PICTURES

Pisagua/Iquique Crustal Tomography to Understand the Region of the Earthquake Source

R/V Marcus Langseth MGL1610 Cruise Report

R/V Marcus Langseth entering the port of Arica

October 23 to December 9, 2016
Arica, Chile – Arica, Chile

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Emilio Vera (University of Chile, Santiago) – co-Chief Scientist
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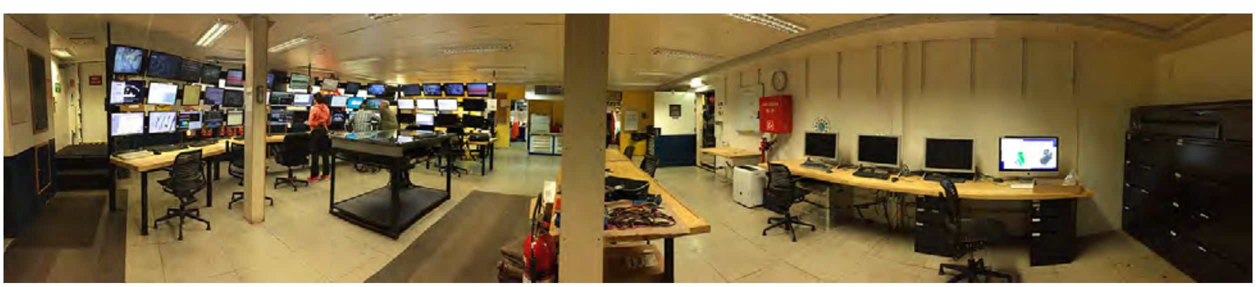
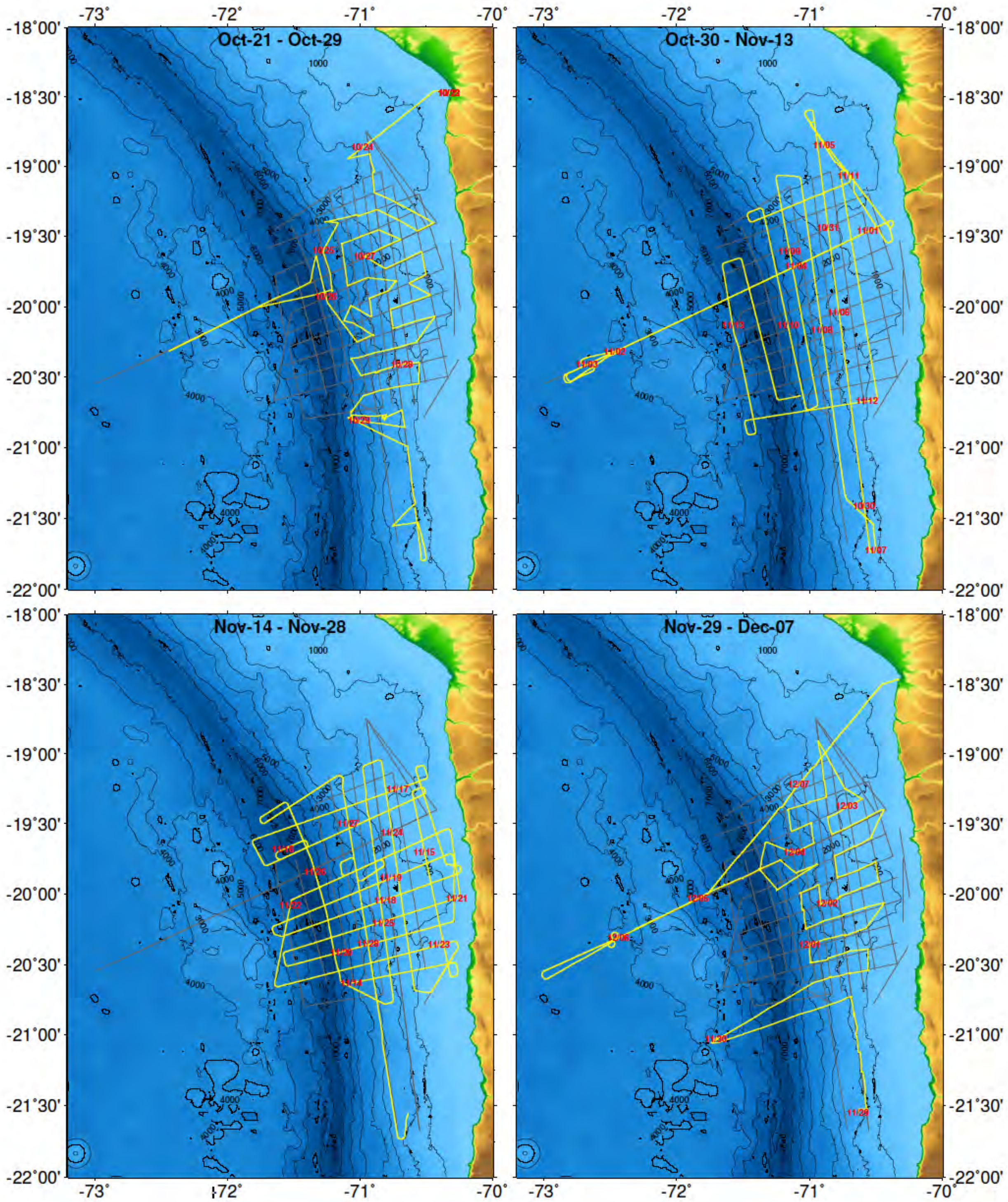
Table of Contents



Panoramic view of the main lab.

Frontspiece:
Track of MGL1610 in 4 parts:
OBS deployment;MCS, part 1;MCS, part 2; OBS recovery



Cruise Participants:

Technical personnel

Participant	Group/Affiliation	Position
Robert Steinhaus	L-DEO OMO	Chief Science Officer
David Martinson	L-DEO OMO	Science Officer – Nav/IT
Todd Jensvold	L-DEO OMO	Science Officer - Acq
David Manderfeld	Atlas Personnel	Acq- Contractor
Tom Spoto	L-DEO OMO	Chief Source Mechanic
Alan Thompson	L-DEO OMO	Marine Science Technician (Nav)
Gilles Guerin	L-DEO OMO	Marine Science Technician (Acq/IT)
Josh Kasinger	L-DEO OMO	Source Mechanic
TBD	Atlas Personnel	Source - Contractor

Protected species mitigation personnel

Participant	Group/Affiliation	Position
Cassandra Frey	RPS	Lead PSO
Brooke Stanford	RPS	PAM operator / PSO
Karla Rios	RPS	PSO
Yessica Vincenzio	RPS	PSO
Belen Sharon Torres	RPS	PSO

Science party members

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Redito, Ricardo M. Bosun USA
Quinn, Tara J. AB USA
Remegio, Tito H. Jr OS USA
Tucke, Matthew S Chief Engr. USA
Romero, Michael A. 2nd Asst Engr. USA
Connolly, Leo J. 3rd Asst. Engr. USA
Billings, Jack C. Oiler USA
McLean Fuller, Hervin Steward USA

Robinson, Daniel J. Chief Mate USA
Martin, Kevin J. 3rd Mate USA
Orias, Anthony M. AB USA
Cereno, George G. AB USA
Cole, Joshua P. OS USA
Stewart, Samuel C. 1st Asst. Engr. USA
McGean, Patrick A. 3rd Asst. Engr. USA
Kononchik, Gregory R. Oiler USA
Mallar, Michael A. Oiler USA
Martines, Leoncio R. Cook USA

Shipboard science party: (kneeling, front) Tom Spoto, (front row, left to right) Allan Thompson, Mark Gibaud, Michael Riedel, Jan Handel, Carsten Lehmann, Leo Connolly, Florian Petersen, Ernie Aaron, Josh Kasinger, Emilio Vera; 2nd row: Dave Martinson, Robert Steinhaus, man in the shadows, Felipe Gonzales; on stairs, from top to bottom: Cassie Frey, Brooke Stanford, Karla Rios, Yessica Vincenzio, Kathy Davenport, Emma Myers, Josh Manger, Sara Alhisni, Anne Tréhu, Sharon Torres

1. Scientific Objectives

The April 1, 2014 Mw 8.2 Pisagua earthquake offshore north Chile partially filled a well-recognized seismic gap that had not experienced a very large earthquake since a pair of earthquakes in 1868 and 1877. The rupture sequence was marked by an unusually long and distinct precursory period that was well recorded by onshore seismic and geodetic instruments deployed as part of the Integrated Plate Boundary Observatory Chile (IPOC) and is widely considered as an event that has great potential for contributing to a better understanding of how slip evolves to generate a large earthquake (e.g. Schurr et al; 2014; Ruiz et al., 2014; Brodsky and Lay, 2014; Burgmann, 2014; Hayes, 2014). Figure 1A shows the earthquake history of northern Chile and southern Peru since 1868.

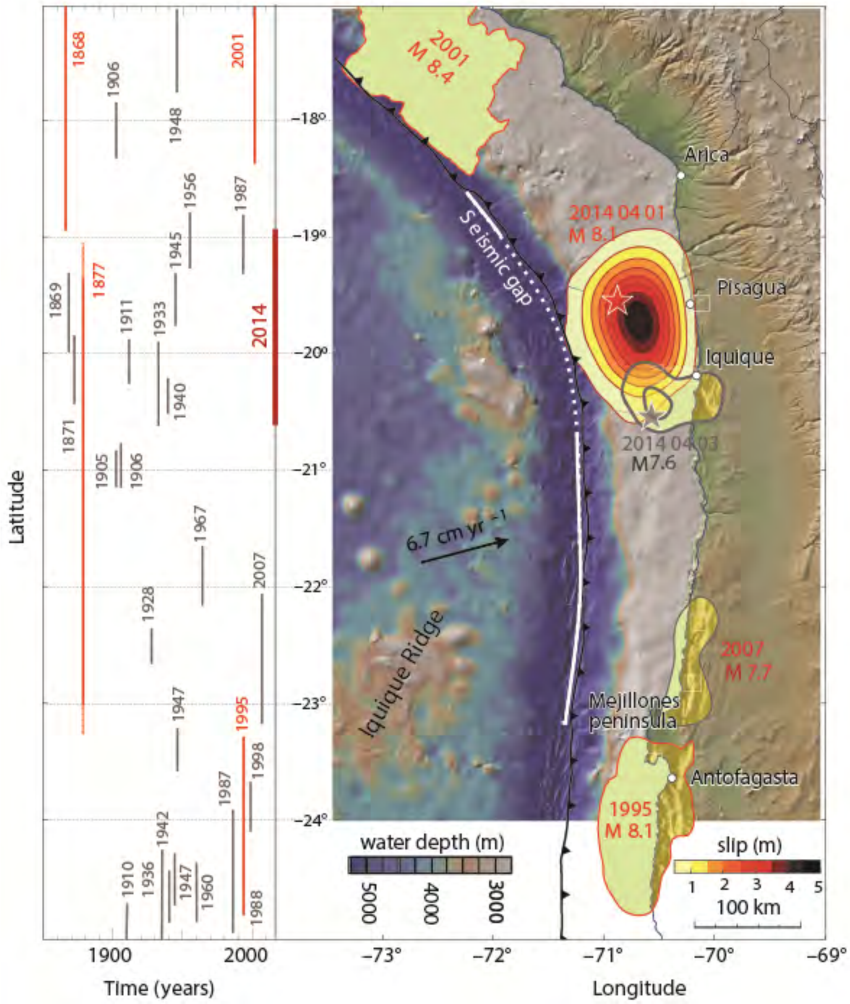


Figure 1A. Vertical lines labeled show the estimated latitudinal extent of the rupture zone in different earthquakes, with the largest events highlighted in red. Figure 1B shows the topography of the seafloor. The Nazca/South America plate boundary and relative plate velocity are also shown. The Schurr et al. (2014) slip model is shown with a contour interval of 1 m. The rupture areas of other recent earthquakes are also shown. The dashed white line shows the segment of the plate boundary that ruptured during the 2014 earthquake, and the solid white line shows the remaining gap. Has the entire gap ruptured at once, it could have generated an earthquake as great as ~M9. (adapted from Schurr et al., Nature, 2014)

The pattern of foreshock activity (Figure 2) is correlated with a donut-shaped relative gravity high (Schurr et al., in review) and the patch of greatest slip corresponds to the gravity low in the middle of the "Mogi donut" (Figure 3). Moreover, southward propagation of the rupture stopped at the northern edge of a large gravity high, which also is correlated with an apparent band of relatively low pre-earthquake coupling, as derived from onshore GPS data (Metois et al., 2013).

These correlations all suggest that crustal structure and/or composition strongly affected the slip history. No crustal-scale, controlled-source seismic observations exist in the Pisagua earthquake source region, however, and the resolution of the gravity data does not allow for a detailed geologic interpretation of the apparent correlation between structure and slip. The seismic tomography and reflection imaging data acquired during this survey will be used to develop a high-resolution model of upper and lower plate crustal structure in this region to address the following hypothesis:

Slip during plate boundary earthquakes is controlled in large part by the geologic structure of the upper and lower plates and the rheological properties of the boundary zone between them. Superimposed on these deterministic aspects of fault heterogeneity may be apparently chaotic behavior resulting from rate-dependent friction and short time-scale temperature and pressure perturbations.

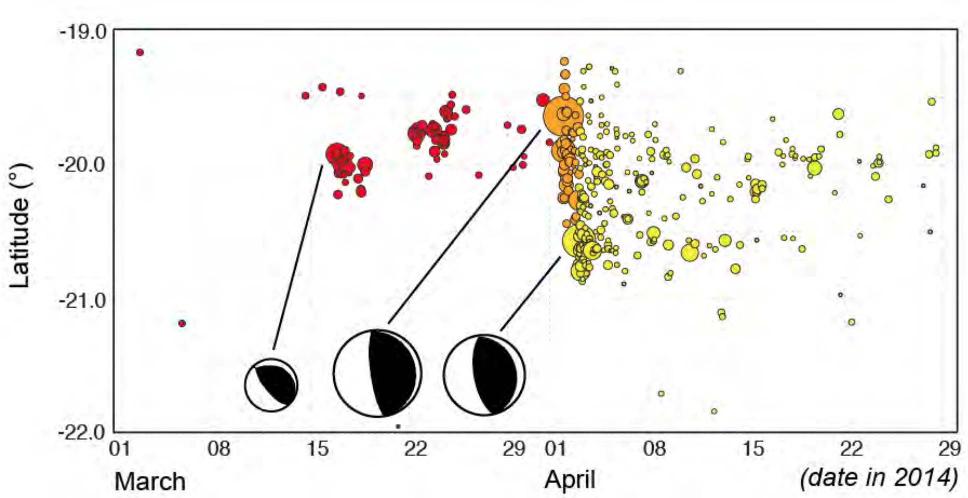


Figure 2. Earthquake sequence shown as a function of time. The focal mechanism for the mainshock and the largest fore- and aftershocks are also shown (from Hayes et al., 2014). Note 2 distinct clusters of foreshocks and the distinctly different mechanism for the largest foreshock, appears to have occurred on a splay fault in the upper plate (Schurr et al., in review).

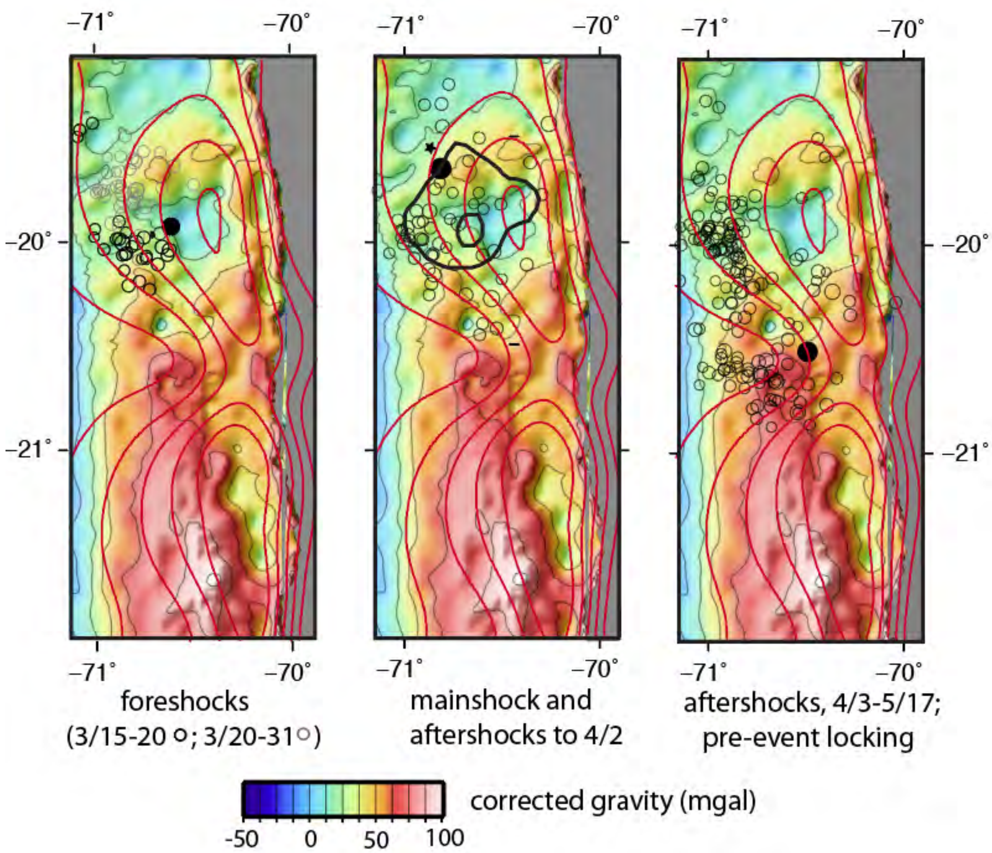


Figure 3. Earthquake sequence overlain on free-air gravity from Sandwell and Smith v18.1 accessed via GeoMapApp (left panel). The left panel shows the locations of 2 major foreshock clusters as open circles scaled by magnitude, with the largest foreshock shown as a solid dot. The middle panel shows the NEIC epicenter of the mainshock (black dot) and immediate aftershocks as well as slip contours from the model of Duputel et al. (2015). The right panel shows later aftershocks, including the epicenter of the largest (M7.7) event. Red lines on all three panels show pre-earthquake locking contours from Metois et al. (2013) constrained by onshore geodetic data.

2. Survey Design

The original survey design was for a 2-ship experiment, with R/V Sonne deploying and recovering OBSs and R/V Marcus Langseth shooting seismic data. Proposals were submitted to both the NSF and the German funding agency. Alternatives were suggested in case only one proposal was funded or if both were funded but the ships were not available at the same time. Both proposals were ultimately recommended for funding, but at different times. Consequently, we developed the 2-phase scenario described in this section. The NSF cruise, originally scheduled for late 2015 or early 2016, represents phase 1, and the GEOMAR cruise, planned for 2019, represents phase 2. After several delays, the NSF cruise presented in this report occurred in late 2016.

The objective of phase 1 was to image the source region using controlled sources recorded on a multichannel streamer and an array of ocean bottom seismometers. The OBS array consisted of 50 short-period, 4-component OBSs provided by the SIO group of the US OBSIP and 19 short-period OBSs provided by GEOMAR. Five of the GEOMAR OBSs were rated to ocean depths up to 8000 m and were shipped to Arica, Chile for this experiment. The other 14 GEOMAR OBSs (rated to 6000 m water depth) had spent the past 2 years on the seafloor and were recovered and redeployed during PICTURES.

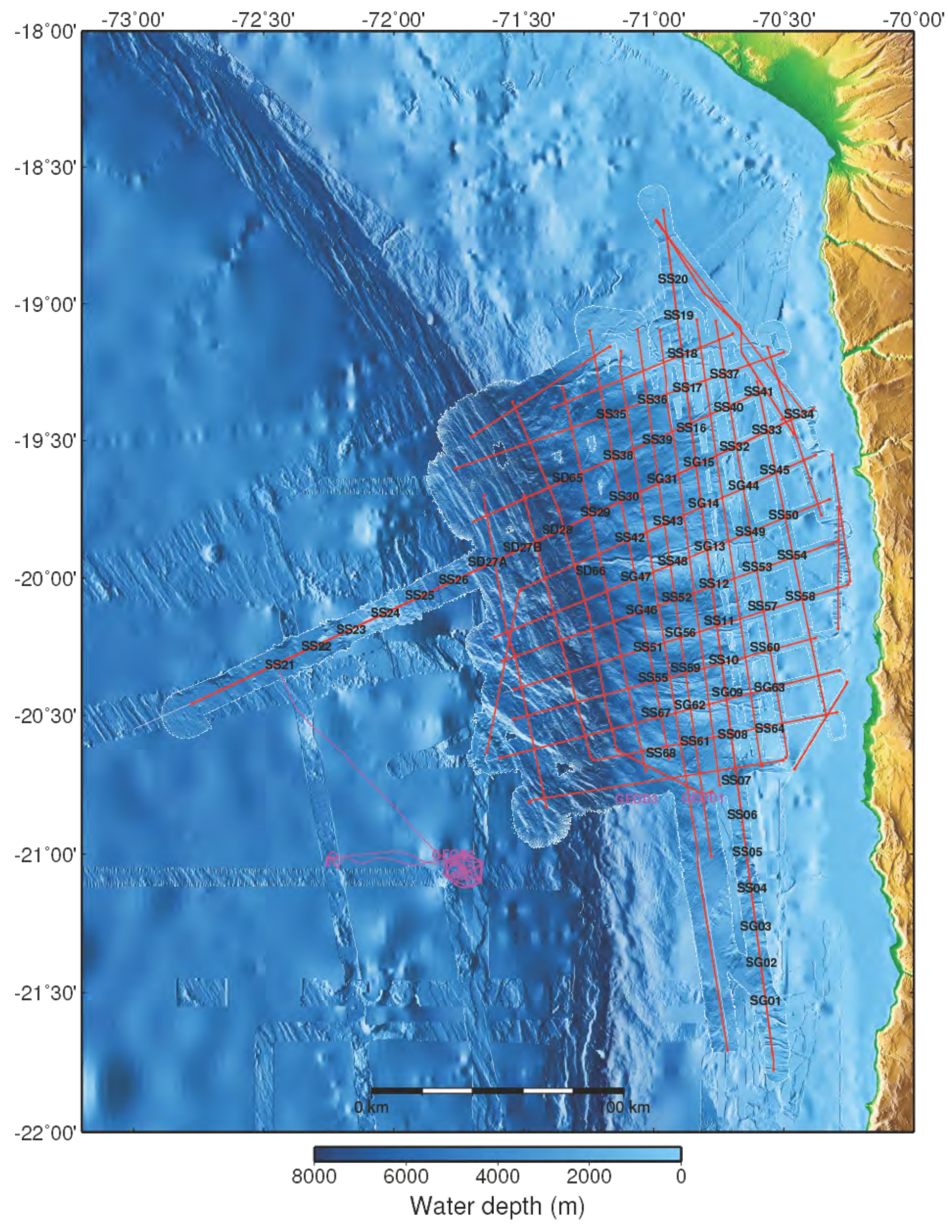


Figure 4. Locations of OBSs and geodetic arrays overlain on bathymetry. Bathymetry includes new data acquired during PICTURES as well as data from previous cruises (accessed via GeoMapApp, www.geomapapp.org; Ryan et al., 2009). OBS instruments codes are SS for sites with SIO OBSs, SG for GEOMAR 6000-m OBSs, and SD for GEOMAR 8000-m OBSs. GEOD1-3 are the geodetic arrays; pink line is the wave glider track. Red lines are shot lines.

The footprint of the OBS array, shown in Figure 4, includes two long linear arrays that cross and extend from the 2D grid. The SW/NE linear array extends across the Iquique Ridge to better characterize the structure of the Nazca plate. The SE/NW linear array extends across the "creeping" region that may have acted as a barrier to slip in 2014 and into the remaining gap, which corresponds to a gravity high (Figure 3). Data from this profile will be used to help plan the experiment design for Phase II. GEOMAR recoveries and redeployments were interspersed with SIO deployments.

The two long profiles were shot twice: once at a shot interval of 300 m (~120 s) prior to deployment of the multichannel streamer to provide observations of upper mantle refracted arrivals to offsets of ~100 without interference from water-borne energy from the previous shot; and once at a shot interval of 50 m (~20 s) with a 12.5-km long, 1008 channel hydrophone streamer. A shorter line was also acquired in the NE part of the survey region to join the two long lines. Shooting began at the southern end of the survey region, with the long EW line called OBS03, followed by OBS02 (the short connecting profile) and OBS01. We then retraced our track to shoot the MCS profiles. The long EW MCS profile contains a gap and is treated as two profiles, MC01 and MC01A.

The rest of the shots were acquired in a grid pattern over the main part of the array using a shot interval of 125 m and an 8-km long streamer. The streamer was shortened from 12.5 km (1008 channels) to 8 km (640 channels) to save time on turns and allow for a faster towing speed of 4.5 kts, allowing us to acquire more line length and shots within the allotted time. The shot interval of 125 m represents a compromise between the need for close shot spacing and the need to avoid interference from previous shot noise.

A total source volume of 6600 cubic inches, provided by 4 strings of 10 airguns each, was used for all profiles. The source was towed at 12 m depth for the 300 m and 125 m shot intervals and at 9 m depth for the 50 m shots. Figure 5 shows the configuration of the streamer and source array.

XBTs were acquired at 4 hour intervals during MCS shooting of the 2 long profiles (MC01/01A and MC03) to provide constraints on temperature for seismic oceanography and approximately daily for the rest of the cruise. XBTs were also acquired at two of the sites where seafloor geodetic information was uploaded (see below).

Swath bathymetric (EM122) and 3.5 kHz (Knudsen) subbottom profiling data were acquired when acquiring seismic data. Our permit did not allow for acquisition of high-frequency seafloor acoustic imaging data when we were not shooting airguns, except for a brief period just before deploying or recovering an OBS (needed to ensure that the instruments was being deployed in a suitable site). Consequently, we were not able to use unused contingency time to acquire additional swath mapping data in this region, which contains large regions of complex structure for which no swath bathymetric data are available

Additional underway data included ADCP, gravity, magnetics, and meteorological and oceanographic parameters. Figure 5 shows selected underway data in map view. Maps showing selected underway data are shown color-coded along the track in Figure 5. Graphs for each day are shown in appendix A. Gravity data are not shown because of export control regulations, but processed gravity data should be available from the R2R web site within a few months of the cruise.

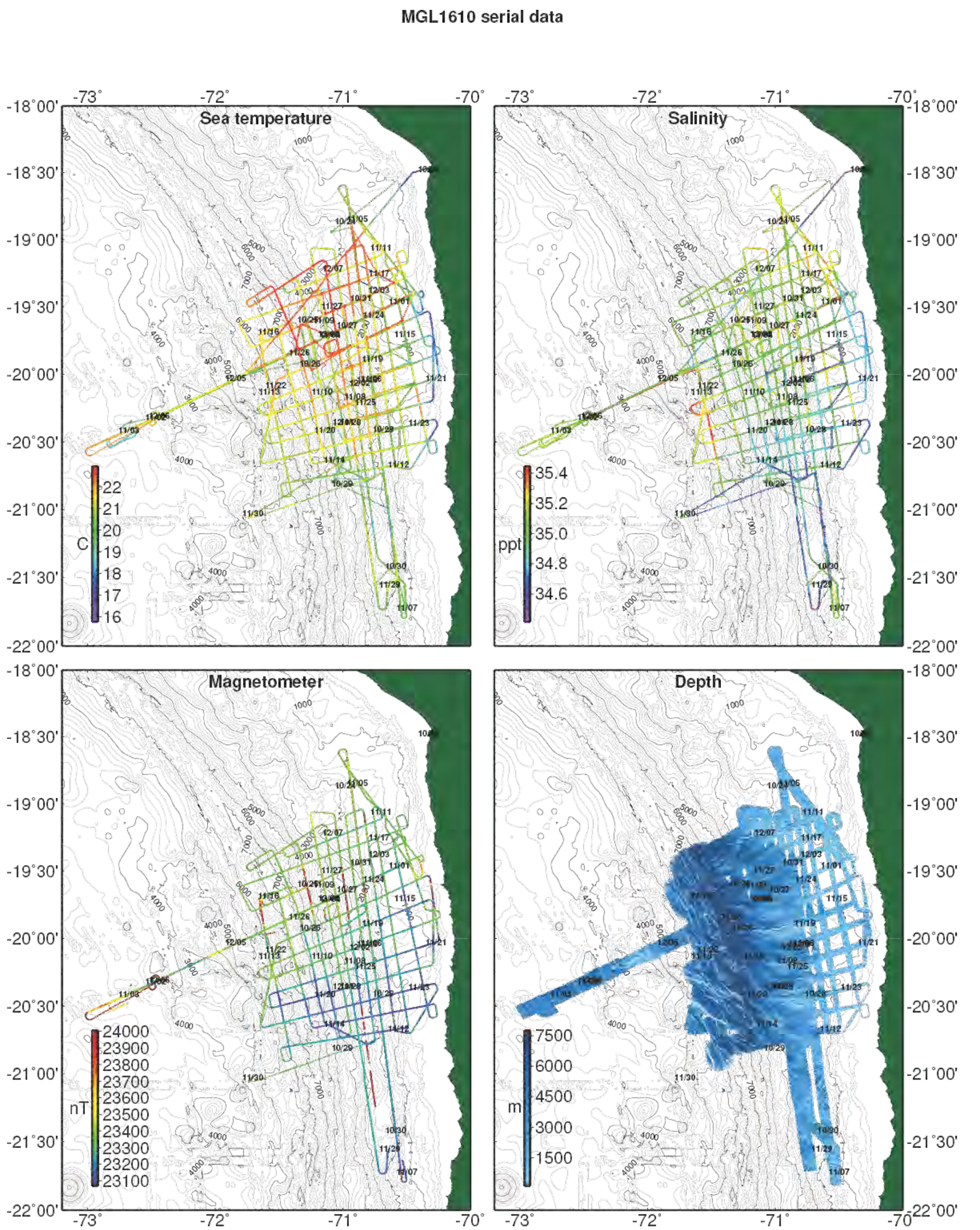


Figure 5. Maps showing environmental temperature, salininty, magnetics and bathymetry along track. Graphs of these and other serial data acquired during MGL1610 are shown in appendix A.

As an add-on to this project, we uploaded geodetic data from 3 seafloor arrays that had been installed by GEOMAR in December 2015. Although the original plan was to upload data from one of the sites located ~50 nm outside the primary work area using a Liquid Robotics Wave Glider deployed and recovered from R/V Langseth, the data rate for communication between the Wave Glider and the seafloor array proved to be too slow to be practical. We therefore obtained permission to transit to the 3rd site during unused contingency time to upload data using a transducer deployed from the ship at that site as well as at the 2 sites located adjacent to the OBS array. The locations of the geodetic arrays and the path of the wave glider are shown in Figure 4.

Finally, when it became apparent that there would be additional unused contingency time and we had not exhausted the shot allowance in our IHA, we sought permission to delay recovery of the last 6 OBSs (SS21-SS26; figure 4) and fire additional sources off the end of line OBS01 to the boundary of our permit area, thus extend coverage of the structure of incoming plate. These shots are referred to as line OBS01A. A request to use additional contingency time to extend swath bathymetric mapping was denied because of complications in the permitting process.

3. Cruise Narrative

(Note: Midnight UTC = 2100 Local time. All times below are in UTC.)

October 19-22: Science party arrived in Arica, Chile between on October 19-21. R/V Marcus Langseth arrived in Arica on the afternoon of October 21, with most of the science party watching from the top of El Morro. The science party moved on board on the morning of October 22.

October 23/JD297: We left port at 19:00. Seas were calm and the swell was <2 m. Because our IHA only allows multibeam and subbottom profiling during seismic operations, no bathymetric data were collected during the transit to the first site. Gravity, ADCP, and other general underway data were acquired. The EM122 and 3.5 kHz subbottom profiler were only turned on briefly on at 1500 m distance from a planned OBS site in order to verify that the water depths picked from maps prior to the cruise was accurate and that there were no obvious topographic deterrents to deployment. The EM122, 3.5 kHz and ADCP were all turned at off at 100 m distance to avoid possible interference when communicating acoustically with the OBS during deployment.

October 24/JD298: We arrived at the first waypoint at 00:05, where a rosette test of 25 of the SIO OBS releasers was conducted to 2000 m water depth. The test was completed at 02:30, and we proceeded to our first OBS drop site – SS20. The OBS drop was completed at 04:00. An additional 10 SIO OBSs were deployed and one GEOMAR OBS (deployed December 2015) was recovered by midnight.

October 25/JD299: Two GEOMAR OBSs and seven SIO OBSs were deployed by 19:09, when we deployed the first of 5 GEOMAR deep-water OBSs.

October 26/JD300: The 5th deep-water OBS was deployed at 00:22 and we began alternating between OBS drops and recoveries. By the end of the day, 13 OBSs had been deployed and 5 had been recovered. We held our first science party meeting at 15:30 local time. Robert Steinhaus presented an overview of operations as illustrated by a video made by students during MGL1211.

October 27/JD301: Nineteen OBS were deployed and 3 were recovered. The dynamic spreadsheet originally developed by William Wilcock for the Cascadia Initiative proved to be very useful for adjusting time estimates for future deployments and redefining parameters. We found that we had overestimated the amount of time needed on site for deployments. Both OBS groups were very efficient and ready to drop an OBS as soon as we arrived at a site. Student watch-standers showed great initiative at helping with deployments.

October 28/JD302: Today brought a change in pace, with the first attempts to upload data from a geodetic array deployed on the seafloor by GEOMAR in December 2015 at site GEOD1 (GEOMAR Area 3) in ~5250 m water depth. After only being able to upload ~2/3 of one (out of 10) array element in 1.45 hours because of poor signal to noise ratio, we abandoned this attempt and moved to the second geodetic upload site in ~3000 m water depth (GEOD2/Area 1). Before attempting to upload data, the chain that hangs below the transducer to stabilize it in the water column was taped up to damp any noise that might result from movement of the chain in response to swell (which was relatively small, a ~1.5 m). Upload at this site was successful, with data from 8 array elements uploaded in 6.7 hours. GEOMAR OBSs were successfully recovered at each of the geodetic data upload sites. We then deployed 2 SIO OBSs before returning to GEOD1. A total of 4 SIO OBSs and 1 GEOMAR OBS was deployed over the course of the day. We held our second science party meeting at 15:30 local time. Anne Tréhu presented the scientific rationale for PICTURES, which stimulated some interesting discussion.

October 29/JD303: The second attempt to upload data at GEOD1 was successful, with remainder of the data uploaded in 5.5 hrs. The deployment phase of the cruise was completed at 15:25 with the deployment of 3 more SIO OBSs, 2 GEOMAR OBSs, and recovery and redeployment of 1 GEOMAR OBS. This was ~48 hours earlier than originally anticipated at the beginning of the cruise but within a few hours of when anticipated after revising estimation parameters after the first day of deployments, demonstrating the value of near real-time updates of a dynamic spreadsheet for predicting the time of upcoming operations. At 16:14 the passive acoustic monitoring (PAM) was deployed to survey the region for submerged mammals. At 16:24, the magnetometer was deployed. The airgun array was in the water by 18:01, and testing began. Shooting of line OBS03 started at 19:17 with a total volume of 6600 cubic inches provided by 35 active airguns. At 22:39, as the line was passing over OBS SG03, the gun array was powered down for 4 minutes to a single 40 cubic inch gun because of the presence of a whale.

October 30/JD304: We continued shooting at a 300 m interval and 5 kt speed, leading to a shot interval of ~120 s, enough to provide "clean" data to an offset of 200 km. Although there were several times when the mitigation gun was needed because of the presence of protected species, and loss of one gun string for two shots to fix lines, no shut-downs were required (see tables for details). Many in the science party and crew took advantage of the privilege of a weekly 15-minute phone call home. We had an informal science party meeting during which we discussed preparing maps and plots of serial data for the cruise report, input to the cruise blog, and possible processing sequences for the data we will be collecting very soon. Weather continued to be favorable. All systems go! We held a science party meeting at 15:30 local to discuss the cruise report, blog and on-board processing. We decided to start meeting daily.

October 31/JD305: Line OBS03 was completed at 08:26, and we started the turn to OBS02. Line OBS02 was started at 09:45. Cassie entertained the lab with her Halloween costume – Princess Lea – and the galley treated us to Milky Ways with breakfast. The day proceeded smoothly with several brief periods when the mitigation gun only operated because of sightings of a turtle and several whales. Near the beginning of OBS01 (21:09), there was a prolonged period (21:12 to 23:23) when the guns had to be powered down and only the mitigation gun operated because of whales "milling about" over a topographic feature on the seafloor. Once past that feature, however, shooting proceeded without interruption well into the next day. During the daily science meeting, Emilio demonstrated using SeismicUnix to display shot gathers and a program for interactive forward modeling of 1D velocity structure consisting of layers with either a constant velocity or velocity gradient overlain on a reduced seismic section.

November 1/JD306: Today was uneventful. We proceeded along Line OBS01, shooting at a 300 m interval. There were no protected species sightings. The EM122 data were noisy when crossing the trench, and the system was turned off and restarted. At the daily science meeting we continued the data processing discussion and looked at SegDSee as a tool for quality control of shot gathers.

November 2/JD307: We completed shooting at a 300 m interval (end of line OBS01) at 02:34. The magnetometer was brought on board at 02:36, the EM122 and 3.5kHz were turned up at 03:13, and all guns were on deck by 04:06. We then proceeded to OBS site SS21 to recover and redeploy the OBS in order to get a first look at the OBS data. Spares were available to construct a new instrument package, and only the acoustic release system from the recovered OBS had to be reused, resulting in rapid turnaround. This operation was completed at 07:34 and was followed by launch of the waveglider at 07:49. It was with much trepidation that we watch this little "puppy" dash away from the ship on her lonely trip to GEOMAR Geodesy site "Area 2." However, she has been faithfully calling home with updates, and has had several cargo ships to keep her company on her voyage (much to the consternation of those responsible for her). Fortunately she obeys commands to steer clear of this marine traffic.
Streamer deployment began at 08:45 and continued on through most of the day. The operation went very smoothly, with only minor delays to readjust some of the rigging. The objective of getting the guns in the water before nightfall was easily met, with guns in the water and the first mitigation shot fired at 19:42. This smooth operation partially compensated

for having to miss watching the Cubs win the World Series for the first time in 108 years! After some testing and repairs to gun string 2, everything was good to go at 23:19. An eventful day!

November 3/JD308: The first official shot of line MC01 was fired at 00:10. XBTs were acquired every 4 hours for this profile. Guns were shut down at 21:24 because of a sea lion sighting. Line MC01 was ended at 21:46 and MC01A was started at 22:28 as guns were back to full power after starting ramp-up at 21:56. This leaves a 4.24 km gap in MC01 between OBSs SD28 and SS30.

November 4/JD309: MC01A continued until EOL at 09:53. At 10:02, while in the turn from MC01A to MC02, the guns were again shut off because of a sea lion and were restarted at 10:43. MC02 was started at 13:38, but a gun shut-down was required at 14:33 because of a sea turtle. Guns were back at full volume at 14:48. MC02 proceeded without problems until 18:19, when we were forced to change course to avoid a long-line fishing boat that was dragging 6 miles of line to fish for sharks. This course complicates geometry for a significant portion of MC02. There was also a short power down for whales at 22:16 to 22:23.

November 5/JD310: The EOL for MC02 was reached at 02:16 and the SOL for MC01 was crossed at 05:17, although the streamer was not completely aligned with the planned track. We resumed the pattern of an XBT every 4 hours for MC03. A 18:17 the magnetometer was pulled because reading were erratic. It was repaired and redeployed at 19:07.

November 6/JD311: We continued to shoot MC03 with XBTs every 4 hours. There were interruptions at 15:15-15:24 and 16:07-16:21 for dolphins and a turtle, respectively. EOL was reached at 23:14. The main lab was decorated with multilingual signs to great Kathy for the midnight watch on her birthday. The magnetometer was recovered at 23:39.

November 7/JD312: Streamer was partially recovered to shorten it to 8 km. This operation took from 5:15 to 6:22. The magnetometer and PAM were deployed at 9:28 and redeployment of the airgun array at 12 m depth began at 9:36. Guns were fired up and running smoothly by 12:26, in ample time for arrival at the start of line M16A at 12:41. The magnetometer started behaving erratically and was down and back up several times over the course of the day before finally settling down around 19:36. There were several brief power downs for protected species.

November 8/JD313 (election day): The end of line MC16A was reached at 14:35, and line MC15 was started at 17:04. Mitigation shots were fired during the turn. The day proceeded without major events. There were several short power downs.

November 9/JD314: MC15 was completed at 14:18 and MC11 began at 16:11. The day passed without significant events on the ship.

November 10/JD315: MC11 ended at 11:19 and MC12 began at 14:02 and ended at 22:28. There was one power down for a sea turtle.

November 11/JD316: MC13 began at 01:21 and ended at 23:04. There were several power downs for whales and sea lions. MC17 started at 23:15.

November 12/JD317: MC17 ended at 11:47 and MC18 started at 14:25 and ended at 21:58. MC07 started at 22:08. We were in deeper water and there were no sightings of protected species that required power downs.

November 13/JD318: At 04:56, half the guns were brought down for servicing. MC07 continued at half power to EOL at 05:56. Guns were tested during the turn onto line MC22, which started at 08:16 with only half of the guns firing. Full power was achieved at 09:30, although the streamer was not yet completely in line. The turn at the end of MC22 began at 21:36, although shots continued until 21:44. MC10 started at 21:53. The EM122 was down briefly for testing from 04:15 to 04:25.

November 14/JD319: MC10 continues without incident until the EOL at 10:05. There was a power down for a sea lion during the turn. MC09 started at 13:03 and was marked by a brief power down for a whale from 15:28 to 15:34. The EM122 was down briefly for testing from 04:15 to 04:25.

November 15/JD320: EOL was reached for MC09 at 05:51, and shooting of MC08 began at 08:05 with the stream not yet in line. After several short power down periods for protected species and gun servicing, MC08 ended prematurely at 22:21 with a crash of the recording system. We circled back to overlap the end of MC08 and continued with MC08A. These two lines can be merged into a single line with no loss of fold.

November 16/JD321: We were on line for MC08A at 03:05 and reached EOL at 06:50. MC04 began at 09:44 and continued through the rest of the day. The EM122 was down briefly twice: from 11:52 to 11:55 and from 12:21 to 12:24. The unfortunate discovery was made that the 3.5 kHz had not been saved since 04:36 on November 12. Data storage was restarted.

November 17/JD322: MC04 was completed at 02:55 and MC05 began at 05:18. The streamer was in line by 06:00, and MC05 was completed at 14:02. Guns were serviced prior to starting the next line and considerable “wear-and-tear” was noted. MC19 began at 17:02 but has to move to the mitigation gun almost immediately (from 17:04 to 17:23) because of a protected species sighting. There was a second power down from 20:20 to 20:39, but the day otherwise passed uneventfully.

November 18/JD323: MC19 was completed at 10:30 and MC06 was begun at 12:20. At 23:12, the guns were shut down because of the sighting of a dead whale. However, it was rapidly determined that this whale – bloated, covered with birds, and smelling very bad – had been dead for a long time, and guns were restarted at 23:15. The carcass was documented by photos.

November 19/JD324: MC06 continued without incident until 06:07, when an outside turn onto MC20 began. During the turn, gun strings 1 and 2 appeared to be tangled, but fortunately they came apart as the track straightened out. The FLIR infra-red camera was very valuable for monitoring the guns in the dark. MC20 was completed at 12:43 and MC21 began at 13:56 after another outside turn.

November 20/JD325: MC21 ended at 05:12. MC25 began at 07:10 and ended uneventfully at 0:13 on JD326.

November 21/JD326: MC24 started at 0:24 and ended uneventfully at 06:36. MC23 started at 07:35. Two power downs were required lasting 10 and 82 minutes, respectively. The longer power down period was almost dead center of the array. We may have an opportunity to pick up that segment of line as we approach the end of the MCS phase of the survey. MC23 ended at 23:27 and MC26 started at 23:30.

November 22/JD327: MC26 proceeded without interruption and ended at 07:34. There was one brief power down and several failures of the EM122 grid engine during this line, which was completed at 01:32 on JD328.

November 23/JD328: MC28 started at 02:11. A course change was needed to avoid a fishing boat near the end of the line at 07:03, and MC28 was ended at 07:08, earlier than originally planned. MC29 was started at 08:46. Several power downs were called, including one that lasted 74 minutes when a group of ~13 sperm whales approached the ship. They put on quite a show! A boat drill gave everyone the opportunity to enjoy some sunshine on a beautiful day.

November 24/JD329: MC29 was finished at 06:52 with the magnetometer fluctuating occasionally near the end of the line. MC30 started smoothly at 08:58. Another course change was needed to avoid yet another fishing boat at 11:30. The new path parallel to the line was maintained until we turned back online three hours later (14:30). Seemingly another normal day livened up with Thanksgiving hand turkey decorations, a delicious dinner, and general celebration shared by all.

November 25/JD330: Line MC30 was finished at 07:25 and MC31 promptly started at 07:56. A power down was issued quickly after the line began at 09:21, but full volume was resumed even more quickly, after a mere 8 minutes. MC31 was ended at 13:03, turning a few minutes earlier than planned due to more fishing gear. MC32 was started at 13:10 and experienced a longer 30-minute power down (14:01 to 14:33). MC32 was finished at 19:51, with MC32A immediately started at 19:53.

November 26/JD331: MC32A was finished at 01:13 with the next line, MC32B, immediately started again at 01:15. The gun volume was reduced to half for maintenance (06:24) until the end of the line at 07:01. Maintenance was finished through the turn to the next line and we were back to full volume at the start of MC33 at 10:54. MC33 was finished without issue at 19:01 and MC34 began promptly at 19:37. A science meeting was held today to discuss next blog entries, potential next meeting topics, map projections, and the process for loading bathymetry and MCS into Kingdom Suite.

November 27/JD332: Line MC34 was ended midline at 05:23 to fill in a gap in previous EW line MC23. From start to end, this small piece of line, MC23A, only took 3 hours to complete (10:01 to 12:56) and we headed back to resume MC34, now called MC34A. Guns were shut down in transit for a few minutes (13:17 to 13:21) due to marine mammal sightings. Once back to the line, we began the last segment MC34A at 15:48. However, the turn onto this last segment was somewhat overshot, and the streamer took longer than usual to properly align (18:00). Our science meeting today was a presentation by Florian Petersen on marine geodesy and the GeoSEA project portion of this cruise.

November 28/JD333: MC34A was continued today, but altering our course around fishing gear at 08:52. Rather than return to line and deal with streamer misalignment again, we maintained a path with an azimuth parallel to the original course. MC34A was ended at 18:34. This marks the official end to the MCS portion of the PICTURES cruise! The EM122 bathymetry and 3.5kHz Knudsen subbottom profiler were turned off once shooting was finished. The magnetometer and airgun array were recovered. After dinner, streamer recovery began at 20:54. The streamer came in smoothly, with the birds removed (and stored) accordingly.

November 29/JD334: Streamer recovery was completed shortly after the day began (00:25). OBS recovery was in full swing only 8 minutes later, with 3 GEOMAR instruments and 4 SIO instruments recovered by 12:58. We then transited to GeoSEA Area 2 to recover the wave glider and upload the remaining geodetic data. The focus of the day's science meeting was the cruise report, with the basic outline reviewed and assignments made. Everyone involved in the wave glider recovery watched an example video from an earlier mission on the R/V Sonne. The glider, constantly moving, played a little hard to get initially, but was ultimately on board at 19:51. The acoustic transducer was then deployed, and the geodesy upload started at 19:59. The glider base was covered by a thick layer of barnacles, which was removed as the data upload continued through the rest of the day. The transducer had to be recovered at 23:50 and the ship repositioned to optimize the download.

November 30/JD335: The transducer was redeployed (00:29) and upload finished early on (02:17), total of 6 hours. An XBT cast was made at 02:34. We then transited back to OBS site SS68 to resume recovery. SS68 was on deck at 09:30. An additional 8 OBSs were recovered by the end of the day (through SS55).

December 1/JD336: Recoveries continued smoothly, with 12 OBS recoveries (through SS52).

December 2/JD337: Recoveries continued smoothly, with an additional 14 recoveries (through SS16).

December 3/JD338: Recoveries continued, with 12 recoveries accomplished (through SG13).

December 4/JD339: Recoveries continue, with recovery of all but the final six OBSs completed by 22:02. Kathy Davenport introduced the group to crustal tomography using large aperture seismic data by presenting highlights from her PhD thesis on the crustal structure of southeastern Oregon and southwestern Idaho (the IDOR project). We discussed reciprocity and the difference between logistics and geometry onshore and offshore. We then began the transit to the beginning of Line OBS01A, where we deployed the guns and magnetometer.

December 5/JD340: We conducted a “figure of merit” test by acquiring magnetics data in a “Figure 8” pattern to calibrate the impact of the ship and airguns on the magnetics data before starting up the guns at first light. Line OBS01EX began at 12:13 and was completed at 18:51. The magnetometer and gun recovery was complete by 19:52, and recovery of the last 6 OBSs began. The fourth ARGO float was released at 23:11.

December 6/JD341: The final OBS was on deck at 12:50 and the fifth ARGO float was released at 12:56. Underway to Arica.

December 7/JD342: Pilot on board at 10:50 and at the dock at ~11:00. Time for demobilization.

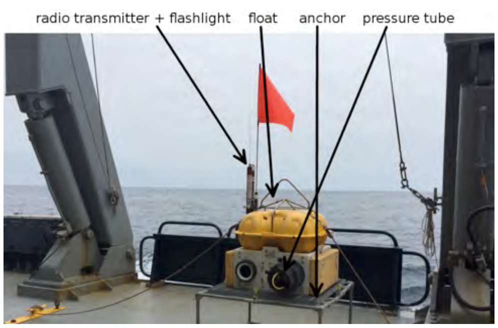
4. Operations and data archiving

OBS: Table 1 gives the deployment parameters for the SIO and GEOMAR OBS deployments. The location given is the location of the ship at the moment when the instrument was released from the line and started to drop to the seafloor. The seafloor position of these instruments will be more precisely determined during post-cruise processing by using arrival times of the water waves from shots near the instruments to locate the instruments. Particle motions of water waves will also be used to orient the horizontal components (e.g. Tréhu, 1984). For the SIO OBSs, a clock correction is calculated assuming a linear drift rate between when the clock was set prior to deployment and when it was compared to the GPS clock after recovery. No clock drift is cited for the GEOMAR OBSs because they contain a new data logger developed at GEOMAR that nominally does not drift. Figure 6 shows the two types of OBSs during deployment and a schematic of the ship track during deployment and recovery. Table 2 gives parameters for the GEOMAR OBS recoveries for instruments deployed in December 2015.

Signals were observed on all 4 components of the all SIO OBSs. The clock on one OBS (SS55) reset itself and another clock had a large drift rate (SS45). It is not yet known whether accurate timing is recoverable for these instruments, which recorded good waveform data. Scans of the OBS data sheets for each instrument documenting pre-deployment tests, serial numbers of components, clock calibration information and deployment and recovery notes are archived with the data. Two GEOMAR OBSs were not recovered (SDxx, SDxx); all others recorded good data on all components.

The OBS at site SS21 was recovered and the data were downloaded after completion shoot lines OBS03, OBS02 and OBS01 because we were near the site and preparing to deploy the streamer. This allowed us to get a first look at data quality, evaluate the distance to which the airgun signals propagate in this environment, and test a minor modification to the software to generate segy data. An OBS comprised partly of spare parts and partly of recovered parts was redeployed at the same site (now called SS21A).

All PICTURES data from SIO-OBSIP and GEOMAR (Table 1) will be archived at the IRIS-DMC along with this report and scans of the original data sheets for all of the instruments (www.iris.edu). The data will be archived both in continuous seed format and as segy files cut based on the shot instants. The receiver locations and source-receiver offsets in the segy headers are based on the ship's position when the instrument was released. (Table 1) and should be updated by the user after relocating the instrument on the seafloor. Metadata will be open access as soon as the data are archived. Waveform data will be open access 2 years after submission to the DMC and are available with the PI's permission prior to that data. GEOMAR data from the instruments deployed in December 2015 and recovered during MGL1610 (Table 2) will be archived in the Kiel with the Ocean Science Information System (OSIS-Kiel) with the rest of the data for expedition SO244 (portal.geomar.de/osis; metadata available 2 weeks after the cruise).



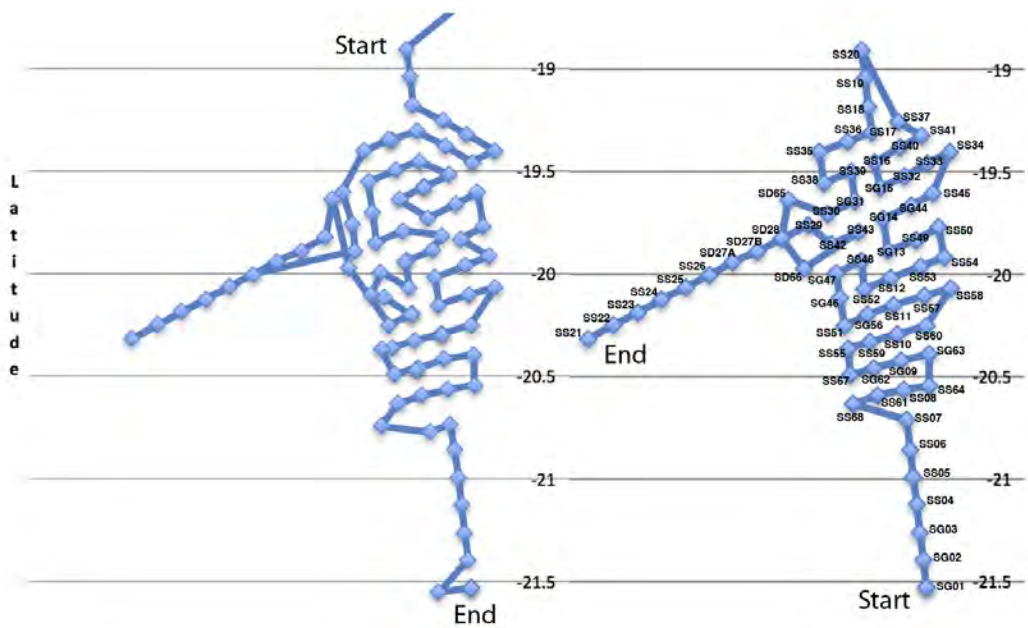


Figure 6. Top left – SIO OBS; top right – GEOMAR OBS; bottom: bottom left - ship track during combined GEOMAR recovery and SIO/GEOMAR deployment at the beginning of MGL1610; bottom right – ship track during the OBS recovery at the end of MGL1610.

Table 1. OBS deployment sites. SS indicates an SIO OBS; SG indicates a GEOMAR OBS; SD indicates a new GEOMAR deep-water OBS (rated to water depth up to 8000 m). All SIO data have been examined. If there is no comment, then good data were recorded on all 4 components.

Station Name	JD	Date (UTC)	Time (UTC)	Latitude (South)	Decimal minutes	Longitude (West)	Decimal minutes	Decimal Latitude	Decimal Longitude	Water Depth (m)	Comment
SS04	303	29/10	10:06	21	7.4351	70	37.3592	-21.12392	-70.62265	1827	
SS05	303	29/10	9:05	20	59.4605	70	38.4183	-20.99101	-70.64031	1639	
SS06	302	28/10	22:04	20	51.3072	70	39.6203	-20.85512	-70.66034	1785	
SS07	302	28/10	21:13	20	43.9583	70	41.01	-20.73264	-70.6835	1913	
SS08	302	28/10	2:50	20	33.8341	70	41.7505	-20.5639	-70.69584	1641	
SS10	301	27/10	15:01	20	17.6494	70	43.8667	-20.29416	-70.73111	2112	
SS11	301	27/10	9:50	20	9.1553	70	44.9519	-20.15259	-70.7492	2100	
SS12	301	27/10	8:57	20	1.1606	70	46.1519	-20.01934	-70.7692	1383	
SS16	300	26/10	20:02	19	27.1067	70	51.3522	-19.45178	-70.85587	1430	
SS17	298	24/10	13:37	19	18.3956	70	52.2146	-19.30659	-70.87024	980	
SS18	298	24/10	6:29	19	11.016	70	53.5388	-19.1836	-70.89231	1520	
SS19	298	24/10	5:17	19	2.4051	70	54.317	-19.04009	-70.90528	1580	
SS20	298	24/10	4:04	18	54.5032	70	55.5751	-18.90839	-70.92625	1526	
SS21	299	25/10	13:39	20	18.9004	72	26.4026	-20.31501	-72.44004	4423	recovered 2/11 to check data.
SS21A	307	2/11	7:34	20	18.911	72	26.2897	-20.31518	-72.43816	4423	deployed 2/11
SS22	299	25/10	12:23	20	14.8425	72	17.8438	-20.24737	-72.2974	4158	
SS23	299	25/10	11:15	20	11.1236	72	9.7461	-20.18539	-72.16244	2853	
SS24	299	25/10	10:19	20	7.4937	72	1.9849	-20.1249	-72.03308	3330	
SS25	299	25/10	9:18	20	3.7784	71	54.0032	-20.06297	-71.90005	4555	
SS26	299	25/10	8:16	20	0.2751	71	46.2253	-20.00459	-71.77042	4564	
SS29	299	25/10	2:29	19	45.5281	71	13.4504	-19.7588	-71.22417	5244	
SS30	300	26/10	16:53	19	42.2222	71	6.8087	-19.7037	-71.11348	4221	
SS32	300	26/10	21:14	19	31.1567	70	41.4659	-19.51928	-70.6911	772	
SS33	298	24/10	11:14	19	27.561	70	33.9587	-19.45935	-70.56598	775	
SS34	298	24/10	10:07	19	24.1366	70	26.5332	-19.40228	-70.44222	735	
SS35	298	24/10	22:36	19	24.1905	71	9.7823	-19.40318	-71.16304	3153	
SS36	298	24/10	14:41	19	20.964	71	0.2609	-19.3494	-71.00435	1697	
SS37	298	24/10	7:41	19	15.3708	70	43.5584	-19.25618	-70.72597	1049	lost flag
SS38	300	26/10	17:53	19	33.1421	71	8.1428	-19.55237	-71.13571	3634	
SS39	300	26/10	18:57	19	29.8005	70	59.1325	-19.49668	-70.98554	2412	
SS40	298	24/10	12:24	19	22.7277	70	42.8315	-19.37879	-70.71386	870	
SS41	298	24/10	8:51	19	19.3042	70	35.7653	-19.32174	-70.59609	934	
SS42	300	26/10	15:52	19	51.0093	71	5.5655	-19.85016	-71.09276	4142	
SS43	300	26/10	14:43	19	47.5684	70	56.6033	-19.79281	-70.94339	3070	
SS45	301	27/10	3:14	19	36.3233	70	32.4577	-19.60539	-70.54096	729	timing problem
SS48	300	26/10	10:11	19	56.1693	70	55.5849	-19.93616	-70.92642	2689	
SS49	301	27/10	5:34	19	49.9209	70	37.6677	-19.83201	-70.62779	1303	
SS50	301	27/10	4:27	19	46.2048	70	30.0888	-19.77008	-70.50148	998	
SS51	300	26/10	2:34	20	14.9467	71	1.3166	-20.24911	-71.02194	3995	
SS52	300	26/10	9:15	20	4.2115	70	54.7723	-20.07019	-70.91287	2730	
SS53	301	27/10	7:45	19	57.6375	70	36.0748	-19.96063	-70.60125	1236	
SS54	301	27/10	6:43	19	54.8547	70	28.1539	-19.91425	-70.46923	1177	
SS55	301	27/10	17:46	20	21.5888	71	0.1499	-20.35981	-71.0025	4261	timing problem
SS57	301	27/10	10:55	20	6.1648	70	34.8674	-20.10275	-70.58112	1179	
SS58	301	27/10	12:00	20	4.0091	70	26.1853	-20.06682	-70.43642	1150	
SS59	301	27/10	16:51	20	19.4447	70	52.7579	-20.32408	-70.8793	3277	
SS60	301	27/10	13:43	20	14.9955	70	34.296	-20.24992	-70.5716	1071	
SS61	302	28/10	3:53	20	35.5076	70	50.4769	-20.59179	-70.84128	2436	
SS64	302	28/10	1:54	20	32.5767	70	33.155	-20.54295	-70.55258	884	
SS67	301	27/10	20:21	20	29.3178	70	59.4729	-20.48863	-70.99122	4063	
SS68	302	28/10	4:58	20	37.9057	70	58.3632	-20.63176	-70.97272	3772	
SG01	303	29/10	15:24	21	31.607	70	33.8398	-21.52678	-70.564	2026	
SG02	303	29/10	11:58	21	23.4779	70	34.9231	-21.3913	-70.58205	1912	
SG03	303	29/10	11:03	21	15.6646	70	36.3736	-21.26108	-70.60623	2010	
SG09	301	27/10	23:42	20	24.7988	70	43.0061	-20.41331	-70.71677	1959	
SG13	300	26/10	12:08	19	53.0835	70	47.0895	-19.88473	-70.78483	1824	

Table 1 (continued).

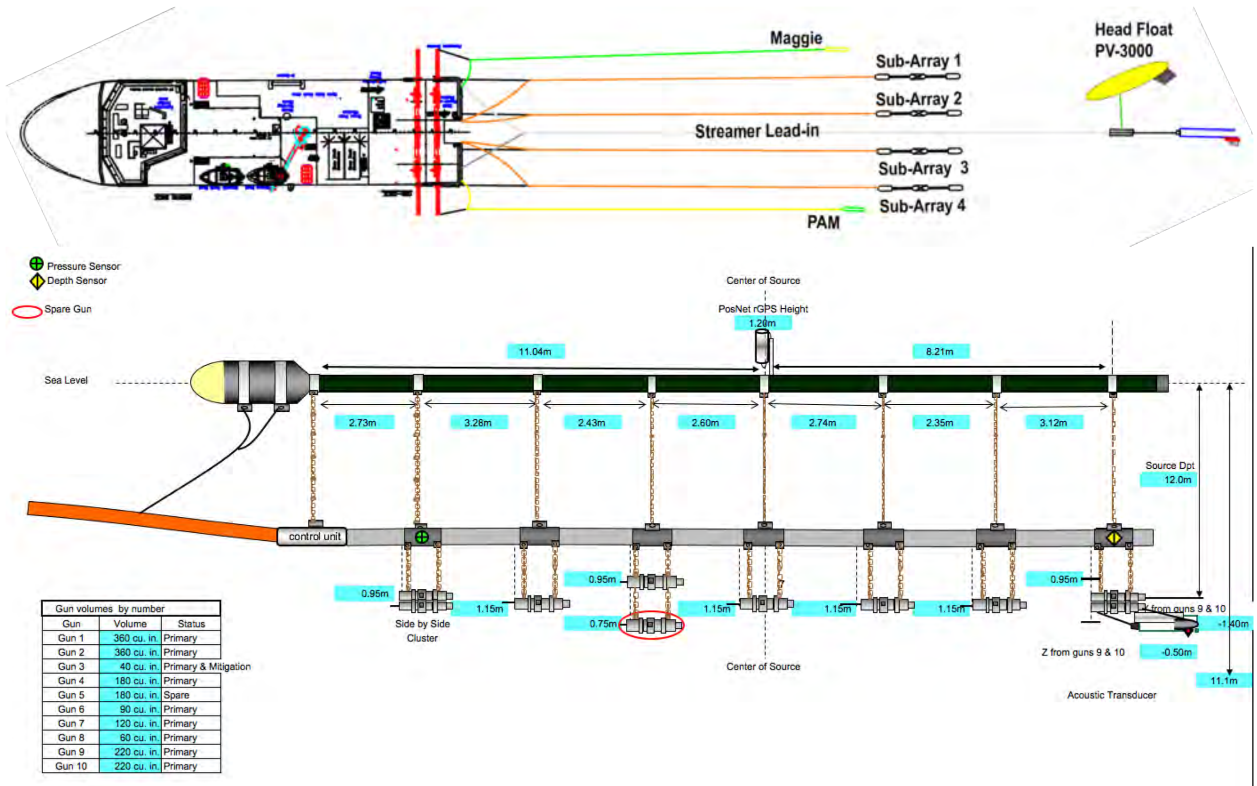
SG14	301	27/10	1:11	19	43.6218	70	48.498	-19.72703	-70.8083	1840	
SG15	300	26/10	22:14	19	34.5916	70	49.622	-19.57653	-70.82703	1694	
SG31	301	27/10	0:01	19	38.3579	70	57.9682	-19.6393	-70.96614	3046	stopped saving 22/11 at 07:00; flash card error
SG44	301	27/10	2:22	19	39.7083	70	39.3041	-19.6618	-70.65507	783	stopped saving 22/11 at 23:00; flash card error
SG46	300	26/10	5:45	20	6.9403	71	2.908	-20.11567	-71.04847	4184	no strobe
SG47	300	26/10	8:09	19	59.6053	71	4.1077	-19.99342	-71.06846	4050	
SG56	300	26/10	3:30	20	11.7476	70	53.8139	-20.19579	-70.8969	2984	
SG62	301	27/10	21:26	20	27.84	70	51.6156	-20.464	-70.86026	2877	stopped saving 24/11 at 02:00; flash card error
SG63	302	28/10	0:49	20	23.6857	70	33.2892	-20.39476	-70.55482	954	
SD27A	299	25/10	19:09	19	56.4238	71	38.1815	-19.9404	-71.63636	6100	stopped logging 3.5 hrs after deployment; battery problem
SD27B	299	25/10	20:01	19	53.3129	71	30.3448	-19.88855	-71.50575	6720	pressure tube flooded
SD28	299	25/10	20:57	19	49.3915	71	22.3393	-19.82319	-71.37232	7033	
SD65	299	25/10	22:10	19	38.1198	71	19.9249	-19.63533	-71.33208	5610	
SD66	300	26/10	0:22	19	58.2987	71	14.6097	-19.97165	-71.2435	6075	

Table 2. GEOMAR OBSs deployed in December 2015 and recovered during MGL1610.

Station Name	JD	Date (UTC)	Time (UTC)	Latitude (South)	Decimal minutes	Longitude (West)	Decimal minutes	Decimal Latitude	Decimal Longitude	Water Depth (m)	Comments
OBS08-N1	298	24/10	15:31	19	20.7049	71	1.6856	-19.34508	-71.02809	1742	
OBS07-N2	299	25/10	1:18	19	36.1641	71	16.6205	-19.60274	-71.27701	4903	
OBS06-N5	299	25/10	4:59	19	53.0096	71	12.8195	-19.88349	-71.21366	5348	
OBS12-C3	300	26/10	4:33	20	12.0259	70	54.1372	-20.20043	-70.90229	3006	
OBS05-C2	300	26/10	7:18	20	6.0112	71	7.1515	-20.10019	-71.11919	4819	
OBS11-C1	300	26/10	11:06	19	56.4466	70	55.8792	-19.94078	-70.93132	2747	
OBS10-N4	300	26/10	13:18	19	48.9677	70	43.3878	-19.81613	-70.72313	1500	
OBS09-N3	300	26/10	22:49	19	34.6745	70	49.9336	-19.57791	-70.83223	1734	no radio
OBS13-C4	301	27/10	15:43	20	17.5805	70	43.8256	-20.29301	-70.73043	2104	
OBS03-S1	301	27/10	22:36	20	28.0097	70	52.7835	-20.46683	-70.87973	5023	
OBS04-C5	301	27/10	19:20	20	21.9453	71	3.9852	-20.36576	-71.06642	2910	
OBS01-S3	302	28/10	7:05	20	44.4377	71	3.946	-20.74063	-71.06577	5356	
OBS02-S2	302	28/10	13:00	20	46.1036	70	48.0392	-20.76839	-70.80065	2501	
OBS15-X2	303	29/10	14:00	21	33.0282	70	44.9844	-21.55047	-70.74974	2797	

MCS: Lines numbers were set up in advance and do not represent the actual shooting order. All lines are prefaced by MC. Lines MC01 and MC08 were interrupted and the continuations are labeled MC01A and MC08A. An "A" is included in the name for MC16A because the first shotpoint for MC16 was relocated; there is no MC16. MC32A and MC32B represent continuations of MC32 after a change in azimuth. MC23A is a patch to a segment of MC23 during which the guns were shut down. MC34A is the continuation of MC34 after shooting MC23. MC01, MC01A, MC02 and MC03 were shot with a 1008 channel, 12.5-km long streamer, a shot point spacing of 50 m, a sampling rate of 2 ms and a total record length of 20 s. The rest of the lines were shot with a 640 channel, 8-km long streamer, 2 ms sample rate and total record length of 16 s. Through an unfortunate oversight, the opportunity to record exploratory ultra-long records because of the long interval between shots was overlooked.

Figure 7 is a schematic showing the relationship between the streamer, airgun strings, magnetometer and PAM (passive acoustic monitor for listening to whales). Figure 8 is a schematic of the shipboard data integration and logging system.



Gun volumes by number		
Gun	Volume	Status
Gun 1	360 cu. in.	Primary
Gun 2	360 cu. in.	Primary
Gun 3	40 cu. in.	Primary & Mitigation
Gun 4	180 cu. in.	Primary
Gun 5	180 cu. in.	Spare
Gun 6	90 cu. in.	Primary
Gun 7	120 cu. in.	Primary
Gun 8	60 cu. in.	Primary
Gun 9	220 cu. in.	Primary
Gun 10	220 cu. in.	Primary

Figure 7. (top) Schematic illustration of the relationship between the ship, airgun array, magnetometer and PAM. The distance between the center of the airgun array and the center of the first hydrophone group (shown in red) is 220 m. The minimum distance between the gun array the the first hydrophone of the streamer is 20x m, and was verified by measuring the arrival time of the direct wave at the first group. The gun array measures 18x18 m. The center of this square is the position of the array given in the shot time record. (bottom) Configuration of one of the gun strings. All 4 have the same configuration The array contains 40 airguns ranging in volume from 40 to 360 cubic inches. The mitigation gun is 40 cubic inches.

Because shots were also being recorded on OBSs and onshore seismometers, start-of-line and end-of-line shot points generally include partial turns when the streamer was not completely aligned with the line. Those shot points have been included in the headers of the shot, CMP-sorted and brute-stack segy files, but the lines should be trimmed by the user for conventional MCS data process. This is discussed further in the discussion of shipboard processing. With the exception of MC08/08A and MC23/23A, holes due to shut-downs for protected species were not reshot. This grid of lines is shown schematically in Figure 9 and the endpoints of lines and shotpoint numbers are giving in Table 4. In most cases, a mitigation gun was fired and recorded during "power downs," preserving the shot-point numbering and spacing. In a few cases, the guns were completely shut off, leaving an actual gap in the line. Missing shots and shots when only the mitigation gun was fired are given in Table 5.

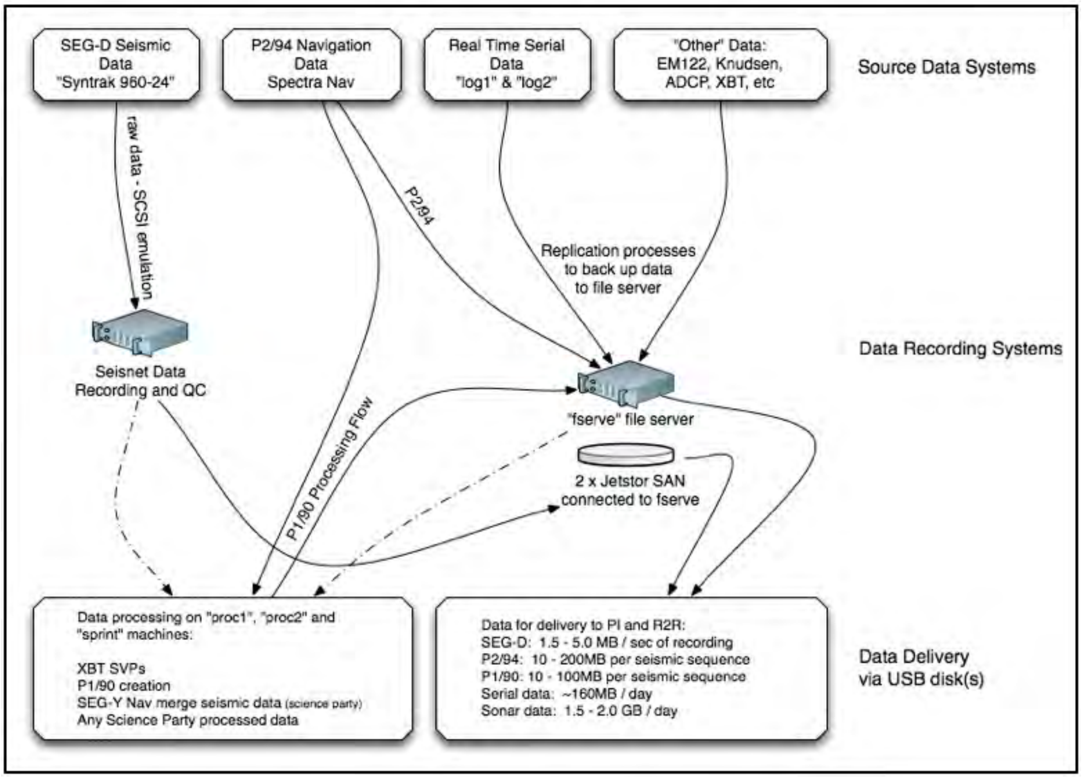


Figure 8. Schematic of the shipboard data acquisition and integration system.

All raw MCS data will be archived at the LDEO Academic Seismic Portal (ASP) along with this report and all additional metadata on the navigation, streamer and gun array. Stacked and migrated sections will be archived with the UTIG ASP. ***These data will be open access as soon as they are archived, although we ask that investigators coordinate studies using these data with the PI and join the PICTURES working group. The PI plans to organize a bi-monthly newsletter and conference calls to minimize duplication of effort, enhance data integration and collaboration, and protect the interests of students working on the data***.

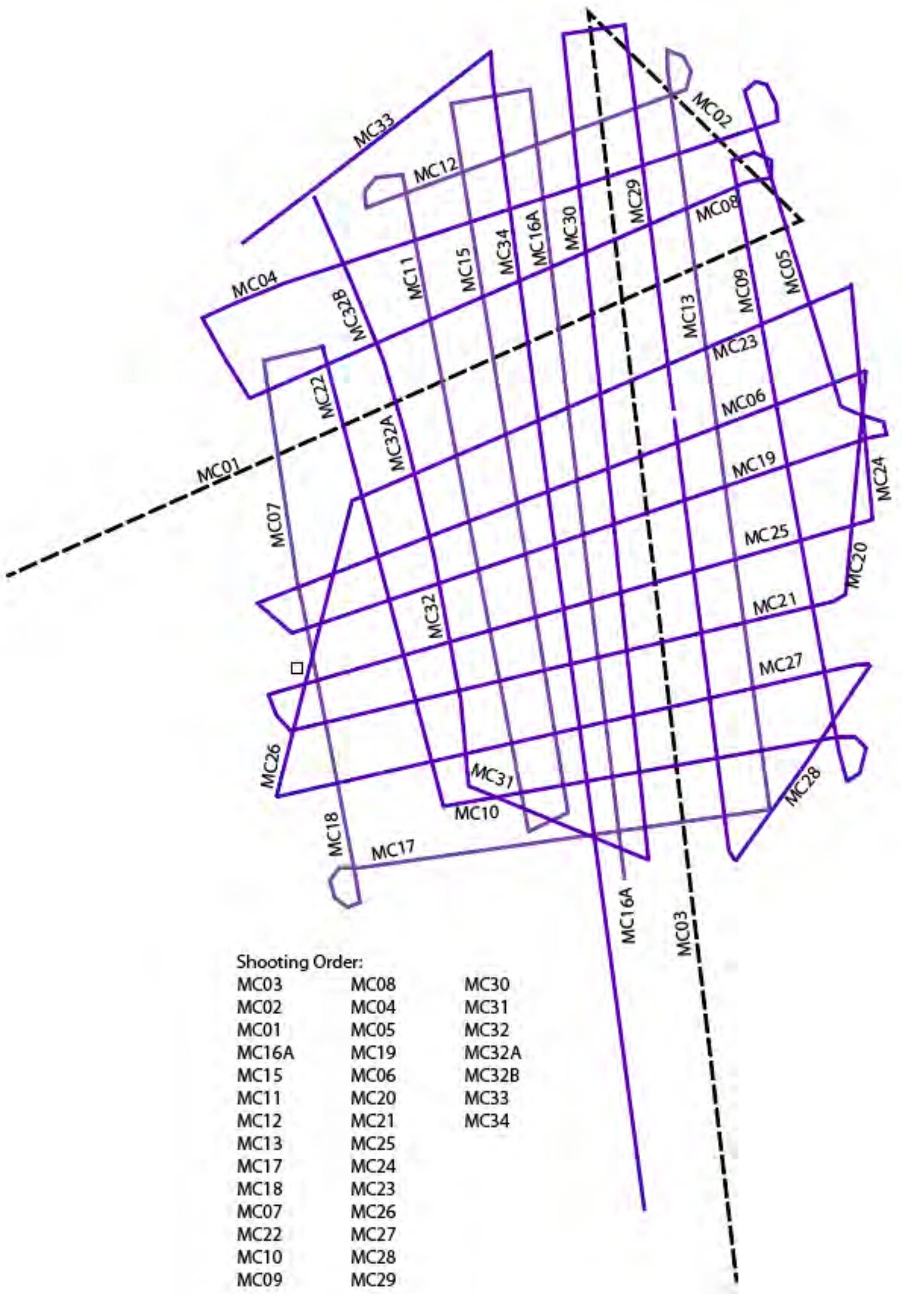


Figure 9. Schematic diagram of MCS lines.

Kongsberg EM122 multibeam echosounder: Our IHA permitted acquisition of EM122 swath bathymetry only when shooting airguns. We obtained permission to briefly monitor bathymetry within 1 km of OBS drop shots to ensure that the instrument was not being dropped in a location with strong topographic roughness when a smoother site was available nearby. Continuous acquisition (with a few minor gaps) began on October 29 at 17:00 and ended on November 28 at 15:00 with completion of the MCS survey. New swath bathymetric data acquired during

Table 4: Start of Line (SOL) and End of Line (EOL) time and geographic coordinates for each MCS profile.

Line Number	Latitude	Longitude	Latitude S (deg:min:s)			Longitude W (deg:min:s)			SP	Time (hr:min:s)	JD	comment
MC01	-20.401849	-72.666042	20	24	6.657	72	39	57.752	5001	0:10:24	307	SOL
MC01	-19.777502	-71.050983	19	46	39.006	71	3	3.537	8273	21:23:51	308	EOL
MC01A	-19.751084	-71.192406	19	45	3.901	71	11	32.660	8409	22:28:08	308	SOL
MC01A	-19.407673	-70.437329	19	24	27.622	70	26	14.383	10170	9:53:29	309	EOL
MC02	-19.473439	-70.464241	19	28	24.381	70	27	51.269	10890	13:38:23	309	SOL
MC02	-18.699026	-70.984260	18	41	56.494	70	59	3.335	12924	2:16:20	310	EOL
MC03	-18.661098	-70.963318	18	39	39.951	70	57	47.945	13001	5:18:31	310	SOL
MC03	-21.722427	-70.542621	21	43	20.737	70	32	33.434	19836	23:14:35	311	EOL
MC16A	-21.007647	-70.779565	21	0	27.529	70	46	46.433	19932	12:42:46	312	SOL
MC16A	-19.092199	-70.063843	19	5	31.917	70	3	49.835	21645	14:35:15	313	EOL
MC15	-19.100362	-71.246900	19	6	1.303	71	14	48.839	22142	17:04:33	313	SOL
MC15	-20.654540	-70.941454	20	39	16.344	70	56	29.233	23542	14:18	314	EOL
MC11	-20.698475	-71.030807	20	41	54.510	71	1	50.904	23936	16:11:14	314	SOL
MC11	-19.303341	-71.354849	19	18	12.028	71	21	17.458	25201	11:19	315	EOL
MC12	-19.377128	-71.384198	19	22	37.659	71	23	3.114	25957	14:02:01	315	SOL
MC12	-19.106831	-70.695207	19	6	24.592	70	41	42.744	26584	23:28	315	EOL
MC13	-19.063936	-70.762003	19	3	50.170	70	45	43.209	26938	1:21	316	SOL
MC13	-20.653958	-70.493454	20	39	14.247	70	29	36.433	28364	23:04	316	EOL
MC17	-20.660852	-70.504894	20	39	39.068	70	30	17.618	28730	23:15	316	SOL
MC17	-20.814510	-71.482722	20	48	52.237	71	28	57.799	29556	11:57:34	317	EOL
MC18	-20.827657	-71.413812	20	49	39.565	71	24	49.723	29972	14:25:26	317	SOL
MC18	-20.278314	-71.535379	20	16	41.932	71	32	7.366	30469	21:58:54	317	EOL
MC07	-20.266531	-71.539769	20	15	59.513	71	32	23.170	30935	20:08:52	318	SOL
MC07	-19.697962	-71.650773	19	41	52.664	71	39	2.781	31447	5:56:45	319	EOL
MC22	-19.701254	-71.498910	19	42	4.516	71	29	56.076	31948	8:16:29	318	SOL
MC22	-20.652752	-71.240323	20	39	9.906	71	14	25.164	32818	21:44:15	318	EOL
MC10	-20.659323	-71.230413	20	39	33.563	71	13	49.485	32844	21:53:19	318	SOL
MC10	-20.487403	-70.294931	20	29	14.650	70	17	41.750	33639	10:05:45	319	EOL
MC09	-20.495737	-70.337853	20	29	44.653	70	20	16.269	33999	13:03	319	SOL
MC09	-19.282860	-70.603713	19	16	58.295	70	36	13.367	35096	5:51:26	320	EOL
MC08	-19.313419	-70.573047	19	18	48.307	70	34	22.970	35979	8:05:47	320	SOL
MC08	-19.746639	-71.580730	19	44	47.900	71	34	50.629	36908	22:21:23	320	EOL
MC08A	-19.680196	-71.425323	19	40	48.704	71	25	31.161	46765	3:05	321	SOL
MC08A	-19.794735	-71.692585	19	47	41.046	71	41	33.305	47011	6:50:26	321	EOL
MC04	-19.601554	-71.764455	19	36	5.596	71	45	52.037	47951	9:44:52	321	SOL
MC04	-19.176089	-70.498752	19	10	33.921	70	29	55.506	49078	2:55	322	EOL
MC05	-19.161463	-70.562211	19	9	41.266	70	33	43.960	49968	5:18:11	322	SOL
MC05	-19.774451	-70.355285	19	46	28.024	70	21	19.027	50538	14:01	322	EOL
MC19	-19.863330	-70.291055	19	51	47.987	70	17	27.798	50963	17:02:17	322	SOL
MC19	-20.301839	-71.585968	20	18	6.621	71	35	9.483	52114	10:30	323	EOL
MC06	-20.214190	-71.610434	20	12	51.084	71	36	37.563	52959	12:20	323	SOL
MC06	-19.713441	-70.322635	19	42	48.387	70	19	21.485	54125	6:06:59	324	EOL
MC20	-19.748981	-70.289763	19	44	56.331	70	17	23.147	55001	6:46:09	324	SOL
MC20	-20.184823	-70.292601	20	11	5.361	70	17	33.363	55387	12:43	324	EOL
MC21	-20.217549	-70.379526	20	13	3.176	70	22	46.292	55986	13:56:02	324	SOL
MC21	-20.511442	-71.540491	20	30	41.190	71	32	25.767	56990	5:12:31	325	EOL
MC25	-20.403530	-71.518413	20	24	12.708	71	31	6.287	57038	7:10:42	325	SOL
MC25	-20.021789	-70.252910	20	1	18.439	70	15	10.476	58162	0:13	326	EOL
MC24	-20.009020	-70.246443	20	0	32.471	70	14	47.194	59011	0:24:26	326	SOL
MC24	-19.550654	-70.315161	19	33	2.353	70	18	54.578	59421	6:36:11	326	EOL
MC23	-19.552356	-70.380262	19	33	8.481	70	22	48.944	59966	7:35:30	326	SOL
MC23	-20.043748	-71.513690	20	2	37.493	71	30	49.283	61011	23:27:55	326	EOL
MC26	-20.046513	-71.516048	20	2	47.446	71	30	57.773	62002	23:30:48	326	SOL
MC26	-20.634133	-71.642210	20	38	2.877	71	38	31.955	62533	7:34:06	327	EOL
MC27	-20.651689	-71.590366	20	39	6.079	71	35	25.317	63050	8:24:13	327	SOL
MC27	-20.336230	-70.283306	20	20	10.427	70	16	59.901	64176	1:32:58	328	EOL
MC28	-20.378663	-70.258169	20	22	43.185	70	15	29.407	65001	2:11	328	SOL
MC28	-20.693377	-70.460792	20	41	36.158	70	27	38.852	65327	7:08	328	EOL
MC29	-20.680195	-70.064905	20	40	48.701	70	3	53.658	66004	8:46:36	328	SOL

MC29	-19.056966	-70.836477	19	3	25.077	70	50	11.316	67457	6:52	329	EOL
MC30	-19.097276	-70.976323	19	5	50.192	70	58	34.761	68007	8:58:09	329	SOL
MC30	-20.752076	-70.747594	20	45	7.475	70	44	51.339	69485	7:25:24	330	EOL
MC31	-20.774756	-70.777911	20	46	29.122	70	46	40.480	69979	7:56:20	330	SOL
MC31	-20.626330	-71.136533	20	37	34.789	71	8	11.520	70305	13:03	330	EOL
MC32	-21.620156	-71.142457	20	97	12.560	71	8	32.846	70915	13:10:15	330	SOL
MC32	-20.133826	-71.250486	20	8	1.775	71	15	1.750	71355	19:51:07	330	EOL
MC32A	-20.131293	-71.251269	20	7	52.655	71	15	4.568	72003	19:53:15	330	SOL
MC32A	-19.751336	-71.366250	19	45	4.810	71	21	58.500	72353	1:13	331	EOL
MC32B	-19.748897	-71.367374	19	44	56.028	71	22	2.547	73003	1:15	331	SOL
MC32B	-19.356612	-71.544878	19	21	23.803	71	32	41.562	73381	7:01	331	EOL
MC33	-19.485205	-71.700782	19	29	6.737	71	42	2.816	73944	10:55:24	331	SOL
MC33	-19.156338	-71.166962	19	9	22.818	71	10	1.063	74479	19:01:41	331	EOL
MC34	-19.174067	-71.126133	19	10	26.641	71	7	34.078	75031	19:37:39	331	SOL
MC34	-19.892850	-71.017179	19	53	34.259	71	1	1.846	75674	5:23:38	332	EOL
MC23A	-19.778768	-70.901422	19	46	43.565	70	54	5.120	80447	10:01:54	332	SOL
MC23A	-19.867780	-71.109004	19	52	4.008	71	6	32.416	80638	12:56:11	332	EOL
MC34A	-19.752836	-71.044084	19	45	10.210	71	2	38.704	81548	15:48:15	332	SOL
MC34A	-21.708013	-70.717118	21	42	28.847	70	43	1.625	83301	18:34:07	333	EOL

Table 5. Shotpoint notes from watchstander review of all SEGD files. Mitigation (pink) and missing (teal) shots are highlighted.

Line number	Tape no.	First FFID	Last FFID	First Shot	Last Shot	Shot interval (m)	Gun Depth (m)	Streamer Depth (m)	Source Volume (cubic in.)	Comment
OBS01			1		879	300	12		6600	no streamer
OBS01A										no streamer
OBS02			2977		3305	300	12		6600	no streamer
OBS03			965		2091	300	12		6600	no streamer
MC01	3	192	1002	5001	5811	50	9	9	6600	SOL, EOT
	4	1003	2002	5812	6811	50	9	9	6600	SOT, EOT
	5	2003	3002	6812	7811	50	9	9	6600	SOT, EOT
	6	3003	3464	7812	8273	50	9	9	6600	SOT, EOL
				8274	8408					Gap between 01 and 01A - No shots
MC01A	7	3465	4464	8409	9408	50	9	9	6600	SOL, EOT
	8	4465	5228	9409	10170	50	9	9	6600	SOT, EOT, EOL, last three FFID have the same SP #10170
				10171	10889					Line change
MC02	9	5229	5380	10890	11041	50	9	9	6600	SOL to last shot with streamer misaligned
	9	5325	5381	10986	11042	50	9	9	6600	streamer straight
				11043	11056					Missing shots
	9	5382	5404	11057	11079	50	9	9	80	migation shots; note missing shots 14 before and 2 after
				11080	11081					Missing shots
	9	5405	5976	11082	11653	50	9	9	6600	good shots
	9	5977	6228	11654	11905	50	9	9	6600	line curves around long-line fishing boat
	10	6229	6561	11906	12238	50	9	9	6600	SOT, last shot before power down
				12239						Missing shots
	10	6562	6572	12240	12250	50	9	9	80	mitigation shots, note missing shots 1 before and 2 after
				12251	12252					Missing shots
	10	6573	7228	12253	12908	50	9	9	6600	SOT,EOT
	11	7229	7244	12909	12924	50	9	9	6600	SOT, EOL
				12925	13004					Line change
MC03	12	7245	7398	13005	13158	50	9	9	6600	SOL, streamer misaligned
	12	7399	8244	13159	14004	50	9	9	6600	streamer straight, EOT
	13	8245	9244	14005	15004	50	9	9	6600	SOT, EOT
	14	9245	10244	15005	16004	50	9	9	6600	SOT, EOT
	15	10245	11244	16005	17004	50	9	9	6600	SOT, EOT
	16	11245	12244	17005	18004	50	9	9	6600	SOT, EOT
	17	12245	12806	18005	18566	50	9	9	6600	SOT
				18567						Missing shots
	17	12807	12821	18568	18582	50	9	9	80	mitigation shots, note missing shots 1 before and 3 SP after
				18583	18585					Missing shots
	17	12822	12935	18586	18699	50	9	9	6600	full power
				18700						Missing shots
	17	12936	12966	18701	18731	50	9	9	80	mitigation shots, note missing shots 1 SP before and 2 SP after
				18732	18733					Missing shots
	17	12967	13244	18734	19011	50	9	9	6600	full power, EOT
	18	13245	14069	19012	19836	50	9	9	6600	SOT, EOT, EOL
		14070		19837	19929					Line change; Missing FFID?
MC16A	19	14071	14333	19930	20192	125	12	9	6600	SOT, first good shot
	19	14334	14363	20193	20222	125	12	9	80	mitigation shots, note missing shot 20223

				20223						Missing shots
	19	14364	14366	20224	20226	125	12	9	80	mitigation shots, note missing shot 20223
	19	14367	14499	20227	20359	125	12	9	6600	full power
	19	14500	14502	20360	20362	125	12	9	80	mitigation shots, note missing shot point after (20363)
				20363						Missing shots
	19	14503	14684	20364	20545	125	12	9	6600	full power
				20546						Missing shots
	19	14685	14709	20547	20571	125	12	9	80	mitigation shots, note missing shot before (SP #20546)
	19	14710	15069	20572	20931	125	12	9	6600	full power, EOT, FFID 14736 SP 20598 impact noise on streamer
	20	15070	15783	20932	21645	125	12	9	6600	SOT,EOT,EOL
		15784		21646	22141					Line change; Missing FFID?
MC15	21	15785	16007	22142	22364	125	12	9	6600	SOT,SOL, first good shot
	21	16008	16009	22365	22366	125	12	9	80	migation shots
	21	16010	16784	22367	23141	125	12	9	6600	full power, EOT
	22	16785	16804	23142	23161	125	12	9	6600	SOT, first good shots
	22	16805	16806	23162	23163	125	12	9		noisy SP
	22	16807	17123	23164	23480	125	12	9	6600	good shots
				23481						Missing shots
	22	17124	17128	23482	23486	125	12	9	80	migation shots; note missing shots sp #23481
	22	17129	17184	23487	23542	125	12	9	6600	full power, EOT, EOL
	23	17185	17185	23542	23542	125	12	9	80	only one SP mitigation shot; SP 23542 is duplicated
				23543	23935					Line change
MC11	24	17186	17283	23936	24033	125	12	9	6600	SOL,SOT, first good shots
	24	17284	17294	24034	24044	125	12	9	80	migation shots
	24	17295	18185	24045	24935	125	12	9	6600	full power, EOT
	25	18186	18451	24936	25201	125	12	9	6600	SOT, EOT, EOL
				25202	25956					Line change
MC12	26	18452	18542	25957	26047	125	12	9	6600	SOT,SOL, first good shot
	26	18543	18549	26048	26054	125	12	9	80	migation shots
	26	18550	18570	26055	26075	125	12	9	6600	good shots
	26	18571	18577	26076	26082	125	12	9	80	migation shots
	26	18578	19079	26083	26584	125	12	9	6600	full power, EOT, EOL
				26585	26937					Line change
MC13	27	19080	19765	26938	27623	125	12	9	6600	SOT,SOL, first good shot
	27	19766	19776	27624	22634	125	12	9	80	migation shots, missing one shot sp # 27635
				22635						Missing shots
	27	19777	20015	27636	27874	125	12	9	6600	good shots, missing one shot sp # 27875
				27875						Missing shots
	27	20016	20063	27876	27923	125	12	9	6600	good shots, missing one shot sp # 27875
	27	20064	20079	27924	27939	125	12	9	80	start migation shots, EOT
	28	20080	20081	27940	27941	125	12	9	80	SOT, last mitigation shot
	28	20082	20170	27942	28030	125	12	9	6600	good shots, missing one shot sp # 28031
				28031						Missing shots
	28	20171	20183	28032	28044	125	12	9	80	migation shots, missing one shot sp # 28045
				28045						Missing shots
	28	20184	20292	28046	28154	125	12	9	6600	full power
	28	20293	20317	28155	28179	125	12	9	80	migation shots, missing one shot sp # 28180
				28180						Missing shots
	28	20318	20394	28181	28257	125	12	9	6600	full power
	28	20395	20426	28258	28289	125	12	9	80	migation shots, missing one shot sp # 28290
				28290						Missing shots

	28	20427	20500	28291	28364	125	12	9	6600	full power, EOT, EOL
				28365	28729					Line change
MC17	29	20501	20559	28730	28788	125	12	9	80	SOL,SOT, mitigation shots
	29	20560	21327	28789	29556	125	12	9	6600	full power, EOL, EOT
				29557	29971					Line change
MC18	30	21328	21825	29972	30469	125	12	9	6600	SOT,SOL, EOT, EOL
				30470	30934					Line change
MC07	31	21826	22274	30935	31383	125	12	9	6600	SOT,SOL
	31	22275	22338	31384	31447	125	12	9		first shot with half of guns,EOL
	31	22339	22340	31448	31449	125	12	9	80	EOT, mitigation shots
				31450	31947					Line change
MC22	32	22341	22406	31948	32013	125	12	9		SOT,SOL, with half of gun
	32	22407	23211	32014	32818	125	12	9	6600	full power, first good SP #32016, EOT, EOL
				32819	32843					Line change
MC10	33	23212	24007	32844	33639	125	12	9	6600	SOT,SOL, EOT, EOL
				33640	33998					Line change
MC09	34	24008	24162	33999	34153	125	12	9	6600	SOT,SOL
	34	24163	24169	34154	34160	125	12	9	80	migation shots
	34	24170	25007	34161	34998	125	12	9	6600	EOT, good shots
	35	25008	25064	34999	35955	125	12	9	6600	SOT, EOL
	35	25065	25105	35056	35096	125	12	9	6600	shots after EOL, EOT
		25106								Missing FFID
MC08	36	25107		35097		125	12	9	6600	SOT, missing FFID #25106, and there is only one SP at the SOT and before the SOL.
				35098	35978					Line change
	36	25108	25263	35979	36134	125	12	9	6600	SOL, first good shots
	36	25264	25292	36135	36163	125	12	9	80	migation shots, missing one shot sp # 36164
				36164						Missing shots
	36	25293	25382	36165	36254	125	12	9	6600	full power, missing one shot sp #36255
				36255						Missing shots
	36	25383	25392	36256	36265	125	12	9	80	mitigation shots
	36	25393	25694	36266	36567	125	12	9	6600	full power, EOL, EOT, missing one shot #36568
				36568						Missing shots
	36	25695	25989	36569	36863	125	12	9	6600	full power, EOL, EOT, missing one shot #36568
		25990		36864	46764					Line change
MC08A	37	25991	26237	46765	47011	125	12	9	6600	SOT,SOL, EOT, EOL
				47012	47950					Line change
MC04	38	26238	27237	47951	48950	125	12	9	6600	SOT, SOL, EOT
	39	27238	27365	48951	49078	125	12	9	6600	SOT, EOT, EOL
				49079	49967					Line change
MC05	40	27366	27936	49968	50538	125	12	9	6600	SOT,SOL, EOT, EOL
				50539	50962					Line change
MC19	41	27937	27939	50963	50965	125	12	9	6600	SOL,SOT, first good shots
				50966						Missing shots
	41	27940	27957	50967	50984	125	12	9	80	mitigation shots, note missing shots 1 #50966 and 1 #50985
				50985						Missing shots
	41	27958	28152	50986	51180	125	12	9	6600	full power
	41	28153	28174	51181	51202	125	12	9	80	migation shots
	41	28175	28936	51203	51964	125	12	9	6600	full power, EOT
	42	28937	29086	51965	52114	125	12	9	6600	SOT, EOT, EOL
				52115	52958					Line change
MC06	43	29087	29799	52959	53671	125	12	9	6600	SOT,SOL, first good shot

	43			53672	53675	125	12	9		4 missing SP # 53672, #53673, #53724, #53725
	43	29800	30086	53676	53962	125	12	9	6600	full power, EOT
	44	30087	30249	53963	54125	125	12	9	6600	SOT, EOT, EOL
				54125	55001					Line change
MC20	45	30250	30635	55002	55387	125	12	9	6600	SOT,SOL, EOT, EOL
				55388	55985					Line change
MC21	46	30636	31635	55986	56985	125	12	9	6600	SOT, SOL, EOT
	47	31636	31640	56986	56990	125	12	9	6600	SOT,EOT,EOL
				56991	57037					Line change
MC25	48	31641	32640	57038	58037	125	12	9	6600	SOT, SOL, EOT
	49	32641	32765	58038	58162	125	12	9	6600	SOT, EOT, EOL
MC24	50	32766	32767	58163	58163	125	12	9	6600	SOT, 2 FFID with the same SP number, mitigation,
				58164	59010					Line change
	50	32768	33178	59011	59421	125	12	9	6600	SOL, EOT, EOL
				59422	59965					Line change
MC23	51	33179	33205	59966	59992	125	12	9	6600	SOL, SOT, streamer misaligned
	51	33206	33394	59993	60181	125	12	9	6600	streamer straight, missing 2 SP #60182, #60183
				60182	60183					Missing shots
	51	33395	33402	60184	60191	125	12	9	80	mitigation shots
	51	33403	33719	60192	60508	125	12	9	6600	full power
	51	33720	33811	60509	60600	125	12	9	80	mitigation shots
	51	33812	34178	60601	60967	125	12	9	6600	good shots, EOT
	52	34179	34207	60968	60996	125	12	9	6600	SOT, EOT, EOL
		34208	34221	60997	62001					Missing FFIDs; Line change
MC26	53	34223	34754	62002	62533	125	12	9	6600	SOT,SOL, EOT, EOL
				62534	63049					Line change
MC27	54	34755	34773	63050	63068	125	12	9	6600	SOT,SOL
	54	34774	34795	63069	63090	125	12	9	6600	streamer misaligned
	54	34796	35582	63091	63877	125	12	9	6600	streamer straight
	54	35583	35597	63878	63892	125	12	9	80	mitigation shots
	54	35598	35754	63893	64049	125	12	9	6600	full power, EOT
	55	35755	35881	64050	64176	125	12	9	6600	SOT, EOT, EOL
				64177	65000					Line change
MC28	56	35882	36208	65001	65327	125	12	9	6600	SOT,SOL, EOT, EOL
				65328	66003					Line change
MC29	57	36209	36498	66004	66293	125	12	9	6600	SOT,SOL
	57	36499	36578	66294	66373	125	12	9	80	mitigation shots, missing one SP #66374
				66374						Missing shots
	57	36579	36660	66375	66456	125	12	9	6600	full power
	57	36661	36671	66457	66467	125	12	9	80	mitigation shots
	57	36672	36696	66468	66492	125	12	9	6600	full power
	57	36697		66493		125	12	9	80	mitigation shots, only one SP
				66494	66509	125	12	9		missing 16 Shots points from #66494 to 66509 inclus
	57	36698	36704	66510	66516	125	12	9	6600	full power, EOL, EOT, missing one shot #66517
				66517						Missing shots
	57	36705	36716	66518	66529	125	12	9	80	mitigation shots
	57	36717	37208	66530	67021	125	12	9	6600	full power, EOT
	58	37209	37644	67022	67457	125	12	9	6600	SOT,EOT,EOL
				67458	68006					Line change
MC30	59	37645	37810	68007	68172	125	12	9	6600	SOT,SOL

	59	37811	38007	69173	68369	125	12	9	6600	turning for fishing boat (misaligned)
	59	38008	38644	68370	69006	125	12	9	6600	back tol line, EOT
	60	38645	39123	69007	69485	125	12	9	6600	SOT, EOT, EOL
				69486	69978					Line change
MC31	61	39124	39209	69979	70064	125	12	9	6600	SOT,SOL, missing SP #70065
				70065						Missing shots
	61	39210	39214	70066	70070	125	12	9	80	mitigation shots, missing SP #70071
				70071						Missing shots
	61	39215	39448	70072	70305	125	12	9	6600	full power, EOT, EOL
				70306	70914					Line change
MC32	62	39449	39504	70915	70970	125	12	9	6600	SOT,SOL, missing SP #70971
				70971						Missing shots
	62	39505	39537	70972	71004	125	12	9	80	mitigation shots, missing SP #71005, #71006
				71005	71006					Missing shots
	62	39538	39886	71007	71355	125	12	9	6600	full power, EOL, EOT
				71356	72002					Line change
MC32A	63	39887	40237	72003	72353	125	12	9	6600	SOT,SOL, EOT, EOL
MC32B	64	40238	40576	73003	73341	125	12	9	6600	SOT,SOL
	64	40577	40616	73342	73381	125	12	9	3300	half of gun array, EOT,EOL
				73382	73943					Line change
MC33	65	40617	41152	73944	74479	125	12	9	6600	SOT,SOL, EOT, EOL, full power
				74480	75030					Line change
MC34	66	41153	41179	75031	75057	126	12	9	6600	SOL,SOT, streamer straight
	66	41180	41226	75058	75104	127	12	9	6600	streamer misaligned
	66	41227	41796	75105	75674	128	12	9	6600	streamer straight, EOT, EOL
				75675	80446					Line change
MC23A	67	41797	41988	80447	80638	129	12	9	6600	SOT,SOL, EOT, EOL, steamer misaligned
				80639	81547					Line change
MC34A	68	41989	42988	81548	82547	130	12	9	6600	SOT, SOL, EOT
	69	42989	43742	82548	83301	131	12	9	6600	SOT,SOL, EOT, EOL

Table 6. Times and geographic coordinates of power down/off periods during lines.

Line	power down/off						power up					
	day/month	hr:min	latitude S		longitude W		day/month	hr:min	latitude S		longitude W	
OB03	29/10	22:39	21	31.5862	70	34.2296	29/10	22:43	21	31.2487	70	34.2774
	30/10	11:42	20	26.5751	70	43.2342	30/10	12:11	20	24.4527	70	43.5267
	30/10	21:42	19	37.2686	70	49.9835	30/10	22:14	19	35.0204	70	50.2838
OB02	31/10	15:43	19	5.3108	70	40.4760	31/10	15:47	19	5.5932	70	40.2458
	31/10	18:57	19	18.0758	70	30.0277	31/10	19:29	19	20.2281	70	28.2667
	31/10	20:16	19	23.3083	70	25.7400	31/10	20:28	19	24.0774	70	25.1187
OB01	31/10	22:12	19	23.8849	70	25.0125	31/10	23:23	19	26.3665	70	30.4392
MC01	03/11	21:24	19	46.6396	71	15.0383	03/11	21:46	19	46.0725	71	13.7751
MC02	04/11	14:33	19	24.9086	70	30.2024	04/11	14:48	19	23.9966	70	30.8201
	04/11	22:16	18	57.3457	70	48.7565	04/11	22:23	18	56.9452	70	49.0332
MC03	6/11	15:15	21	9.2500	70	37.3450	6/11	15:24	21	9.8646	70	37.2594
	6/11	16:07	21	12.8361	70	36.8446	6/11	16:21	21	13.7600	70	36.7110
MC16A	7/11	16:35	20	42.9740	70	49.3765	7/11	17:06	20	40.6044	70	49.7275
	7/11	21:56	20	19.2892	70	52.9184	7/11	22:18	20	17.5809	70	53.1723
MC15	8/11	20:28	19	20.8658	71	11.9252	8/11	20:30	19	21.0477	71	11.8900
	9/11	13:22	20	35.1914	70	57.2881	9/11	13:27	20	35.5530	70	57.2205
MC11	9/11	17:40	20	35.5407	71	3.3126	9/11	17:51	20	34.6730	71	3.5142
MC12	10/11	15:23	19	20.3421	71	17.1176	10/11	15:30	19	20.1489	71	16.6150
	10/11	15:49	19	19.6091	71	15.2037	10/11	15:55	19	19.4377	71	14.7591
MC13	11/11	11:42	19	49.6355	70	37.7655	11/11	11:53	19	50.4451	70	37.6254
	11/11	16:22	20	9.6989	70	34.2589	11/11	16:38	20	10.8849	70	34.0519
	11/11	18:00	20	16.8552	70	33.0003	11/11	18:14	20	17.8186	70	32.8340
	11/11	19:52	20	25.1522	70	34.5453	11/11	20:14	20	26.8634	70	31.2408
	11/11	21:25	20	32.0403	70	30.3333	11/11	21:55	20	34.1818	70	29.9601
MC09	14/11	15:28	20	19.4515	70	22.5453	14/11	15:34	20	19.0360	70	22.6365
MC08	15/11	10:26	19	23.1823	70	44.4892	15/11	10:58	19	24.0576	70	46.1962
	15/11	12:22	19	26.5667	70	52.3086	15/11	12:32	19	26.8642	70	52.9974
MC19	17/11	17:04	19	51.8700	70	17.6151	17/11	17:23	19	52.4557	70	18.9642
	17/11	20:20	19	56.9205	70	32.0930	17/11	20:39	19	57.4345	70	33.5905
MC06	18/11	23:12	19	54.5382	70	32.4003	18/11	23:15	19	54.3995	70	49.0456

MG1601 are shown in Figure 5. An automated data cleaning process using mbsystems was implemented to remove noisy data points, and data were gridded with a grid spacing of 100 m.

Raw data can be downloaded from the Rolling Deck to Repository (R2R) web site (http://www.rvdata.us/catalog/MGL1610). Data will also be incorporated into the Global Multi-Resolution Topography (GMRT) data base, available through GeoMapApp (www.geomapapp.org).

Expendible Bathythermograph (XBT): XBTs were generally acquired once a day. However, fewer XBTs were acquired during OBS deployment and recovery since bathymetric data were not being acquired and XBTs were acquired every 4 hours when shooting the 2 long lines at 50 m shot intervals. XBT sites are given in Table 7. The locations of XBTs are shown in Figure 10 and plots of the velocity/depth functions are shown in Appendix D.

Data are open access and can be downloaded from the Rolling Deck to Repository (R2R) web site (http://www.rvdata.us/catalog/MGL1610).

Knudsen 3260 3.5 kHz subbottom profiler: Like the EM122, Knudsen 3.5 kHz data acquisition was restricted to when seismic data were being acquired. Data were saved in keb-format (binary data files, which can be replayed using Knudsen post-cruise playback software) and converted to SEG-Y format. ASCII files containing parameter settings and navigation information were also recorded (kea-fomat). The Knudsen ping rate was not synced with the EM122, improving the quality of the 3.5 kHz data. Acquisition began on October 29 at 17:46 and ended on November 28 at 18:34, when acquisition of MCS data was complete. Unfortunately, data saving was accidentally turned off and no digital data were saved from 04:36 on Nov 12 until 19:49 on Nov 16.

Data are open access and can be downloaded from the Rolling Deck to Repository (R2R) web site (http://www.rvdata.us/catalog/MGL1610).

RDI 75 kHz Acoustic Doppler Current Profiler: ADCP data were acquired throughout the cruise at the 75 kHz. Data were processed during the cruise using University of Hawaii UHDAS software. For each day of the cruise, the archive includes map views of shallow current speed, direction and sea surface temperature, and of the north-south and east-west components of the current as a function of depth versus time, latitude and longitude (i.e. 4 plots/day for 75nb and 4 for 75bb).

The raw data, plot archive, and reprocessed data are available from the from Joint Archive for Shipboard ADCP data at the University of Hawaii (ilikai.soest.hawaii.edu/sadcp/) or from the R2R web site (www.rvdata.us/catalog/MGL1610).

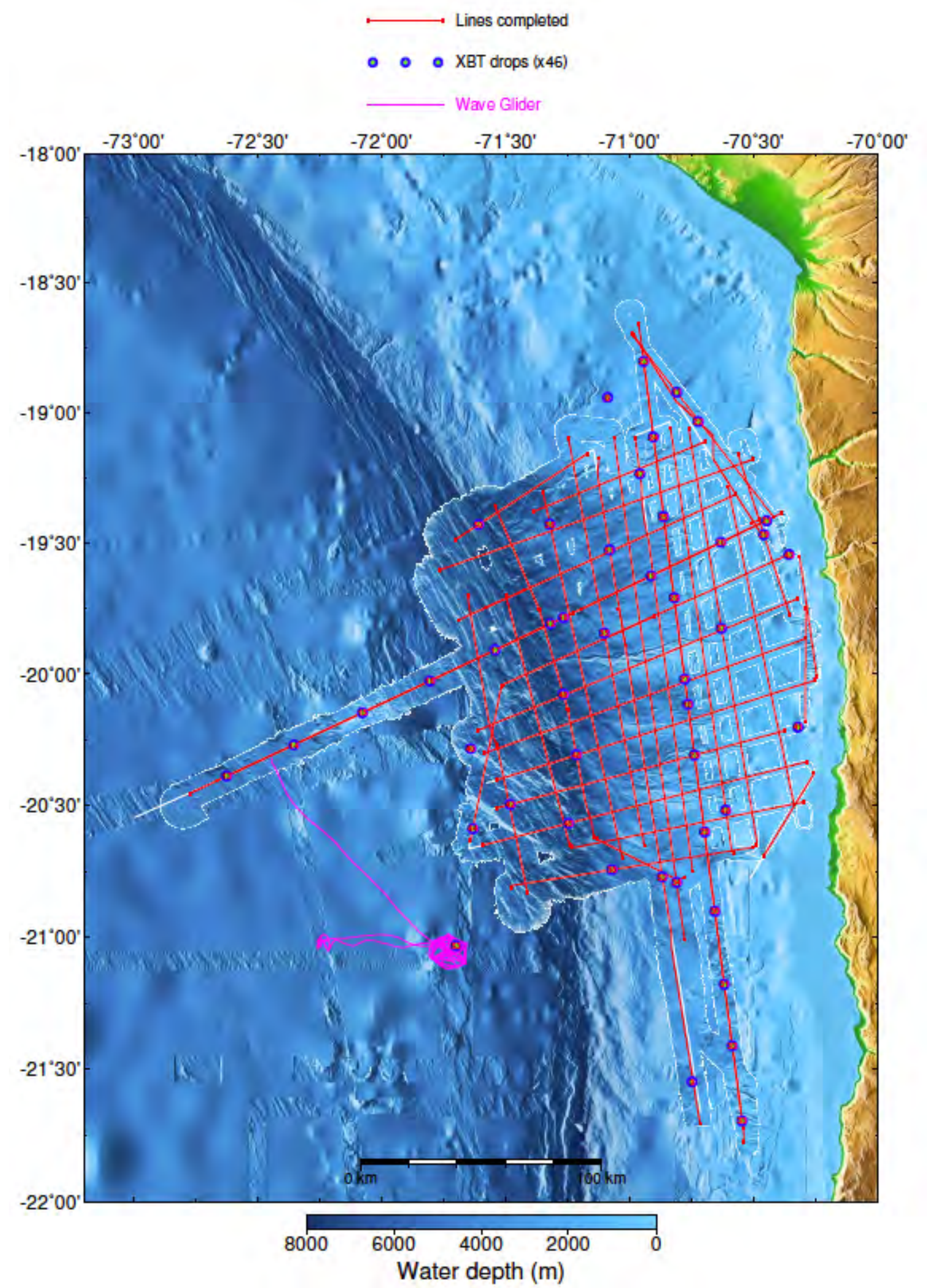


Figure 10. Map showing location of XBT casts.

Table 7. XBT drops. LGD - Last Good Depth. Assumed salinity was taken from the meaured value at the sea surface.

Date	Time	Seq. #	Lat deg (S)	Lat min	Long deg (W)	Long min	Probe Type	Water depth (m)	Assumed Salinity Value (ppt)	Surface sound velocity	Sound velocity at 6.1 m m/s	Last Good Depth m	Water temperature at LGD (°C)	Sound velocity at LGD (m/s)	Imported to SIS
10/24/16	1:21:44	8	18	56.4304	71	5.34229	T-5/20	2295	35.149	1515.73	1500.68	1828.21	2.58	1484.23	Yes
10/29/16	13:45:36	9	21	32.86938	70	44.9707	T-5	2780	35.047	1514.7	1514.61	1695.7	2.8	1483.06	Yes
10/30/16	15:44:29	10	20	6.9364	70	45.92627	T-5	2005	35.213	1518.2	1518.12	1827.6	2.65	1484.56	yes
10/31/16	13:09:13	11	18	55.27234	70	48.65674	T-5	1514	35.164	1518.07	1518.14	1517.8	3.71	1484.31	Yes
11/1/16	9:37:49	12	19	48.5332	71	19.28125	T-5	6536	35.161	1517.75	1517.81	1827.6	2.61	1484.35	Yes
11/3/16	0:46:55	13	20	23.0774	72	36.8318	T-5	4651	35.16	1519.2	1518.13	1826.5	2.69	1484.59	Yes
11/3/16	4:42:45	14	20	16.22607	72	21.3291	T-5	4250	35.418	1514.92	1514.98	1825.3	2.55	1484.06	Yes
11/3/16	8:45:52	15	20	8.89819	72	4.77832	T-5	2842	35.418	1515.2	1515.27	1826.5	2.57	1484.16	Yes
11/3/16	12:53:38	16	20	1.6106	71	48.4126	T-5	4873	35.293	1515.93	1515.8	1829.9	2.6	1484.31	Yes
11/3/16	16:51:05	17	19	54.5271	71	32.5835	T-5	6393	35.162	1522.9	1517.66	1826.5	2.57	1483.99	No
11/3/16	21:06:55	18	19	47.11877	71	16.11914	T-5	5420	34.993	1515.92	1521.56	1826.5	2.55	1484.08	No
11/4/16	2:54:44	19	19	37.5083	71	54.84229	T-5	2502	35.249	1518.4	1518.06	1827.6	2.52	1483.98	Yes
11/4/16	7:07:17	20	19	29.81372	70	37.93457	T-5	677	35.35	1518.07	1518.11	674.9	6.31	1480.69	No
11/4/16	9:42:26	21	19	24.80664	70	26.91504	T-5	754	35.322	1516.18	1518.92	769.5	5.81	1480.25	No
11/4/16	20:41:31	22	19	2.04285	70	43.50879	T-5	1486	35.193	1518.73	1525.82	1485.5	2.99	1480.29	No
11/5/16	7:14:18	23	19	48.20068	70	56.62109	T-5	1481	35.218	1518.65	1518.53	951.8	4.67	1478.61	No
11/5/16	11:12:11	24	19	5.51965	70	54.28027	T-5	1489	35.115	1517.64	1517.64	1503.5	2.99	1480.56	Yes
11/5/16	15:21:42	25	19	23.85571	70	51.80322	T-5	1180	35.115	1518.8	1524.62	1190.4	3.92	1478.67	No
11/5/16	19:35:59	26	19	42.53674	70	49.26758	T-5	1992	35.235	1519.02	1525.31	1829.9	2.47	1483.71	No
11/5/16	23:46:27	27	20	1.1908	70	46.71191	T-5	1480	35.178	1518.53	1524.26	1495.1	3	1484.51	No
11/6/16	3:41:59	28	20	18.54602	70	44.33643	T-5	2074	35.25	1519.1	1518.76	1829.9	2.47	1483.75	Yes
11/6/16	7:41:15	29	20	36.11951	70	41.91992	T-5	1604	34.914	1516.85	1516.86	1613.9	2.81	1481.65	Yes
11/6/16	11:44:41	30	20	54.18384	70	39.42383	T-5	1754	34.886	1516.74	1516.75	1768.6	2.57	1483.18	Yes
11/6/16	15:38:42	31	21	10.83716	70	37.125	T-5	1975	34.752	1511.74	1517.35	1829.9	2.55	1483.88	No
11/6/16	19:04:02	32	21	24.77368	70	35.17725	T-5	1951	35.147	1513.09	1523.82	1823.6	2.48	1483.68	No
11/6/16	22:53:56	33	21	41.7771	70	32.80713	T-5	1254	35.004	1517.17	1522.84	1270.2	3.54	1478.84	No
11/7/16	15:32:46	34	20	47.46042	70	48.69727	T-5	2718	34.878	1514.79	1521.45	1829.9	2.28	1482.74	No
11/9/16	3:13:19	35	19	50.57983	71	6.10449	T-5	4166	35.135	1519.18	1519.19	1829.9	2.49	1483.73	Yes
11/10/16	9:36:10	36	19	25.56787	71	19.33398	T-5	4409	35.123	1518.78	1516.56	1825.3	2.5	1483.82	Yes
11/11/16	11:41:13	37	19	49.56592	70	37.77588	T-5	1292	35.138	1518.55	1518.58	1292.2	3.54	1479.44	Yes
11/12/16	6:39:42	38	20	44.76892	71	4.399	T-5	5549	34.877	1517.31	1515.3	1827.6	2.49	1483.83	Yes
11/17/16	9:40:19	39	19	28.09741	70	27.53271	T-5	673	34.811	1513.21	1511.96	673.6	6.21	1480.33	Yes
11/18/16	11:11:18	40	20	17.0896	71	38.56543	T-5	4835	35.369	1520.02	1520.06	1829.9	2.5	1483.68	Yes
11/19/16	13:11:38	41	20	12.21045	70	19.31348	T-5	721	34.772	1509.8	1509.73	716.2	5.81	1479.22	Yes
11/20/16	4:26:11	42	20	29.8501	71	28.9248	T-5	5451	35.247	1520.13	1520.14	1825.3	2.44	1483.56	Yes
11/21/16	7:15:08	43	19	32.52295	70	21.40332	T-7	395	34.748	1505.56	1505.56	390.8	10.06	1490.41	Yes
11/22/16	6:57:22	44	20	35.33044	71	37.96729	T-5	4186	35.184	1519.53	1519.42	1829.9	2.43	1483.56	Yes
11/22/16	12:53:57	45	20	34.15027	71	14.83301	T-5	7237	34.944	1519.21	1519.2	1829.9	2.55	1484.09	Yes
11/23/16	11:00:52	46	20	31.09924	70	36.76025	T-5	1221	34.781	1514.35	1514.41	1240.2	3.82	1479.79	Yes
11/24/16	10:51:26	47	19	14.07202	70	57.54248	T-5	1431	35.165	1522.27	1522.3	1337.2	3.49	1479.98	Yes
11/25/16	17:28:00	48	20	18.45377	71	12.92139	T-5	6623	34.89	1520.66	1526.45	1820.1	2.6	1484.02	No
11/25/16	20:39:00	49	20	4.6167	71	16.06836	T-5	6856	34.96	1521.78	1527.01	1824.2	2.56	1484.11	No
11/26/16	12:17:02	50	19	25.75598	71	36.62744	T-5	7415	35.134	1522.82	1522.85	1829.9	2.56	1484.15	Yes
11/27/16	0:22:40	51	19	31.53052	71	4.85303	T-5	3415	35.095	1523.3	1528.78	1826.5	2.56	1484.13	No
11/28/16	5:45:19	52	20	46.30981	70	52.10938	T-5	3211	34.528	1511.97	1511.94	1829.9	2.55	1484.12	Yes
11/30/16	2:32:00	53	21	2.016885	71	42.08398	XCTD-2	N/A	35.077	1449.52	1426.3	1846	2.4	1489.88	No

Bell Aerospace BGM-3 gravimeter: Gravity data were acquired during the MGL1610. The gravimeter was calibrated in Arica prior to the cruise. An ad-hoc correction was applied to the data to display approximate gravity readings for monitoring by the watchstanders but only raw count data were saved.

The gravity data, along with calibration information, navigation, and ship acceleration data, is archived at R2R (www.rvdata.us/catalog/MGL1610). R2R staff will correct gravity data and make free-air anomaly data available to the community in a timely manner. Data will be open access as soon as they are archived.

Geometrics 882 magnetometers: Magnetic data were acquired whenever possible using one of two towed magnetometers. Magnetic declination at 0 elevation, latitude -20, longitude -72 on Nov 11, 2016: 3.26°W, changing by 0.18°W/year (Model IGRF12). A “figure of merit” tests was conducted with the airgun array deployed (Figure 7) near the end of the cruise (December 5). Magnetic anomaly data are shown in map view in Figure 5 and versus time in Appendix A.

Data can be downloaded from the Rolling Deck to Repository (R2R) web site (http://www.rvdata.us/catalog/MGL1610)

ARGOS float deployments: As a service to NOAA, we deployed 5 ARGOS floats at the following locations.

***Table 8**. Locations where ARGOS floats were deployed.*

OBS site	Float number	Latitude (deg. S)	Latitude (minutes)	Longitude (deg. W)	Longitude (minutes)	JD	time
SS21	#26/F0684	20	18.515	72	25.534	299	14:15
OBS15-x2	#82/F0710	21	33.038	70	45.009	303	14:06
SS10	#60/F014	20	17.639	70	43.909	336	05:02
SS25	#22/F0704	20	18.887	72	27.048	340	23:48
SS21	#26/F0716	20	00.213	71	46.388	341	12:54

Meteorological and seasurface temperature/salinity data: Data acquisition was running during the entire cruise. We had fine weather for the whole cruise. Swell was <2m most of the time. There were occasional white caps with winds up to ~20 kts, but winds were never sustained long enough to build up a large, local swell. Seasurface temperature and salinity are shown in map view in Figure 5 and as profiles versus time in Appendix A.

Data can be downloaded from the Rolling Deck to Repository (R2R) web site (http://www.rvdata.us/catalog/MGL1610).

5. Acoustic Seafloor Geodesy

In December 2015, the RV Sonne cruise SO244 successfully installed 23 acoustic geodetic seafloor transponders as part of the geodetic network GeoSEA (Geodetic Earthquake Observatory on the SEAfloor). The target of this installation is a segment of the Nazca-South American plate boundary on the marine forearc and outer rise of the South American subduction system around 21°S. This portion of the plate has last ruptured in an earthquake in 1877 and was identified as a seismic gap prior to the 2014 Iquique/Pisagua earthquake (Mw=8.1). The southern portion of the segment remains unbroken and is currently in the latest stage of the interseismic phase of the seismic cycle. Seafloor geodetic measurements provide a way to monitor crustal deformation at high resolution comparable to the satellite-based GPS technique upon which terrestrial geodesy is largely based. The GeoSEA Network is distributed over three target areas: Area 1 on the middle continental slope consists of 8 transponders located in pairs on four topographic ridges, which are surface expressions of faults at depth. Area 2 is located on the outer rise seaward of the trench where 5 stations monitor extension across plate-bending related normal faults. Area 3 is located at water depth >5000 m on the lower continental slope where an array of 10 stations measures diffuse strain build-up.

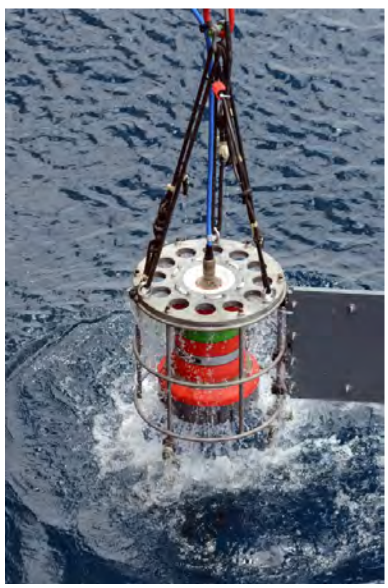


Fig. 11 : High Performance Transducer lowered from the side of R/V Marcus G Langseth

The indirect seafloor acoustic ranging methods provide relative positioning by using precision acoustic transponders (Autonomous Monitoring Transponder, AMT) that include: pressure sensors to monitor possible vertical movements as well as the tide effect corrections, tiltmeters in order to measure their inclination as well as any change in the seafloor and sound velocity (SV) sensors to correct for sound speed variations in the water column. The High Performance Transducer lowered from the side of the RV Marcus G. Langseth (Figure11) provides the communication to the seafloor transducers and download of data.

Table 9. Locations of seafloor geodetic monuments from which data were uploaded acoustically. Stations A101-A108 are in Area1; stations A201-205 in Area2; A301-A310 in Area 3.

Station	Latitude	Logitude	Data kB	Battery
A101	20°47,943 S	70°48,910 W	380	74.00%
A102	20°47,677 S	70°48,460 W	408	71.00%
A103	20°47,577 S	70°48,995 W	430	72.00%
A104	20°47,373 S	70°48,521 W	406	75.00%
A105	20°48,118 S	70°49,381 W	429	76.00%
A106	20°47,792 S	70°49,444 W	429	75.00%
A107	20°47,884 S	70°49,825 W	430	75.00%
A108	20°47,611 S	70°49,994 W	517	72.00%
A201	21°03,370 S	71°43,846 W	504	72.00%
A202	21°03,089 S	71°43,923 W	504	71.00%
A203	21°03,439 S	71°44,135 W	505	67.00%
A204	21°03,127 S	71°44,256 W	411	71.00%
A205	21°03,330 S	71°43,846 W	505	68.00%
A301	20°47,035 S	71°4,011 W	392	74.00%
A302	20°47,561 S	71°4,945 W	322	76.00%
A303	20°46,853 S	71°3,520 W	370	77.00%
A304	20°46,565 S	71°4635 W	386	72.00%
A205	20°46,955 S	71°5,068 W	411	74.00%
A306	20°46,584 S	71°4,051 W	174	72.00%
A307	20°48,037 S	71°4,088 W	323	75.00%
A308	20°47,897 S	71°3,595 W	387	74.00%
A309	20°47,682 S	71°3,186 W	317	74.00%
A310	20°47,237 S	71°3,846 W	392	72.00%

The GeoSURF Wave Glider (Figure 12) is an autonomous, environmentally powered ocean-going platform by Liquid Robotics that uses wave motion for forward propulsion. The Wave Glider is composed of two main parts: the float contains all sensors and communication units and a sub holds a wing rack, which is connected to the float with a 6 m long flexible umbilical tether. Directional control is accomplished with a rudder on the Glider sub unit. The float on water surface is equipped with satellite communication systems (Iridium Satellite LLC) for remote transmission of data, global positioning system and weather station. It also contains batteries to provide power during night times when the Solar Panels cannot produce energy. The GEOMAR Wave Glider is equipped with a compatible SonardyneLtd. AMT telemetry receiver in the rear part of the float unit, which is the acoustic communication gateway to the autonomous monitoring transponders on the seafloor. The Wave Glider communicates periodically via satellite communication its position and accomplishes the commands given by the watchkeeper.

The Wave Glider was deployed at the western end of the multichannel seismic line MC16A and traveled to target Area 2 on the outer rise, where it dodged passing ships and tried to upload data. It was recovered near the western end of Line MC01 during recovery of OBSs.

Figure 12. The GeoSURF Wave Glider with its proud papa, Florian Petersen.

6. PSO and PAM: Procedures and observations:

A crew of 5 protected species observers stood watch during the entire cruise. Generally, 2 observers were on visual watch during daylight hours, with a 3rd observer in the lab around the clock watching the Seiche^{TM} Passive Acoustic Monitoring (PAM) system. Source power was increased gradually ("ramp-up" when the source was initially fired up and after any shut down lasting more the 8 minutes. The observers followed the logic tree shown in Figure 13 when deciding whether to call for a "power down" (i.e. shutting off all but a small 40 cubic inch "mitigation" airgun) or a "shut down" (complete shut-down of all airguns). Times and positions of data gaps due to power or shut downs are given in Tables 5 and 6, respectively. The complete final monitoring report will be found on the NOAA site with all the other project documents at:

http://www.nmfs.noaa.gov/pr/permits/incidental/research.htm under the heading: Lamont-Doherty Earth Observatory/NSF Seismic Survey in Southeast Pacific Ocean (2016)

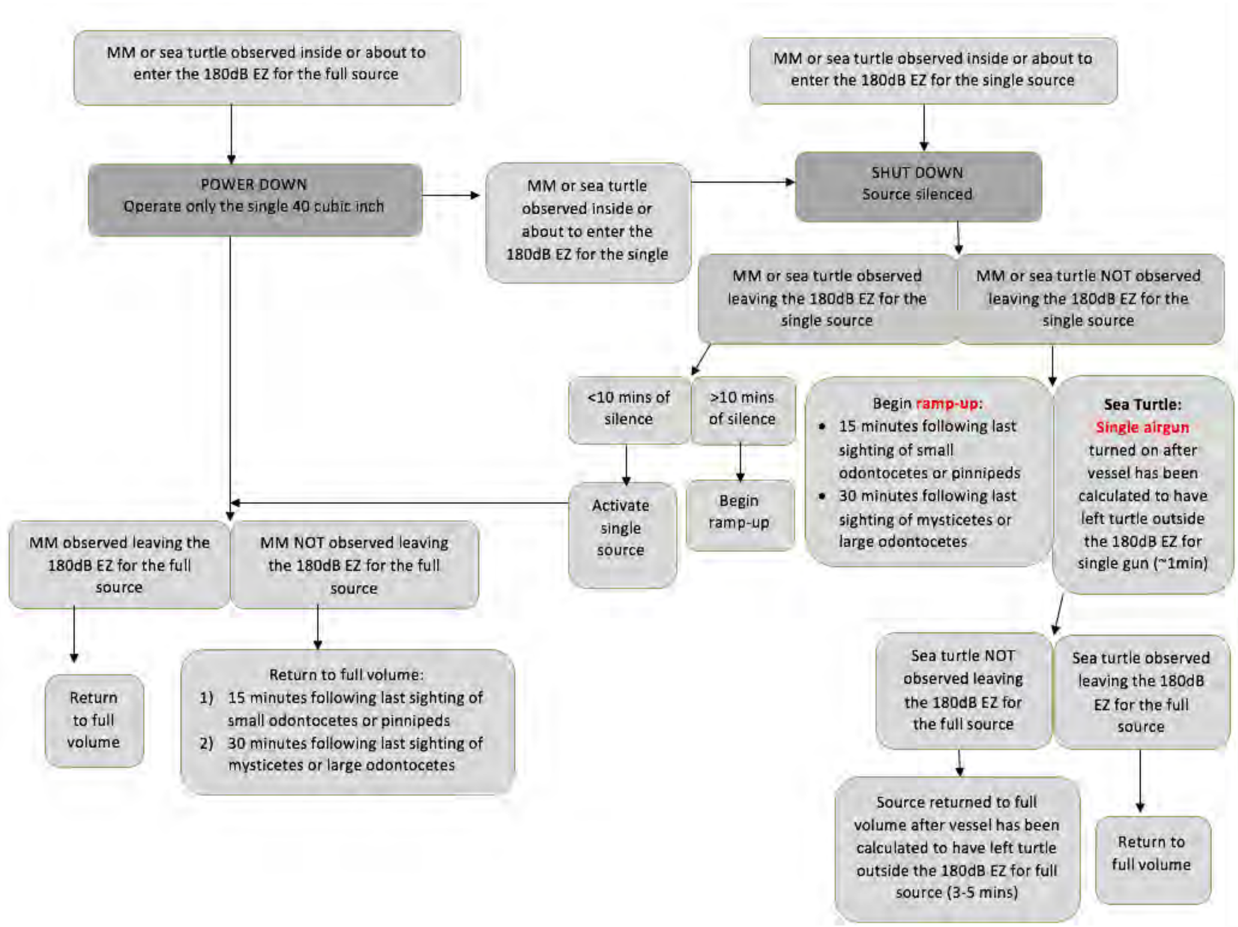


Figure 13a. Logic tree for determining actions to mitigate impact of airguns of protected species.

7. Shipboard processing of MCS data:

Raw data were recorded for 20 s/shot at a sample rate of 2 ms with each shot in a separate SEGD format file, with files grouped in directories that served as virtual "tapes." Students reviewed each segd file, using SegDSee v. 3.0 for Unix by Segrey Pavluhkin. Students noted the first and last ffid and shot number in each "tape" (directory), whether there were any missing shots, when the streamer appeared to be straight, and other noteworthy features. Those hand-written notes were reviewed and summarized in a spreadsheet included here as Table 5.

We followed two parallel processing streams on board. In one stream, the near traces (to an offset of 1000 m) were processed through decimation, sorting, addition of CDP trace numbers to the headers, filtering, normal moveout (NMO), stack, and Stolt migration. A simple geometry in which the streamer is always in line with the CDP line and shots were exactly the specified distance apart was assumed when defining the geometry, and a velocity of 1500 m/s was used for

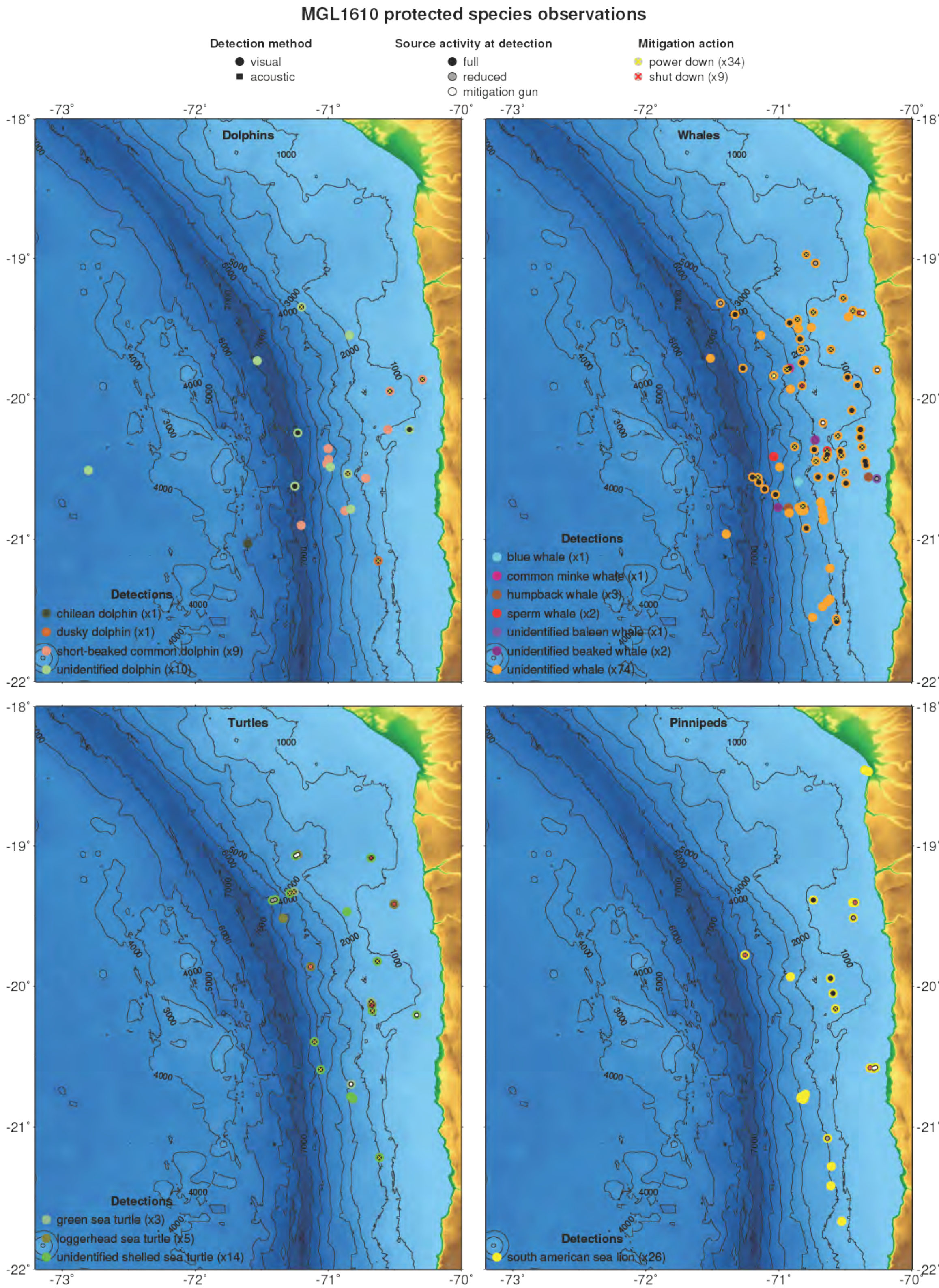


Figure 13b. Summary of protected species observations.

both the NMO and Stolt migration. A complete set of seismic sections processed in this manner with shotpoint positions converted from geographic to UTM zone 19K coordinates using the GMT "mapproject" routine was loaded into Kingdom Suite along with the high-resolution bathymetric map for evaluation of data quality and preliminary interpretation. This data processing sequence, which was built primarily using SeismicUnix is given in Appendix C.

In parallel, Kathy Davenport worked with ProMAX to determine midpoint locations and enter UTM coordinates into the trace headers of undecimated SEG-Y files for archiving. The p190 (UKOOA) navigation files containing the UTM zone 19K coordinate information for sources and receivers were produced by Dave Martinson. A description of the ProMAX import process for the PICTURES data is in Appendix C – part 2. Plots of the midpoint distribution for each line are shown in Appendix X+1. A subset of the data from line MC09 was also input into Promax so that students could experience interactive velocity analysis and compare the impact on the final stack. The midpoint distributions are shown graphically in Appendix C – part 3.

Effects of including larger offsets and of including velocities determined through interactive analysis of refracted as well as reflected data when stacking and migrating data were also examined. Some results of this analysis will be given in section 9.

8. Shipboard processing of OBS data

The SIO OBS data were corrected for clock drift and converted both to continuous day file in mini-seed format and cut into SEG-Y files using the shot times recorded by the MCS system. The position of the instrument when it was released from the ship was used for cutting the traces for the SEG-Y files and offsets were calculated based on this position and the position of the source. Both the instrument position and the offset will be updated in the headers once the instruments have been relocated on the seafloor using observed travel times of water waves from shots passing near the instruments. Data were filtered and plotted for quality control and preliminary processing. Table 3 summarizes data recovery.

The GEOMAR OBS data were backed up but not cut into SEG-Y files on board but will be available to project investigators by late January 2017.

9. Preliminary results

During the cruise, we generated preliminary migrated sections of all of the MCS data, as described in section 4, as well as developed more detailed analyses of a subset of the data. We also took a first look at data recorded on SIO OBSs. Here we present a few preliminary results, which indicate that the data quality is excellent and that, with further analysis, we should be able to achieve the primary project objects as well as address a number of additional, related questions.

The data constrain the structure of the incoming oceanic crust. The seaward end of MCS line 01 (Fig. 14) was processed using an interval velocity model determined from refractions and wide-angle reflections observed on the entire 12.5-km long streamer (Fig. 15) and are shown in Figure 16. The base of the crust (Moho), layer 2A/2B boundary, and crustal faults are all clearly imaged. Further processing is needed to constrain possible anisotropy in mantle velocity and changes in the velocity structure as the oceanic crust as it is subducted.

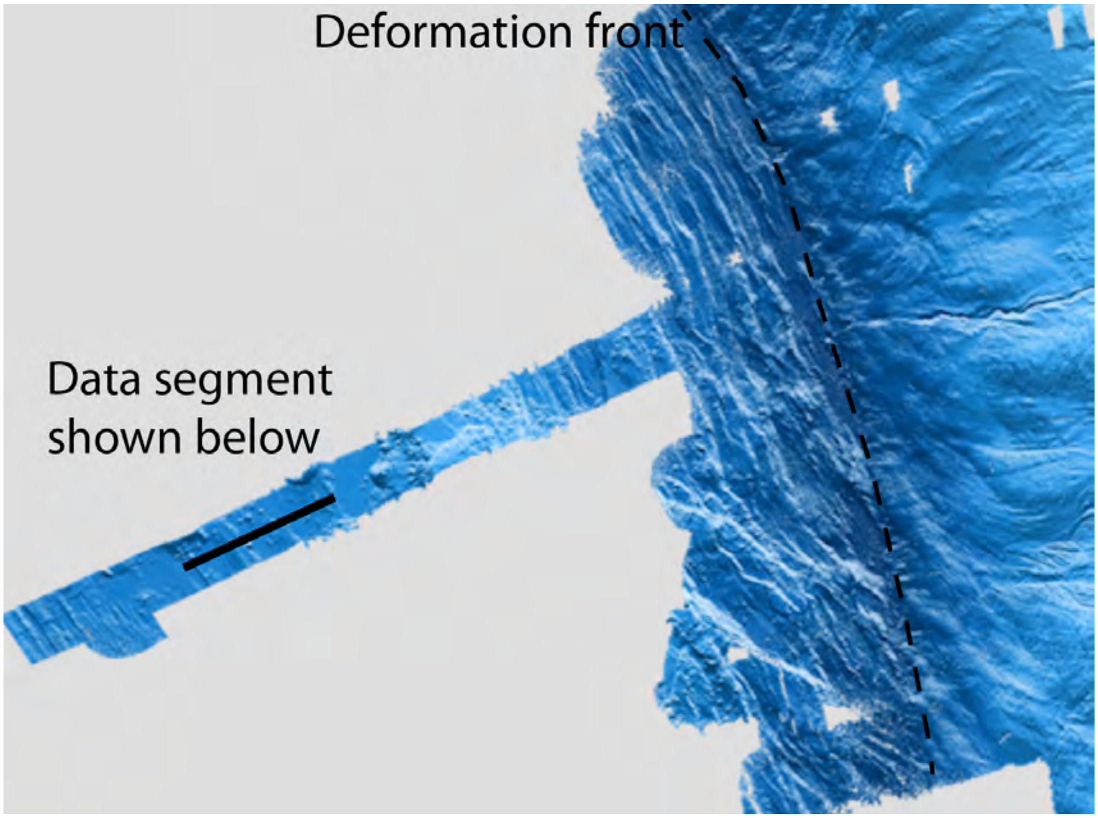


Figure 14. Location of the examples of MCS data shown here overlain on swath bathymetric data acquired during MCS data acquisition

The data also clearly show the impact of subducting topography on the structure of the outer accretionary wedge. Two contrasting crossings of the deformation front are shown in Figure 17. Topography on the subducting plate near the trench creates sediment ponds and deforms them. The structure of the subducting plate is apparent in the seafloor topography for at least 20 km from the deformation front (Figure 14), suggesting coupling between the plates and plastic deformation of the overlying plate in this region.

A preliminary assessment of the OBS data indicates that all SIO OBSs recorded the entire experiment. A narrow-band 6.5 Hz resonance was observed intermittently on geophone components of a few OBSs; the impact on achieving cruise objectives, however, appears to be minor. Clear Pg and PmP arrivals are observed on instruments throughout the array (e.g. Figure 17-19). Many local and regional earthquakes are also observed, providing additional information to constrain the velocity model derived from controlled source data and relate it to local tectonic activity. All but 2 of the GEOMAR OBSs appear to have also recorded the entire experiment, although we were not able to evaluate data quality during the cruise. Two instruments had timing issues that may impact timing precision. Combining MCS constraints on the decollement depth and characteristics with constraints on the position of the Moho of the subducted plate in the OBS data will provide important constraints on evolution of the plate boundary at depths at which slip in very large earthquakes occurs.

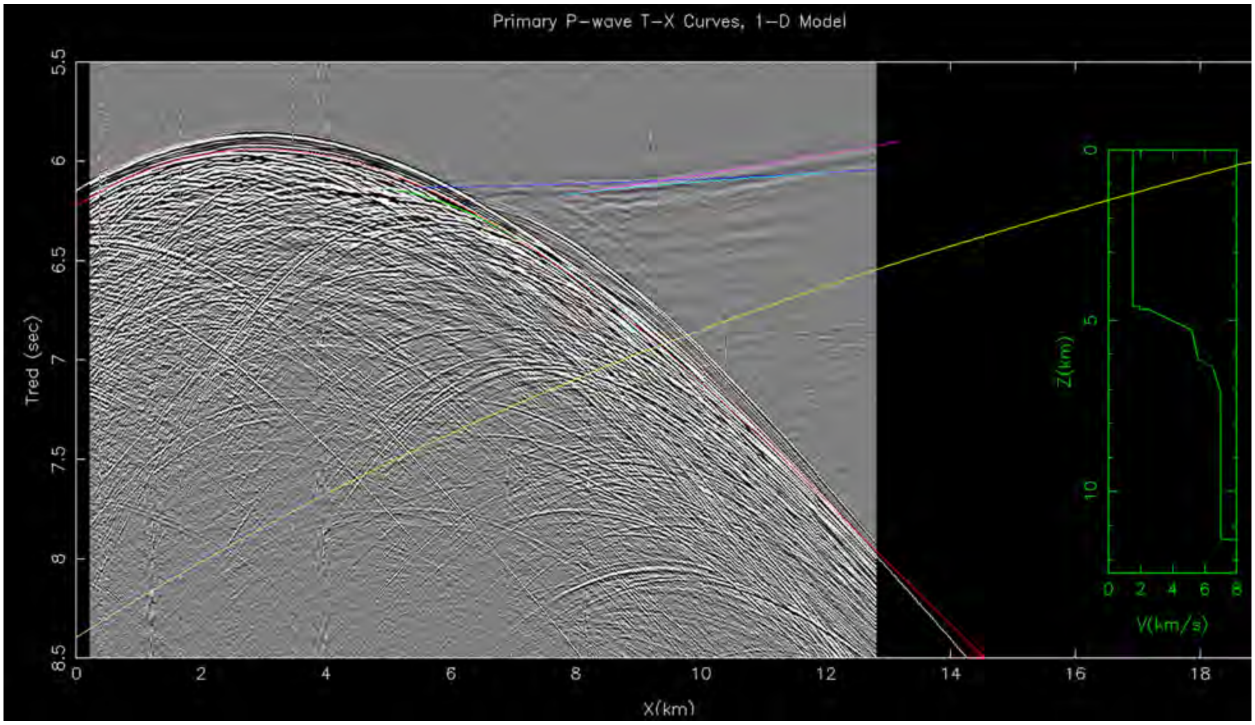


Figure 15. 1D velocity model of a shot gather recorded on the 12.5-km long streamer. The location of this shot gather is shown in Figure XZ.

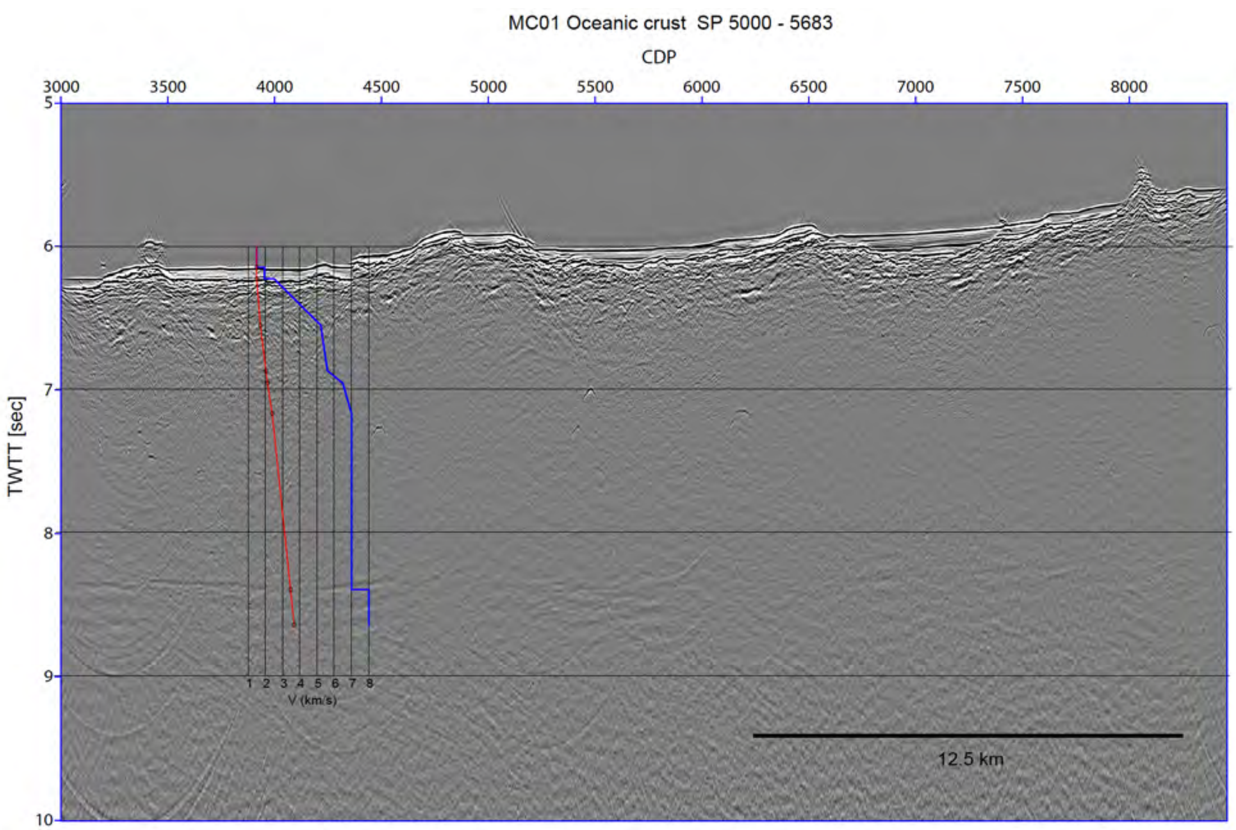


Figure 16 (previous page). Section of data processed using the entire 12.5-km streamer and the velocity model of Figure XY (blue line) converted to an rms velocity model and "hung" from the seafloor. Data were migrated using the phase shift migration routine in Seismic Unix.

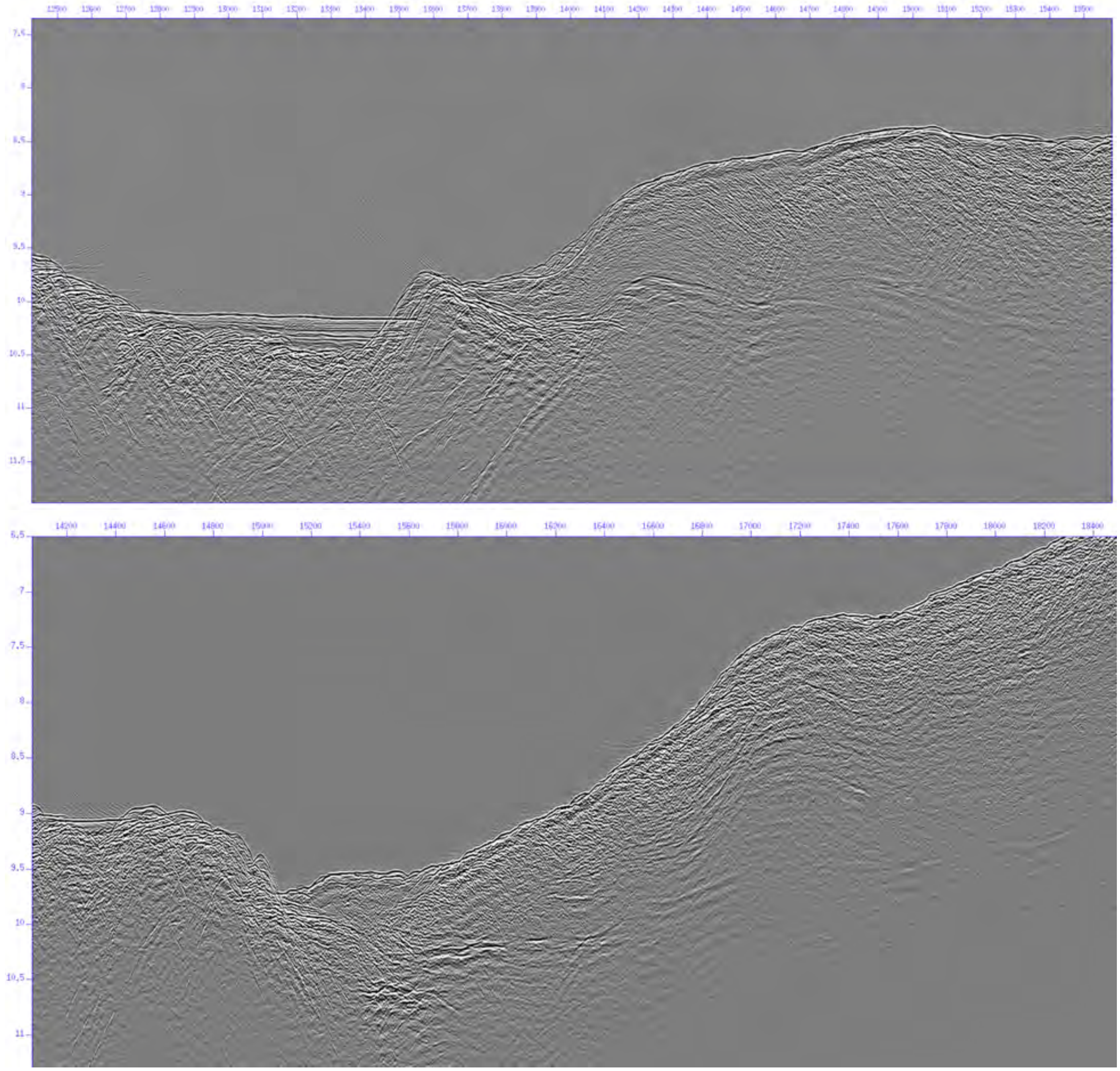


Figure 17. Two examples of crossings of the deformation front from MC25 (top) and MC27 (bottom).
The distance landward of the deformation front to which the plate boundary/decollement reflection could be imaged with preliminary shipboard processing varied. On all dip profiles, it can be traced continuously for several 10s of km. On dip profile MC08 this reflection is clear along the entire profile. It is also observed on several of the strike lines.

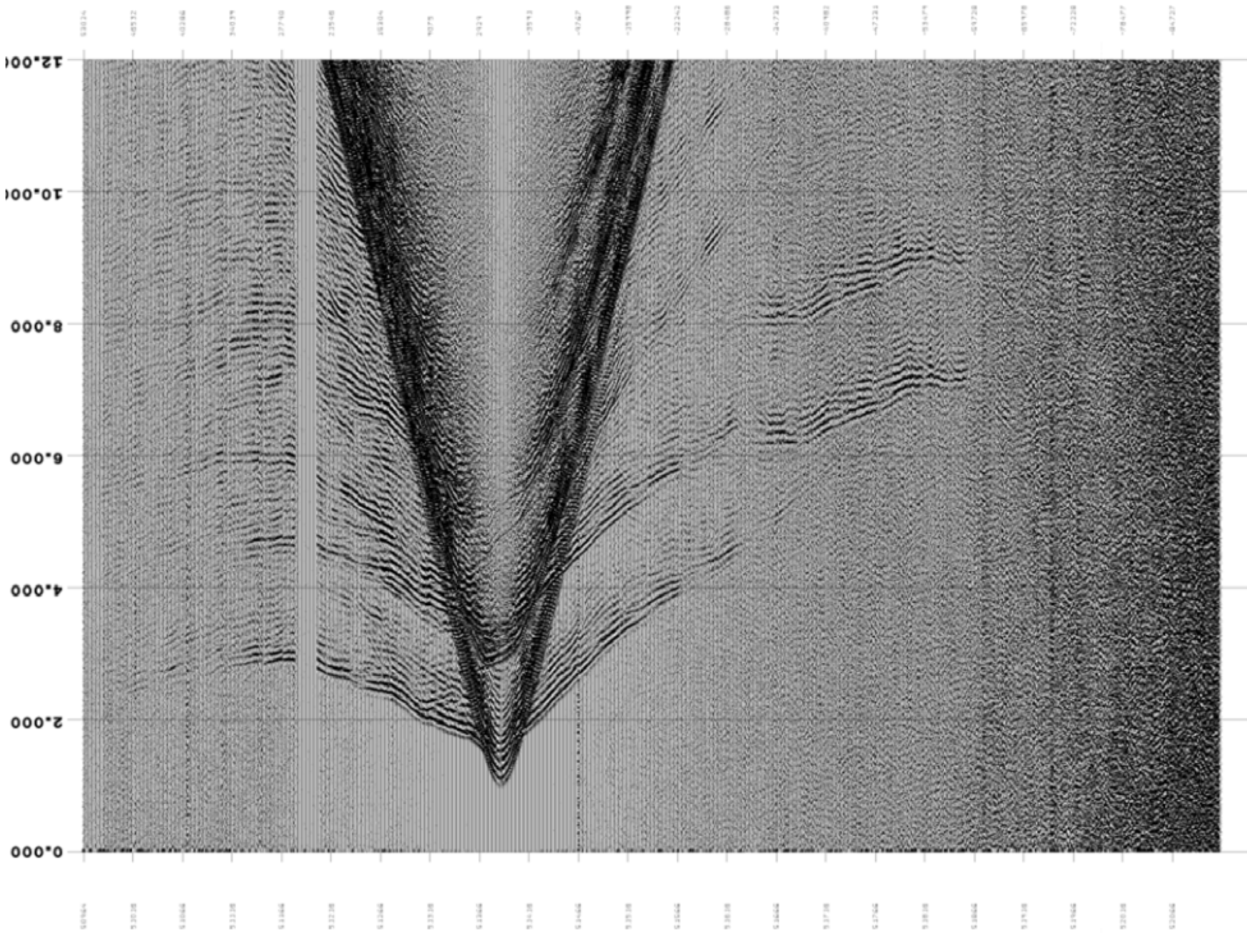


Figure 17. Line MC19 recorded on OBS SS12. Offsets are labeled along the top of the record section; shot numbers are labeled along the bottom. Vertical axis is travel time reduced by 6500 m/s.

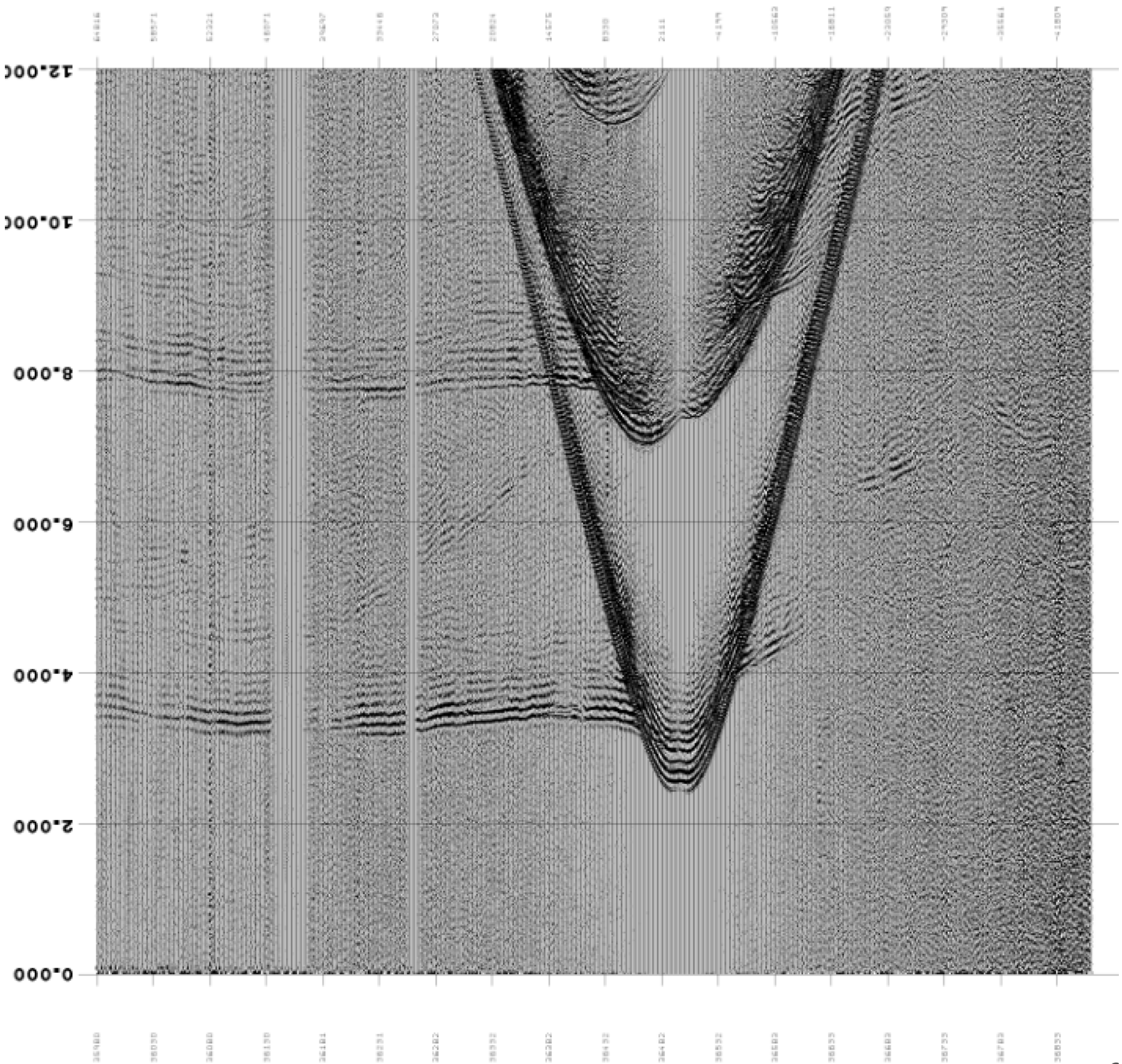


Figure 18. Line MC08 recorded on OBS SS38. Offsets are labeled along the top of the record section; shot numbers are labeled along the bottom. Vertical axis is travel time reduced by 6500 m/s.

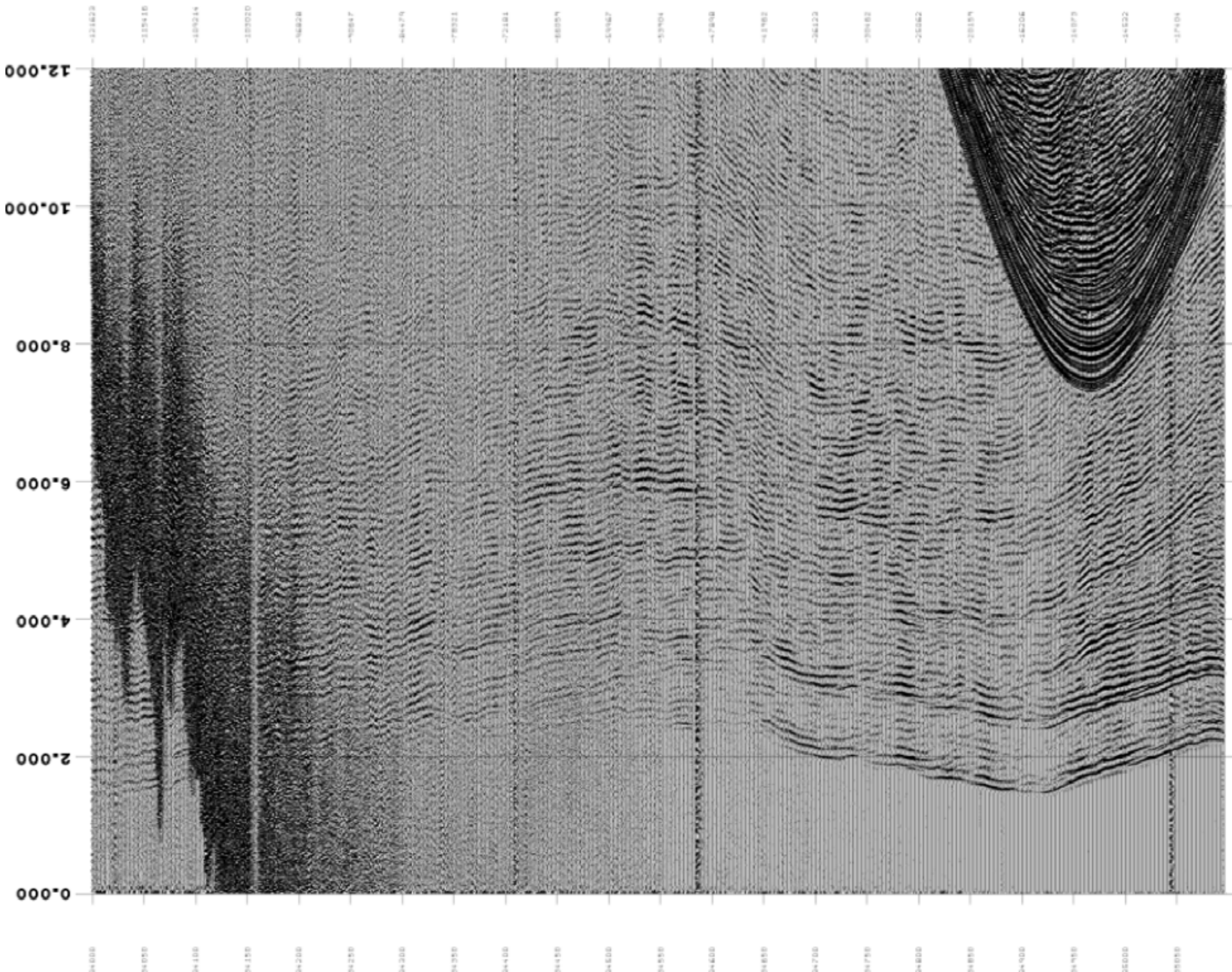


Figure 19. Line MC09 recorded on OBS SS34. Offsets are labeled along the top of the record section; shot numbers are labeled along the bottom. Vertical axis is travel time reduced by 6500 m/s. Note that this example shows an OBS that was offset from the shot line.

10. Summary and recommendations

The crew of the R/V Langseth and technical staff for both OBS and MCS data acquisition did an excellent job. The speed of Langseth's LAN needs improvement. Slow connections between the computers on board interfered at times with efficient data processing. It is also difficult to keep up with changes in NOAA requirement for permits for seismic and acoustic work in the ocean, which can result in confusion and missed opportunities.

11. Acknowledgements

This project was funded by the U.S. National Science Foundation (NSF) through grant XXXX to Oregon State University, which provided salary and travel support for Tréhu and Davenport, and travel support for participants Alhisni, Gonzalez Rojas, Handel, Myers, and Vera. NSF also supports the crew and technical support staff for the R/V Marcus Langseth, which is operated by the Lamont-Doherty Earth Observatory and for the Scripps Institute of Oceanography Ocean Bottom Seismic Instrument Program (SIO-OBSIP), which provided technical support and instrumentation. The German Ministry of Science provided funding for salary and travel support for Lehmann, Peterson, and Riedel and shipping and support for the GEOMAR OBSs.

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Appendix A. This section shows plots of some of the serial data streams recorded during MGL1610. These data are available from the R2R (Rolling Deck to Repository) web site: www.rvdata.us

R2R project is an attempt to systematically preserve all underway data acquired by ships in the UNOLS fleet. The data streams shown here are illustrative of the data available. Bathymetry shows the center beam of the EM122 swath. There are large gaps in coverage while we were deploying and recovering ocean bottom seismometers because we were only permitted to acquire bathymetric and subbottom profiling data while shooting airguns, with the exception of brief periods when deploying or recovering instruments, when accurate knowledge of the water depth and seafloor character were essential. Gravity is not shown because the raw gravity data stream was in counts uncorrected for ship motion. The data will be corrected by the R2R group and is of limited use in that form. A gravity tie was completed in Arica prior to the cruise. The first magnetometer deployed when we started seismic data acquisition was very noisy, but it was swapped for the spare and data quality improved markedly.

(Appendix A plots are in a separate, 46 page document.)

Appendix B: MCS data processing stream A, assuming simple geometry. Generate stacked and migrated sections and input those sections into Kingdom Suite for quality control and prelimnary interpretation.

A simple procedure for converting segd shot files for a seismic line into a cmp sorted, Seismic Unix (su) files with cdp, cdp-trace# (cdpt), and water depth at source (swdep) included in the trace header.

">:" means type the following on a command line in a unix window.

Step 1:

Once a line has been completed, make a working directory for the line.

Copy MC_processing/scripts/segdr_sxgxoffcdp_8km (for lines shot with the 8-km streamer; use segdr_sxgxoffcdp_12km for the 12 km streamer) to the working directory and make the following 3 edits:

Set “ep1” to the first shot of the line being processed.

Set “MCxx” in “fileout” to the name of the line name being processed.

Change the tape number to the first tape of the line.

>:./segdr_sxgxoffcdp_8km

Rerun segdr_sxgxoffcdp_8km for each successive tape for the line after changing only the tape number. The new shots were appended to the existing file.

The final product of segdr_sxgxoffcdp_8km is a unique SeimicUnix (.su) shot file that contains all the shotsof the line and has simple geometry information defined in the headers.

Step 2:

Sort the shot file by cdp and within each cdp by offset using the following command:

>:susort< MCxx_sp.su > MCxx_cdp.su cdp offset

Step 3:

Extract a list of the cdp numbers present in file MCxx_cdp.su , and store them in file cdp.dat usingthe following command:

>:sugethw< MCxx_cdp.su key=cdp output=geom> cdp.dat

cdp.dat is a (one column X #traces lines) ascii file that you can check using any text editor.

Step 4:

Using the fortran program "makecdpt" (written by Michael Riedel), generate the ascii file cdpt.dat that contains the cdp trace number (cdpt)
for each trace of the MCxx_cdp.su file:

>:../scripts/makecdpt<cdp.dat >cdpt.dat

Convert cdpt.dat into a binary file cdpt.bin using:

>:a2b < cdpt.dat n1=1 >cdpt.bin

Step 5:

Create a new file MCxx_cdpt.su that contains the cdp trace number (cdpt) in the headers (needed for some processing software):

>:sushw< MCxx_cdp.su key=cdptinfile=cdpt.bin> MCxx_cdpt.su

Step 6:

Verify that MCxx_cdpt.su is correct and then delete MCxx_cdp.su:

>:rm MCxx_sp.su MCxx_cdp.su

Move MCxx_cdpt.su to folder cdp_gathers and rename the working directory from MCxx to MCxx_done

Step 7:

Apply nmo, stack and Stolt migration to traces with offset <1000 m; assume v=1500 for nmo and migration:

>:suwind<MCxx_cdpt.su key=offset min=200 max=1000 | sunmovnmo=1500 tnmo=0 | sustack key=cdp>MCxx_stack_v1500_off1000.su

(get cdpmax by looking at the header of the last trace in MCxx_stack_v1500_off1000.su with suxedit)

```
>: sustolt<MCxx_stack_v1500_off1000.su cdpmin=685 cdpmax=yyyyydxcdp=6.25 tmig=0 vmig=1500
>MCxx_stack_v1500_off1000_stolt_v1500.su
```

These files can be processed further with SeismicUnix. Convert to sgy for transfer to other software (Sioseis, ProMax, Kingdom Suite)

Step 8:

Converted .su files to .sgy files using the following command:

```
>:segyhdrs< filename.su | segywrite tape=filename.sgy
```

Step 9:

Use "awk" to extract the columns with shot number, source latitude and source longitude from the shotlog files prepared used to cut OBS data to generate segy files:

```
awk '{if(NR>2) print $5, $4, $1}' <MGL1610lineno.shotlog | gmt mapproject –R –C0/0 -Ju19K/1:1 -F |
interpxy >lineno _UTM.dat
```

For GMT v4.8

```
awk '{if(NR>2) print $5, $4, $1}' <MGL1610MC02.shotlog | mapproject -R –C0/0 -Ju19K/1:1 –F | interpxy >
MC02_UTM.dat
```

[interpxy.f is 22-line fortran program that takes standard input and output and interpolates 19 X,Y positions between adjacent shots. The sgy files have been cut so that they start with the first full-fold cmp. For MGL1601 data shot at a 125 m interval, the shot number increments once every 20 cmps.]

Step 10:

Using TextWrangler, paste in the SeiSee header lines (file "seisee_header_XYinsert.txt") in front of each MCxx_UTM.txt file and then "Save As" MCxx_UTMw.txt with WINDOWS line breaks. Move that folder to the PC with Kingdom Suite.

Step 11:

Open the .sgy files in folder MGL1610_sgycut one by one with SeiSee.
Go to the "File" menu and "Import Trace Headers from ASCII file" You will get a pop-up menu that asks you to choose the file. The blue bar at the base of window will fill as the job proceeds. Look at headers, and if they look good, go back to the "File" menu and choose "Save As"
This will write a file with the new headers that can be loaded into Kingdom Suite.

Step 12: Load the file into existing Kingdom Suite project MGL1610.

In the "Surveys" menu in Kingdom Suite go to "Import SEG Y" and choose

"Import Multiple 2D SEG Y files with coordinates" (the 2nd button).
Then click "Next"

Next window should have the correct defaults (Standard, Disk, Time) –
Click "Next"

Choose the file you wish to load and click "Open"

Next window specifies what type of data – you want "amplitude" (which is the default). Click "Next"

Next window needs some editing:

Click box for "Use disk file name as the line name"
Specify byte 21 for "shotpoint" (we are using cdp values as the key for the data and have loaded interpolated UTM XY locations for each cdp).
The other boxes should not need editing – check that X and Y are starting in bytes 71 and 77.
Final box should say that sample interval is 0.004s, there are 4001 samples/trace, and there are 16 s of data. If not, there is a problem. If yes, then click "Next" and data should load with a little box that updates as traces are loaded.

Once data have loaded, go to "Assign 2D shotpoints to traces" in the "Survey" menu. The box for "Define by starting shotpoint and traces per shotpoint" should be on. Hit OK.

The line should appear on the map, and you can plot it by clicking on the map. Use the ruler in the data plot window to adjust scales. Use F5 and F6 keys to increase and decrease amplitude. Use the color bar with a wand to change or adjust palettes – explore the data.

Listing of shell script segdr_sxgxoffcdp_8km.sh (written by Emilio Vera):

```
#!/bin/sh
#
# Reads SEGD field shot files (.RAW), converts them
# to Seismic Unix (su) files and sets header variables
# offset, sx, gx, cdp, ep (shot point number), and
# swdep (source water depth). Reads all the files in
# one tape and concatenates them in fileout
#
# ***********************************************
#
ep1=23936
fileout=MC11_sp.su
#
dirsegd=/data/seismic/MGL1610-segd
#
bin=6.25
#d = 2 * bin
d=`bc -l << END
$bin*2
END`
#
dxsp=125
dxgf=12.5
offg1=220
```

```
asx=`expr 4779 - $dxsp \* $ep1`
#
for file in $dirsegd/TAPE0024.REEL/R??????_*.RAW

do

spnum=`strings -a $file | head -n10 | grep UTC | cut -c37-42`
wdepth=`strings -a $file | head -n10 | grep UTC | cut -c81-86`

#num=`ls $file | cut -c42-48`

segdread tape=$file use_stdio=1 |
sushw key=swdep a=$wdepth |
sushw key=offset a=$offg1 b=$dxgf |
suchw key1=sx key2=ep a=$asx b=$dxsp |
suchw key1=gx key2=sx key3=offset b=1 c=-1 |
suchw key1=cdp key2=sx key3=gx b=1 c=1 d=$d |
sufilter f=90,120 amps=1.,0. | suresampnt=4001 dt=0.004 >> $fileout

echo $file $spnum $wdepth

done
#
```

Appendix C – part II. Geometry definition using ProMax.

The Landmark ProMAX 3D package available onboard the R/V Langseth includes a module to import UKOOA navigation data into the internal ProMAX database and calculate source-receiver midpoints. This information was then be tied to the raw SEG-D shot gathers and written into SEG-Y files with UTM coordinates in the headers.

In ProMAX 3D:
1. Create an Area, Line, and Flow. Add module "3D Marine Geometry Spreadsheet" and execute the flow.

2. Go to FILE/UKOOA Import and select the p190 navigation file
   Select format "Standard UKOOA 90 Marine 3D"
   Close the tables that pop up and apply the format

3. Open the SOURCES table
   Fill in SOURCE, FFID, and shot depth columns; FFIDs should be set to zero for source locations where the guns did not fire
   Select Auto-Azimuth to calculate line azimuth from the coordinates

4. Open the BIN tab
   Select "Assign Midpoints by: Existing index number mappings in the TRC"

CMP binning:
   CMP bins for the archive data were created using a simple geometry that mimicked a 2D bin assignment by including the full spread of the line at each bin space, regardless of the width. A nominal bin layout was calculated based on line azimuth and bin dimensions, then refined using the interactive graphical bin tools. A detailed description of the bin assignment tools can be found in the ProMAX geometry help document (dispread.pdf) on page 120.

5. Select Binning/Bin Midpoints
    Fill in ONLY Azimuth , Grid Bin X Dimension, Grid Bin Y Dimension
    Click "Calc Dim" to calculate bin dimensions, then save the Bin Space
Select "Define binning grid"
    In the XY Graph, select DISPLAY/MIDPOINT/Control Points/Black
    Select GRID/Open/[Name of Bin Space saved in previous step]
    Review and adjust grid parameters
    Save the revised bin space.
Select Binning/Bin Midpoints
    LOAD the saved bin space
    Set starting CDP number
    Apply

6. QC midpoint Bin data
    Select saved bin space and review the fold distribution

7. Finalize Database

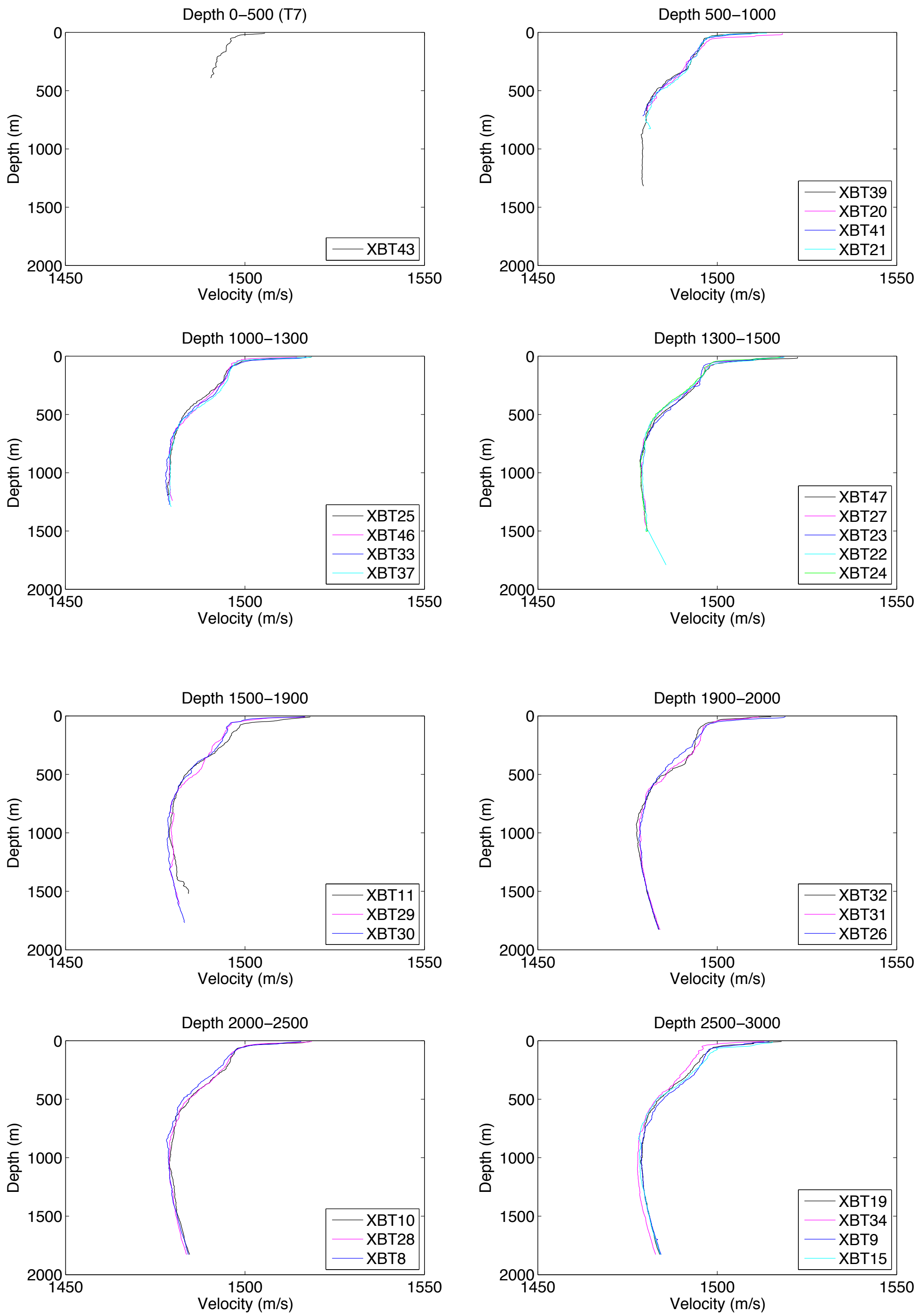
8. Index the Database
    The final step in the geometry assignment is to make the database searchable so imported SEG-D files can be linked to it. Go to FILE/LOOKUP Indexing
    and run all options except "SRF" and "ALL"

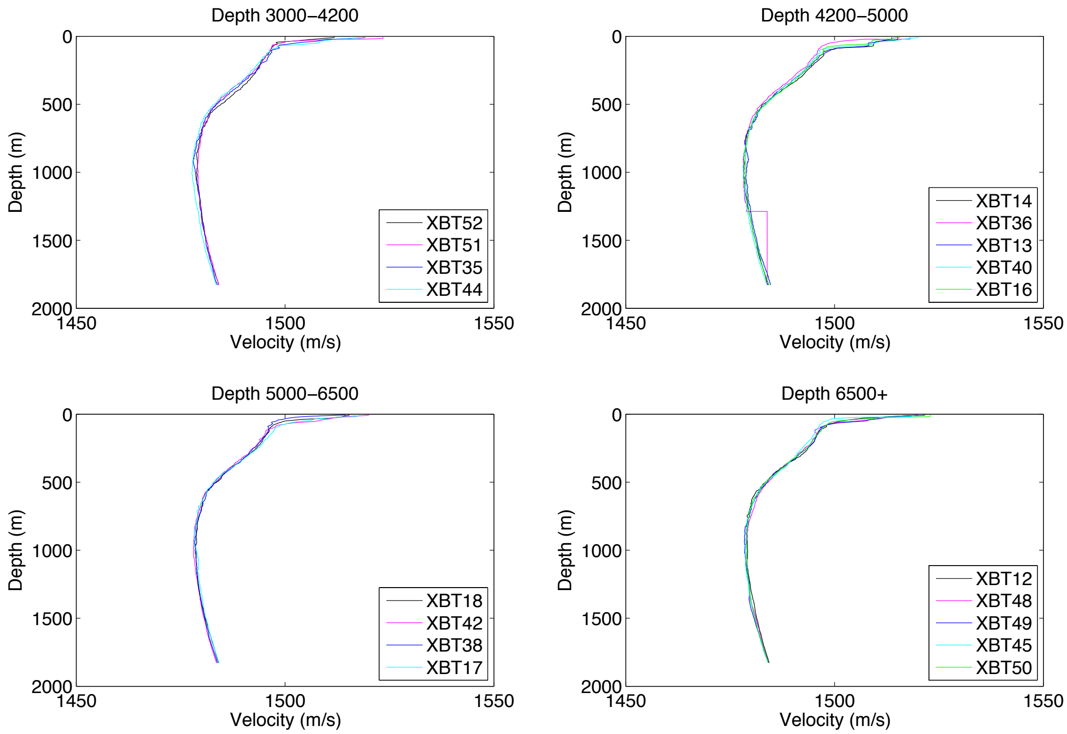
9. Data import and link to database
    In a new flow, add modules SEG-D Input, Inline Geom Header Load, and SEG-Y Output. Select the appropriate input and output files.
    For PICTURES, we linked the SEGD files to the database based on FFIDs.

Appendix C: Sioseis scripts for quality control of OBS data.

```
/usr/local/bin/sioseis << eof
procs diskin debias shift filter gains plot end
diskin
 ipath /Volumes/MGL1610_OBS/SEGY/Segy2/SS$2-2/SS$2_Trehu_$3.segy sort shot fno $4 lno $5 end
end
shift
 fno 1 lno 100000 redvel 6500 end
end
filter
 fno 1 lno 1000000 pass 6 30 fillen 101 end
end
gains
 fno 1 lno 1000000 type 8 rscale 10 alpha 1 end
end
plot
 nibs 2859 vscale 0.666666 nsecs 12 trpin 100 scalar $6 wiggle 100 pctfil 100
 def 0.02 clip 0.015 srpath plotsingle/$1_SS$2_$3_$4to$5_scale$6_rv6500_bp6to30.rs ann shotno ann2 range
taginc 50 tlines 2.0 end
end
end
eof
```

Appendix D: Sound velocity as a function of water depth derived from XBT data. Profiles are grouped by water depth. A salinity of 35 ppm was assumed.




Depth 3000−4200
Depth (m)
Velocity (m/s)
0
500
1000
1500
2000
1450
1500
1550
XBT52
XBT51
XBT35
XBT44
Depth 4200−5000
Depth (m)
Velocity (m/s)
XBT14
XBT36
XBT13
XBT40
XBT16
Depth 5000−6500
Depth (m)
Velocity (m/s)
XBT18
XBT42
XBT38
XBT17
Depth 6500+
Depth (m)
Velocity (m/s)
XBT12
XBT48
XBT49
XBT45
XBT50