funding will increase 17% to $560.6 million. This is $13.5 million above the Clinton administration’s request. Last year’s increase for education and human resources was 4.7%.

Perhaps responding to the ever-growing backlog of modernization needs, House and Senate conferees attempted to allocate for academic research facilities and instrumentation by 100% to $100 million, $45 million over the administration’s request.—Richard M. Jones, American Institute of Physics

Passage Delayed by ASRM Inclusion

PAGE 465

In a late development that will delay but is not expected to seriously affect the NSF funding portion of the appropriations bill, the full House returned the bill to the House-Senate conference on October 6, refusing to debate the bill because it includes $158 million to fund the shuttle’s planned Advanced Solid Rocket Motor (ASRM) project. The House had voted in June to kill this project, but the Senate voted to continue it. The conferees attempted a compromise, involving minimal funding for the ASRM, but the House rejected this attempt. Although some say the ASRM is needed for missions in the 1990s, others say it is not expected to seriously affect the NSF budget. This year’s increase in NSF funding was 6.3%.

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Environmental Change Profiled in Greenland Ice Core Record

PAGES 465-466

The longest continuous high-resolution record of climate response available in the Northern Hemisphere, covering approximately 250,000 years, is the focus of Union sessions U31D, U32C, and U41B, "Climate from Central Greenland Core Records 1, II, and III." This climate record has been provided by the Greenland Ice Sheet Project 2 (GISP2), which successfully reached bedrock on July 1, and its European-led counterpart, the Greenland Ice Project (GRIP). Presentations will focus on information obtained from analyses of the over 3,000-m-deep ice core samples retrieved by both projects.

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