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Seismic Survey of Lake Baikal, Siberia
Cruise Report: RV Balkhash
25 August to 25 September 1992

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Introduction

A comprehensive multichannel seismic-reflection (MCS) and ocean bottom seismometer (OBS) seismic-refraction survey of Lake Baikal, Siberia (Figure 1; Plate 1) was undertaken during August-September 1992 as a collaborative research project by U.S. and Russian scientists (Table 1). This project was supported by funding from the U.S. Geological Survey, the U.S. National Science Foundation and the Russian Academy of Sciences. Over 2200 km of multichannel seismic-reflection data on 42 profiles and over 500 km of seismic-refraction data on 4 OBS profiles were acquired during this study. On board seismic processing facilities were utilized for quality control and demultiplexing of seismic data during the cruise. Lost survey time due to weather was about 7 days, but most planned seismic profiling was completed, including the reshooting of profiles where necessary. This seismic study was carried out on two vessels, the RV BALKHASH for MCS work and the TITOV for OBS deployments. This report summarizes the general seismic program and the operations on the BALKHASH. Operations on the TITOV are summarized in a companion report by tenBrink and others (1993). A detailed description of the logistical and technical aspects of the seismic program, including all seismic systems, is given in the companion report by Nichols and others (1993).

Geologic Setting

The Baikal Rift in western Siberia is one of the most active continental rifts on Earth, extending over 1800 km along the active tectonic boundary between the Siberian craton and a mosaic of continental fragments of southeastern Asia (Logatchev and Florensov, 1978; Tapponnier and Molnar, 1979; Zonenshain and Savostin, 1981). Lake Baikal overlies the central part of this rift system where the largest synrift sedimentary basins have developed (Figure 2).

Lake Baikal is the world's deepest lake and largest fresh water body, containing nearly 20% of the world's surficial fresh water supply. Lake level is 455.6m above sea level and the deepest part of the lake, in the central basin, is at a depth of 1637m (although our echo sounder reads 1702m at deepest point) below lake level. Its location in the center of the Asian continent, high latitude and thick sedimentary deposits make it potentially one of the most important sources of information on climate change since the Miocene and possible even since the Oligocene. Besides complementing the marine records and lower latitude records of paleoclimate found elsewhere in the world, its isolation and unusually thick sedimentary section make it a high resolution calibration site for continental climate records.

Lake Baikal is characterized by three major bathymetric basins separated by large structural highs (Figure 2). The southern and central basins are separated by the Selenga Delta, a large sedimentary structure which overlies a series of cross-rift and rift-parallel basement highs. The central and northern basins are separated by the Academichesky Ridge, an elongate ridge of crystalline basement and sedimentary rock which is the northeast prolongation of Ol'khon Island. Sedimentary fill exceeds 7000m in the central basin and in a narrow basin just west of the Selenga Delta, the Selenga Basin. At least 7000m of synrift sediments fill the southern basin and over 4000m of sediments fill the northern basin (Hutchinson and others, 1992). Age of these synrift sedimentary rocks is estimated to range from Oligocene to present, with the thickest sections being of Pliocene and younger age (e.g. Logatchev and Zorin, 1987). These age constraints are inferred from sedimentary units that rim the basins (Nikolayev and others, 1985; Mats, in press). There are no actual age data for the deeper synrift sedimentary units in these rift basins.

The two major barriers in Lake Baikal, Selenga Delta and Academichesky Ridge, are astride transition zones between regions of different deformation patterns in the rift. The Selenga Delta is the largest surficial sedimentary feature at Lake Baikal. Depositional patterns (e.g. seismic facies and stratigraphic sequences) within a delta developing over an active tectonic zone have provided essential information at other rift systems on the interplay between structural evolution and paleoenvironment fluctuations (Scholz and Rosendahl, 1990). Selenga Delta overlies the transition from strike-slip dominated deformation to the southwest and more dip-slip faulting in the central Baikal region (Zonenshain and Savostin, 1981; Balla and others, 1990; Doser, 1991a,b). An east-west trending bathymetric and structural ridge, which shoals to the east, forms the southern edge of the delta. Posol'skiy Bank tops the eastern end of this ridge where a steep, east-facing fault exposes Miocene and younger sedimentary rock (Hutchinson and others, 1992). The northern edge of the delta appears to overlie a series of northeast-trending structures. These ridges are sites of active neotectonic activity, characterized by both numerous earthquakes and recent faulting. Proval Bay on the northern edge of the Selenga Delta formed during the large earthquake of 1862 and Posoljsky Gulf on the south side of Sarma Delta earlier originated in the same way (Solonenko, 1978; Golonetsky and Misharina, 1978). The sediment bar along the western edge of Proval Bay appears to overlie one of these ridges, which continues northeast along the coast. Thus, the sediment distribution on the east side of the lake is controlled to a significant extent by ongoing deformation within the underlying crust.

The Academichesky Ridge marks the boundary between more focused deformation to the south and a more distributed region of deformation which includes the north Baikal Basin and the Barguzin Basin to the east (Tapponnier and Molnar, 1979). This broadening of the zone of deformation is accomplished partially by the splaying of the main western border fault, the Obruchevskiy Fault, into the Primorskiy and Morskiy Faults separated by the Ol'khon block which includes Ol'khon Peninsula, Ol'khon Island and Academichesky Ridge (Agar and Klitgord, in press). The Primorskiy Fault separates the Ol'khon block from the Siberian Craton and merges with the Baikalskiy Fault to form the main western border fault of the north Baikal basin. The northward thickening sediment fill on the western edge of the Ol'khon block and in the north Baikal basin records the changing character of this northern barrier as it deforms in response to the broadening rift. The elevated eastern edge of the Ol'khon block coincides with the Morskiy Fault, the western border fault of the central Baikal basin. This fault continues northeast past the east side of Ushkanji Island and merges into a series of small faults along the shoaling (east) side of the north Baikal basin on the Barguzin coast. A zone of intense faulting characterizes the synrift sediment fill in the eastern half of the central Baikal basin (Hutchinson and others, 1992). This part of the central Baikal basin projects northward to the east of Svyatoy Nos Peninsula where it merges into the Barguzin Basin to the east.

Scientific Objectives

This seismic survey of Lake Baikal had two basic objectives: (1) to investigate the character, timing and distribution of sedimentation and crustal deformation in an active lacustrine rift system and (2) to construct a detailed seismic-stratigraphic framework for these basins, ultimately to be used for site selection of a deep drill hole in Lake Baikal. Such a framework is critical for evaluating lengthy high-resolution paleoclimate records from drill core samples and well log data. Previous multichannel seismic-reflection profiling in Lake Baikal during 1989 (Hutchinson and others, 1992) had revealed the general character of the interaction between evolving structural features in the rift architecture and sedimentation patterns. This information enabled us to focus these present studies on the regions which contain the best (most comprehendible?) records of crustal deformation processes and sedimentation within the rift and the paleoclimate history of the rift. To accomplish these objectives, the surveys were focused on two regions, the Selenga Delta (Figure 3) and the Academichesky Ridge (Figure 4).

Selenga Delta Survey

The seismic-reflection survey of the Selenga Delta region (Figure 3) focused on acquiring a grid of profiles for elucidating the seismic stratigraphy and depositional architecture of the delta and changes in deposition patterns between the south and central Baikal basins. The resulting understanding of shifting depositional pathways and variability in acoustic character should enable us to investigate the interplay between crustal deformation and sedimentation. The Selenga Delta region is the primary site for a future deep stratigraphic test drill hole for paleoclimate studies. A series of 100m cores are planned over the next few years as a precursor to the major drilling project. Grids of seismic profiles over Posol'skiy Bank, the ridges along the north edge of Selenga Delta and the saddle between Selenga Delta and

Bugul'deika at the southern edge of Ol'khon Peninsula enable us to identify potential targets of stratigraphic significance for these 100m holes. The OBS line planned for the delta region had to be canceled because of mechanical problems on the TITOV during the final days of our survey program.

Academichesky Ridge Survey

The seismic-reflection survey of the Academichesky Ridge region focused on the depositional and deformational history of the central Baikal basin, and the changing patterns of sedimentation across and along Academichesky Ridge. The 1989 MCS data had indicated that a major phase of deformation was focused along the eastern side of the central Baikal basin, extending northward into the rift zone of the Barguzin Basin. A detailed grid of seismic data was acquired to image this transition zone between the central Baikal and Barguzin Basins, elucidating the character and perhaps timing of this structural link between two rift basins, one offshore and one onshore. The character of the fault pattern in this transition between the two basins should enable us to evaluate the significance of strike-slip vs dip-slip faulting in the rift system's evolution. Similarly, the grid over the north end of the Ol'khon block, Academichesky Ridge, should provide essential stratigraphic and structural control for understanding the deformation and sedimentation history of a fragmenting hangingwall block in the transition zone between the central and northern Baikal basins. Bathymetric and seismic data had indicated that is was probably not possible to acquire an unbroken stratigraphic link between these two basins, but the distinctive acoustic character of several of the depositional sequences in the fill of both rift basins provides promise for establishing reasonable stratigraphic ties. Truncated stratigraphic units on the eastern edge of Academichesky Ridge, eastern edge of both central and northern Baikal basins and thin depositional units on the west side of Academichesky Ridge provide numerous targets for 100m drill hole sampling. The relatively simple gross basement structure of the region and broad, deep sedimentary basins make this region the best zone for studying the deeper crustal structure of the rift. OBS profiles were located along strike in the central Baikal basin and the north Baikal basin and across strike of Academichesky Ridge and these two basins.

Field Systems and Field Operations

Personnel and equipment for the seismic survey were provided by the U.S. Geological Survey, Duke University and Southern Branch of the Institute of Oceanology. Detailed operational report is given in Nichols and others (1993). Operational responsibilities were divided between the U.S. and Russian teams, with the Russians responsible for the airgun and streamer and with the U.S. team responsible for the data acquisition, data processing and navigation systems, although both Russian and U.S. personnel participated in all of the operations. A ten-gun airgun array and streamer depth-control bird system were leased by USGS, NSF and the Institute of Oceanology from a Russian company in Gelendzhik. This gear, two compressors, a modified 96-channel seismic streamer, and backup seismic acquisition system were transported to Lake Baikal by the Russian team. Three 8'x8'x20' containers with electronic equipment, compressor and generator, and field supplies were shipped from USGS Woods Hole for this program. This shipment included a DFS-V seismic-acquisition system, 8

OBS systems, 2 MASSCOMP computers for tape DEMUX and initial data processing and a complete GPS navigation system. Sixteen hundred 1/2" x 2400', 6250 BPI magnetic tapes were shipped for data logging and DEMUX data. The original field tapes were air-freighted back to the U.S. and DEMUX tapes were sent to Gelendzhik. A more complete set of DEMUX tapes was generated after the cruise at the USGS seismic processing facility in Denver, Colorado. In addition to miscellaneous supplies, a large supply of food stores were shipped to augment the Russian food stuffs on the ship. Last year's smaller survey had shown that considerable time was lost trying to keep the ship supplied with adequate food for even a two-week cruise.

Ships:

The multichannel seismic operations were undertaken aboard the vessel RV BALKHASH. The vessel is one of four ships of this class operating on Lake Baikal. It has a length of 46m, beam of 9.6m, draught of 3.3m and a displacement of 480 tonnes. Maximum cruising speed is 12.8 knots. During the MCS and OBS surveys, the average speed was 4.0 to 4.4 knots. It carries a crew of 6 and a complement of up to 20 scientists. For this MCS survey, a team of 25 Russian and American scientists was squeezed aboard the vessel. Some limitations of the vessel were related to weather state. Because of the large amount of gear mounted on the deck of the ship, it was only certified for work in weather with winds less than 20m/sec (40 knots) and seas less than 2 meters. Other restrictions included the need to come into port every ten days for the crew although this was somewhat flexible.

The ocean-bottom seismometers (OBS's) were deployed and recovered with the vessel TITOV. This is a smaller class vessel than the BALKHASH, with a length of 25m, beam of 6m, draught of 2.5m and a displacement of 120 tonnes. Its cruising speed is about 10 knots. The ship had enough space for 5 scientists uncomfortably. It carries a crew of seven. It was just refitted for this seismic work and a wooden hut was built on its center deck for OBS electronic work. The OBS spheres were too large to be taken below to the small lab room on the ship. The 8 OBS's took up all available space on the deck. The Titov proved to be an inadequate vessel on this lake for OBS work because of its inability to hold station while recovering instruments in anything but moderately good weather. With great effort, the team on the Titov successfully deployed and recovered seven complete OBS lines (with 5 to 7 instruments each line), even though the Balkhash was only able to shoot along five of these lines because of weather limitations.

Communications:

Communications between the two ships were a constant problem. Use of the ship's HF radio produced severe EM noise on the ship and disrupted navigation, firing and recording systems. Thus, use of this radio was limited. A shorter range ship's radio was adequate when the ships were within a range of less than 100km. For line of sight communication, hand-held VHF radios were used. Communication between bridge and lab on the Balkhash was via the same VHF FM radios.

Multichannel Seismic-Reflection System:

The three components of the multichannel seismic (MCS) system, source, receiver and recorder, were brought as self-contained units to Baikal. Basic MCS operations were conducted in a 8'8'20' dog house brought from Gelendzhik and mounted on the fan tail of the Balkhash. Stable electrical power for these systems was provided by a 3.5kw UPS converter/transformer power system linked to the ship's main power supply and a 7kw diesel-powered generator shipped from Woods Hole. Detailed descriptions of these systems are given in the companion report by Nichols and others (1993) and only a brief outline is provided here.

Seismic Sources:

Energy source for the seismic reflection profiling was a tuned airgun array of ten airguns (Figure 5). Total volume of the array was 1665 cu.in (27.3 liters). The airguns were sleeve-type guns built in Russia and divided into 3 clusters towed from two points, port and starboard, on the fan tail. The port array was a cluster of four 213 cu.in. (3.5 liters) airguns towed in series with 1.3m, 1.5m and 1.3m spacing between guns. The starboard array was two clusters separated by 3 meters, also towed in series. The first cluster consisted of a 152 cu.in. (2.4 liters) and then two 213 cu.in. (3.5 liters) guns separated by 1.5m and 1.3m followed by three 79 cu.in. (1.3 liters) guns separated by 1.5m each in the second cluster. Center of each of these arrays was approximately 25m behind the ship. Shot spacing for the MCS profiling was by time, with the time spacing adjusted to give a distance spacing of approximately 50m. At a speed of 4.0 kts to 4.4 kts this required a firing interval of 25 to 23 seconds. At this firing rate the pressure in the airgun array remained around 1900 psi.

Energy source for the seismic-refraction profiling was an untuned array of two 60 liter airguns (total 7320 cu.in.). These guns were fired at a two minute interval during the OBS lines. The three compressors were not able to keep full pressure on the guns and the pressure varied from 1600psi to 1700psi for most of these lines.

Air pressure for the airgun system was provided by 3 compressors mounted on the bow of the ship. A 178 CFM (37 liter/min at 2000 psi) Price Model A-35AC compressor was brought from the U.S. in one of the containers. This compressor is a 4-stage unit producing 2000psi. The compressor is diesel engine driven and has a self-contained cooling system. The two Russian compressors each produced 12 liters/min at 2000 psi. These three compressors were capable of maintaining approximately 1900 psi for the airgun array firing at a 23 to 25 second rep rate. This firing rate was necessary to maintain a 50m shot spacing with ship speeds varying from 3.9 kts to 4.4 kts. The guns were generally towed at a depth of 6 meters.

Seismic Receiver:

The seismic streamer was a 96-channel array with 25m groups. The array was constructed at the Southern Branch of the Institute of Oceanology with Russian hydrophones, a German wiring system and covered with a Dutch made plastic jacket. The physical sections were in 100m lengths with four 25m groups each. This 2400m active streamer was proceeded by a 400m inactive lead-in section, providing a total maximum offset of 2870m between the center of the airgun array to the center of the far channel. This offset, however, changed on occasion as noted in the observer logs. During a set of short lines on the north side of the Selenga Delta, only 48 channels were used and the streamer was 1200m shorter. Pressure depth sensor and bird control units were placed forward of the tail buoy before sections 1, 5, 9, 13,17, 21, and 25 (between channels 0/1, 16/17, 32/33, 48/49, 64/65, 80/81 and after 96) and depth sensors and compass units were placed before sections 3, 7, 15 and 23 (between channels 8/9, 24/25, 56/57 and 88/89) from tail buoy. In general, the streamer was kept in the depth range of 7 to 12 m.

Seismic Acquisition Recording System:

Seismic data from the 96-channel seismic array was recorded on 1600 BPI 1/2" magnetic tape with a DFS-V seismic acquisition system. Sample rate was 4 milliseconds and record lengths were 7 to 9 seconds depending on sediment thicknesses. The north Baikal basin lines were shot with 7 second records and the rest of the lines were shot with 9 second records. On the OBS line 5 coincident with MCS line 92-17, the large volume airguns and streamer were used simultaneously, and data were shot at 2 minute rate and recorded for 16 seconds. A summary of record lengths is given in Table 2.

Seismic Processing System:

Part of the agreement with our Russian colleagues on the acquisition program pertained to the use of the USGS DFS-V recording system over the Russian system owned and brought to Baikal by the Southern Branch of the Institute of Oceanology. Noise problems prevented simultaneous recording by both systems, and since the Russian system records at only 800 BPI, it was agreed that we would use the DFS-V for data acquisition during the entire cruise. In this case, the US team agreed to provide demultiplexed tapes of recorded data to the Russian team. Demultiplexing was completed on one USGS Masscomp computer, then dumped via ethernet to another Masscomp computer, which was used for writing SEG-Y tapes and plotting data for quality control. Because of the limited disk space available (particularly on the demultiplexing computer), it generally took about 2.5 hours to read in and demux, transfer, and write out and plot one SEG-B field tape. At the end of the cruise, about 65% of all the lines had been demuxed and written in SEG-Y format for the Russians (see Table 2 for summary of which lines have been demuxed). A team of 3 people stood watches and kept up 24 hour a day demultiplexing during the entire cruise and during mid-cruise port calls. Because of the cumbersome demux process and severe limitation on disk space, no in-cruise processing was attempted, except to produce raw shot-gather and common offset plots.

The SEGB 9-track field tapes were demultiplexed (DEMUX) and copied in SEGY format to 1600 BPI 9-track tape. Field tapes were demultiplexed on a MASSCOMP 5500 using software written by K. Roy-Chowdhury (Princeton University) and modified by T. O'Brien (USGS); SEGY files were written to hard disk. The two common types of software errors occurred during the demultiplex process were (1) non-SEGB code and (2) sync errors. When non-SEGB code errors occurred, we usually were able to reprocess without an error at the same shot file. When sync errors occurred, the data could not be processed beyond the bad shot file, because the software was unable to skip bad files and process the remaining files. As a quality control, when sync errors occurred, we counted the number bytes in each record on the field tape. Tapes with non-SEGB code errors usually had too many bytes/shot record, and tapes with sync errors usually had too few bytes/shot record. Most of the field tapes with sync errors were found to have only a few bad shot files. We extracted single-channel files (near-trace, mid-trace, and far-trace) from each demultiplexed file. Single-channel files and Demultiplexed files were copied via Ethernet to hard disk on a MASSCOMP 6000. From there, the SEGY data was copied to 9-track tape and plotted using SIOSEIS seismic data processing software written by P. Henkart. All of the data that were demultiplexed, approximately two-thirds of the data that were acquired, was copied to 9-track tape for the Russian scientists. Each field tape that was processed resulted in about 1.7 tapes of SEGY data. We usually plotted shot gathers for each field tape for quality control and the near-trace (channel 95 or 96) profiles for each seismic line, as well as some mid-trace and far-trace plots. These single-channel files were copied to 8-mm tape.

Navigation System:

Navigation on the Balkhash was based on an Ashtech GPS Receiver Model XII and the Titov navigation was based on a Magellan PRO-1000 receiver. A standard Ashtech nongeodetic antenna was located on the top of the mast above the bridge at the end of the port cross tree. This location put it 28.5m forward of the stern of the ship. Navigation data were sent every 10 seconds via an RS-232 port to an IBM-PC AT computer. Navigation software was developed by USGS Woods Hole and provided the ability to enter way points, navigate real time along a given track and display results, including distance off track and along track, etc. Navigation was set up on the bridge, near the only chart table on the ship. A remote screen was used by the helmsman for steering the ship. Shot instant information was initiated via a hydrophone in the gun array and transmitted as a 5-volt pulse to the navigation lab and recorded on the Ashtech receiver during MCS and OBS lines. Shot point numbers and times were calibrated and logged in navigation every 15 minutes, with final shout point navigation interpolated between these 15 minute calibration points.

Magnetometer system:

A marine proton precession magnetometer (MPM5M) was used on all profiles. It is a toroidal sensor and uses Oktan or similar hydrocarbon fluid for the working fluid. Sensitivity of the magnetometer was 0.1 nT. Working range of the sensor was 20,000 to 70,000 Nt. The system has a variable sampling rate of 1, 3, 5, 10, 20 and 60 seconds. A sampling rate of 10 seconds was used on this cruise. The instrument was towed 150 meters behind the ship. Data was digitally recorded on an IBM PC-AT compatible computer. The system was designed and built by Dr. Ivan I. Belyaev at the Institute of Oceanology, Russian Academy of Sciences, Moscow. It can be used as part of a gradiometer system is desired.

Cruise Log:

The Balkhash departed Lystvyanka at 1600h on 25 August 1992. Shortly after departing port, the multichannel seismic gear was deployed and tested before commencing survey work. The survey started on the south side of Selenga Delta and its overlap with the south Baikal basin. The MCS lines were labelled as even numbers for northwest-trending dip lines and odd numbers for northeast trending strike lines. A summary of each of these lines is given in Table 2, including start and end times and positions, length of line, field tape numbers, etc. The MCS survey was interrupted to undertake OBS lines at points that minimized the time lost from the MCS profiling. The change of source airguns required about 6 hours, so we attempted to minimize the number of changes by shooting short lines OBS 2 and OBS 1A with the smaller MCS airgun array. Besides these changes in source, the other breaks in our survey were caused by a need for the Balkhash to be back in Lystvyanka on 3 September and about 6 days of bad weather including a snow storm at beginning of September. The schedule of seismic profiling was as follows:

25 Aug	--1600h depart Lystvyanka
25 Aug to 1 Sept	-- MCS profiling - Selenga Delta
	MCS lines 92-02, 92-04, 92-06, 92-08, 92-10,
	92-26, 92-28, 92-30, 92-01, 92-03, 92-07,92-09
	• short streamer
	92-12, 92-14, 92-16, 92-18, 92-20, 92-22,92-24
1 Sept to 2 Sept	-- ship business - Peschanaya Bay
2 Sept to 5 Sept	-- ship business and weather delay - Lystvyanka
5 Sept to 7 Sept	-- weather delay - Peschanaya Bay
8 Sept to 10 Sept	-- OBS line 1 w/big guns along MCS 92-13 and 89-15
10 Sept to 13 Sept	-- MCS Profiling-Academichesky Ridge-Central Basin
	MCS lines 92-38, 92-40, 92-42, 92-44, 92-46,
	92-48, 92-50, 92-21, 92-23
	OBS line 2 along MCS line 92-46
14 Sept	-- Weather delay - northeast side Ol'khon Island
15 Sept to 16 Sept	-- MCS profiling - Academichesky Ridge-north basin
	MCS line 92-17 along OBS line 4
17 Sept to 17 Sept	-- OBS line 4 w/big guns & streamer - north basin
18 Sept to 19 Sept	-- MCS profiling - Academichesky Ridge- north basin
	MCS lines 92-15, 92-54, 92-56, 92-58, 92-60
20 Sept	-- Weather delay and ship business - Barguzin Bay
21 Sept to 24 Sept	-- MCS profiling - central basin - Selenga Delta
	MCS lines 92-11, 92-13, 92-19, 92-23, 92-25,
	92-32, 92-34, 92-36, 92-52
	OBS line 1A along MCS line 92-13
24 Sept	-- 1000h streamer work & final equipment shut down
25 Sept	-- end of cruise - Lystvyanka

Quality Control Summary

The following is a summary of the quirks, noise problems, and/or data gaps associated with the lines collected during this cruise. In general, data quality was quite good to excellent, but problems did arise during various stages of acquisition. In most cases these were a consequence of equipment performance, and/or the matching (or mismatching) of Russian and American components. On occasion communication difficulties between Russian and American watchstanders produced other problems in coordinating navigation and the recording lab. This situation was most evident at the start of the survey but in general sorted itself out quickly.

Some gaps in data due to missed shots are found on most lines during the first half of the cruise. In many cases this was on account of bad tape. The 3M 777 tapes varied in width, in some cases had BOT markers on the wrong side of the tape, and in one case had continuous perforations down the center of the tape. Transport #1 of the DFS-V had numerous problems (mainly a bad head), therefore we stopped using this transport during the second half of the survey. The last third of the data acquisition was completed using Transport #2 alone and 3M 700 "BLACKWATCH" tape. During demultiplexing some tape errors were overcome, but the software in hand could not cope with sync errors. When these were encountered, there was simply no way to read past that part of the field tape, thus there are gaps (up to 100+ shots in length) in our near-trace plots in those localities. We were usually able to identify only 1-3 bad shots associated with each sync error. These errors are better handled during the onshore processing at USGS-Denver where more sophisticated software is available. The lines are grouped together and are discussed in the order in which they were acquired.

lines 92-01, 02, 04 (all 24-fold)

channels 2 dead, 68, 71, 89 weak, but signal evident after gain applied. Occasional random noise spikes due to poor connection on one analog fm board on dfs-v. First neartrace plots after demux indicate t-0 offset from field tape to field tape, suggesting that ramp-up time on the two dfs-v transports is not the same. Also, outgoing pulse generally not seen on neartrace and near channels, indicating that gun has been fired some amount of time prior to the ramp up of tape transport, and the start of recording. See neartrace plot for these lines and note 3-5 ms shift every 8* shots.

Lines 92-06 (24-fold)

lab rewires record start/firing sequence so there is no deep water delay, but so that the DFS-V fires gun, and t-o is known exactly. Shift problem between successive field tapes disappears.

Line 92-08 (24-fold)

we discover on this line that DFS-V will not number shot files over 999. After file 999, next shot is # 0, then 1, 2, 3, etc. Labels on field reels are correct (eg. 1000, 1001, 1002), So must renumber in demux. File number on display on DFS-V increments over 999, but these are not written onto the SEG-B tape.

Line 92-10, 10a (24-fold)

problems about 1/3 of the way into this line forced us to break off shooting, circle, and restart line about S.P. 240. It was here that we discovered that noise from the use of the ship's HF radio was obliterating any signal coming in from the streamer. In addition, we had some data gaps due to tape and tape drive problems. Line 10a is fairly clean.

Lines 92-12, 14, 16, 18, 20, 22, 24 (12-fold)

shot with only 48 channels and last half of streamer (50-m shot spacing, 12.5-m groups, 12 fold coverage). All other lines are 24-fold with the exception of line 0BS-17 which is nominally six-fold (see below).

Line 92-07 (24-fold)

4 channels weak or dead for most of line 7
channel 89 noisy, reels 115-117. Notice that channels 33-38 are weak (reduced sensitivity) but signal:noise ratio appears ok after gain is applied.

Lines 92-03, 3a, 26, 28, 30. (24-Fold)

streamer condition/noise situation about the same as line 07. During line 3, stopped and pulled in streamer to work on birds (streamer had been sinking). Line 3a is continuation of line 3. Channel 72 is intermittently noisy. Pull in cable after line 30 due to high seas (approaching 2 m). End leg 1.

Line 92-09 (24-fold)

short line shot while transiting to start of Sarma Delta to Posolskiy bank OBS line, located very close to border fault, with considerable noise, sideswipe, etc. Probably most useful as single channel section. This line should receive low priority in terms of data processing.

streamer work during the middle of the survey resulted in different lead-in offsets. Processors should carefully examine observer log at beginning of each line.

Lines 92-38, 40, 42, 44, 48 (24-fold)

3 channels dead, 6 channels spread out along length of streamer weak, plus channels 33-38 all weak. High amplitude noise spikes become evident on line 42. These are not isolated among specific channels, but appear to be distributed randomly over all channels. One channel tends to be noisy for a period of 10 or so shots. Source of noise is not exactly known, but probably in streamer or patch panel of lab. Noise may correlate with increase in wave height or with increase in ship vibrations (develop from change in main engine rpm's). Line 40 is broken into two parts (40 and 40a); this situation as a result of firing circuit problems.
Line 92-23 (24-fold)

transit line between 38 and 40, near border fault on Ol'khon Island. Not likely to produce good mcs section due to proximity of steep scarp and fault. Low priority for data processing.

Lines 92-50, 50a, 50b

this is broken up because of line location adjacent to Svyatoy Nos Peninsula. Channel/streamer conditions same as for lines 38-48 except that spikes were more prevalent and of higher amplitude.

Lines 92-46, 21

streamer situation same as on lines 50, 50a, 50b.

Line 92-17 (24-fold and 6-fold)

switch to one tape transport at start of this line. This means that 2 shots are missed at each tape change. File numbers however, do not increment these missed shots between the tape changes (i.E. Last files on reel x may be 75, 76, 77, and first files on reel y are 78, 79...). Ultimately, this was preferable to the much larger gaps (as many as 20 shots) that were occurring frequently when transport #1 would not function properly at tape changes. Streamer repair prior to start of line 17 removes group of weak channels (33-38) and another dead channel. At start of line we have 3 dead channels and 4 weak. Channel 24 becomes very noisy after several hundred shots.

At the end of line 17, we reversed direction, changed guns to the large 2x60 litre array, and began to shoot for OBS recording. We decided to leave the streamer in the water and record this line multichannel as well. Thus line OBS-17 is 6-fold line, with shots recorded at 2 minute intervals (nominally 200 m, but in many instances probably closer to 250m shot interval).

Lines 92-15, 60, 58, 56, 54 (24-fold)

2 dead channels, intermittently dead, 1 noisy (intermittent), 6-7 weak, although these are spread out along entire shot gather. These lines are 7 sec in length except for 92-60 (8 sec) and 92-15 (8 sec).

Lines 92-13, 36, 34, 32, 52, 11, 25 (24-fold)

all lines 9 sec in length. 3-4 Dead channels on most shot gathers, 5 weak channels. Line 25 has data gaps similar to those on earlier lines because we ran out of blackwatch tape. Using 777 tape resulted in parity errors at several localities along the length of the line. 50 Hz noise developed on 7-10 channels in rear of streamer towards the end of line 25.

Cruise Summary:

This seismic study of Lake Baikal was an unqualified success with the acquisition of over 1800km of high quality seismic reflection data. Single-channel monitor records of the profiles reveal a high-resolution of seismo-stratigraphic features above the water-bottom multiple and basement imaging below this multiple on many profiles. Improved resolution over the 1989 multichannel seismic-reflection data from Lake Baikal demonstrates the advantage of using a small tuned airgun array. The seismic grids over the Selenga Delta and Academichesky Ridge regions (Figures 3 and 4) will enable us to define the stratigraphic and structural framework of these regions with a resolution necessary to meet the scientific objectives outlined above.

Acknowledgements:

The success of this cruise was due primarily to the hard work of the cruise personnel listed in Table 1 and to D.R. Hutchinson and T. Moore, our co-principal investigators for this project. Over three years of effort focused at Gelendzhik and Woods Hole culminated in this one month survey of Lake Baikal. We thank Director M. Grachev and V. Fialkov of the Limnological Institute and Director M. Kuzmin of the Institute of Geochemistry for their continued support of this project. The land support at Lystvyanka directed by Alec Bardardinov was invaluable for getting things out of the "system" and the ship on the lake. We are grateful to P. Hearn for all of his efforts over the last 3 years in Reston, Moscow and Irkutsk helping to make this cooperative cruise a reality. We acknowledge the cooperation and assistance of Captain Gorbunov, Chief Engineer Vaskovskiy and the crew of the Balkhash. We also acknowledge the land support out of Woods Hole provided by T. Aldrich, T. O'Brien, B. Irwin and J. Newell. On board processing was made possible by the loan of a MASSCOMP Demultiplexing System by R. Phinney of Princeton. Financial support for this seismic study was provided by the U.S. Geological Survey, U.S. National Science Foundation and the Russian Academy of Sciences. Ship time on the Balkhash was provided by the Limnological Institute, Russian Academy of Sciences and the Baikal International Center for Environmental Research (BICER).

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Figures Captions:

Figure 1: Multichannel seismic reflection profiles acquired during 1992 seismic survey of Lake Baikal.

Figure 2: Major tectonic and morphologic features in the Lake Baikal region of the Baikal Rift, Siberia. Features discussed in the text are indicated. Bathymetric contours at 500m interval are shown. Inset shows location of Lake Baikal relative to the Siberian Craton and the mosaic of microplates of southeast Asia (from Zonenshain and Savostin, 1981).

Figure 3: The Selenga Delta region. Locations of 1992 MCS lines are superimposed on bathymetric contour map. Contour interval 100m.

Figure 4: The Academichesky Ridge region. Locations of 1992 MCS lines are superimposed on bathymetric contour map. Contour interval 100m.

Figure 5: Schematic diagram of airgun array and streamer array used during the 1992 MCS survey.

Plate 1: Shot point navigation chart for multichannel seismic reflection profiles acquired during 1992 and 1989 seismic surveys of Lake Baikal. Line numbers are prefixed by 89 or 92 to indicate the year of acquisition.

TABLE 1 Cruise Personnel

RV BALKHASH

Captain: Yuri Gorbunov
Chief Engineer: Nikolai Vaskovskiy

Co-Chief Scientists:
- Alexander Ja. Golmshtok,Institute Oceanology,Gelendzhik,Russia
- Kim D. Klitgord, U.S. Geological Survey, Woods Hole, MA USA
- Christopher A. Scholz, Duke Univ. Marine Lab, Beaufort, NC USA

Chief of Operations:
- Leonid Akentiev, Institute of Oceanology, Gelendzhik, Russia
- David Nichols, U.S. Geological Survey, Woods Hole, MA USA

Scientific Party:
- Judi Allen, U.S. Geological Survey, Menlo Park, CA USA
- Ivan Beliyev, Institute of Oceanology, Moscow, Russia *
- Yegor Czerniawski, Institute of Oceanology, Moscow, Russia
- Alexander Elnikov, Institute of Oceanology, Gelendzhik,Russia
- David Foster, U.S. Geological Survey, Woods Hole, MA USA
- Valedi Gorjunov, Concern Ros Oil and Gàs, Krasnodar, Russia*
- Sergei Hanukayev, Institute of Oceanology, Gelendzhik, Russia
- Eugene Konyev, Institute of Oceanology, Gelendzhik, Russia
- Sergei Kraskovsky, Institute of Oceanology, Gelendzhik, Russia
- Alexander Kurochkin, Concern Ros Oil & Gas, Krasnodar, Russia
- James McGill, Duke University Marine Lab, Beaufort, NC USA
- Yuri Pavlov, Institute of Oceanology, Gelendzhik, Russia
- Alexander Pisetsky, Institute of Oceanology, Gelendzhik,Russia
- Christopher Schneider, US Geological Survey, Woods Hole MA USA
- Victor Trofimenko, Institute of Oceanology, Gelendzhik, Russia*
- Alexander Tupikin, Concern Ros Oil and Gas, Krasnodar, Russia
- Derek Unger, U.S. Geological Survey, Woods Hole, MA USA
- Hal Williams, U.S. Geological Survey, Menlo Park, CA USA
- Nikita Yazichyen, Institute of Oceanology, Gelendzhik, Russia *
- Anatoly Zinoviev, Institute of Oceanology, Gelendzhik, Russia

* First leg of cruise.

RV TITOV

Chief Scientist:
- Uri Ten Brink, U.S. Geological Survey, Woods Hole, MA USA

Chief of Operations:
- Gregg Miller, U.S. Geological Survey, Woods Hole, MA USA

Scientific Party:
- Alik Bardardinov, Limnological Institute, Irkutsk, Russia
- Marc Behrendt, U.S. Geological Survey, Woods Hole MA USA
- Dwight Coleman, U.S. Geological Survey, Woods Hole MA USA

TABLE 2 Multichannel Seismic Lines

1992 Lake Baikal Expedition

I. Selenga Delta Survey

Line #	Start JD/Time GMT	End JD/Time GMT	Start Position Lat/Long	End Position Lat/Long	Course (Deg.)	Length (km)	Shot Points	Field Tapes	Demux Tapes
92-01	238/1335	238/1743	51.839187 105.201538	51.708272 105. 560398	120	28.7	1-559	1-8	1-12
92-02	238/1920	239/0003	51.783275 105.629878	52.090187 105.567790	353	34.4	1-683	9-17	159-172
92-04	239/0345	239/0918	52.149588 105.670052	51.781968 105.768477	170	41.5	1-785	18-28	173-187
92-06	239/1123	239/1830	51.816655 105.879713	52.266202 105.760130	188	50.7	1-989	29-42	13-34
92-08	239/2136	240/0433	52.314267 105.841190	51.850557 105.962125	171	52.3	1-1002	43-54	188-206
92-10	240/0846	240/1300	51.950325 105.988007	52.245475 105.955628	005	32.9	1-612	55-61	
92-10A	240/1826	241/0005	52.068813 105.999790	52.422245 105.909685	351	39.8	268-1082	62-70	35-49
92-12	241/0425	241/0707	52.470325 105.999658	52.324805 106.121902	153	18.2	1-389	71-75	207-211
92-14	241/0818	241/1122	52.345822 106.177128	52.513743 106.077735	340	19.9	1-445	76-81	50-59
92-16	241/1242	241/1517	52.524907 106.160012	52.388360 106.283577	152	17.4	1-375	82-86	212-215
92-18	241/1654	241/1948	52.407888 106.389797	52.578732 106.276337	338	20.5	1-419	87-92	216-220
92-20	241/2118	242/0009	52.590038 106.377202	52.430018 106.531377	149	20.7	1-412	93-97	60-68
92-22	242/0121	242/0425	52.460978 106.594765	52.655743 106.479348	340	23.0	7-447	98-103	221-225
92-24	242/0528	242/0843	52.659595 106.548983	52.488147 106.745412	145	23.3	6-608	104-110	69-74

92-07	242/1529	243/0830	52.655717 106.592597	51.865662 105.436463	230	118.2	1-2430	111-143	75-125
92-03	243/1317	243/1550	51.851045 105.503015	51.899353 105.747687	072	17.7	1-332	144-148	
92-03A	244/1028	244/1355	51.885353 105.679752	51.957947 106.033893	072	25.7	1-495	149-155	
92-26	244/1640	244/2125	51.882703 105.956752	52.093382 105.576487	312	35.1	1-682	156-165	126-139
92-28	244/2342	245/0237	52.176468 105.680445	52.210797 105.959250	079	19.4	1-422	166-171	140-149
92-30	245/0417	245/0530	52.289487 105.978502	52.340715 105.859858	305	9.9	1-174	172-175	150-153
92-09	245/0618	245/0744	52.373735 105.863812	52.450612 105.945473	033	10.2	2-209	176-178	154-158
92-36	265/1551	265/1918	52.849025 107.015898	52.654285 107.283753	136	28.2	1-525	488-495	486-498
92-34	265/2111	266/0139	52.625468 107.138132	52.862920 106.797945	319	35.0	1-680	496-505	
92-32	266/0335	266/0704	52.768828 106.716980	52.587982 106.976357	139	26.7	1-515	506-512	
92-52	266/0833	266/1159	52.551538 106.868065	52.729437 106.616167	319	26.1	1-495	513-519	
92-19	266/1249	266/1650	52.758522 106.685255	52.766733 107.167087	088	32.5	1-614	520-528	
92-11	266/1746	267/0753	52.724958 107.152532	52.250042 105.765342	241	108.0	1-2137	529-558	
92-25	267/1436	268/0035	52.470092 106.005275	51.762662 105.854090	188	79.4	1-1512	562-584	
92-07a					050	test line	1-219	559-561	

II. Northern Basin Survey

Line #	Start JD/Time GMT	End JD/Time GMT	Start Position Lat/Long	End Position Lat/Long	Course (Deg.)	Length (km)	Shot Points	Field Tapes	Demux Tapes
OBS-1	252/1230	254/0008	52.279397 105.764838	53.440452 108.565840	055	228.6	1-1061	n/a	n/a
92-38	254/0850	254/1355	52.916518 108.017030	53.189915 107.698697	325	37.2	3-727	179-188	226-241
92-23	254/1455	254/1624	53.225780 107.757848	53.311995 107.841777	030	11.1	1-214	189-191	242-247
92-40	254/1734	254/1942	53.315293 107.782635	53.191763 107.888783	145	15.5	2-287	192-195	
92-40A	255/0029	255/0437	53.216315 107.860125	52.977203 108.135752	145	32.4	241-860	196-204	
92-42	255/0617	255/1516	53.045970 108.212940	53.567310 107.624362	324	70.0	1-1321	205-224	248-278
92-44	255/1719	256/0148	53.626742 107.728718	53.163815 108.271807	145	62.9	1-1202	225-242	
92-48	256/0550	256/1330	53.342660 108.521755	53.787465 108.004835	326	60.2	2-1110	243-260	
92-50	256/1634	256/2116	53.846367 108.207237	53.576083 108.004835	145	32.9	1-680	261-270	279-295
92-50A	256/2232	256/2334	53.566688 108.459222	53.624195 108.402952	329	7.4	1-148	271-272	
92-50B	257/0046	257/0453	53.584013 108.369010	53.347857 108.635690	146	31.7	1-635	273-284	450-464
92-46	257/0812	257/1603	53.251878 108.376358	53.700253 107.846888	325	61.0	1-1180	285-302	296-323
92-21	257/1651	257/2235	53.666790 107.792267	53.254498 107.878360	172	46.2	1-839	303-316	
92-17	259/1002	260/0734	53.416355 107.550832	54.431367 109.430088	047	167.3	4-3269	317-363	324-449
92-17A OBS-4	260/1506	261/1240	54.434412 109.436113	53.454992 107.572120	229	163.9	5-641	364-379	353-377

92-15	261/1925	262/0908	53.345518 107.837772	54.083445 108.898247	040	117.5	1-2055	380-409	
92-60	262/0949	262/1327	54.111128 108.856885	54.194463 108.437973	289	28.9	1-545	410-416	
92-58	262/1500	262/2243	54.121297 108.429113	53.956347 109.289370	108	59.3	1-1138	417-429	408-428
92-56	263/0021	263/0752	53.891477 109.172728	54.053518 108.329163	289	58.2	1-1143	430-442	
92-54	263/0859	263/1403	53.998117 108.311295	53.703195 108.658417	145	40.0	1-780	443-451	471-485
92-13 OBS-1A	264/1941	265/1349	53.501733 108.722485	52.816503 107.016140	237	137.3	1-2589	452-487	465-470

Summary: 2072.4km MCS profiles with tuned gun array
163.9 km MCS profiles with 2 big airguns

Julian Day 238 = 25 August 1992
Julian Day 269 = 25 September 1992

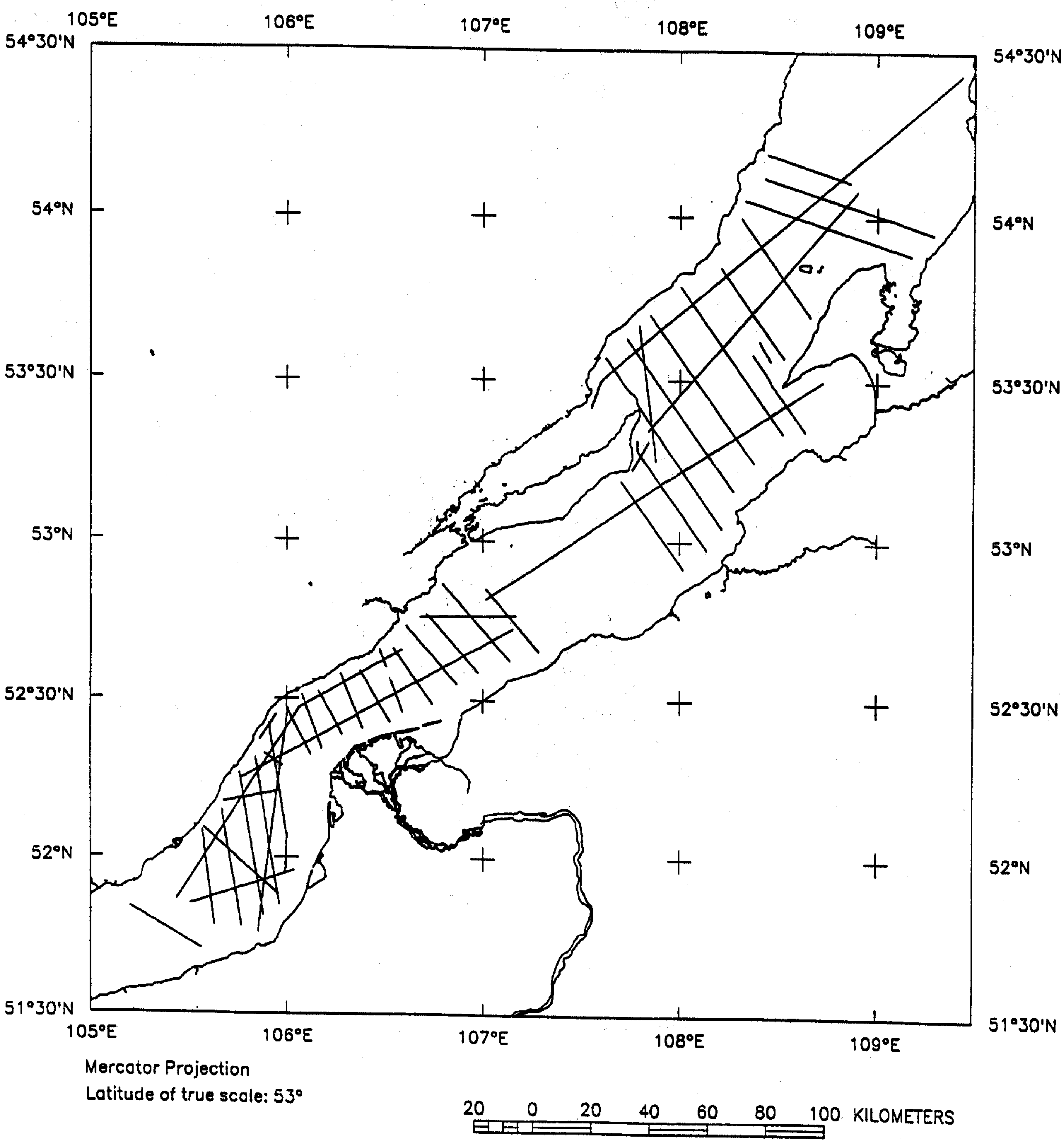

Figure 1: Multichannel seismic reflection profiles acquired during 1992 seismic survey of Lake Baikal.

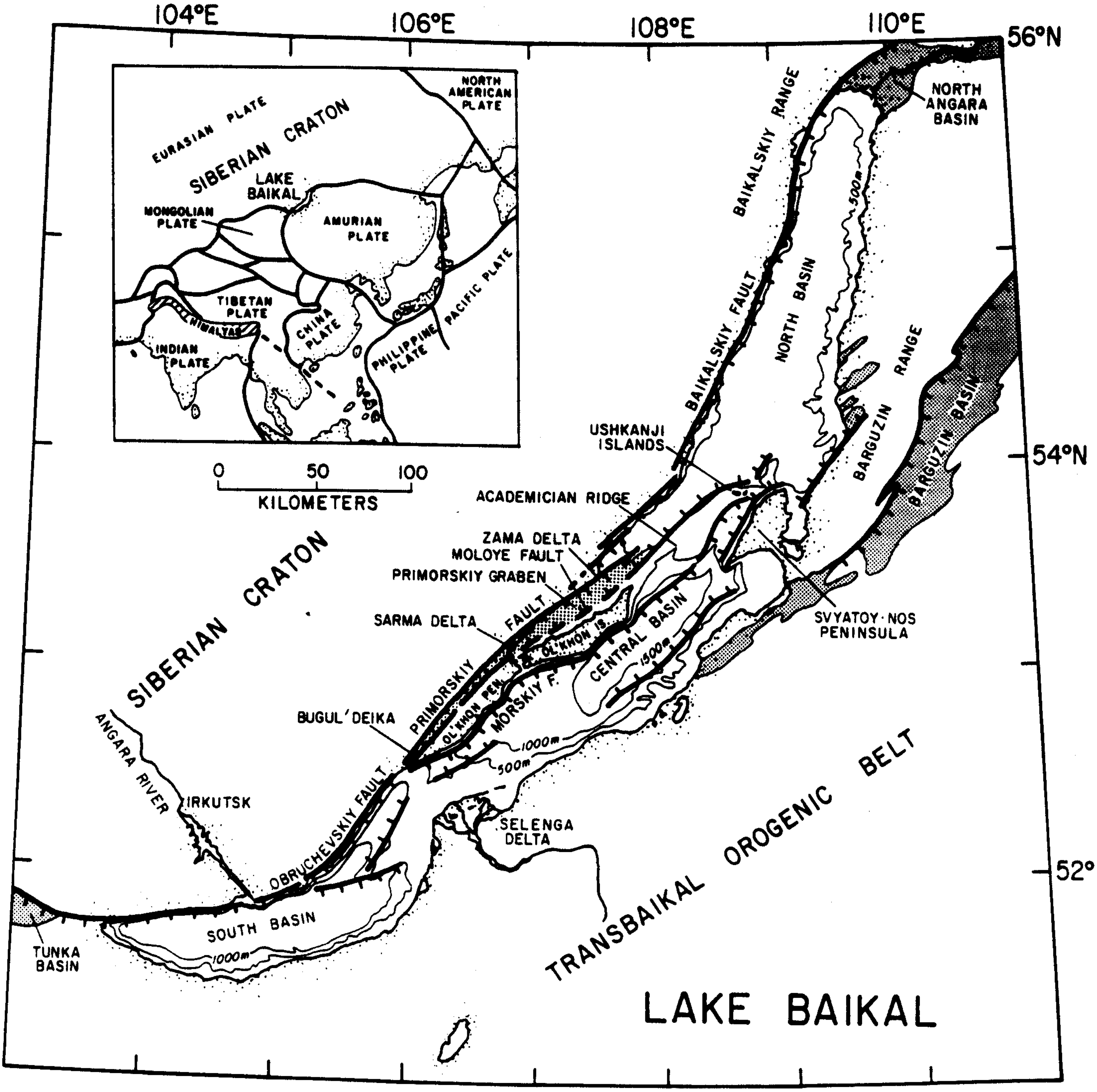

Figure 2: Major tectonic and morphologic features in the Lake Baikal region of the Baikal Rift, Siberia. Features discussed in the text are indicated. Bathymetric contours at 500m interval are shown. Inset shows location of Lake Baikal relative to the Siberian Craton and the mosaic of microplates of southeast Asia (from Zonenshain and Savostin, 1981).

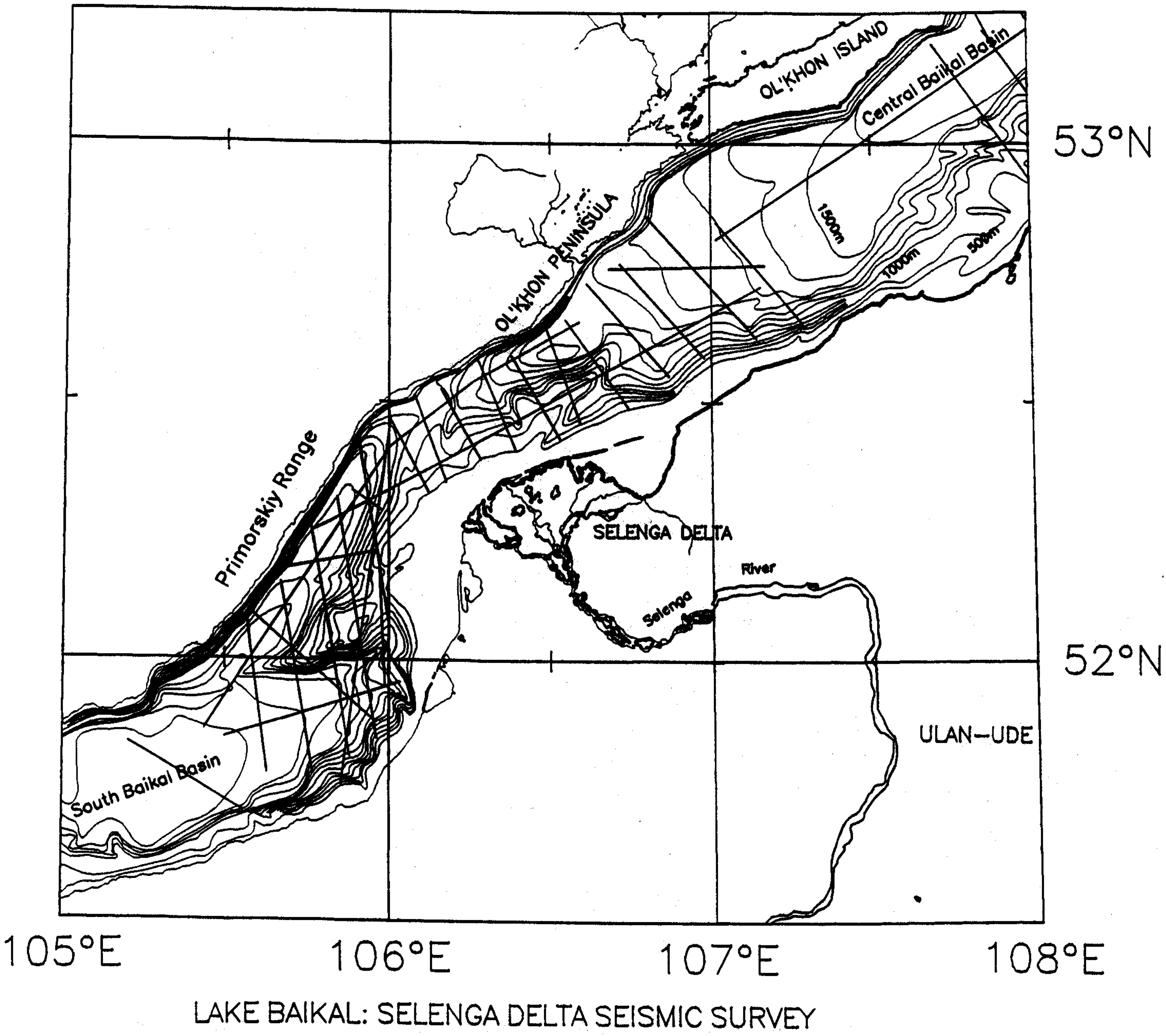

Figure 3: The Selenga Delta region. Locations of 1992 MCS lines are superimposed on bathymetric contour map. Contour interval 100m.

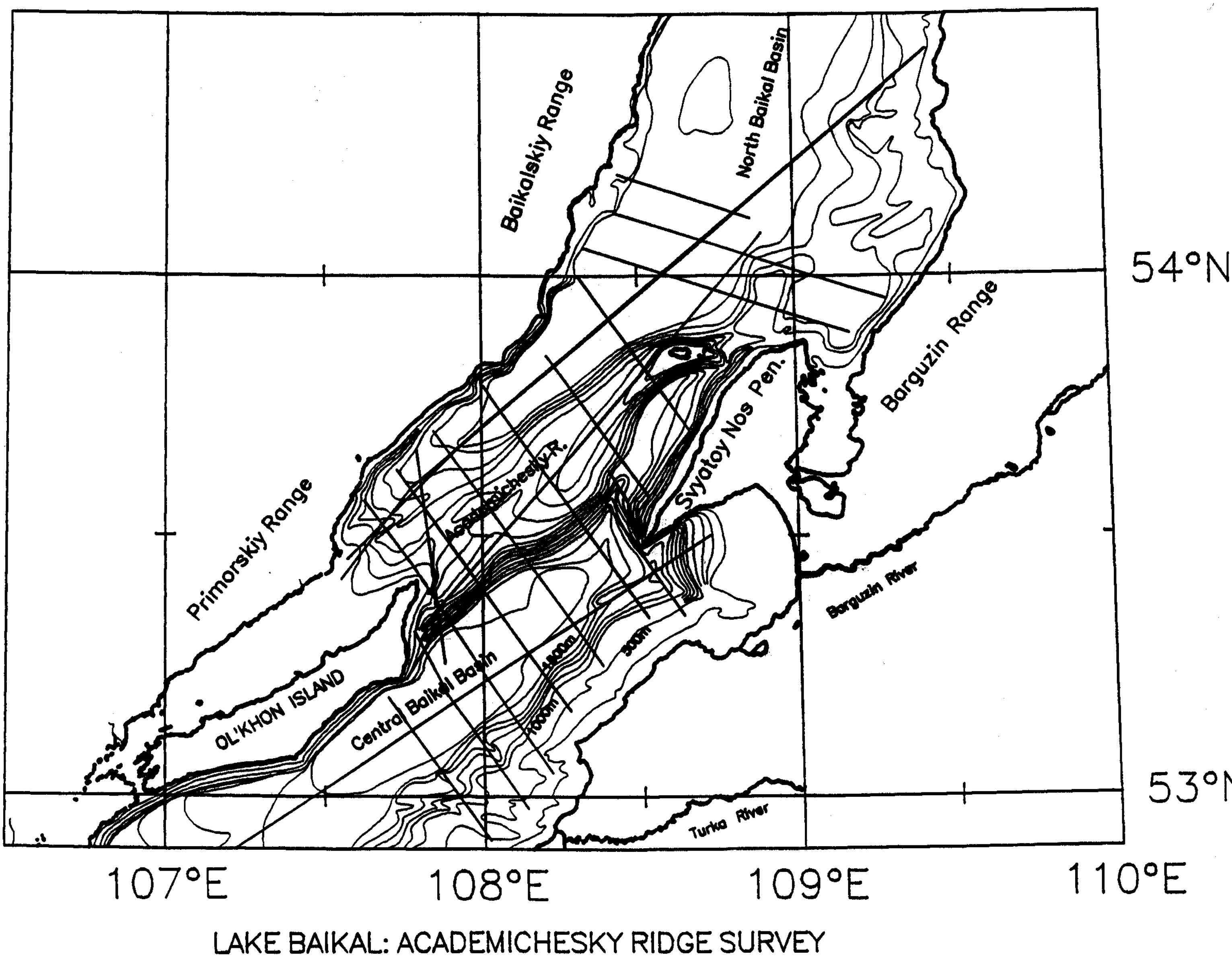

Figure 4: The Academichesky Ridge region. Locations of 1992 MCS lines are superimposed on bathymetric contour map. Contour interval 100m.

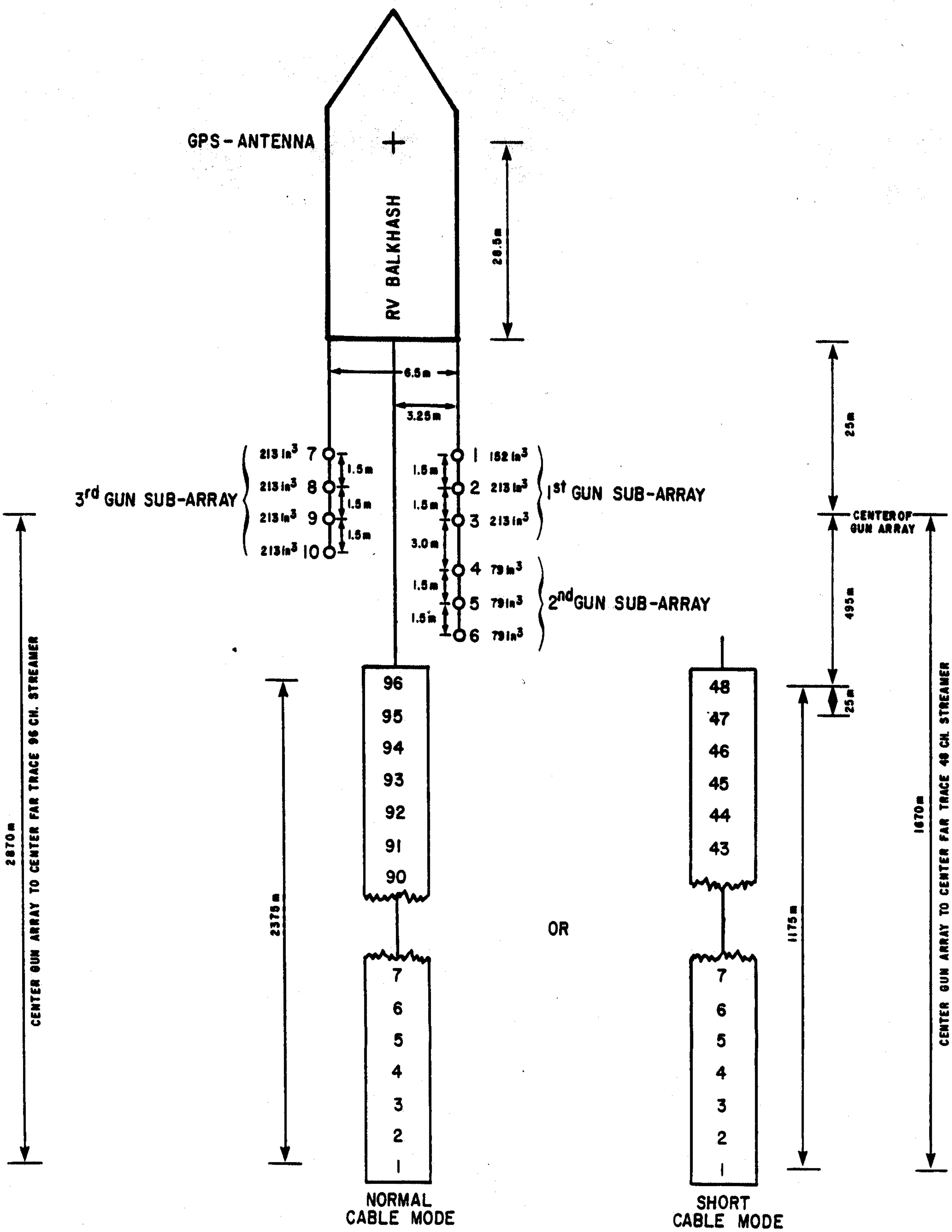

Figure 5: Schematic diagram of airgun array and streamer array used during the 1992 MCS survey.