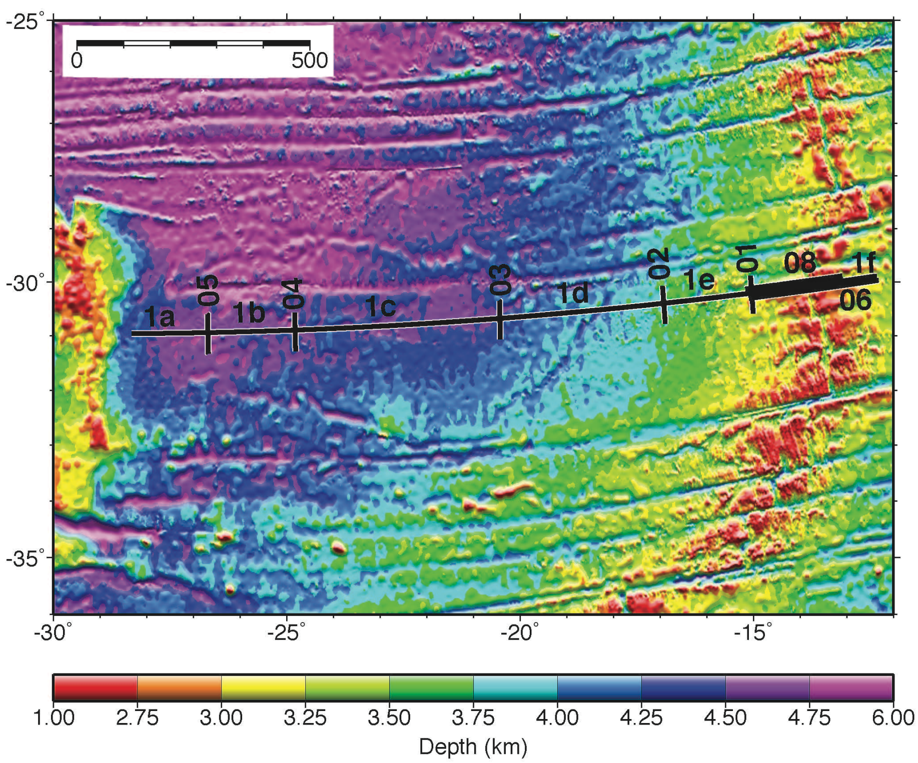
CRUISE REPORT

CREST: Crustal Reflectivity Experiment Southern Transect
South Atlantic multichannel seismic and ocean bottom seismometer experiment

January 4 – February 25, 2016



CONTENTS

A. CREW AND SCIENCE PARTY

Science Party

Bobby Reece, TAMU – Chief Scientist
Gail Christeson, UTIG – Co-Chief Scientist
Akhil Amara, TAMU – Watchstander
Justin Estep, TAMU – Watchstander
John Greene, TAMU – Watchstander
Clint Koch, U. Arizona – Watchstander
Lindsay Henning, U. Western Washington - Watchstander
Stacey Worman, UTIG – Watchstander
Alexis Wright, CCNY/USGS – Watchstander

Woods Hole Oceanographic Institution (WHOI) OBS Technicians

Dan Kot
Peter Lemmond

LDEO Technical Support

Robert Steinhaus – Chief Science Officer
David Martinson – Science Officer
Todd Jensvold – Science Officer
Graeme Stewart – Marine Tech (ACQ)
Klayton Curtis – Marine Tech (ACQ)
Shane Traceski – Marine Tech (Nav)
Tom Spoto – Chief Source Mechanic
Josh Kasinger – Marine Tech Source
Carlos Gutierrez – Marine Tech Source

LDEO Captain & Crew

Mark Landow – Master
Breckenridge Crum – Chief Mate
Mason Reed – 2nd Mate
Tim Dexter – 3rd Mate
Matthew Tucke – Chief Engineer
Rich Williams – 1st Engineer
Joe Nasta – 2nd Engineer
Christian Collins – 3rd Engineer
Jason Woronowicz – Bosun
George Cereno – AB
Josh Schaffner – AB
Jeromie Webster – AB
Shepard Raines – OS
Aaron Putnam – OS
Eric Rosson – Steward
Ricky Rios – Cook
Carl Fleenor – Electrician
Fernando Uribe – Oiler
Braden Handley – Oiler
Rudy Florendo – Oiler

Protected Species Observers (PSOs)

Amanda Dubuque – Lead Observer
Amy Piko – Lead PAM Observer
Cassandra Frey – Observer
Heidi Malizia – Observer
Sheila O'Dea – Observer

B. SCIENCE PARTY TRAINING

The transit to the study area lasted 12 days; we utilized this time to train the watchstanders for the tasks ahead. Each transit day consisted of listening to lectures and having discussions from 9 am to lunch. The chief scientists lectured on the basics of seismic acquisition and processing, as well as fundamentals of oceanic crust seismic structure. The students were assigned readings of three chapters from a geophysics text and ten articles on reflection, refraction, and abyssal hills. Each student led a discussion on one of the assigned articles during our school hours.

In the afternoons, we held a hands-on lab to teach seismic reflection processing using the Paradigm modules Echos and Geodepth. We taught the steps necessary to process the data in Paradigm by working up ocean crust data from the Hess Deep rift and Blanco fracture zone.

C. SCIENCE PARTY WATCH SCHEDULE

Bobby Reece, midnight – noon
Gail Christeson, noon – midnight
Stacey Worman, 6 am – 6 pm

Akhil Amara, Lindsay Henning, 12 - 4
John Greene, Clint Koch, 4 - 8
Justin Estep, Alexis Wright – 8 - 12

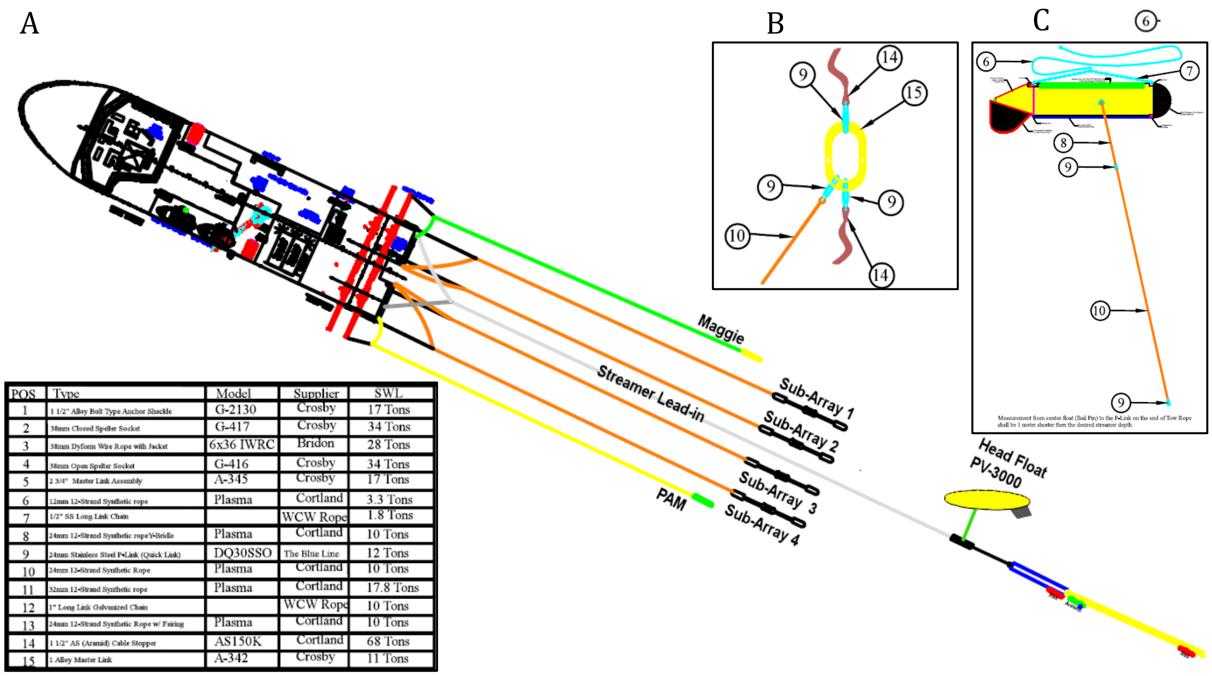
D. PROJECT OBJECTIVES

This project is a unique seismic reflection and refraction study of crustal structure along a single flowline from the Mid-Atlantic Ridge (MAR) to the Rio Grande Rise, where the age of the seafloor ranges from 0 to 70 Ma, and slow-to-intermediate half spreading rates range from <15 to >30 mm/yr. The first geophysical study of crust produced at any spreading rate to cover such a long span of time with a 12.5 km streamer, this 1500 km multi-channel seismic (MCS) reflection profile together with five ocean bottom seismometer (OBS) crossing profiles acquired site survey information critical for the success of a proposed (IODP 853-Pre) ocean drilling transect. This study of slow-to-intermediate spread crust will extend studies of crustal structure and evolution to lower spreading rates, and address several key questions regarding the nature of oceanic crust: What is the structure of crust produced at slow-to-intermediate rates, and how does it vary with age and spreading rate? How variable (or uniform) is the structure of the crust along a single flow line over a long period of time? How rapidly does the upper crust (Layer 2A) mature? How do the structure and evolution of crust accreted at slow-to intermediate rates compare with crust produced at high rates along the East Pacific Rise and intermediate rates at the Juan de Fuca Ridge?

E. MULTICHANNEL SEISMIC (MCS)

a. MCS Operations

Multichannel seismic (MCS) data collection used 12587.5 m of Sercel Seal solid streamer with a total of 1008 channels. Receivers are located within the streamer every 12.5 m and thus the common mid point (CMP) spacing is 6.25 m. The 40 Bolt airguns were deployed in 4 linear arrays with the full source being 36 guns at 6600 cubic inches in volume. Four 180 cu. in. guns served as hot spares. Data were acquired in demultiplexed SEGD format at 2 ms and were recorded for 15 seconds for the main lines and 14 and 12 seconds for the supplementary lines. The shot spacing was 37.5 m during the MCS profiles. Below is a table summarizing the MCS lines acquired during MGL1601. We recorded ~2683 km of MCS and accomplished our imaging objectives. This included imaging a single profile (flowline) from the Mid-Atlantic Ridge to the Rio Grande Rise, where the age of the seafloor ranges from 0 to 70 my. We also acquired 5 crossline profiles (isochrons) corresponding with the OBS lines, and 2 extra (contingency) lines crossing (normal to) the ridge. 10 shorter profiles along the turns were collected during the transition between collecting ridge-normal data and ridge-parallel data, although some of these data were acquired without full source volume because of maintenance operations. During data collection, watchstanders from the science crew maintained a 30 min log with location data, water temperature and salinity values, water depth, shot number, and pertinent events. The science tech crew maintained a detailed observer log.



POS	Type	Model	Supplier	SWL
1	1 1/2" Alloy Bolt Type Anchor Shackle	G-2130	Crosby	17 Tons
2	38mm Closed Spelter Socket	G-417	Crosby	34 Tons
3	38mm Dyform Wire Rope with Jacket	6x36 IWRC	Bridon	28 Tons
4	38mm Open Spelter Socket	G-416	Crosby	34 Tons
5	2 3/4" Master Link Assembly	A-345	Crosby	17 Tons
6	12mm 12-Strand Synthetic rope	Plasma	Cortland	3.3 Tons
7	1/2" SS Long Link Chain		WCW Rope	1.8 Tons
8	24mm 12-Strand Synthetic ropeY-Bridle	Plasma	Cortland	10 Tons
9	24mm Stainless Steel P-Link (Quick Link)	DQ30SSO	The Blue Line	12 Tons
10	24mm 12-Strand Synthetic Rope	Plasma	Cortland	10 Tons
11	32mm 12-Strand Synthetic rope	Plasma	Cortland	17.8 Tons
12	1" Long Link Galvanized Chain		WCW Rope	10 Tons
13	24mm 12-Strand Synthetic Rope w/ Fairing	Plasma	Cortland	10 Tons
14	1 1/2" AS (Aramid) Cable Stopper	AS150K	Cortland	68 Tons
15	1 Alloy Master Link	A-342	Crosby	11 Tons

Figure 1. *A) Streamer and gun configuration during MGL1601. Not to scale. B) Outer Lead-in Connection. C)PV2000 & PV3000 Lead-in float rigging.*

Table 1. *Multichannel seismic profile acquisition information.*

Line	Sequence Number	Line length (km)	Start of Line				End of Line				Tape Number	First Shot Point	Last Shot Point	Total Shots
			SOL Latitude	SOL Longitude	SOL Date	SOL Time (UTC)	EOL Latitude	EOL Longitude	EOL Date	EOL Time (UTC)				
1A	07	160.09	-30.9605	-28.2970	1/29/16	16:53	-30.9407	-26.6218	1/30/16	12:32	1 - 4	722	4991	4270
T0	08	41.78	-30.9523	-26.5964	1/30/16	12:53	-31.3295	-26.6156	1/30/16	17:56	6 - 7	1817	2931	1115
5	09	80.33	-31.3225	-26.6805	1/30/16	19:04	-30.5986	-26.7047	1/31/16	5:05	8 - 10	668	2810	2143
T1	010	34.13	-30.6264	-26.7607	1/31/16	6:03	-30.9354	-26.8432	1/31/16	10:20	11 - 11	877	1787	911
1B	011	198.38	-30.9434	-26.8267	1/31/16	10:32	-30.8933	-24.7544	2/1/16	10:32	12 - 17	640	5930	5291
T2	012	39.15	-30.9281	-24.7262	2/1/16	11:11	-31.2817	-24.7478	2/1/16	15:55	18 - 19	1887	2931	1045
4	013	79.50	-31.2845	-24.8121	2/1/16	16:57	-30.5677	-24.8302	2/2/16	2:30	20 - 22	643	2763	2121
T3	014	30.86	-30.6128	-24.9027	2/2/16	4:10	-30.9412	-24.9751	2/2/16	8:05	23 - 23	964	1787	824
1C	015	439.39	-30.8993	-24.9508	2/2/16	8:24	-30.6750	-20.3672	2/2/16	13:38	24 - 35	667	12384	11718
T4	016	36.26	-30.7352	-20.3398	2/4/16	14:39	-31.0628	-20.3602	2/4/16	19:04	36 - 36	1963	2930	968
3	017	78.60	-31.0608	-20.4250	2/4/16	20:16	-30.3520	-20.4428	2/5/16	5:50	37 - 39	667	2763	2097
T5	018	6.83	-30.4036	-20.5169	2/5/16	7:36	-30.6695	-20.5930	2/5/16	11:17	40 - 40	970	1152	183
1D	019	348.60	-30.6833	-20.4879	2/5/16	12:34	-30.3930	-16.8564	2/7/16	7:21	41 - 51	895	10191	9297
T6	020	35.63	-30.4536	-16.8251	2/7/16	8:25	-30.7759	-16.8256	2/7/16	12:47	52 - 52	1980	2930	951
2	021	53.18	-30.7793	-16.8905	2/7/16	13:59	-30.0723	-16.9511	2/8/16	7:49	53 - 55	667	2085	1419
T7	022	23.29	-30.1934	-17.0376	2/8/16	2:48	-30.4060	-17.0730	2/8/16	5:44	56 - 56	1150	1771	622
1E	023	201.26	-30.4112	-17.0507	2/8/16	6:00	-30.2017	-14.9723	2/9/16	6:25	57 - 62	667	6034	5368
T8	024	40.05	-30.2220	-14.9413	2/9/16	6:57	-30.5846	-14.9462	2/9/16	11:51	63 - 64	1862	2930	1069
1	025	78.60	-30.5890	-15.0064	2/9/16	13:04	-29.8819	-15.0669	2/9/16	23:06	65 - 67	667	2763	2097
T9	026	37.24	-29.8759	-15.1245	2/10/16	0:03	-30.2160	-15.1902	2/10/16	4:55	68 - 68	774	1767	994
1F	027	274.69	-30.2218	-15.2803	2/10/16	5:03	-29.8908	-12.3572	2/11/16	15:27	69 - 76	631	7956	7326
6	028	144.86	-29.9672	-12.3221	2/11/16	16:54	-30.1578	-13.8087	2/12/16	11:13	77 - 80	950	4813	3864
6A	029	123.34	-30.1598	-13.8253	2/12/16	11:28	-30.3075	-15.0981	2/13/16	2:47	81 - 84	4864	8153	3290
8	030	201.49	-30.1333	-15.1736	2/13/16	5:32	-29.8891	-13.1040	2/14/16	5:59	85 - 90	667	6040	5374

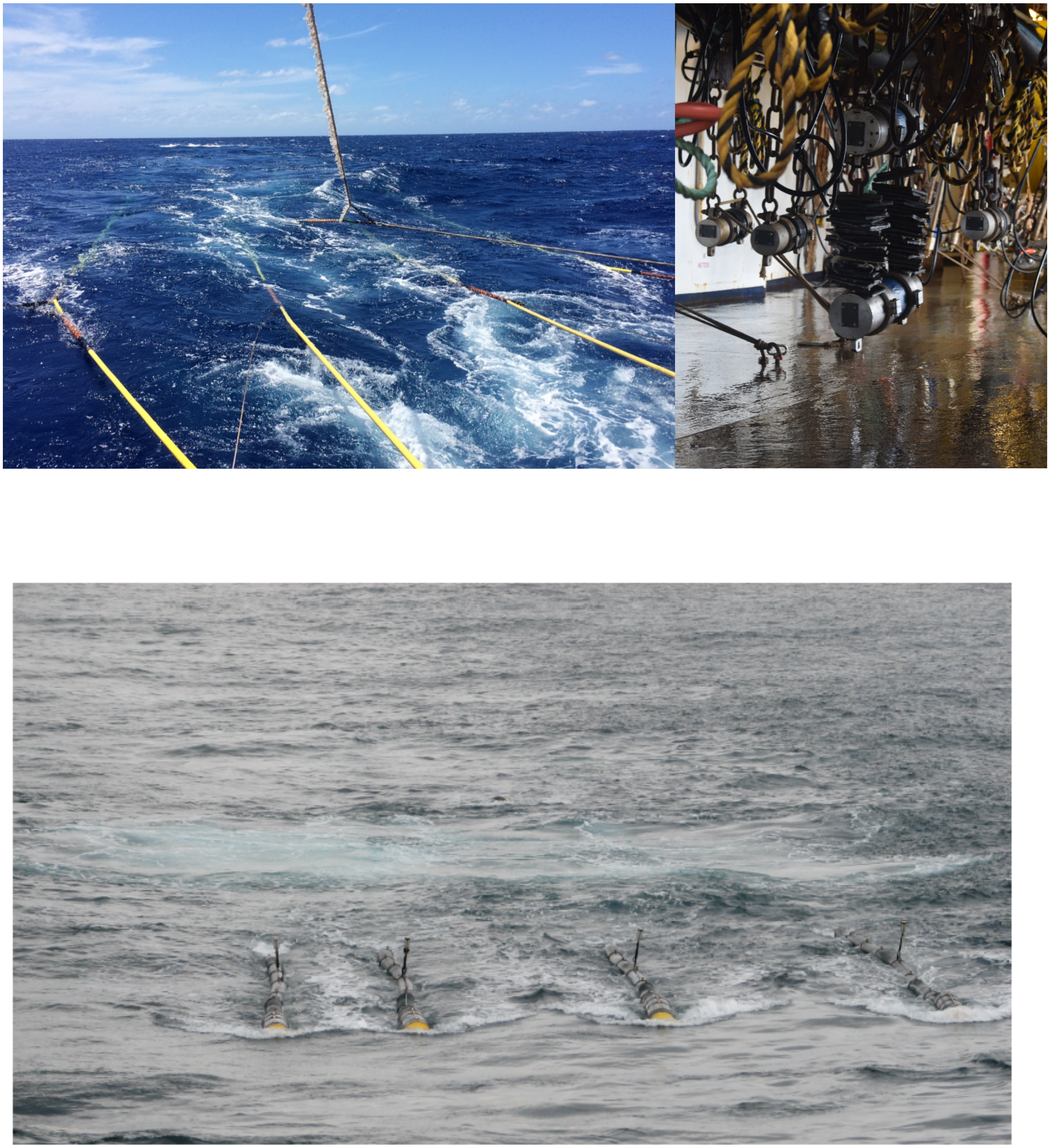


Figure 2. *Linear air gun arrays shown onboard and towed behind the vessel. The arrays were spaced 6 m apart and totaled 40 guns of which 36 were active for a total of 6600 cu. in.*

b. MCS Data Processing

Once a line was acquired and recorded to the ship's onboard data storage, all data from the line were copied over the network and concatenated into one SEGD file. Using a workstation running on the ship's onboard data server, PROC2, the science party processed the reflection data using Paradigm 2011.2 Echos. We imported each SEGD file into Echos, resampled from 2 to 4 ms, and applied the following geometry: 1008 channels, 220 m near offset, 12.5 m receiver interval, and 37.5 m shot spacing. An initial CMP sort and brutestack with a velocity of 1500 m/s were performed in order to pick the water bottom and reference the data when picking velocities.

Pre-stack corrections applied to shot gathers included: a band pass filter (3, 7, 100, 120 Hz); noise suppression from 3 – 10 Hz at a factor of 0.2 with a smoothing length of 60 ms (SUPPRESS); spherical divergence correction using a time squared gain; multi-channel deconvolution with a 20 ms gap and 81 ms filter length. Header math was applied to calculate a static shift to flatten the seafloor using the picked water bottom before the deconvolution was performed and then the static shift was removed afterwards.

These processed shots were then sorted into CMPs and velocities picked for normal moveout. Velocities were manually picked every 200 CMPs for the seafloor and the sediment-basement interface. A Matlab script was then used to apply an initial velocity function based on IODP drill hole 504B to the sub-sediment oceanic crust. Mutes were also picked every 200 CMPs once the velocity function was applied.

Next the CMPs were NMO corrected using the preliminary velocity function, muted using the picked mutes, and stacked. A new water bottom was then picked on the newly stacked data. A post-stack F-K Migration was performed using the Layered Media Zero Offset Migration with a mute applied above the newly picked water bottom.

Some processing operations were performed subsequently on the TAMU Origin laptop in Paradigm 15.5 Echos due to increased processing power. The processed CMPs were exported from Paradigm 2011.2 Echos in SEGY format. A pre-stack time migration was then performed using the MIGTX Time-Space Kirchoff Migration method, as well as the alternate Geodepth method, 2D Kirchoff P-wave travel time curve fitting. After the migration, the migrated CMPs were stacked.

c. MCS Sample Data

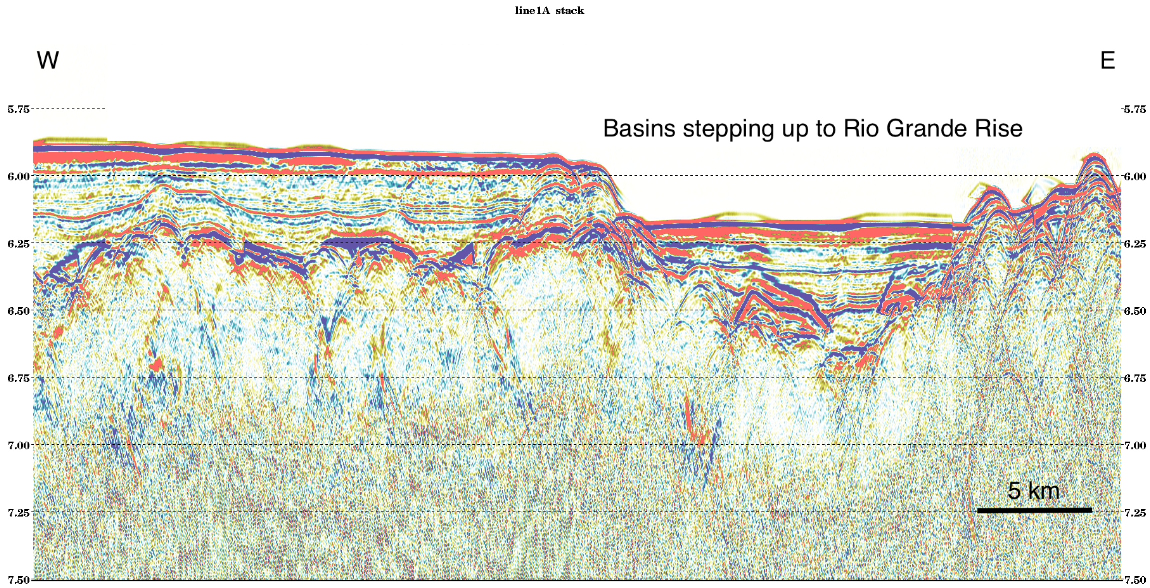


Figure 3. *Seismic reflection profile (stack) of line 1A. Crustal age 65 my (flowline). Spreading rate 20 mm/yr (halfrate).*

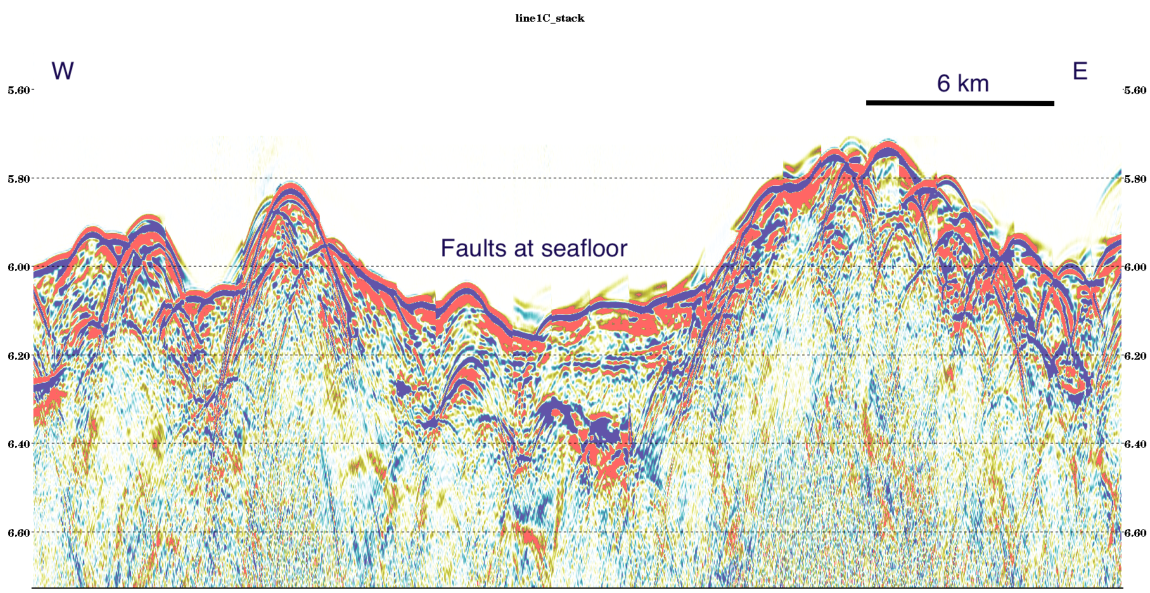


Figure 4. *Seismic reflection profile (stack) of line 1C. Crustal age 40 my (flowline). Spreading rate 24 mm/yr (halfrate).*

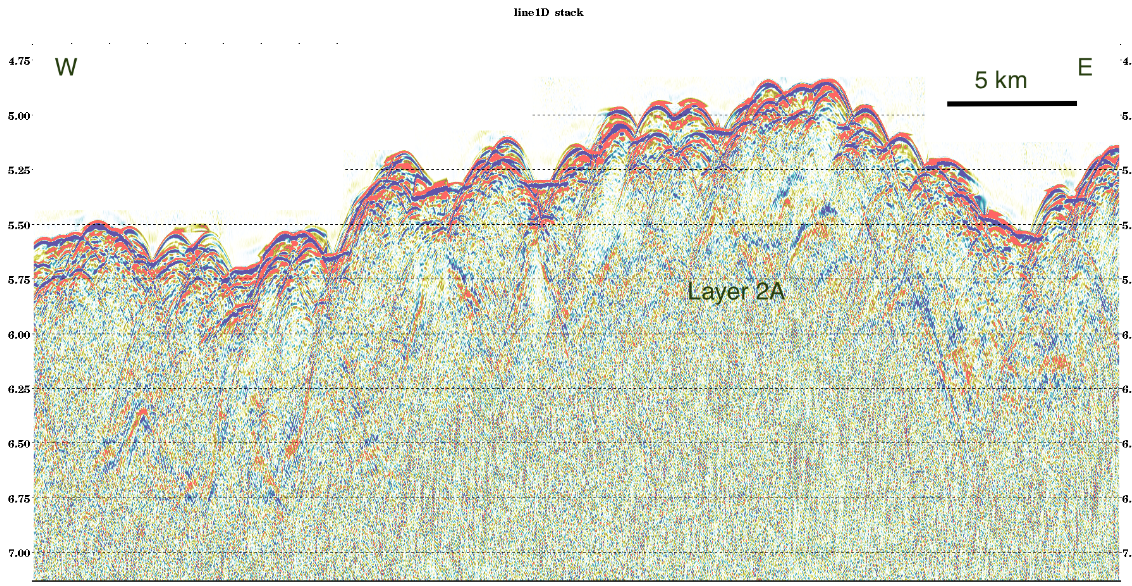


Figure 5. *Seismic reflection profile (stack) of line 1D. Crustal age 20 my (flowline). Spreading rate 25 mm/yr (halfrate).*

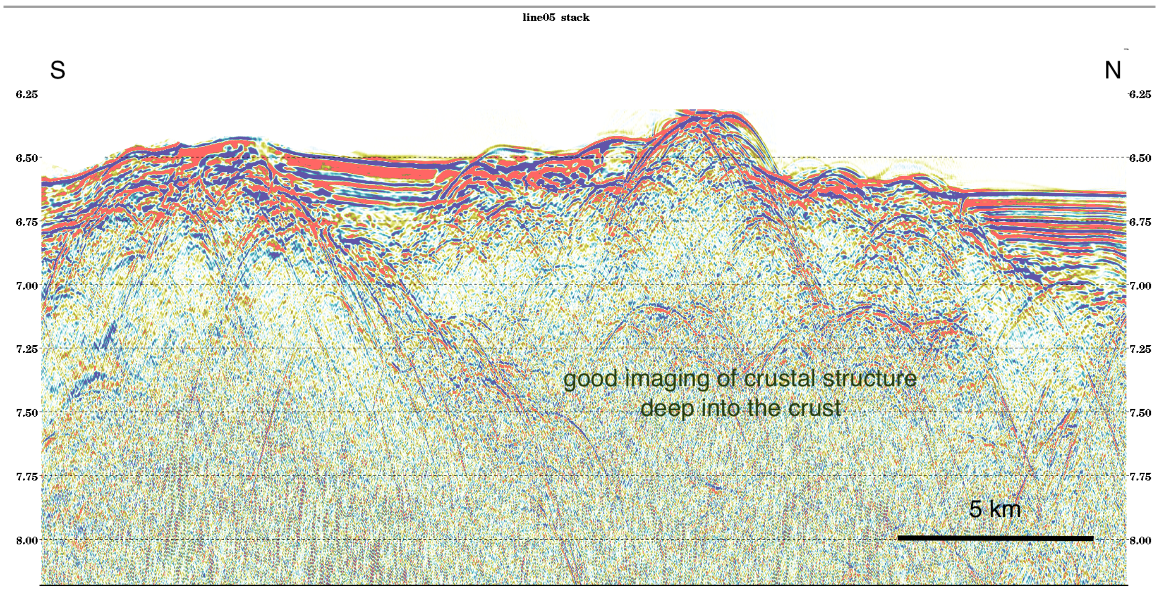


Figure 6. *Seismic reflection profile (stack) of line 05. Crustal age 63 my (isochron line). Spreading rate 15 mm/yr (halfrate).*

F. OCEAN BOTTOM SEISMOMETERS (OBS)

a. OBS Operations

OBSs were deployed at 10 km spacing along 5 profiles during the CREST project; each profile utilized 7 instruments. A total of 35 deployments and recoveries were carried out, with all instruments successfully recording data. For deployments, OBSs were prepared by Peter Lemmond and Dan Kot from Woods Hole Oceanographic Institution (WHOI) inside the WHOI OBS van. The OBS was then brought out on deck and deployed using the A-frame when the bridge informed the deck crew that the ship was on site. After deployment Peter and Dan ranged acoustically to the instrument to ensure that it was sinking before we moved on to the next site. After all instruments were deployed the sound source array was deployed and the ship traversed back over the profile, with a source interval of 150 m. The geophone sensor package on each OBS is attached to the side of the plastic housing by a galvanic link that dissolves in seawater after ~4 hours, so each profile included a run-in to allow time for the sensor packages to deploy. Upon completion of the profile, the sound source array was recovered. OBS recovery operations consisted of sending an acoustic signal to each OBS releasing it from the seafloor, waiting for the OBS to rise through the water column, visually locating the instrument when it reached the sea surface, and then recovering the OBS using the A-frame.

The first 11 instruments were recovered without incident, and acoustic communications were made through the hull-mounted Knudson transducer. All other recoveries were unusual in that acoustic communications could not be positively established with the instruments on the seafloor. Tests eventually showed that the hull-mounted Knudson transducer was no longer transmitting at the required frequency, and an over the side 'dunk' transducer was utilized for acoustic communications. With the dunk transducer acoustic ranges were not received until the OBSs rose above ~1000 m water depth, but all instruments did successfully receive the acoustic release command while on the seafloor even though confirmation of a release was not received acoustically.

Figure 7. OBS deployment using the starboard A-frame.

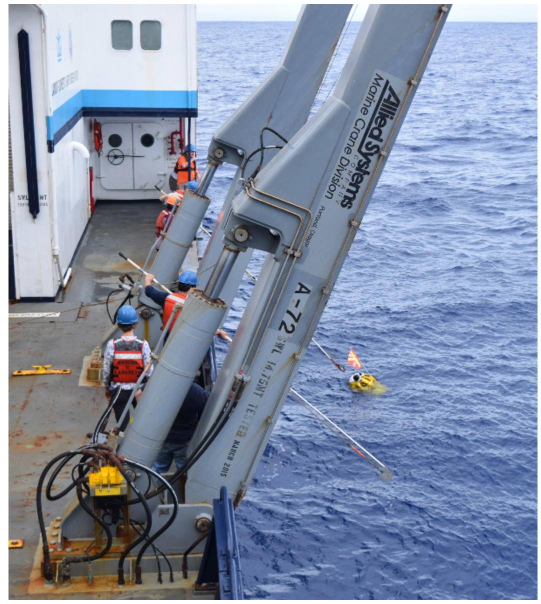


Figure 8. OBS recovery using hooks and the A-frame.

Table 2. *OBS Deployment and Recoveries*

OBS	Unit Depth (m)	Latitude *Deployment* *Recovery*	Longitude *Deployment* *Recovery*	Time *Deployment* *Recovery*
101	D10	-29.93981	-15.06201	1/16/201 10:48
	3649	-29.93914	-15.06291	1/17/2016 07:17
102	D04	-30.02957	-15.05409	1/16/2016 11:40
	3712	-30.02957	-15.05666	1/17/2016 09:23
103	D50	-30.11914	-15.04624	1/16/2016 12:37
	3365	-30.12159	-15.04975	1/17/2016 11:30
104	D18	-30.20889	-15.03882	1/16/2016 13:59
	3102	-30.21311	-15.03783	1/17/2016 13:42
105	D44	-30.29841	-15.03138	1/16/2016 15:05
	3051	-30.30077	-15.03133	1/17/2016 15:20
106	D15	-30.38823	-15.02393	1/16/2016 16:02
	2934	-30.39086	-15.02185	1/17/2016 17:09
107	D03	-30.47770	-15.01593	1/16/2016 16:56
	3085	-30.47873	-15.01660	1/17/2016 19:00
201	D40	-30.13082	-16.94633	1/18/2016 11:11
	3543	-30.13139	-16.94462	1/19/2016 23:44
202	D90	-30.22065	-16.93857	1/18/2016 10:11
	3723	-30.22282	-16.94091	1/20/2016 02:13
203	D09	-30.31011	-16.93081	1/18/2016 09:15

	3596	-30.31478	-16.93252	1/20/2016 03:47
204	D35	-30.39953	-16.92324	1/18/2016 08:10
	3719	-30.40347	-16.92226	1/19/2016 11:39
205	D34	-30.48937	-16.91544	1/18/2016 07:20
	3678	-30.49241	-16.91294	1/19/2016 09:31
206	D25	-30.57910	-16.90783	1/18/2016 06:27
	3733	-30.58090	-16.90383	1/19/2016 07:19
207	D02	-30.66879	-16.90005	1/18/2016 05:33
	3666	-30.67357	-16.89609	1/19/2016 05:14
301	D03	-30.40995	-20.44128	1/21/2016 01:40
	4129	-30.40657	-20.43882	1/21/2016 23:51
302	D15	-30.50003	-20.43964	1/21/2016 02:29
	4507	-30.50050	-20.44012	1/22/2016 02:56
303	D44	-30.58999	-20.43679	1/21/2016 03:18
	4232	-30.59232	-20.43833	1/22/2016 05:16
304	D18	-30.67983	-20.43439	1/21/2016 04:03
	4198	-30.67826	-20.43669	1/22/2016 07:32
305	D50	-30.76964	-20.43256	1/21/2016 04:47
	4204	-30.77257	-20.43072	1/22/2016 09:50
306	D04	-30.85974	-20.43005	1/21/2016 05:42
	4281	-30.86426	-20.42750	1/22/2016 11:59
307	D10	-30.94977	-20.42763	1/21/2016 06:42
	4306	-30.94925	-20.42503	1/22/2016 14:49
401	D62	-30.62588	-24.82854	1/23/2016 16:52
	4828	-30.62695	-24.83195	1/24/2016 21:38
402	D26	-30.71580	-24.82672	1/23/2016 16:11
	4829	-30.71354	-24.83023	1/24/2016 18:53
403	D31	-30.80565	-24.82446	1/23/2016 15:30
	4481	-30.80043	-24.82798	1/24/2016 16:37
404	D49	-30.89568	-24.82259	1/23/2016 14:51
	4328	-30.88931	-24.82814	1/24/2016 14:30
405	D39	-30.98568	-24.81986	1/23/2016 14:12
	4445	-30.97905	-24.82189	1/24/2016 12:13
406	D51	-31.07526	-24.81745	1/23/2016 13:25
	4453	-31.06794	-24.81600	1/24/2016 09:59
407	D60	-31.16453	-24.81470	1/23/2016 12:45
	4466	-31.16009	-24.81402	1/24/2016 07:36
501	D26	-30.67226	-26.69649	1/25/2016 07:08
	4974	-30.67018	-26.69752	1/26/2016 02:59
502	D31	-30.76189	-26.68412	1/25/2016 08:02
	4931	-30.75985	-26.69788	1/26/2016 05:25
503	D49	-30.85188	-26.69189	1/25/2016 08:50
	4948	-30.85072	-26.69944	1/26/2016 07:59
504	D39	-30.94167	-26.68965	1/25/2016 09:37
	5012	-30.94022	-26.69247	1/26/2016 10:34

505	D06	-31.03167	-26.68761	1/25/2016 10:26
	4956	-31.03331	-26.69081	1/26/2016 12:49
506	D11	-31.12158	-26.68517	1/25/2016 11:12
	4781	-31.12184	-26.68798	1/26/2016 15:03
507	D60	-31.21152	-26.68307	1/25/2016 11:58
	4917	-31.21414	-26.68712	1/26/2016 17:36

b. OBS Instrumentation

The WHOI model D2 OBS is a compact, relatively lightweight system, which allows recording of three components of ground motion and one acoustic channel at sample rates up to 250 Hz. The D2 is comprised of two glass balls containing electronics and batteries enclosed within a rigid plastic housing. The system stands 39" high and weighs approximately 115 lb in air.

The upper glass ball (17" diameter) contains a Quanterra signal-processing unit (Q330), a Quanterra 20 Gbyte hard drive containing an ethernet hub, an EdgeTech acoustic release board, GPS antennae, recovery aids, and custom electronics. A Seascan clock is located on a system control board and is accessible via a serial ASCII current loop. Recovery aids include four flashers and a programmable VHF radio with a minimum range at sealevel of ~2 nmi. The VHF antennae is attached to the inside surface of the glass ball. The Q330 includes operating software, a low-power analog-to-digital converter with 140 dB dynamic range, digital filters, clock, and 8 Mbytes of buffer memory. Engineering data and four channels of signal are continuously recorded and intermittently logged via an ethernet connection onto the disk drive in miniSEED format. For this experiment we used a sample rate on all data channels of 200Hz. In the lower glass ball (10" diameter) are battery packs comprised of both alkaline and lithium cells that supply power separately to the Q330 and hard drive, the recovery electronics board and aids, and to the EdgeTech release board used for acoustic ranging and supplying a current to the anchor release burn-wire. Ethernet connections can be used to change and program the operating software and to recover data from the hard drive.

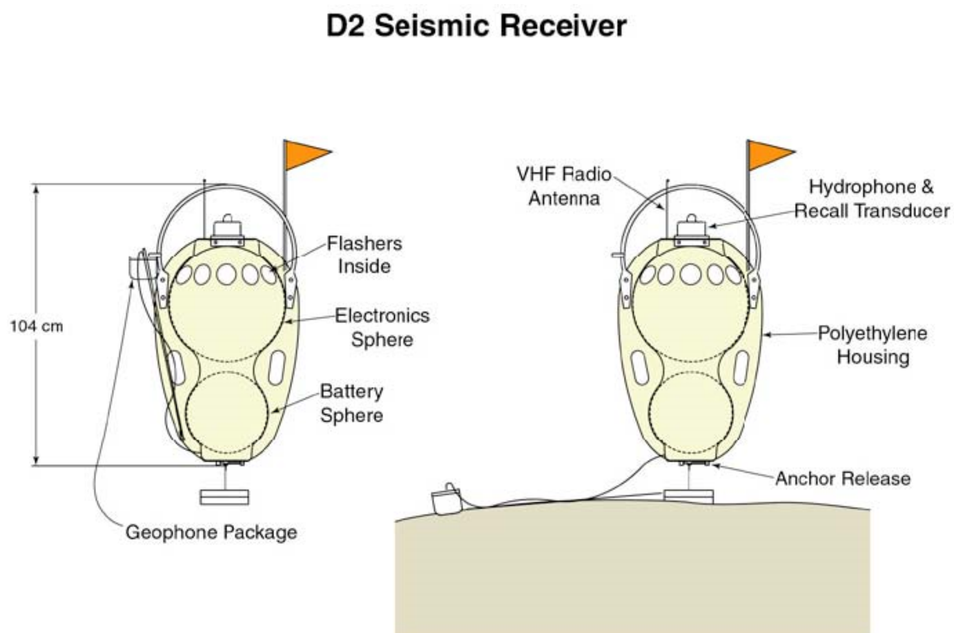


Figure 9. *D2 ocean bottom seismometer (OBS).*

The external plastic case provides protection for the glass balls and structural rigidity. An ITC 12 kHz acoustic transponder is attached to the upper cover of the case. Next to the transponder is a HighTech model HTI 1-90-U hydrophone. Three orthogonally mounted 4.5 Hz geophones are mounted in a 5" diameter (5.5" high) titanium case (Fig. 9), which is attached by a weighted cable through the plastic case to the upper electronics ball. The case is filled with high viscosity silicone oil. Internal gimbals allow the geophones to passively orient themselves with respect to gravity through 180 degrees of motion. Prior to deployment, a bail is screwed to the seismometer case, and the bail is hooked to the tip of a 23" long fiberglass wand. The bottom of the wand is attached to the base of the plastic housing by a rotatable joint. The tip of the wand and the seismometer are raised and attached to the side of the plastic housing by a galvanic link that dissolves in seawater after ~4 hours. When the link dissolves, gravity carries the sensor can out and away from the D2. The sensor can slips from the tip of the wand, which is then pulled up and away from the can by a bungee cord.

The D2 has ~25 lb of buoyancy and is weighted by a 55 lb steel plate anchor (6"x15"x2"). A 9" length of stainless steel wire rope to a 2" diameter ring connects the anchor plate. The ring is held to the D2 by a lever arm. One end of the lever arm is attached to the D2 base plate by a burn-wire that can be severed by an electric current triggered by a coded acoustic signal to the EdgeTech transponder. A battery that is separate from the battery supplying power to the Q330 and the hard drive powers the burn-wire and the release electronics.

c. *OBS Sample Data*

All OBSs recorded high-quality data, and, in general, the hydrophone channel data had a higher signal-to-noise ratio than the vertical channel data. Below we present sample record sections from each profile. OBS 302 displays clear Pg, PmP, and Pn phases, typical of homogeneous oceanic crust with a crustal thickness of 6-7 km (Fig. 10). In contrast, data for OBS 502 looks quite different, and possible PmP and Pn phases would indicate a thinner heterogeneous crust. On other instruments, such as OBS 102 and OBS 202, there is no clear PmP, while on OBS 402 there might be a PmP arrival but it is not as distinct as that displayed for OBS 302 (Fig. 11). Good shear (Sg) arrivals are observed on many instruments.

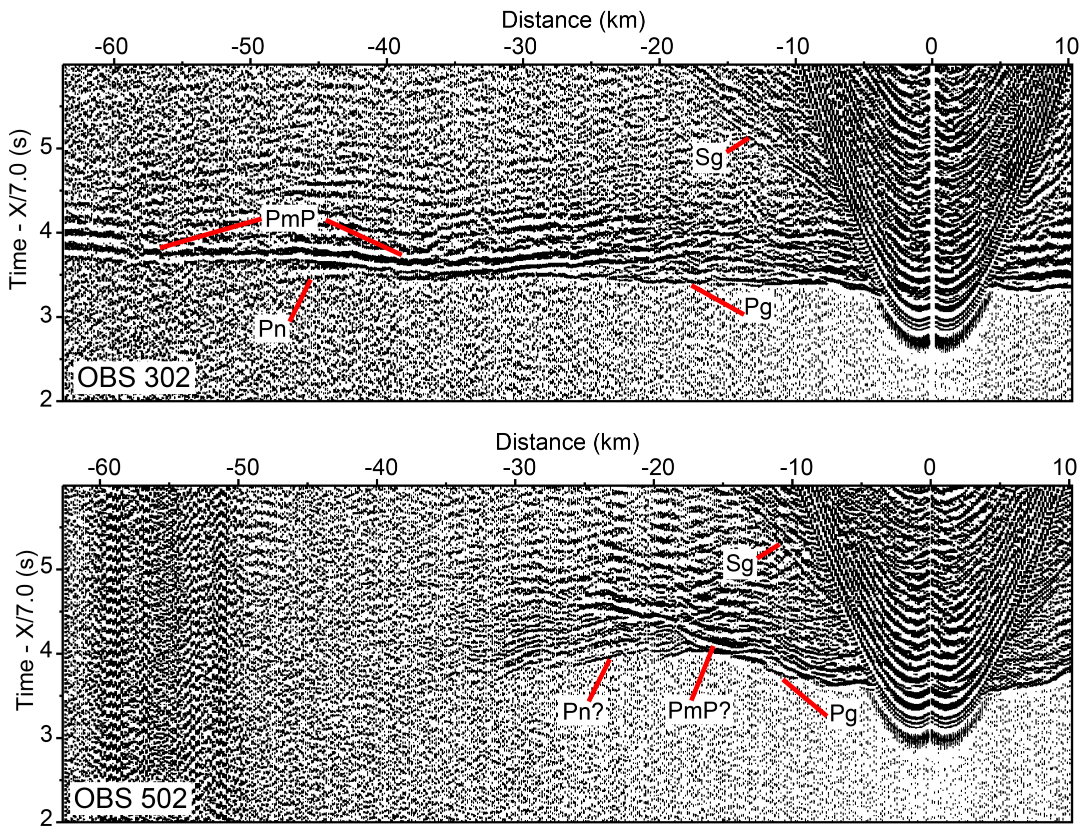


***Figure* 10.** *Top) Hydrophone channel record section for OBS 302 on profile CREST03 showing clear Pg, PmP, and Sg arrivals. Bottom) Hydrophone channel record section for OBS 502 on profile CREST05. Possible PmP and Pn arrivals are observed at much closer offsets than for OBS 302.*

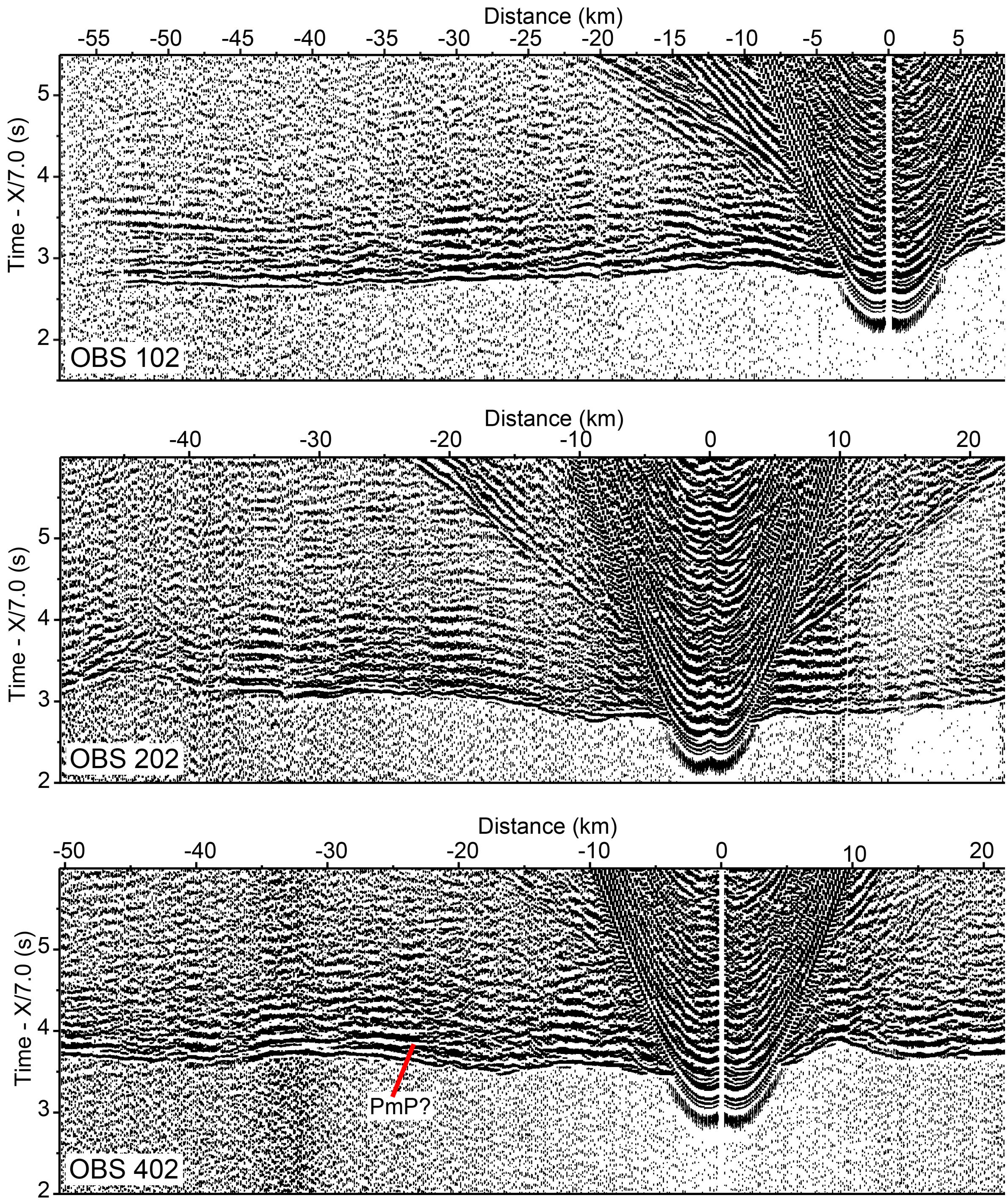


Figure 11. *Hydrophone channel record sections for OBSs 102, 202, and 402 on profiles CREST01, CREST02, and CREST04, respectively. No clear PmP arrivals are observed for OBS 102 or OBS 202; a possible PmP arrival is observed for OBS 402.*

G. MULTIBEAM BATHYMETRY (MB)

a. MB Operations and Processing

Multibeam bathymetry data were collected using the *Kongsberg EM-122* system. Processing was completed using *CARIS HIPS and SIPS 9.0.21*. The data were separated into two separate projects to better facilitate processing (Names: MGL1601 and MGL1601_2). The following values were used to process and correct the data. Corrections were made for vessel heave, pitch and roll, and water sound velocity. Errant pings were removed using the swath editor.

System: Kongsberg EM 122
Beams: 432
Transducer pitch offset: -4°
TPU values:

MRU to Trans X: -2.3 | *Nav to Trans X: 0*
MRU to Trans Y: 34.36 | *Nav to Trans Y: 20.2*
MRU to Trans Z: 11.79 | *Nav to Trans Z: 7.49*

Vessel plan view shape
Stern: 17 m across
Bow to stern: 71.5 m
Length from stern that is constant ship width: 50 m
Plan view RP
Stbd to unit: 8.5 m
Stern to unit: 35 m
Profile view shape
Height: 12 m
Keel to unit: 5.9 m

b. Expendable Bathythermograph (XBT) Operations

XBT drops were conducted to create sound velocity profiles for the water column to calibrate the multibeam bathymetry data. Two types of Lockheed Martin Sippican XBT probes were used during the cruise: T-5 and T-7. T-5 probes were used at ship speeds less than 5 knots, while T-7 probes were used for ship speeds in excess of 5 knots.

Table 3. *Expendable Bathythermograph (XBT) Log.*

Date	Seq. #	Lat deg (S)	Lat min	Long deg (W)	Long min	Probe Type	Surface Salinity Value (ppt)	Last Good Depth m	Water Temp (C)at LGD	Sound Velocity at LGD
1/16/16	2	28	17.74194	15	24.34692	T-7	36.156	898.9	4.58	1485.27
1/16/16	3	30	7.37256	15	2.72913	T-5	35.742	1788.9	2.91	1493
1/18/16	4	30	36.62866	16	19.54175	T-7	35.82	890.7	4.47	1484.51
1/19/16	5	30	18.63086	16	19.55.97681	T-5	36	2191.30	2.92	1499.64
1/21/16	6	30	40.56689	20	26.078	T-5	36	2208.4	3.21	1500.75
1/23/16	7	31	9.52051	24	41.54663	T-7	35.47	911.1	4.23	1483.35
1/25/16	8	30	26.29736	26	41.77197	T-5	35.404	2226.1	2.92	1500.01
1/25/16	9	30	51.86255	26	41.48291	T-5	35.404	2199.6	3.06	1499.69
1/30/16	10	30	56.86792	27	2.62817	T-5	35.539	2236	2.94	1499.96

2/1/16	11	30	54.76367	25	23.8042	T-5	35.42	2231.6	4.02	1504.26
2/2/16	12	30	52.63452	24	17.1106	T-5	35.597	2193.5	4.61	1506.09
2/32016	13	30	49.15137	22	53.52026	T-5	35.668	1535.1	3.01	1488.65
2/6/16	14	30	33.0962	18	40.5616	T-5	35.74	2213.4	2.82	1499.35
2/7/16	15	30	7.1903	16	56.8285	T-5	36.156	2207.3	2.74	1498.9
2/8/16	16	Probe failed								
2/8/16	17	Probe failed								
2/9/16	18	30	13.14673	15	7.89001	T-5	35.866	2211.7	2.86	1499.63
2/12/16	19	30	8.3634	13	39.3627	T-5	35.614	2222.8	2.73	1499.29

Launch Procedure:

1. On XBT Computer (Sippican), open WinMK21 software. The icon should be on the desktop.
2. In WinMK21, choose 'Options/Post Processing' and set the XBT salinity value to measured surface salinity value (ppt).
3. Choose 'Options/Probe Selection' and select the probe type to be used.
4. Click the 'New Drop' button. A screen will appear with a graph. Wait for communications with the MK21 board to be established and text indicating that it is OK to Load the Probe will appear.
5. Radio the person manning XBT gun on the deck and have them load the probe. Note that on the Langseth a flume is mounted on the port side such that the XBT/XCDT will be deployed outboard of the widest towpoint for 2D seismic operations.
6. Once loaded, you will see the display change to testing probe, then after several seconds it will indicate that it is OK to Launch Probe.
7. Radio the XBT 'gunner' and have them launch/drop the probe.
8. Allow the drop to proceed then hit CTRL C once the drop is complete (when the temperature increases rapidly on the plot; see figure below).

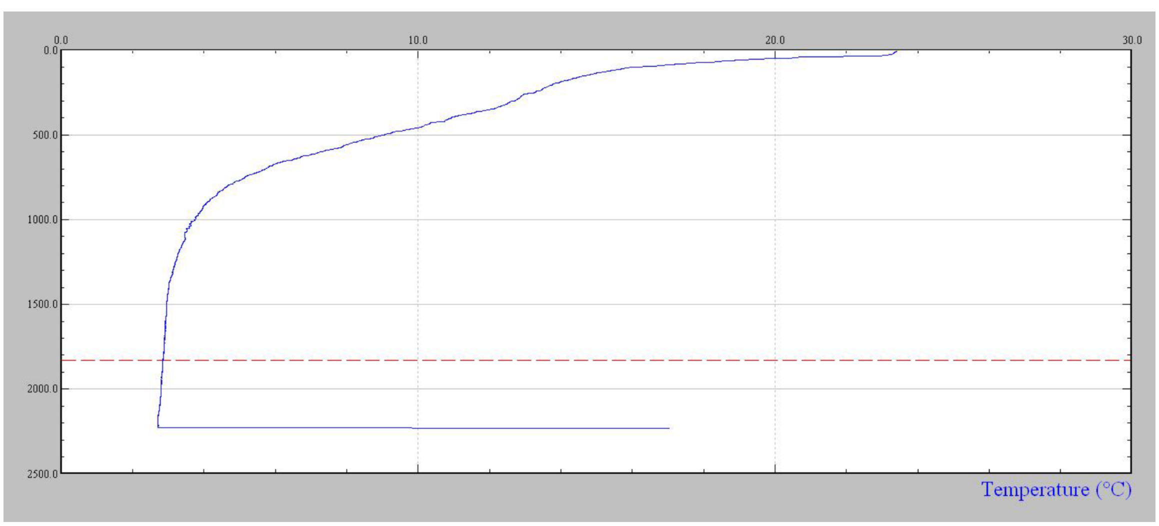


Figure 12. *Temperature vs. depth for sequence #19.*

9. Prepare data for import into Seafloor Information System (SIS): Open .edf file and delete erroneous data at bottom of profile (anything below last good depth). Save as and add "_edited" to file name.
10. Because the XBT only extends through the upper portion of the water column, the velocity profile must be extrapolated to the ocean bottom. Open SVP editor, click: file, import, Sippican(.edf) and choose "_edited" file.
11. Click: Tools, Extend Cast.
12. Click: Tools, Express, click "ok" to deliver profile to SIS.

Create Combined SVP File:

1. Open the first SVP file with Notepad. The following header was used:
[SVP_VERSION_2]
MGL1601_CombinedSVP.svp

2. Create a header for the velocity file using this format:

Section	016-000	00:00:00	-000:00:00	-000:00:00
	Year-Seq#	*Drop time*	*Latitude*	*Longitude*

3. The next SVP file should be copied and pasted in the row after the first profile ends, with no blank row in between. Repeat for all SVPs as acquired- update the header information for each.

4. Save and close.

H. MB SAMPLE DATA

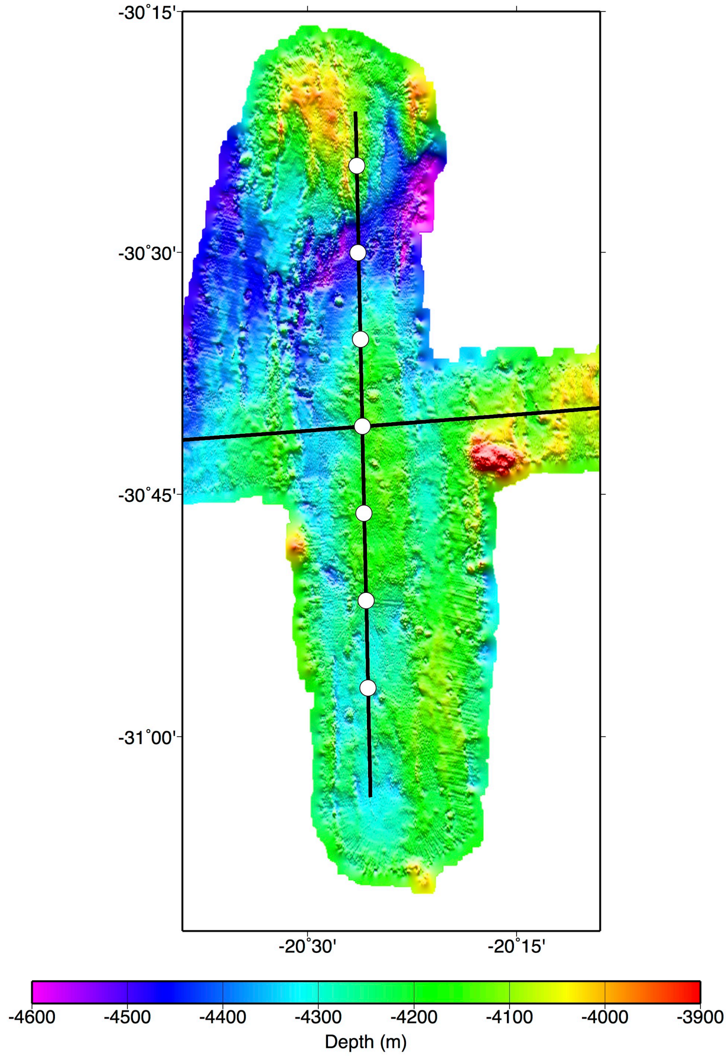


Figure 13. *Multibeam data acquired for this project in the vicinity of line 03 (north-south). Black lines- MCS tracks; white circles- OBS locations.*

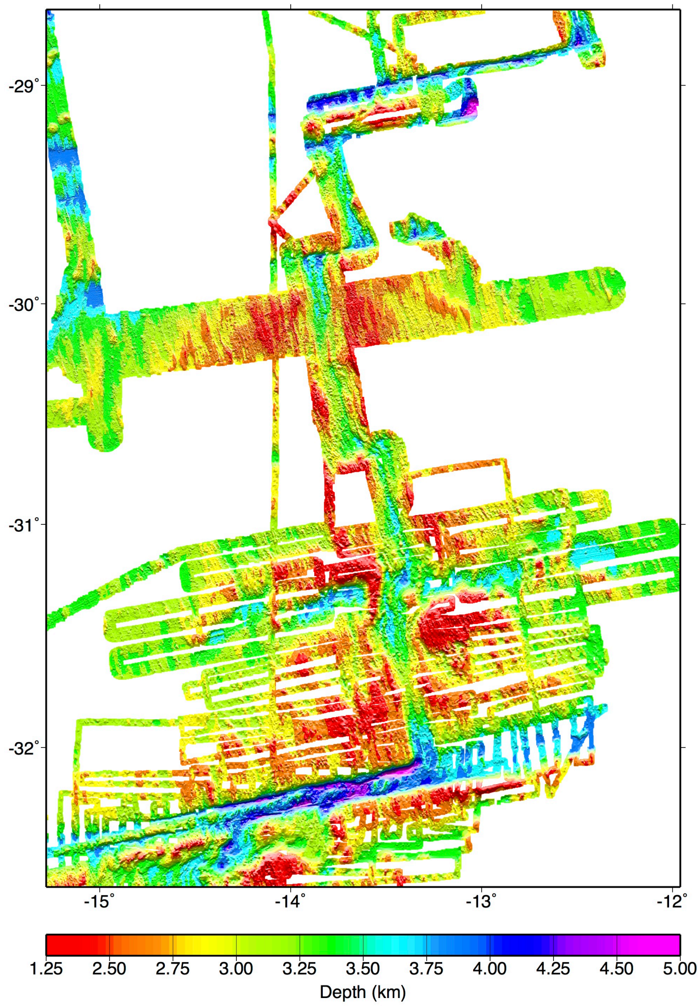


Figure 14. *Multibeam data acquired for this project combined with legacy multibeam at the Mid Atlantic Ridge*.

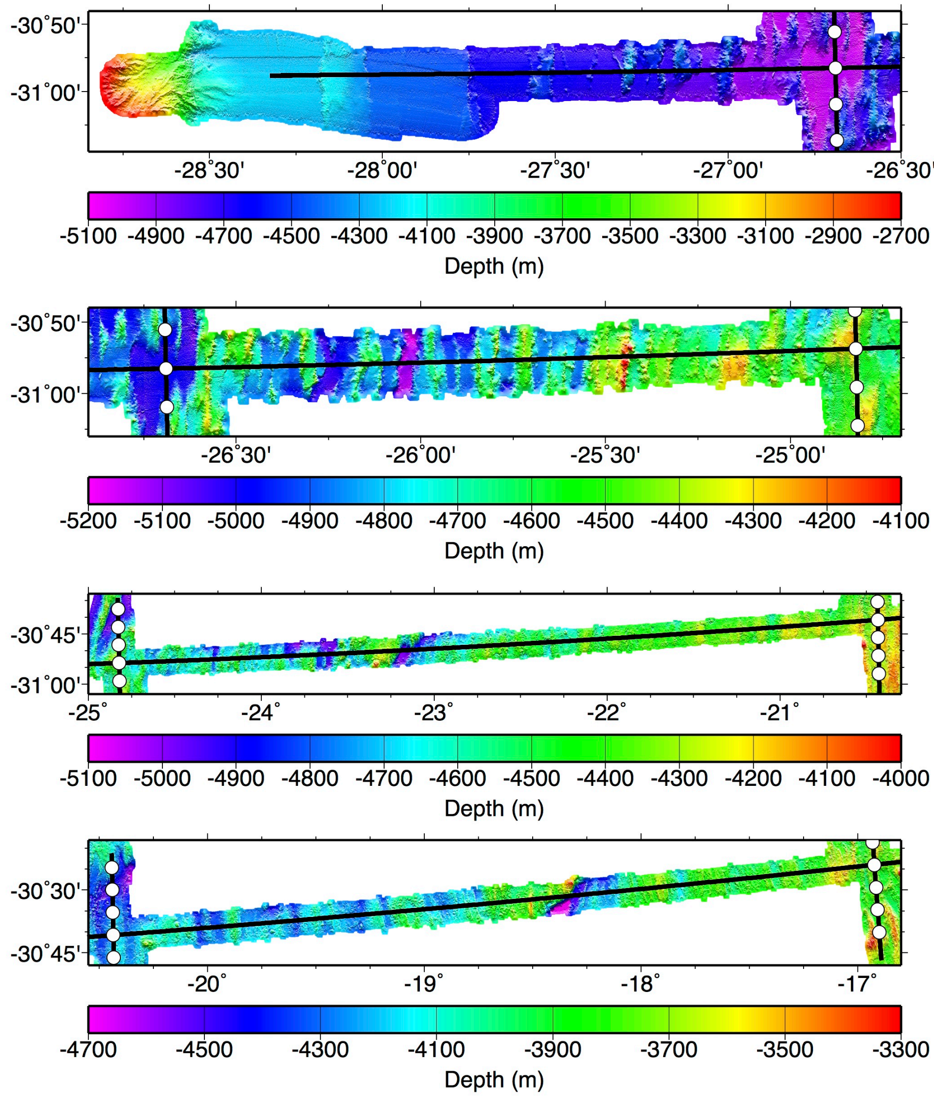


***Figure 15**. Multibeam data acquired for this project shown along MCS profiles (black), with OBS locations (white). From top, the horizontal MCS lines are 1A (with north south line 05), 1B (with north south lines 05 and 04 left to right), 1C (with north south lines 04 and 03 left to right), and 1D (with north south lines 03 and 02 left to right).*

I. INCIDENTS AND DAILY LOG

Table 4. *MCS acquisition incident log.*

Line 1A

Time UTC	FILE	SP	Tape	Description
16:53	1	722	1	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
12:32:40	4270	4991		LGSP Source vol. 6240cu.in S1G5 S2G5, S3G5, S4G5 spares S1G2 No Fire detected

Line 1B

Time UTC	FILE	SP	Tape	Description
10:32:31	1	640	12	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise visible on streamer
11:49:27	281	920	12	Turn noise no longer visible
12:12:01	361	1000	12	Streamer is straight (mostly)
02:43:31	3559	4198	15	Start S4G4 No Fire Detected, Volume 6420cu in.
02:45:44	3567	4206	15	End S4G4 No Fire Detected, Volume 6420cu in.
02:46:01	3568	4207	15	S4G4 Disabled, S4G5 Enabled, Volume 6600cu in.
07:23:57	4593	5232	16	LGSP due to telemetry errors
07:24:13	4594	5233	16	Start telemetry fault on SEAL, only recording 630 channels
07:25:45		5239	16	Stopped recording on SEAL to restart streamer, no shots being recorded
07:27:55	4600	5246	16	FGSP, Restarted streamer, recording all channels, telemetry looped through TAPU
10:32:57	5284	5930	17	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G4 spare

Line 1C

Time UTC	FILE	SP	Tape	Description
08:24:09	1	667	24	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise visible on streamer
08:48:24	87	755	24	LGSP due to navigation reboot
08:58:54	96	793	24	FGSP due to navigation reboot
09:38:23	239	937	24	Turn noise no longer visible on streamer
15:39:04	6852	7564	30	Swell bursts visible on shot gathers
17:31:45	7261	7973	31	Lowering streamer to 9.5m d/t strong swell
03:16:12	9389	10101	33	Start, Noise from passing ship coming from astern

04:10:50	9589	10301	33	End, ship noise
13:38:54	11670	12384	35	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares EOT

Line 1D

Time UTC	FILE	SP	Tape	Description
12:34:15	1	59	41	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Streamer at 12 meters, Turn and Swell noise on streamer at SOL
13:10:15	132	992	41	Turn noise no longer visible
13:41:30	245	1105	42	Streamer at 14m d/t high swell
16:06:30		6844		Missed SP d/t power down for sea turtle. Source is now 40 in3
16:10:20		6861		Missed SP d/t power up to full volume. Source is now 6600 in3.
17:59:14	6363	7161	48	Streamer now set to 12m - Intermittent Sea Noise still visible
20:53:47	7007	7900	48	Streamer now set to 11m - Intermittent Sea Noise still visible
22:25:49	7341	8234	49	Streamer now set to 9.5m - Intermittent Sea Noise still visible
01:24:53	7991	8888	49	Streamer now set to 9m - Intermittent sea noise still visible
07:21:27	9287	10191	51	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line 1E

Time UTC	FILE	SP	Tape	Description
06:00:23	1	667	57	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise visible on streamer, streamer still in turn.
07:37:43	346	1025	57	Turn noise no longer visible on streamer, streamer straight.
06:25:54	5287	6034	62	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line 1F

Time UTC	FILE	SP	Tape	Description
05:03:42	1	631	69	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise and swell noise visible on streamer, streamer still in turn.
06:10:03	235	870	69	Turn noise no longer visible, streamer is straight
07:10:24	432	1067	69	LGSP due to Seisnet memory being full and causing SEAL Export to lock up
				Restarted SEAL, Seisnet memory dump
07:31:46	433	1133	70	FGSP

15:27:56	7230	7956	76	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares EOT

Line 01

Time UTC	FILE	SP	Tape	Description
13:04:07	1	667	65	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise on streamer at SOL
14:13:07	239	915		Turn noise no longer visible on streamer
17:12:42	886	1570	65	Intermittent swell noise visible on streamer
23:06:20	2078	2763	67	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
	2079		67	Dummy file EOT

Line 02

Time UTC	FILE	SP	Tape	Description
13:59:46	1	667	53	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise and swell noise visible at SOL
15:18:03	272	950		Turn noise no longer visible
00:07:49	2085	2763	55	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line 03

Time UTC	FILE	SP	Tape	Description
20:16:25	1	667	37	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise and swell bursts on streamer at SOL
21:43:23	310	985		Turn noise no longer visible on streamer
02:31:54	1360	2040	38	Streamer set to 10 meters due to deepening swell, to increase depth stability
04:20:12	1753	2436	38	Streamer set to 12 meters due to deepening swell, to increase depth stability
05:50:29	2079	2763	39	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line 04

Time UTC	FILE	SP	Tape	Description
16:57:17	1	643	20	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise on streamers at SOL
18:22:32	310	960	20	Turn noise no longer visible

18:33:30	351	1001	20	FFFSP
20:21:59	749	1401	20	S2G1 No fire
20:22:16	750	1402	20	S2G1 delta timing error 4.5ms
20:22:32	751	1403	20	S2G1 No fire
20:22:49	752	1404	20	S2G1 No fire
20:23:06	753	1405	20	S2G1 delta timing error -3.15ms
20:37:30	807	1459	20	S2G1 multiple delta timing errors from SP 1459 - 1493
20:46:56	842	1494	20	S2G1 disabled, S2G5 enabled d/t timing errors new vol. 6420, 35 guns
20:47:13	843	1495	20	S2G1 detected as suspected auto firing
21:10:16	926	1582	20	All guns disabled d/t testing for autofiring gun
21:15:29	927	1601	20	All Guns enabled S2G1 disabled, S2G5 enabled vol. 6420, 35 guns
21:15:29	927	1601	20	S2G2, S2G4 timing error -4.0ms
21:29:31	978	1655	20	Gun string 2 disabled to recover for autofire on G2S1 new vol. 4950, 27 guns
23:19:58	1392	2069	21	Gun string 2 deployed and enabled, vol. 6600, 36 guns
02:30:51	2085	2763	22	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line 05

Time UTC	FILE	SP	Tape	Description
12:53:55	1	1817	6	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares S2G1 No Fire Detected
-	-	-	-	Turn Noise on Steamer at SOL
13:16:00	-	1899	6	Missed Shoot Point while sparing out Sub-Array 2
19:04:47	1	668	8	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise at head of streamer at SOL
19:36:28	117	784	8	Turn noise at center of streamer
20:07:44	229	896	8	Turn noise at tail of streamer
20:12:33	246	913	8	Turn noise no longer evident
20:37:31	331	998	8	Streamer out of turn
05:05:26	2143	2810	10	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line 06

Time UTC	FILE	SP	Tape	Description
16:54:12	1	950	77	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise and swell noise on streamer at SOL
18:02:15	241	1191	77	Turn noise no longer visible
11:13:40	3818	4813	80	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line 06A

Time UTC	FILE	SP	Tape	Description
11:28:40	5	4864	81	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Started new line with record length shortened to **14 seconds**
18:19:06	1410	6307	82	Last Full volume shot before Compressor shutdown
18:24:24	1425	6324	82	First Full Volume Shot after Compressor shutdown
02:47:14	3254	8153	84	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line 08

Time UTC	FILE	SP	Tape	Description
05:32:53	1	667	85	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Started new line with record length shortened to **12 seconds**
				Turn noise visible on streamer, streamer still in turn.
06:57:32	314	980	85	Turn noise no longer visible on the streamer, streamer is straight.
05:59:53	5734	6040	90	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line T0

Time UTC	FILE	SP	Tape	Description
12:53:55	1	1817	6	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares S2G1 No Fire Detected
-	-	-	-	Turn Noise on Steamer at SOL
13:16:00	-	1899	6	Missed Shoot Point while sparing out Sub-Array 2
13:16:18	83	1900	6	Source Volume Reduced to 4950 in3. Sub-array 2 secured for Maintenance
14:06:36	271	2088	6	Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares - Multiple Sync Errors Sub-Array 2
14:07:09	272	2099	6	Multiple Sync Errors on Sub-Array 2

14:17:18	309	2126	6	Turn noise no longer visible
17:56:14	1114	2931	7	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5, S5G5, S6G65 spares

Line T1

Time UTC	FILE	SP	Tape	Description
06:03:10	1001	877	10	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise visible on streamer
06:31:29	1100	976	10	Turn noise dissapated
07:00:05	1201	1077	10	Reduced volume for gun testing
07:10:08	1228	1113	10	Full volume resumed. 9 shotspoints missed
08:49:58	1584	1469	10	S4G4 No Fire Detected
09:51:24	1800	1685	10	Turn noise on front end of streamer
10:20:50	1902	1787	10	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line T2

Time UTC	FILE	SP	Tape	Description
11:11:18	1	1887	18	FGSP Source vol. 3300cu.in S1G5 S2G5 Spares - All of Sub-Array 3 & 4 disabled.
11:11:18	1	1887	18	Turn Noise on Streamer.
12:21:12	253	2139	18	Turn Noise No Longer Visible on Streamer
12:24:41	266	2152	18	Sub-Array #4 brought online - Source Vol 4950 in3 Multiple Sync Error
12:24:57	267	2153	18	Multiple Sync Error's Sub-Array 4
12:25:13	268	2153	18	Multiple Sync Error's Sub-Array 4
12:30:57	289	2175	18	Sync Error S2G9 +2.2ms
12:32:19	294	2183	18	Sync Error S2G9 -3.1ms
12:38:35	317	2203	18	Sub-Array #3 brought online - Source Vol 6600 in3 Multiple Sync Error
12:38:52	318	2204	18	Multiple Sync Error's Sub-Array 3
15:55:16	1041	2931	19	LGSP Source vol. 6600cu.in S1G5 S2G5 S3G5 S4G5 Spares
	1042		19	Dummy file EOT

Line T3

Time UTC	FILE	SP	Tape	Description
004:10:18	1	964	23	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

				Turn noise visible on streamer
04:44:39	120	1083	23	Turn noise no longer visible on streamer
07:52:59	780	1744	23	Turn noise visible on streamer
08:05:52	823	1787	23	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line T4

Time UTC	FILE	SP	Tape	Description
14:39:57	1	1963	36	FGSP Source vol. 3300cu.in S1G5 S2G5, spares- Sub-Arrys 3 & 4 onboard for Maintenance.
14:39:57	1	1963	36	Turn Noise visible on Streamer
15:42:08	229	2191	36	Turn noise no longer visible on Streamer
		2466		Missed SP while enabling Sub-Array's 3 &4
16:58:00	504	2467	36	Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares - Multiple Sync Errors
16:58:16	505	2468	36	Multiple Sync Errors -Sub-Array's 3 & 4
19:04:27	967	2930	36	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line T5

Time UTC	FILE	SP	Tape	Description
07:36:10	1	970	40	FSP Source vol. 3300cu.in S1 S2, S3G5, S4G5 spared
				Streamer at 15 meters for depth control in deep swell
				Strong swell noise vislible on streamer
				Turn noise visible on streamer, gun strings 1 and 2 on board for maintenance
08:36:03	212	1181	40	Ramping up gun strings 1 and 2
08:39:27	224	1193	40	FGSP, All 36 guns firing, 6600cu in, full volume.
08:55:15	281	1250	40	Turn noise no longer visible
11:17:38	783	1752	40	EOL LGSP Source vol. 6600cu.in S1 S2, S3G5, S4G5 spared

Line T6

Time UTC	FILE	SP	Tape	Description
08:25:39	1	1980	52	FSP Source vol. 3300cu.in S1G5 S2G5, S3, S4 spares
08:25:39	1	1980	52	Gun strings 3 and 4 on board for maintanence
08:25:39	1	1980	52	Turn noise and strong swell noise visible on streamer
09:06:38	150	2130	52	Turn noise no longer visl\ible on streamer

09:45:17	290	2270	52	Streamer straight.
10:35:12	469	2449	52	Ramping up gun strings 3 and 4, random gun errors.
10:37:47	478	2458	52	S3G1 autofiring
10:38:54	482	2462	52	Shutting down string 3.
10:41:53	493	2473	52	Volume 4950cu in., 27 guns. Recovering string 3 for repairs.
11:59:27	775	2756	52	Test firing S3G1, Volume 5310
12:01:58	784	2765	52	Volume 4950cu in., 27 guns
12:07:02	802	2783	52	Ramping up gun string 3, random gun errors.
12:07:53	805	2786	52	Full volume, firing 6600cu in., 36 guns.
12:08:27	807	2788	52	FGSP, all guns with accurate timing.
12:47:57	949	2930	52	LGSP Source vol. 6600cu.in S1G5 S2G5, S3, S4 spares

Line T7

Time UTC	FILE	SP	Tape	Description
02:48:38	1	1150	56	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
05:24:06	549	1700	56	Starting turn to port onto line 1E
05:29:38	569	1720	56	Turn noise visible at head of streamer
05:44:39	619	1771	56	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line T8

Time UTC	FILE	SP	Tape	Description
06:57:28	1	1862	63	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
06:57:28	1	1862	63	Turn noise visible on streamer, streamer still in turn.
08:38:10	357	2330	63	Turn noise no longer visible on streamer, streamer is straight.
11:51:19	1048	2930	64	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares

Line T9

Time UTC	FILE	SP	Tape	Description
00:03:10	1	774	68	FGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares
				Turn noise and swell noise visible on streamer at SOL
04:41:13	934	1725	68	Turn noise visible on streamer, starting to turn.
04:55:15	976	1767	68	LGSP Source vol. 6600cu.in S1G5 S2G5, S3G5, S4G5 spares