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Ocean Bottom Seismometers Operation during the Seismic Survey of Lake Baikal, Siberia, Autumn 1992.

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SUMMARY

A seismic survey of Lake Baikal, Siberia, was jointly undertaken by U.S. and Russian scientists during August-September of 1992. The experiment was carried out by two ships, the R/V Balkhash, which was equipped with airguns and a multichannel seismic streamer, and the R/V Titov, which was used for the deployment of Ocean Bottom Seismometers. The experiment was funded by the U.S. Geological Survey, the U.S. National Science Foundation, and the Russian Academy of Science. This report summarizes the operation of Ocean Bottom Seismometers (OBS) aboard the R/V Titov. A companion report by Klitgord et al. (1993) summarizes the multichannel seismic program and the operation aboard the R/V Balkhash, and a third report by Nichols et al. (1993) describes the logistical and technical aspects of the entire seismic program.

The objective of the Ocean Bottom Seismometers (OBS) program was to determine the velocity structure of the sediments, crust, and uppermost mantle under the Baikal rift in order to better understand the tectonic evolution of the rift. To this end, a 240-km-long wide-angle reflection and refraction line was collected with 5 OBSs along the axis of the Central Basin using two large (60 liter each) airguns as a sound source. The northern 140 km portion of this line was repeated with 6 OBSs recording a tuned 10-gun array with a total volume of 27.3 liter. Another 160-km-long wide-angle reflection and refraction line along the southern part of the Northern Basin was recorded with 5 OBSs and shot with the two large airguns . A 70 km long tie-line between the Northern Basin and Central Basin lines was shot across the Academician Ridge with the tuned airgun array and was recorded with 4 OBSs. Multichannel seismic (MCS) reflection lines were collected by the R/V Balkhash along all the OBS lines with the exception of the southern 130-km-portion of the Central Basin line which was collected during the 1989 MCS cruise. Many of the OBSs were deployed at the intersection of two orthogonal MCS lines in order to better constrain the shallow 3-D structure. A total of 34 successful deployments and retrievals of USGS OBS, the largest to date in a single survey, were carried out despite the crowded conditions and inadequate facilities on the R/V Titov. Data were recorded in 20 of these deployments. None of the instruments were lost. Initial record sections show good signal to noise ratio on all OBS channels in all the lines persisting to the maximum shot-receiver offsets.

SCIENTIFIC OBJECTIVES

The Baikal rift system is a large and active continental rift, stretching over 1800 km along the boundary between the stable continental platform of Siberia and the continental fragments of southeast Asia. The 600 km long Lake Baikal, which lies at the center of this rift system is divided

Figure 1a. Location of Lake Baikal.

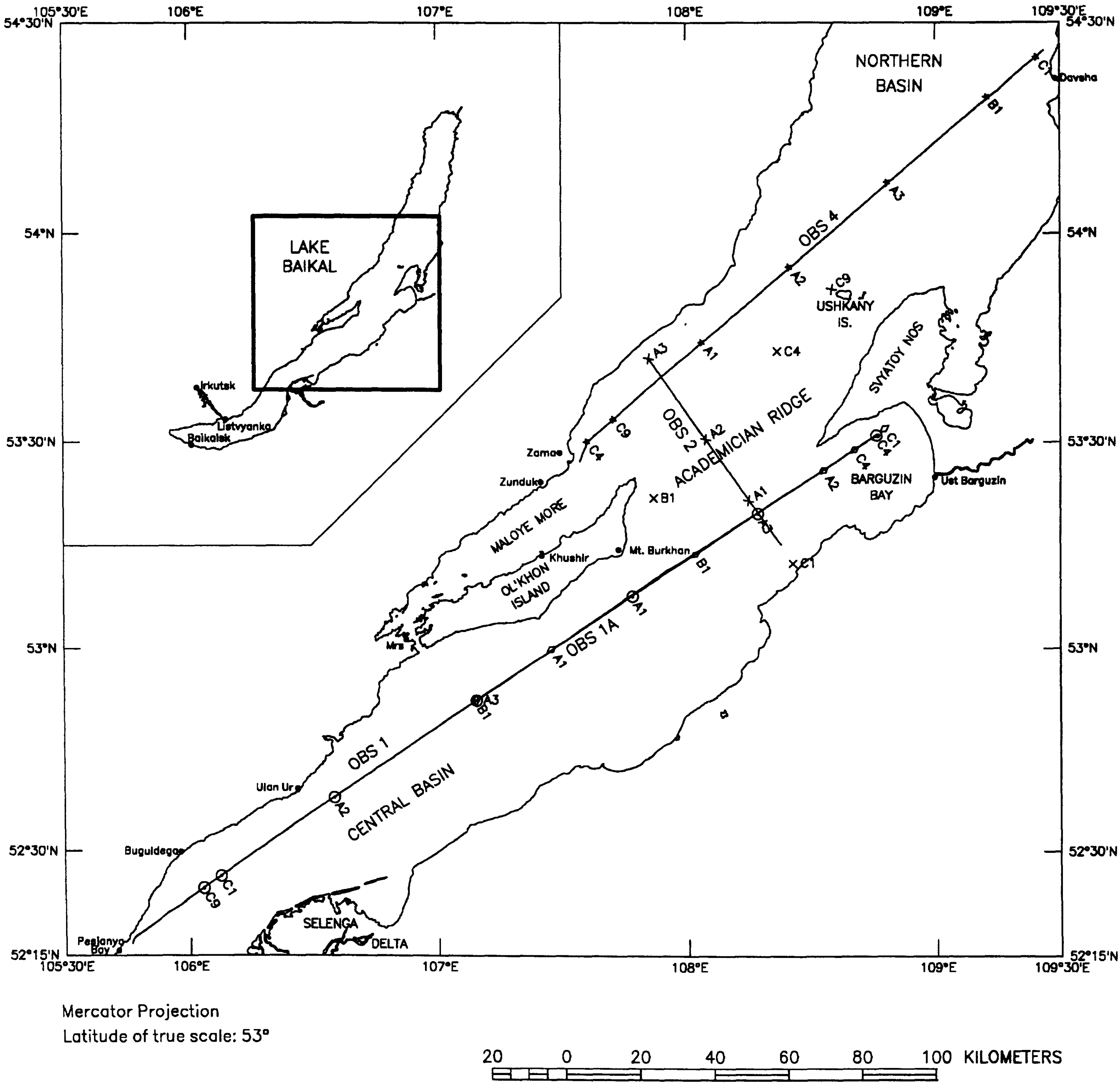

Figure 1b. Location of OBS stations and OBS lines. Circles - Deployment 1 and 2, Crosses - Deployment 3, Stars - Deployment 4, Diamonds - Deployment 5. A1, A2, A3, B1, C1, C4, C9 - Instrument names.

into three bathymetric and tectonic basins, the Southern, Central, and Northern Basins. The Central Basin is the deepest basin reaching more than 1600 m below lake level and having up to 7.5 km of sediments. The scientific objectives of the OBS experiment were:

- To determine the depth to Moho under the Central and Northern Basin in order to resolve whether Moho is elevated under the rift.
- To determine P and S wave velocities for the lower crust and upper mantle in order to identify the role of magma upwelling under the rift.
- To compare among the crustal velocity structures of the Central and Northern Basins, the Academician Ridge, and published velocity structure outside the rift in order to understand the contribution of the preexisting crustal rheology to the development of the rift.
- To determine the velocity of the deep (> 5 km) sedimentary section observed on multichannel seismic records in order to assist in their geological interpretation.

OPERATIONAL OBJECTIVES

- To test two new OBS spheres and their electronics.
- To test several recent improvements to the OBSs including hydrophone connectors, variable sampling rate, backup power supply for release, and time calibration by GPS.
- To make multiple deployments with a minimum turn around time off a modest size ship.
- To test the release and natural buoyancy of the OBS in a fresh water lake.
- To carry out the entire operation off a foreign ship with foreign power supply and foreign radio communication.
- To maintain good communication with the personnel on board the R/V Balkhash at all times in order to maximize the number of deployments and minimize the effect on the collection of multichannel seismic reflection data.

THE USGS OCEAN BOTTOM SEISMOMETERS

The Ocean Bottom Seismometer (OBS) is a self-contained data-acquisition system that is deployed on the ocean floor to record wide-offset seismic data on a 200 Megabyte disk. The US Geological Survey OBS has been designed as a continuous recording system setup to acquire signals from one vertical 4.5 Hertz geophone, two orthogonal horizontal 4.5 Hertz geophones, and one hydrophone. The software controlling the system can select any combination of these four channels to sample at 200 samples/second, providing a record time of 36 hours for all four channels. Once during each acquisition of data into the memory buffer (1,015,808 bytes), the system will record the time of the sample. The time and the data pointer for that time are recorded into a header that gets recorded with each memory buffer of data. There are eight OBS's. Four are housed in small (51 cm in diameter) spheres rated for a depth of up to 500 meters, and the other four OBS's are housed in large (61 cm in diameter) spheres rated to 5,000 meters. Each OBS is powered using 72 alkaline batteries which will run all of the systems for seven days.

The OBS's record data continuously and have time-of-day marks in the data as the only reference to external events. To provide the highest possible accuracy, time is recorded to the nearest millisecond. Each OBS uses an oven-controlled oscillator as a stable clock reference, for which the drift in time can be as little as 0.5 milliseconds/day. This accuracy requires several days of careful calibration and the use of a rubidium (Rb) standard as a reference for the oscillators. All eight OBS data loggers are continuously powered using a 24 volt DC power supply to keep the oscillators at a constant temperature. Prior to each deployment, the frequency of each oscillator is checked and, if necessary, recalibrated. The time-of-day is set via software in each logger using the minute pulse of the GPS satellite clock as a starting trigger. When locked on a satellite, the time is accurate to within 100 nanoseconds, and the Rb standard can used to maintain an accurate time when satellite coverage is not adequate. The offset from GPS time is determined by comparing the second pulse of the data logger with the second pulse of the GPS clock. After each deployment, the offset is measured again to determine the total drift.

The dataloggers in each OBS use a 200 Megabyte hard disk to store the acquired data. The data must be transferred to another storage media each time an OBS is retrieved. A 386 PC with 2.2 gigabytes of hard disk and an exabyte tape drive is used to archive the data. Data are downloaded from the data logger onto the hard disk of the PC. The quality of the data is checked using two programs. One program reads, displays, and checks the header information of each data record. The program will report any errors found. The second program graphically displays the sensor data for all four channels. Once all of the OBS's have been downloaded, the data files are written to Exabyte (8 mm) tape for permanent storage.

Deployment and recovery are simple operations designed to work on a variety of different vessels. The OBS's are programmed, sealed, and stored on deck prior to deployment. When at the point of deployment, the release is tested a final time, and the OBS is then attached to its anchor. The preferred method of deployment uses a winch to lift the OBS and anchor and an A-frame to move the assembly outboard of the ship. The OBS is then lowered to the water surface where a simple rope loop and metal pin is used to release the OBS into the water and freefall to the bottom. An acoustic release is used to free the OBS from its anchor. Once released, the OBS rises to the surface at a rate of 1 meter/second. At the surface, two externally mounted strobes will flash to aid in spotting the floating OBS. The OBS is attached to the lifting line using a snap hook mounted on a pole, and, once the OBS is lifted back aboard, the release is recocked to turn off the strobes. The large OBS and anchor weigh 250 lbs. in air, so the requirements for lifting are not much. A block and tackle are often used (as in this experiment) when no winch is available.

NARRATIVE

Pre-deployment

All of the OBS equipment plus 40 anchors and 3200 alkaline batteries were packed into a standard 20 foot shipping container and sent out in early April as part of a 3-container shipment to Lake Baikal. The equipment arrived in Listvyanka in mid-July. The OBS technician and a translator, arrived in early August to nmobilize the OBS and to assist in mobilizing the multichannel/shooting ship (the R/V Balkash). Prior to embarkation a plywood shack was constructed on board the R/V Titov to serve as the OBS laboratory (see Appendix 6). The experiment took place during the short Siberian automn. The weather throughout the experiment was mild, with the exception of one severe snow storm on September 5-7, and continued rough seas and cold weather in the following week. Air temperature varied between 0°-15° C, and the water temperature was estimated at 5°-10°C. wind speed was generally 5-15 m/s and waves 0.5-1.5 m high. The R/V Titov left the pier of the Limnological Institute in Listvyanka on August 30 at 14:30 local time (9 hours ahead of GMT) following loading of the scientific gear on board that morning. Although the first OBS deployment was scheduled 5 days later, an early departure was necessary, to avoid vandalism in port and to complete sea-going preparation of the ship and its crew. The Titov initially headed south to Baikalsk, on the Trans-Sibirian railroad, to stock on food, but because the late departure meant the supplier will close before arriving at Baikalsk, the R/V Titov changed directions and headed north toward the Selenga delta to rendezvous with the R/V Balkhash. The

Listvyanka shore station had no radio communication with the Balkhash after she left port on August 25, so messages could not be relayed to the scientists on board. The R/V Titov arrived to within VHF radio contact and we communicated successfully with the Balkhash. Afterwards the Titov headed back south to the vicinity of Baikalsk and anchored in shallow waters. The morning of August 31 was spent shopping and in the afternoon we headed north to Buckhta Pesjanaya (Sandy Bay) and tied to the pier. A test was made to test the buoyancy of the OBSs in fresh water and verify that the OBSs float above sea surface and could be detected. September 1 was spent at Pesjanaya Bay. During these three days the OBS lab was outfitted and all OBSs were tested and programmed for the first deployment. A faulty transducer was found and could not be repaired. For lack of spare parts only 7 out of 8 OBSs could be deployed throughout the experiment. Parts were exchanged so that a small sphere (OBS C3) would not be deployed. On September 2, we sailed further north toward the northern end of OBS line 1 stopping on the way to climb to Ulan-Ur to examine an unusual assemblage of carbonatite, garnet peridotite, amazonite, etc. all exposed within a small area. The night was spent at anchor in Barguzin Bay at the northern end of OBS line 1.

Deployment 1 (Central Basin)

At 07:15 local time (hereafter LT) on September 3 we deployed the first OBS C4 along line OBS1 (Fig. 1). Deployment of all OBSs was successful and uneventful. The good weather during the previous days turned into high wind and waves as we deployed the last two OBSs (C1 and C9, Fig. 1). Deployment was completed at 20:23 and the Titov headed back to Listvyanka and arrived there on 9/4 at 02:30 LT. The R/V Balkhash arrived at Listvyanka on the evening 9/2 to allow for personal errands of the ship's chief engineer and was scheduled to leave the next evening and start shooting on 9/4 at 12:00 LT. To our surprise, the captain of the Balkhash refused to leave port, citing a bad weather forecast. The R/V Titov left Listvyanka on 9/4 at 16:00 LT to refuel in Port Baikal. The sea was fairly calm. At 18:00 LT the Titov returned to Listvyanka and I walked over to the Balkhash in another failed attempt to bring the Russian chief scientist on board, to convince the captain to immediately start shooting the OBS line. At 19:00 LT the Titov left for Pesjanaya Bay. On the afternoon of the next day (9/5) the weather deteriorated and rain and sleet began to fall. Nevertheless, an attempt was made at 17:00 LT to recover the southernmost OBS, but as the wind and wave directions were perpendicular to one another, it was impossible for the Titov to keep station. The Titov returned to Pesjanaya Bay at 21:00 LT where she was well protected from the weather. Only during 9/6 did the wind reach gale storm. Wind was blowing first from the northwest and later from the south and raised columns of water. OBS retreival started on 9/7 10:45 LT when the weather improved some, although it was still "too severe" for the much larger Balkhash to work. All 7 OBSs were collected by Sept.8 04:00 LT. They all responded immediately to the release command and had recorded for the entire 36 hours for which they were programmed. This deployment had no data because the Balkhash had not shot the line during the recording window.

Deployment 2 (Central Basin)

At the northern end of the line we turned to redeploy the OBS along the same line (OBS1, Fig. 1) starting at 05:00 LT. The retrieved OBSs were programed and prepared between stations. Weather was still fairly poor. The release mechanism of small sphere OBS C1 malfunctioned and it was not deployed. We finished the second deployment on 9/8 19:30 LT having deployed only 6 OBSs and pulled into Pesjanaya Bay. The Balkhash started shooting from southern end of line at 21:00 LT at a speed of 4 knots. It reached the northern end of the line on 9/10 03:00 LT and turned around and shot back for the remaining 2 hours of OBS recording. On September 9, while the Balkhash was shooting, the Titov sailed to the village of Galauchnaya (3 hours south of Pesjanaya Bay) in an unsuccessful search for food. In the meantime the release mechanism was repaired and OBS C1 was deployed at 9/9 17:11 LT and recorded the last 15 hours of the shooting. At 18:15 LT Titov rendezvoused with R/V Vereschagin off Buguldega to acoustically release a sediment trap for E. Karabanov. After successful release the Titov refueled from the R/V Vereschagin. On 9/10 at 09:20 LT we left Pesjanaya Bay to retrieve the OBSs on line 1. OBS B1 off Olkhon channel was found to have bad gain ranging and the data were rendered useless. OBS A1 would not release. The site was abandoned after 2 1/2 hours of attempts when the R/V Balkhash approached the site as she collected MCS line 92-38. We proceeded to retrieve the remaining two OBS. The tattletale on the northernmost OBS (C4) did not record any data. We finished retrieving OBS C4 on 9/11 03:04 LT and immediately returned to the site of OBS A1. After another hour, the OBS finally released from its anchor and was pulled on board at 09:24 LT. The sea at this time was rough and the R/V Titov found shelter on the leeward side of Olkhon Island at the foot of Mt. Burkhan. On 9/12 at 08:00 LT we attempted to start deployment of OBS Line 2 (along line 92-46 across Academician Ridge) and Line 3 (line 92-15 along Academician Ridge) but rough seas forced us after less than an hour to return to sheltered water. The R/V Balkhash was collecting MCS data and changed the order of the lines to be shot to allow us time to deploy. At 10:30 LT we sailed to the village of MRS at the tip of Olkhon peninsula being protected from the northwesterly wind by the southeastern shore of Olkhon Island. A member of the scientific expedition, Dwight Coleman, was transferred there to a fast boat heading for Irkutsk for an early return to the U.S. The Titov left MRS at 16:30 LT toward Khushir where bread, meat, and vegetables were purchased.

Deployment 3 (Academician Ridge)

After leaving Khushir we headed north to start the third deployment along OBS lines 2 and 3 (Fig. 1). At 23:11 LT we deployed the first OBS (B1) off the tip of Olkhon Island. By that time the sea was calm. Deployment of the 7 OBSs along Line 2 (C1, A1, A2, and A3) and Line 3 (C4 and C9) continued throughout the night and ended at 9/13 08:55 LT off Ushkany Island. From there the Titov headed to Barguzin Bay and anchored offshore Svyatnoy Nos peninsula for a night of fishing for the crew. Balkhash started shooting line 92-46 at 17:00 LT with the 10-gun array every 24 seconds, but by the time she approached the start of line 92-15 (early morning of 9/14) the sea became rough and the captain of the Balkhash ordered the streamer and guns to be pulled on board. The Titov left Barguzin Bay at 08:00 LT and retrieved OBS C1 at the southern end of line 92-15 by 09:02 LT. After rough 3 hours of rough passage across the lake, the R/V Titov rendezvoused with the R/V Balkhash in the sheltered water off Olkhon Island (under Mt. Burkhan). Attempts were made during the afternoon and evening to convince the Russian chief scientist to start shooting Line 3 before the recording time is over at 10:00 LT the next day. Although the sea was calm, the chief scientist did not order his crew to deploy the guns citing that he already promised them the night off. The R/V Titov left the sheltered water at 9/15 06:00 LT to retrieve all remaining OBSs. Retrieval was completed at 20:18 LT and all instruments were found to have recorded data during the shooting of Line 2. The lengthy retrieval was due to the circuitous route that the captain took in order not to be caught in potentially bad weather in the middle of the lake. But by the time retrieval was completed the sea was calm. The Titov was anchored for the night off Zunduk in Maloy More. In summary, off 7 OBS locations on Lines 2 and 3, data were only recorded for shots along Line 2 (4 instruments on line and 3 instruments off line). In addition, the southeastern 14 km of Line 1 were not shot for unknown reason.

Deployment 4 (Northern Basin)

The fourth deployment (Line OBS4) took place in the northern basin and started on 9/16 at 09:04 LT off Zama (OBS C4, Fig. 1). The deployment was interrupted between 10:00 LT and 10:45 LT the Titov for rendezvous with the supply boat Papanin which was on its way to bring food to the Balkhash. Deployment was resumed and successfully completed at 19:56 LT off the mouth of Bolshoy River (OBS C1). The night was spent being anchored near shore by the end of the line. Earlier in the day the R/V Balkhash completed the MCS shooting of this line (MCS 92-17) with the 10-gun array and changed to the two large 60 liter guns. At 9/17 00:00 LT, Balkhash started shooting at 4 knots towing the streamer behind. Shooting was completed at 9/17 21:45 LT. The Titov spent 9/17 tied to the pier at Davsha, near the northern end of the line waiting for an agreed upon radio communication from the Balkhash to announce that the line was completed. Since there was no communication from the Balkhash, and scientists on board the Balkhash gave different shooting speed (4 and 3.25 knots respectively) we waited till 9/18 08:00 LT to start retrieving. Our request was to shoot at 3.25 knots to achieve a 200 m spacing between shot points. However, the Balkhash opted to record the shots of the big guns using the multichannel streamer, requiring that the line be shot at 4 knots to maintain streamer buoyancy. Communication with Balkhash was established at 10:00 LT when the Balkhash requested the Titov to buy cigarettes for its crew, who were threatening to quit. This was unfortunate since the Russian chief scientist released the supply boat that was assigned to him only a day earlier, and since the Titov had just left Davsha where cigarettes could have been cheaply purchased. The retrieval of all OBSs went smoothly, but two OBSs were found not to have recorded data. The oscillator on OBS C1 was detached from the tattletale, probably during deployment. The program on OBS C9 crashed on start-up and never started recording. This OBS had the problem of not transmitting response signals during a pre-deployment test on board but was deployed since the release mechanism functioned. It is hypothesized that both problems were due to a grounding problem. The retrieval of all OBS was completed on 9/18 20:27 LT and the Titov anchored for the night at Zunduk. On the morning of 9/19 the Titov went to Khushir to buy cigarettes for the Balkhash and try to refuel. However, cigarettes were expensive and a hose could not be found to pump fuel from an adjacent ship.

Deployment 5 (Central Basin)

Continuous, but unsuccessful attempts were made during the 9/19 to contact the Balkhash on the HF radio to find the start time for shooting the northern end of OBS line1 (named OBS1A along line 92-13). The Titov could not afford to approach the Balkhash in order to establish VHF radio communication because of lack of fuel. Decision was made to wait in the channel separating Olkhon Island and Olkhon peninsula ("Olkhon Gate") and start deploying at midnight for an anticipated start of shooting at 9/21 10:00 LT. The OBSs had already been programmed to start recording at that time but at 19:00 LT we received a weather forecast predicting a storm overnight. We gambled and aborted deployment and reprogrammed the OBS to start recording 24 hours later. The Titov also moved to the sheltered water off the northern end of Olkhon Island in the hope of getting within VHF range from the Balkhash. Attempts to communicate with the Balkhash continued throughout the night and early morning of 9/20 and finally by 08:00 LT, the Balkhash came on the air and informed that indeed as of 03:00 LT the streamer and gun were ordered by the Captain to be pulled in because of bad weather. By midday the sea calmed and the weather was fine. Unable again to communicate with the Balkhash, a decision was made to reprogram the OBS for the earliest possible recording time, 9/21 03:00 LT. The R/V Vereschagin came alongside in the sheltered water at 14:00 LT, supplied the Titov with 2 tons of diesel oil, and delivered a telex. At 15:10 LT the Titov started toward the southernmost OBS station. Communication was finally established at 16:00 LT at which we learned that the captain of the Balkhash left for the day to buy cigarettes and that the Balkhash will start shooting at or after 9/21 03:00 LT. Deployment of six OBS proceeded smoothly and ended at 9/21 02:15 LT in Barguzin Bay. The Balkhash started shooting the line south from Barguzin Bay at about 04:40. Shooting speed was 3.75 knots with a shot every 27 sec. to ensure that first arrivals from 130 km away are not truncated. Shooting ended at 9/21 23:30 LT. The Titov spent the night anchored off Svyatoy Nos and spent the day tied to the pier in Ust Barguzin. The following night was spent again fishing off Svyatoy Nos. At 9/22 06:11 LT the Titov arrived at the northernmost OBS station, C1, in Barguzin Bay and 10 minutes later the OBS was on board. The second OBS was released and retrieval went smoothly. The third OBS, A2, was released without a problem, but could not be found on the surface. After comparing notes it was found that the captain wrote down the wrong coordinates during deployment and navigated the ship back to these erroneous coordinates. The Titov sailed to the correct location, 3.7 km to the north, and the OBS was found and retrieved. The release of the fourth OBS was uneventful, but the fifth OBS, A1, which was at depth of 1595 m did not release the anchor. Instead of the expected sequence of release sounds (pings) there were random pings, due probably to multiple reflections of the transmitted signal. After a 1.5 hour long attempt the entire length of the transducer cable (30-40 feet) was lowered and the anchor released immediately. Since the bathymetry is flat, it is hypothesized that the the multiples reflect off the thermocline or a more shallow boundary within the water. A similar problem was encountered in the release attempt of the last OBS, A3, so the transducer was lowered to the maximum cable length and the OBS released immediately and retrieved at 18:37 LT. The Titov then headed to Listvyanka as the main generator on the ship no longer functioned due to a broken lever arm. The scientists on the Balkhash requested another deployment across Posol'sky Bank but the captain of the Titov refused to continue working with only one generator. With one (small) generator the power supply to the GPS clock and other electronic equipment became unstable. A sixth deployment was therefore cancelled. Titov arrived at Listvyanka at 9/23 05:45 LT, and demobilization of the equipment on board was completed 10 hours later.

RECOMMENDATIONS

The biggest problems revolved around the acoustic release equipment. The power supplies for the deck electronics need to be replaced with units that are not as susceptible to noise as the existing units. Five of the eight OBS's use the newer releases electronics, while the remaining three still use the older electronics. Since there is no compatibility between the two systems, all of the OBS's need to be converted to use the newer releases. Boards also need to be purchased to provide spares. Currently, a release failure means that the OBS can no longer be used.

Another problem highlighted in this experiment is the limited use for the small OBS spheres. These OBSs can be deployed in water depth less than 500 m. Water depth in the lake was almost everywhere larger than 500 m. In addition, OBSs deployed at water depth shallower than 100 m tend to suffer from a high noise level due probably to wave action. Therefore, there is a limited use for OBSs in wide shallow shelves. The depth limitation meant that the OBSs could not be deployed at even intervals, which adversely affects the interpretation of the data. It is recommended that the small spheres be replaced with larger ones capable of deployment to 5000 m.

The data record time of 36 hours has proven to be only marginal in these type of operations. Using a sampling rate of 100 samples/second, instead of the current 200 samples/second, would increase the record time to 72 hours. Increasing the hard disk from 200 to 500 Megabytes should also be explored. There is no temperature data on these drives yet, but the new drive could double the record time while preserving the original sample rate.

Bad weather during and after the first deployment prevented any retreival of the OBSs for 5 days. The current battery life will maintain operations for approximately 7 days (although this has to be unequivocally tested in the lab). Using small boats that do not have the rough weather capability makes the seven day limit a poor safety margin. This is especially true in operations where one day is required to deploy, 2 days for shooting the line, and another day for recovery. A 3 day weather delay could be disastrous. The safety margin will also be inadequate if the recording window is doubled or tripled in the near future. The solution that should be explored to solve this problem is to use a low-power temperature-compensated oscillator rather than the current high-power oven-controlled oscillator. The oscillator draws by far more power than any other component in the OBS. The change in oscillator would increase the deployment time by a factor of three. In operations where the oven-controlled oscilators are required, lithium batteries should be used to increase the deployment by a factor of two.

The OBS operations in Siberia were successful despite the many problems in the release and recording equipment. The communication problem was severe and should, in the future, warrant the expense of renting satellite communication units. The HF radios used on Russian vessels are inadequate for reliable communications, and the lake was too large for line-of-sight radios such as VHF.

This operation illustrates the problems of using the OBS's in a ship-of-opportunity, multiship operations. There is an increasing need for portability and a decreasing availability of facilities for OBS operations. More spares are needed to quickly repair OBS's, since there is usually not enough time to troubleshoot problems between lines. Longer recording times for the OBS's are needed to ease some of the problems in communications. The larger the time window available for shooting, the more adjustments that can be tolerated in the shooting ship's schedule. A small shipping container should be setup to act as a lab to use in situations where lab space is not available. The plywood lab used on the Titov was too small and unsafe.

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APPENDIX 1

Crew list R/V Titov

Uri S. ten Brink	-	USGS, Scientist
Gregory K. Miller	-	USGS, OBS technician
Alik Badardinov	-	Limnological Institute, Listvyanka, Liason
Marc Behrendt	-	Duke University, Translator
Dwight F. Coleman	-	USGS, assistant (until 9/12/92)
Alexander Sakhalov	-	Captain
Victor Platonov	-	Chief engineer
Sergey	-	Mate
Vasili	-	Oiler
Valera	-	Radio man and deck hand
Valera	-	Deck hand
Alexandra Alexandrovna	-	Cook

APPENDIX 2

Instrument location (see map)

Deployment 1

Locations were similar (within ± 50 m) to these of Deployment 2. The line was not shot.

Deployment 2 - Line OBS1 - Central Basin

OBS I.D.	Lat/Long		Water depth (m)				Comments
	at deployment	at retrieval	deploy	retrieve	map	ranging	
OBS C4	53 30 57 108 45 25	53 30 57 108 45 17	108	112	-	-	Failed to record data
OBS A3	53 19 36 108 16 48	53 19 34 108 16 48	1655	1664	1542	-	
OBS A1	53 07 33 107 46 42	53 07 31 107 46 47	1713	1713	1614	-	
OBS B1	52 52 20 107 09 08	52 52 18 107 09 07	1497	1496	1423	1445	Failed to record data
OBS A2	52 37 57 106 34 46	52 37 55 106 34 49	1131	1143	1028	-	
OBS C1	52 26 22 106 07 18	52 26 21 106 07 19	322	322	~300	-	Started recording at 9/9 09:00 GMT
OBS C9	52 24 36 106 03 10	52 24 38 106 03 12	456	455	~440	-	No hydrophone data

Deployment 3 - Lines OBS2 & OBS3 - Across and along Academician Ridge

OBS I.D.	at deployment	at retrieval	deploy	retrieve	map	ranging	Comments
OBS B1	53 21 52 107 52 03	53 21 50 107 52 00	716	714	+700	-	
OBS C1	53 12 20 108 25 26	53 10 19 108 25 26	143	149	+100	-	
OBS A1	53 21 28 108 14 49	53 21 30 108 14 56	1710	1710	1618	-	
OBS A2	53 30 28 108 04 24	53 30 29 108 04 24	711	711	~580	-	
OBS A3	53 42 00 107 50 53	53 41 59 107 50 53	732	730	~660	-	
OBS C4	53 43 01 108 21 46	53 43 00 108 21 46	365	364	~300		
OBS C9	53 51 59	53 52 05	174	188	-	-	250 m before target because

	108 34 55	108 35 05					bathymetry was deepening

Deployment 4 - Line OBS4 - Northern Basin

OBS C4	53 30 06 107 35 56	53 30 02 107 35 56	174	171	134	168	
OBS C9	53 33 21 107 42 20	53 33 20 107 42 23	499	499	~460	470	Failed to record data
OBS A1	53 44 22 108 03 33	53 44 22 108 03 30	916	917	~840	873	
OBS A2	53 55 11 108 24 34	53 55 12 108 24 36	886	935	~870	885	
OBS A3	54 07 20 108 48 19	54 07 22 108 48 21	922	863	-	876	Multiple transducer returns
OBS B1	54 19 25 109 12 24	54 19 26 109 12 24	698	707	~650	-	Close to submarine scarp ~460 m deep
OBS C1	54 25 07 109 24 21	54 25 07 109 24 19	263	269	-	-	Failed to record data

Deployment 5 - Line OBS1A - Central Basin

OBS A3	52 52 24 107 09 10	52 52 24 107 09 08	1496	1499	~1400	1418	
OBS A1	52 59 53 107 27 23	52 59 56 107 27 24	1681	1386	~1585	1595	
OBS B1	53 13 41 108 01 55	53 13 40 108 01 54	1712	1714	~1605	1630	
OBS A2	53 25 55 108 32 50	53 25 58 108 32 40	1454	1452	~1200	-	Map shows complicated bathy.
OBS C4	53 28 56 108 40 19	53 29 00 108 40 20	420	422	~390	-	
OBS C1	53 31 59 108 47 36	53 31 59 108 47 38	41	41	30-60	-	

Explanations:

1. Horizontal location was measured by GPS using Magellan Pro-1000. Accuracy is estimated to be ± 50 m. Vertical location (lake level) was assumed to be 455 m a.s.l.

2. Water depth at deployment and retrieval was measured by the Titov's sonar NAL-10 (with a frequency of 25 KHz and a range of up to 2 km). The sonar displays water depth in meters which is

calculated using the acoustic velocity of sea water (1500 m/s). The sonar has not been calibrated for at least 2 years and is probably accurate to within 5%.

3. Water depth from map refers to water depth from 1:300,000 Russian navigation charts of Lake Baikal.

4. Water depth from ranging refers to the azimuthal distance measured from an EG&G SeaLink transducer to the OBS at the sea floor. The range is corrected for fresh water velocity (~1440 m/s). The transducer was lowered to ~3 m below sea surface and the range was taken when the ship was stationary at the coordinates of deployment.

APPENDIX 3

Universal Time

Deployment 2 - Line OBS1 - Recording time 9/8 12:00 - 9/10 00:00

OBS	time deployed	hove to station	time released	time spotted on surface	time retrieved on board	Comments
OBS C4	9/7 20:25	9/10 -------	17:55	17:58	18:04	
OBS A3	9/7 20:52	9/10 14:47	14:57	15:19	15:38	
OBS A1	9/8 01:26	9/10 09:55	23:55	9/11 00:18	00:24	Abandoned site at 12:30; returned to site at 23:05
OBS B1	9/8 04:38	9/10 06:31	06:33	06:56	06:57	
OBS A2	9/8 08:06	9/10 03:24	03:25	03:41	03:45	
OBS C1	9/8 08:11	9/10 01:00	01:01	01:05	01:09	
OBS C9	9/8 10:34	9/10 00:24	00:24	00:31	00:35	

Deployment 3 - Line OBS2- Recording time for OBS C1, A1, A2, A3 - 9/13 07:00 - 9/14 19:00
Line OBS3 - Recording time for OBS B1, C4, C9 - 9/13 13:00 - 9/15 01:00

OBS B1	9/12 14:11	9/15 11:18	11:19	11:28	11:45
OBS C1	9/12 16:38	9/14 00:02	00:02	00:05	00:10
OBS A1	9/12 17:55	9/14 23:30	23:42	9/15 00:07	00:11
OBS A2	9/12 19:07	9/15 09:49	09:49	09:59	10:05
OBS A3	9/12 20:37	9/15 03:02	03:09	03:18	03:22
OBS C4	9/12 22:35	9/15 07:52	07:53	07:58	08:03
OBS C9	9/12 23:55	9/15 03:28	03:29	03:31	03:35

Deployment 4 - Line OBS4- Recording time 9/16 15:00 - 9/18 03:00

OBS C4	9/16 00:04	9/18 11:19	11:20	11:22	11:27
OBS C9	9/16 00:40	9/18 10:34	10:36	10:43	10:46
OBS A1	9/16 03:50	9/18 08:33	08:34	08:47	08:50
OBS A2	9/16 05:58	9/18 04:26	06:28	06:39	06:46
OBS A3	9/16 07:57	9/18 03:18	04:00	04:15	04:21
OBS B1	9/16 09:55	9/18 01:01	01:03	01:12	01:16
OBS C1	9/16 10:56	9/17 23:50	23:52	23:55	23:59

Deployment 5 - Line OBS1A - Recording time 9/20 18:00 - 9/22 06:00

OBS A3	9/20 09:21	9/22 09:11	09:19	09:34	09:37	
OBS A1	9/20 10:46	9/22 05:42	07:15	07:38	07:42	Release problem, alleviated by lowering transducer to ~12 m
OBS B1	9/20 13:26	9/22 02:29	02:33	02:57	03:01	
OBS A2	9/20 15:50	9/21 23:03	23:05	9/22 00:01	00:04	
OBS C4	9/20 16:29	9/21 22:02	22:02	22:07	22:18	
OBS C1	9/20 17:05	9/21 21:11	21:12	21:13	21:20	

APPENDIX 4

Balkhash navigation and source information

Navigation on the Balkhash was based on an Ashtech GPS Receiver model XII. The location of the Ashtech antena was 28.5 m forward of the stern of the ship. The distance from the ship's stern to the center of the airgun array was 25 m. The distance to the two large guns was 50 m. The airgun array was towed at a depth of 6 m, and the two large guns were towed at a depth of 25 m.

Shot-instance information was initiated via a hydrophone in the gun array and transmitted as a 5 volt pulse to the navigation computer where is was recorded together with shot location.

OBS Lines 1 (Central Basin) and 4 (Northern Basin) were shot with two 60 liter airguns (total of 7320 cu. in.). These guns were fired at a two minute interval with a pressure of 1600-1700 psi. Average ship's speed during these lines was 4-4.1 knot resulting in nominal shot spacing of about 240 m. An attempt was made to tune the pulse by introducing a delay of 40-60 msec between the firing of the two guns. The first 1.5 hours of shooting Line 1 was spent adjusting the delay.

OBS Lines 2 (across Academician Ridge) and 1A (the northern part of Line 1) were shot with a tuned array of 10 airguns with a total volume of 27.3 liter (1665 cu. in.) and pressure of 1900-2000 psi. The airguns were sleeve-type guns built in Russia. They were divided into three clusters and towed from two points at the fan tail, port and starboard. Shot spacing was 50 m. During Line 2 the ship sailed at 4-4.4 knots and fired at intervals of 23-25 seconds. During Line 1A the ship sailed at 3.75 knots and fired at interval of 27 seconds. Further source and navigation information is detailed in Nichols et al. (1993).

Line	start JD/time	end JD/time	course (deg.)	length (km)	shot points	start position	end position
OBS-1	252/1230	253/2140	054	244.2	1-986	52.279397 105.764838	53.518203 108.76158
OBS-1*	253/2210	254/0008	236	14.0	1001-1061	53.510205 108.741602	53.440452 108.565840
OBS-2/ MCS 92-46	257/0812	257/1603	325	61.0	1-1180	53.251878 108.376358	53.700253 107.846888
OBS-4/ MCS 92-17A	260/1506	261/1210	229	163.9	5-641	54.434412 109.436113	53.454992 107.572212
OBS 1A/ MCS 92-13	264/1941	265/1349	237	137.3	1-2589	53.501733 108.722485	52.816503 107.016140

* Upon arrival at the northern end of Line 1, the Balkhash turned around and repeated the line southward until the recording window on the OBSs ended.

Other MCS lines shot during which OBSs were recording:

MCS 92-21	257/1651	257/2235	173	46.2	1-839	53.666790 107.792267	53.254498 107.878360
MCS 92-15	261/1925	262/0908	040	107.9	1-2055	53.345518 107.837772	54.083445 108.898247
MCS 92-36	265/1551	265/1918	140	28.2	1-525	52.849025 107.015898	52.654285 107.283753
MCS 92-34	265/2111	266/0139	319	35.0	1-680	52.625468 107.138132	52.862920 107.797945
MCS 92-32	265/0335	265/0704	139	26.7	1-515	52.768828 107.716980	52.587982 107.976357

APPENDIX 5

OBS performance

A total of five deployments were carried out during the experiment. On the first deployment OBS A-3 had a failure in it's release prior to deployment. Since the lake bathymetry required the use of large spheres, The release electronics from OBS C-3 was installed in OBS A-3. This meant that 7 OBS's were available for deployment. No other problem were encountered in this deployment. Shooting of the line did not occur because of bad weather, so the instruments were retrieved and redeployed as quickly as possible. The line was shot on the second attempt. OBS C-1 was deployed late due to repair problems in its release (a broken ground wire). On recovery OBS C-4 had no data because of a hard disk failure, and OBS B-1 had no data because of an Analog-to-Digital converter failure. OBS A-1 require repair of its release circuitry before it could be redeployed. Lines 2 and 3 were deployed at the same time. Unfortunately, line 3 was never shot. All instruments worked without problems. In deploying line 4, OBS C-9 had severe release problems. Since it appeared that the chances for recovery were good, this OBS was deployed anyway. The line was shot, and all seven OBS's were recovered. OBS C-9 failed to record any data as the air test of the release prior to deployment caused a power loss which scrambled the dataloggers memory, losing any programming. OBS C-1 failed to record any data because the connector of the oscillator became dislodged. The deployment operations were done by hand using a block and tackle. On this occasion, the line slipped and the OBS hit the water hard, dislodging the oscillator. OBS C-9 could not be repaired, so it was retired from service. OBS B-1 had its hydrophone damaged during recovery (it was replaced by a spare unit). OBS A-1 would indicate that it had released when it had not actually released. This turned out to be a frozen bearing on the release clevis which was repaired. It was necessary to reprogram the OBS's three times before line 1A was actually deployed. Eventually six OBS's were deployed, the line was shot, and all six OBS's were recovered. All instruments worked without problems.

Summary of failed or damaged equipment, which need repair:

2 Releases (for OBSs A3 and C9).

1 hydrophone.

1 battery pack.

1 hard disk.

APPENDIX 6

Ship's operation

The R/V Titov, named after the second Soviet cosmonaut, General German Stepanovitch Titov, Hero of the Soviet Union, is a converted fishing boat with a length of 25 m, width of 5 m, drought of 2 m, and a 137 metric tonne displacement. The ship is owned and operated by the Limnological Institute of the Siberian Branch of the Russian Academy of Science. The age of the ship is unknown but she has been in dry dock for the last five years being rebuilt and refitted for science. This OBS experiment was her maiden voyage. Most of the ship's systems performed well although the sixth deployment had to be cancelled because of a problem with the ship's main generator.

The ship was only minimally suitable for the OBS work and for a long cruise. The only lab space was below deck and accessed through a steep and narrow staircase and a long and narrow corridor. Since there was no way to lower the OBS below deck, a plywood shack was built on deck. The shack covered the only open space on the deck, measuring 2.5 meters by 3 meters. Two doors were built to accommodate the transfer of an OBS inside the lab. The shack had no floor and was flooded when seas were rough or when the deck was washed. The plywood boards were peeling off layers of wood as the cruise proceeded. The structure was held by nails that were driven in at the top of each corner, and ropes were attached from each nail to some fixture on the boat. The ropes helped to keep the box on the deck and kept the box from twisting excessively. A sheet of tarp was tied to the roof to prevent rain from entering the shack. Inside there were two benches. A small one held the dataloggers and a power supply to keep them powered. The other bench held the computer, GPS clock, frequency counter, and the oscilloscope. A VHF radio for communication with the other ship was mounted on the wall. The release deck equipment was stored under the large bench. Two plastic shipping cases were used to keep the batteries and other expendables dry. With an OBS was dismantled inside, there was enough room for two people, as long as they were on friendly terms. The shack was nicknamed the "Winter Palace" for its spartan accommodation and noticeable lack of heat. Work on the OBS under these conditions was difficult. In addition, the ship could not operate under rough weather for fear that the shack would blow away.

The ship has a forward deck cluttered with winches, a life boat, and various entries and covers to spaces below deck. With the shack, and the anchors, and OBSs on deck, there was little room left for movement during deployment and retrieval. Out of 5 winches located on deck, only one was functional and it was located forward were deployment was impossible. All overboard operations were therefore, carried out by hand using a block and a tackle tied to a boom above the center of the boat. The OBS's anchors had to be strategically located all over the ship to avoid any significant list. At the beginning of the expedition, the ship had a bad roll moment from all of the weight sitting high on the deck. This situation improved as the anchors were used up. After each line was deployed, the anchors had to be relocated to redistribute the weight. Security at the dock was a serious problem. Guards were either unavailable or unreliable, and theft was common. This meant that mobilization had to be done all at once, and, once loaded, someone had to remain with the ship at all times.

The crammed living quarters, crowded deck, and small lab were inadequate for a 25-day cruise with 13 people on board. Fortunately, frequent port and beach stops eased the crowding. Additionally, the ship's crew was extremely helpful and considerate and kept the ship in good sanitary conditions. The professionalism and enthusiasm of the ship's captain and crew compensated for the difficult conditions and assured smooth and rapid deployment and retrieval of the OBSs.

APPENDIX 7

Power limitations

In specifying the equipment and supplies for this operation, consideration was made for power, timing accuracy, archiving the acquired data, and general deployment and maintenance parts. The power available on Russian vessels is 220 volts 50 Hertz. Some of the newer vessels use a three-wire system with the lower pin tied to ground, but most use the standard two-wire system with one hot wire and a neutral. Neutral is not tied to ground and can be as much as 150 volts above ground. A grounding network of all pieces of equipment are tied together and then connected to the ship's hull to alleviate any electrical hazard. After installation of the equipment on the ship, any signal grounds on the equipment are also checked and tied to earth ground if necessary. To provide power to the electronics, one primary and two backup systems were used. The primary system uses a 2.2 Kilowatt uninterruptable power supply (UPS) to convert the 220 volt 50 Hertz to 110 volts 60 Hertz. The UPS was modified to eliminate the bypass operation. The circuit that charges the DC battery supply was set for an input of 220 volts 50 Hertz. The rectifier that converts the DC supply to AC is set for 110 volts 60 Hertz. This system provides good isolation from spikes and provides battery backup for short term losses of power. The first backup power system is a 5 Kilowatt diesel-powered generator. Although the power output is twice the power needed, smaller units do not hold up as well under 24 hour operations. The final backup system uses several 1500 watt 220 to 110 volt transformers. This method requires that all of the equipment operate at 50 Hertz.

Providing power for the equipment also proved difficult. The multichannel ship (Balkash) utilized a 6 kW UPS system with an 8 kW generator as backup to power the electronics. The UPS system failed on the first day, and the generator was too large to load onboard the ship. The 2.2 kW UPS system (the primary power for the OBS operations) was used to power the multichannel electronics. The UNIX-based computers used to de multiplex the multichannel data had no power available, so the OBS generator was used to power these systems. This meant that both primary and backup power options for the OBS were no longer available, and the Titov's generators had to be used as the only source of power. The GPS clock, frequency counter, and oscilloscope were modified to operated using 220 volts 50 Hertz. The rest of the electronics were powered using 2, 1500 watt 220 to 110 volt transformers. Because of the wattage limitations, the Rb standard was not used in this operation. Grounding problems still existed even though each piece of electronics was tied to earth ground. The acoustic release electronics performed the poorest of all of the electronics. The external power supply used to power the electronics could not adequately filter out the noise generated by the ship's power. As a result, the receiver circuits were useless. The transmitter worked well, so all release operations were done by transmitting the release signal and assuming that the OBS did release. This procedure did not always work well, as the lake had a strong thermocline that made it occassionally necessary to make many attempts for each release.