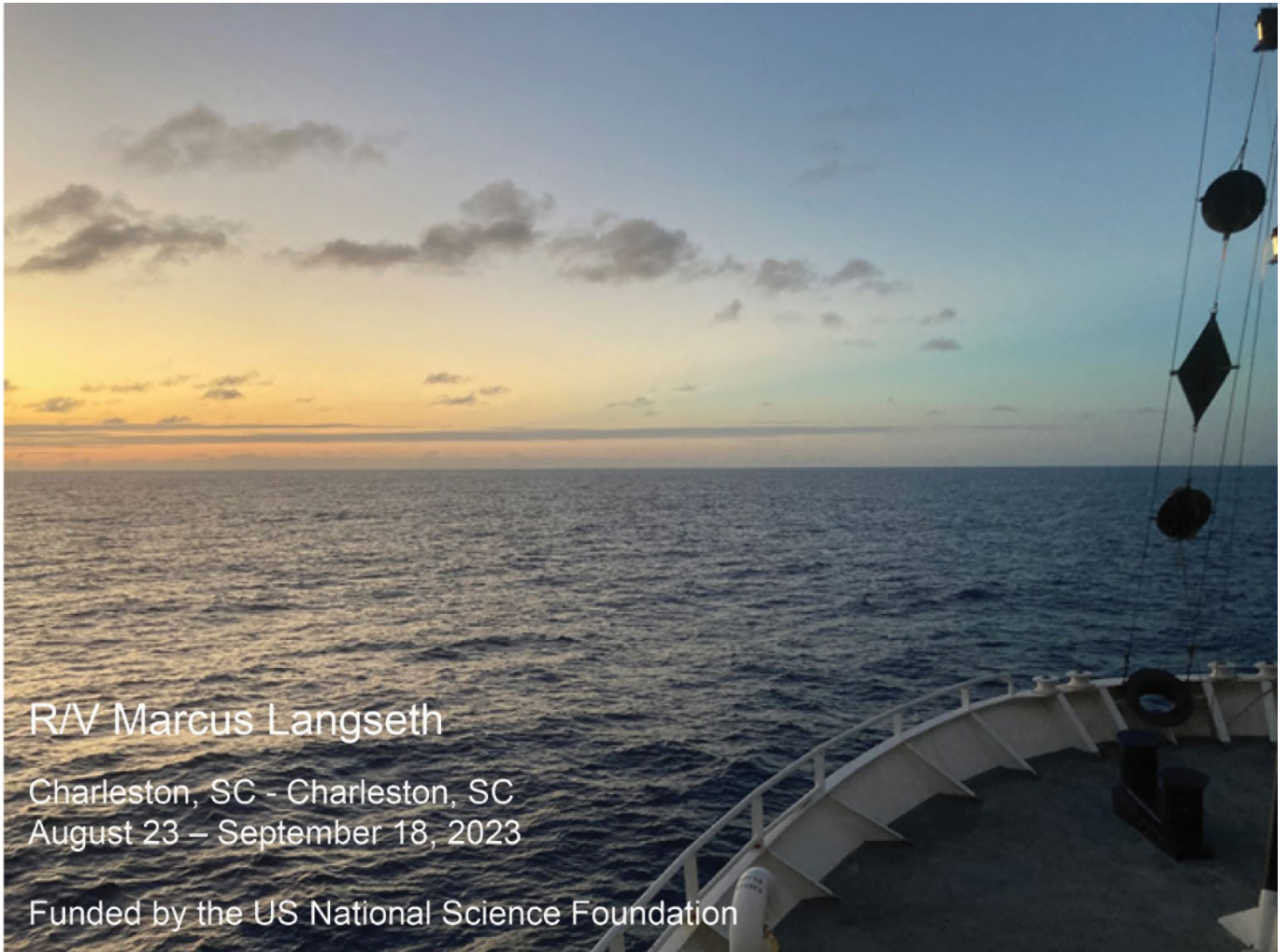


Cruise MGL2310 - FLAME

Florida Atlantic Margin Evolution



R/V Marcus Langseth

Charleston, SC - Charleston, SC
August 23 – September 18, 2023

Funded by the US National Science Foundation

Principal Investigators:

Harm Van Avendonk (UTIG), Nathan Bangs (UTIG), and Anne Bécel (LDEO)

MGL2310 cruise summary:

Expedition MGL2310 on the R/V *Marcus Langseth* was the second cruise in the Summer of 2023 on the Blake Plateau and the southern Carolina Trough. During this cruise we conducted a marine seismic refraction experiment that built on the MGL2309 marine seismic reflection cruise. During the MGL2310 cruise we placed short-period, four-component ocean-bottom seismometers (OBSs) from the Ocean-Bottom Instrument Center on three key seismic lines on MGL2310, scientists conducted an ocean-bottom seismic (OBS) refraction experiment. These two cruises were part of a project funded by the US National Science Foundation. We left Charleston SC on August 23, 2023, and returned to this port on September 14. The project acronym is FLAME (FLorida Atlantic Margin Evolution).

The purpose of cruise MGL2310 was to acquire long-offset ocean-bottom seismic refraction data along three profiles to constrain the seismic velocity structure in the sediments, crust and uppermost mantle. First we deployed 32 OBSs on a 450 km-long line across the Carolina Trough and the Blake Spur Magnetic Anomaly, and shot 2-D refraction data along this transect. A second deployment of 39 OBSs on two shorter transects on Blake Plateau (Line 2 and Line 3, with 21 and 18 instruments, respectively) was followed by shooting 550 km along these two lines and a tie line. The source-receiver geometry gave us good in-line data coverage along Line 2 and Line 3, and also some azimuthal coverage between the lines. The R/V *Marcus Langseth* is equipped with a 6600 in³ acoustic source, which was towed at 10 meter depth, and discharged with a 150 meter shot spacing. Other geophysical data that we collected are swath bathymetry, gravity and magnetics data.

Though the first deployment of the acoustic source took more time than expected, the air-gun array performed quite well with limited maintenance during the seismic shoots. The ocean-bottom seismometer deployments also went smoothly. One instrument on Line 1 was lost, and another OBS on this line did not record data. Due to the arrival of tropical storm Idalia, we improvised some changes to the overall schedule of the project. We deployed OBSs on Line 2 after only half of the instruments on Line 1 were recovered. After this storm passed, and after a medical evacuation, we recovered the remaining OBSs on Line 1, and dropped these on Line 3. We shot Line 2 and 3 with the *Langseth* air-gun array in good weather, but the weather forecast showed that tropical storm Lee was coming our way. We therefore did not use remaining contingency time for science, and returned to Charleston on September 14 after the OBSs were recovered. Towards the end of the cruise we were starting to see larger swells from this storm, but it did not create hazardous situations during then final instrument pick-up.

The science party did not see marine seismic refraction data during the cruise, since the US Navy redacted all OBS records. Between the deployments, the OBSIC team examined whether the instruments were recording, but the data were not analyzed on board.

The science party on the R/V *Marcus Langseth* was composed of the Principal Investigator from the University of Texas Institute for Geophysics and five graduate students from other universities. The student participants were recruited through a call-to-sail program. This group engaged in data acquisition and regular science discussions.

Fact Sheet

Cruise MGL2310 on the R/V *Marcus Langseth*

Project Acronym	Florida Atlantic Margin Evolution (FLAME)
Funding Agency	NSF Marine Geology and Geophysics
Departure from	Charleston, SC: August 23, 2023
Return to	Charleston, SC: September 18, 2023.
Study area bounded by	28°N and 33°N, 80°W and 74°W.

Acoustic source

Array	36 air guns, four strings
Maximum source volume:	6600 in ³ .
Depth:	10.0 meters
Offset behind center of navigation:	236.0 meters
Average pressure:	1941±11 p.s.i.
Shot spacing used:	150 meters

Ocean-bottom Seismometers

Type of instrument	WHOI D2 and SIO LCHEAPO
Sensors	Three-component geophone and hydrophone
Number of lines:	3
Number of instrument drops	71
Sampling rate:	200 Hz

Project Result

Total line kilometers:	1016
Profile kilometers	975
Number of lines	4
Number of line sequences:	8
Number of shots:	6988
Number of XBT drops:	7

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1. Introduction

Cruise MGL2310 on the Blake Plateau and the southern Carolina Trough is an ocean-bottom seismic (OBS) refraction experiment that provides new constraints on the deep structure of these two rifted margins off the southeastern United States. The data gathered during this expedition, along with the seismic reflection data from cruise MGL2309 will help scientists better understand the Mesozoic rifting processes that led to breakup between North America and northwest Africa (Greene et al., 2017). The interpretation of marine seismic reflection and refraction data across these margins will help determine the role of tectonic extension and magmatism in continental rifting, and the state of the mantle during the formation of the oldest oceanic crust.

Many of the world's passive margins experienced extension, magmatism and subsidence at the time of rifting and early seafloor spreading. Normal faults, tilted strata, volcanic wedges may therefore be visible in the seismic data along the inner margin (Franke, 2013). In deeper water we may image rifted crust modified with igneous intrusions or exhumed continental mantle, depending on how much mantle melting took place before continental breakup (Shuck et al., 2019; Whitmarsh et al., 2001). These geophysical constraints on the deep structure of rifted continental margins are consistent with the geometry of active rifts. For example, in the East African rift system, normal faults accommodated thinning of the upper continental crust during the early stages of rifting (Fletcher et al., 2018), while geodetic and geological studies in the northern East African rift have found evidence that the rate of magmatic diking can account for regional plate extension in the final rift episode (Wright et al., 2006). Since the products of continental rifting are well preserved in the deep structure of passive margins, we can infer the relative importance of faulting and magmatism in deep seismic reflection images.

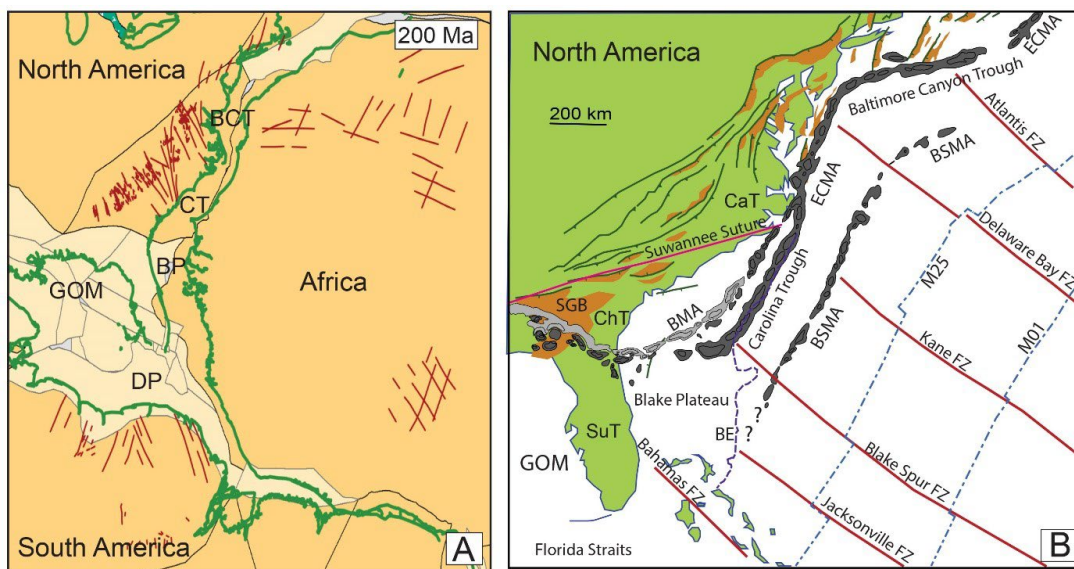


Figure 1.1. A) Configuration of the margins of the southeastern United States before the breakup of Pangea. GOM=Gulf of Mexico; DP=Demerara Plateau, BP=Blake Plateau; CT=Carolina Trough; BCT=Baltimore Canyon Trough. Red lines mark CAMP volcanic dikes. B) Geometry of North American tectonic terranes, onshore rift basins (orange), magnetic anomalies (gray), and fracture zones (red). CaT=Carolina Terrane; ChT=Charleston Terrane; SuT=Suwannee Terrane; ECMA=East Coast Magnetic Anomaly; BMA=Brunswick Magnetic Anomaly; BSMA=Blake Spur Magnetic Anomaly; BE=Blake Escarpment; SGB=South Georgia Rift Basin.

Rifting along the eastern flank of the Appalachian mountains started with extensional deformation in broadly distributed basins around 230 Ma (Withjack et al., 2013), and it initially progressed slowly (Figure 1.1). The final rift episode that led to continental breakup offshore the southeastern United States followed soon after the Late Triassic (201 Ma) flood basalts of the Central Atlantic Magmatic Province (CAMP) (Marzoli et al.,

2011). Because of the fortuitous timing (Schlische et al., 2003), it has been suggested that either high mantle temperatures, mantle dynamics, or the presence of mantle-derived melts in the extending lithosphere ultimately led to the breakup of Pangea (Dalziel et al., 2000; Wilson, 1997). However, there is no geophysical or geochemical evidence that this early Jurassic rift was caused by a plume (Whalen et al., 2015).

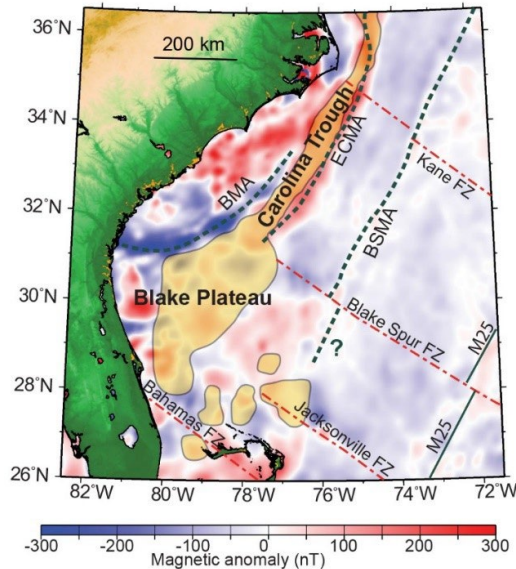


Figure 1.2. Geometry of Blake Plateau, Carolina Trough rift segments on the offshore EMAG2 magnetic map (Meyer et al., 2017). Onshore color scheme represents topography. Orange overlays on the magnetics represent areas where SDR's have been reported. Note that the continuation of the ECMA and BSMA south of the Blake Spur Fracture Zone is tentative. M25 is the oldest central Atlantic magnetic anomaly that is prominent (Greene et al., 2017). Older magnetic isochrons lie in the Jurassic Magnetic Quiet Zone and are more difficult to identify.

The passive margins of the southeastern United States formed after North America and Africa separated (Figure 1.1). An interesting characteristic of these margins is that they decrease in width from south to north (Dillon & Popenoe, 1988). The Carolina Trough is a narrow, margin-parallel basin where volcanic wedges have been imaged as seaward-dipping reflections (SDRs) along the East Coast Magnetic Anomaly (ECMA) (Figure 1.2). This geometry suggests that rifting localized rapidly in offshore basins, and led to lithospheric necking and breakup. To the south, the Blake Plateau forms a wider, circular sedimentary basin. Seismic reflection and refraction studies from the 1960s to the 1980s show evidence that rifting was magma-assisted on both Blake Plateau and the Carolina Trough, but extension did not localize in Blake Plateau (Austin et al., 1990; Holbrook et al., 1994). The difference in rifting style may have resulted from a contrast in mantle temperature or from a difference in the mechanism of melt delivery. The preexisting lithospheric structure may also play a role, since Blake Plateau lies adjacent to the relatively undeformed Gondwanan Suwannee terrane, whereas Carolina Trough lies alongside the Carolina terrane, which was more intensely sheared during Paleozoic accretion to Laurentia.

To determine the mode of crustal thinning and the role of mantle melts in rifting, we use the seismic source and long streamer of the R/V *Marcus Langseth* and OBSs of the national Instrument Center (OBSIC) to gather marine seismic reflection and refraction data along key seismic transects across Carolina Trough and Blake Plateau. With new seismic data we can investigate to what degree structural inheritance of the rifting continental crust and/or a thermal anomaly in the mantle contributed to contrasting styles of rifting offshore the southeastern United States.

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2. Cruise Participants



Figure 2.1. Group photo of the participants in cruise MGL2310, September 6, 2023.

Officers and crew

Mark Landau	Captain
Laura Nelson	Chief Mate
Wilson Pais	Second Mate
Stephen Uramoto	Third Mate
Matt Tucke	Chief Engineer
Samuel Romey	1 st A/E
Sean Kennedy	2 nd A/E
Sara Wright	3 rd A/E
Mike Hill	Electrician
Malcolm Baker	Oiler
David Hall	Oiler
Calvin White	Oiler
Ricky Redito	Bosun
Bronwyn Denard	AB
Inocencio Rimando	AB
Pria Harris	OS
Madeline Ireland	OS
James Davis	Steward
Leoncio Martires	Cook

Langseth technical team

Todd Jensvold	Chief Tech
Koray Ergun	Tech
Riley Lopez	Tech

Klayton Curtis	Tech
Nikko Hernandez	Tech
Aaron Martin	Tech
Malcolm Moody	Chief Mechanic
Leon da Silva Souza	Mech
Sean Seekins	Mech
Michael Coufal	Mech
Tawfik Naas	Mech

Protected Species Observer team:

Cassandra Frey	Lead-PSO
Laura Danos	PSO
Lorena Figueroa	PSO
Ana Lira	PSO
Claudia Portocarrero	PSO

Science party

Harm Van Avendonk	University of Texas Institute for Geophysics	Chief Scientist
Alan Gardner	WHOI	OBSIC
Daniel Kot	WHOI	OBSIC
Nick Matthews	UNOLS	OBS
Ranpeng Li	University of Florida	Watchstander
Victor Obi	Auburn University	Watchstander
Tawfik Yakubu	University of Northern Arizona	Watchstander
Elika Zilis	Western Washington University	Watchstander
Savannah Evans	University of North Carolina at Wilmington	Watchstander

3. Cruise objectives

The objective of cruise MGL2310 was to seismically image the deep structure of the continental margins of the southeastern United States, from the inner margin to the deep seafloor east of the BSMA. This study builds on important data sets that have been collected in the 1980s on the southern Carolina Trough (Austin et al., 1990; Holbrook et al., 1994; Oh et al., 1991). Seismic studies of the Blake Plateau showed basement at depths of 12 km (Sheridan et al., 1981), but its composition and origin are not clear from the existing active-source seismic data. Marine seismic refraction studies of the Carolina Trough (Holbrook et al., 1994; Tréhu et al., 1989) have found evidence of syn-rift volcanics and lower crustal intrusions, but the lateral resolution in these 1980s and 1990s seismic velocity models is relatively low. Estimates of the volume of these igneous additions are therefore inaccurate, and their relationship to lithospheric tectonics is also not well understood. Seismic profiles in the 1980s also did not extend far enough seaward to determine the structure and evolution of the crust in the vicinity of the BSMA.

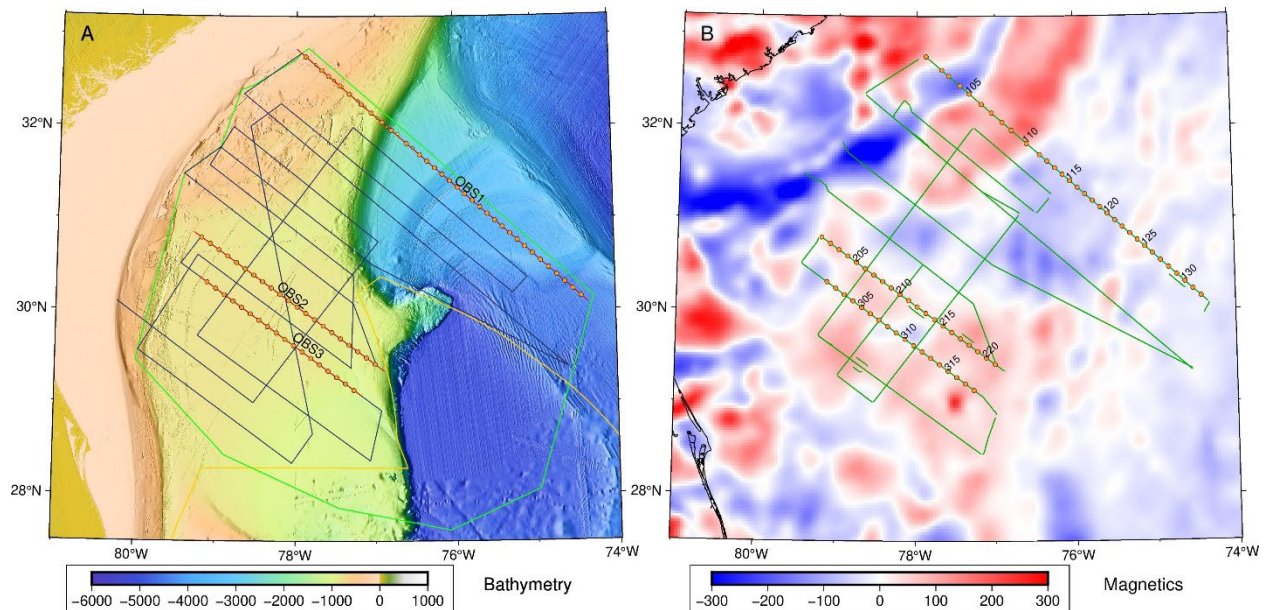
Currently the best constraints on the crustal structure of Blake Plateau come from gravity and magnetic data. The ~250 nT positive East Coast Magnetic Anomaly (ECMA) does not run as far south as Blake Plateau, but the -250 nT negative-polarity Brunswick Magnetic Anomaly (BMA) extends from Blake Plateau westward across the coast into Georgia. Gravity data suggest that the crust is possibly 15 km thick, much thicker than oceanic crust (Hutchinson et al., 1983). Two hundred kilometers east of the ECMA lies the weaker (~50 nT) Blake Spur Magnetic Anomaly (BSMA). Seismic imaging of the deep crustal structure of the Blake Plateau and the magnetic anomalies was therefore an important science objective of cruise MGL2310.

The analysis and interpretation of the ENAM seismic refraction data set near Cape Hatteras (Shuck et al., 2019) showed that the crust between ECMA and BSMA has unusually high seismic velocity, but that it is also quite thin. This combination of characteristics could indicate that the basement between these two magnetic anomalies formed above relatively thick lithosphere (Bécel et al., 2020). The BSMA thus appears to mark the onset of focused seafloor spreading after the culmination of continental rifting in the western Atlantic. One of the objectives of cruise MGL2310 was to examine the variation in crustal structure across BSMA outboard the southern Carolina Trough.

We planned to achieve these science objectives with a rough grid of 2-D marine seismic reflection lines and three marine seismic refraction lines (Figure 3.1). The long OBS refraction line across the Carolina Trough margin (Line 1) will provide constraints on the entire evolution from initial stretching to seafloor spreading. The two shorter seismic OBS refraction lines (2 and 3) will provide much needed constraints on the composition and thickness of the crust of Blake Plateau.

To gather the marine seismic reflection and refraction data we planned for two cruises, first an expedition to obtain marine seismic reflection data with the *Langseth*'s 12-km long streamer (MGL2309), followed by OBS refraction cruise (MGL2310). We did not have permission to work in the EEZ of the Bahamas, so we planned all marine seismic lines in US and international waters to meet our science objectives. For cruise MGL2310 these are

- To record the full *Langseth* acoustic array, 36 air guns with a total volume of 3600 in³ on three linear arrays of four-component ocean-bottom seismometers, spaced 13 km apart, with a total length of 1,000 km. The long transect across the Carolina Trough can make use of existing OBS refraction data from Holbrook et al (1994) which are sparse, but high in quality.
- The shot spacing was set at 150 meters, appropriate for seismic imaging of the deep-lying basement with limited previous shot noise. The acoustic source depth (10 m) depth was chosen specifically for imaging crustal structure.
- Collect underway geophysical data such as multibeam, Knudsen 3.5 kHz data, gravity and magnetic data.
- Archive all geophysical data, document the data acquisition history, navigation, and any report quality issues.



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Figure 3.1. A) Bathymetry map of the Blake Plateau and Carolina Trough. Gray lines are the primary and contingency seismic lines that were planned for cruise MGL2309. Red lines represent the three OBS lines for cruise MGL2310. Orange circles are planned OBS sites for the Langseth cruise. Yellow circles are existing instrument sites from a 1988 project (Holbrook et al., 1994). The orange line shows the Extended Economic Zone of the Bahamas, and the green polygon marks the permitted area (see Appendix A1). B) Magnetic anomaly map with the completed marine seismic reflection lines from cruise MGL2309 in green. Orange circles are planned OBS sites for cruise MGL2310, annotated by site number.

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4. Cruise narrative MGL2310

JD 234 (Tu Aug 22): The science party arrived on board at 17:00UTC. The ship was busy with small maintenance, getting new supplies for the voyages ahead, and a fairly large turnover in the crew.



Figure 4.1. A) The science party assembles in the hotel before joining the vessel. B) Arrival at the dock. C) The R/V *Marcus Langseth* leaves the port of Charleston for cruise MGL2310.

JD 235 (We Aug 23): At 16:30 we held an orientation for the students on the ship. The R/V *Marcus Langseth* left the dock at 19:00. The weather was clear, but there was also a steady breeze. We saw dolphins as we left Charleston behind us. The science party divided up in three 8-hour shifts, and started to adjust sleep schedules. Unfortunately, our first on-board test showed that we had one COVID case in the crew, and measures were taken immediately to isolate that person from the rest for a few days.

JD 236 (Th Aug 24): Our transit to the west end of OBS Line 1 would be approximately 14 hours. The weather was a bit choppy as we approached OBS Line 1. Most of those that were new to these cruises were initially motion sick, but they all took it in stride. The R/V *Marcus Langseth* arrived at the first OBS site, OBS 101, at 07:44. We decided to drop the WHOI and SIO OBSs in a staggered order, beginning with a WHOI OBS. The OBSIC team decided to take it slow on the first few drops to let everyone familiarize with the instrument preparation and deck procedures. The *Langseth* technical team would catch on quickly. The weather also improved over time. The first few OBSs were deployed in very shallow water (< 100 m), and a Gulf Stream current greater than 2 knots. The last OBS of the day was #113, deployed at 23:37.



Figure 4.2. A) Safety training. B) LCHEAPO ocean-bottom seismometers from Scripps Institution of Oceanography. C) OBSIC technician Dan Kot is preparing an instrument for deployment.

JD 237 (Fr Aug 25): The weather was quite good during the OBS deployment of the eastern half of Line 1. The average wave height was about 5-6 feet, and the wind remained steady at 15-20 knots. The teams were now established such that the instruments were going down every hour. Until the deployment of OBS 121 at 7:47 we staggered the SIO and WHOI OBSs, but on the remaining portion of the line we would drop two SIO OBS for each WHOI OBS. The last OBS in this first deployment was #132, and it was dropped at 18:20. Subsequently, the Passive Acoustic Monitoring hydrophone array, and magnetometer were deployed at the east end of OBS Line 1. The deployment of the acoustic array started at 19:02, and by 21:39 all four gun strings were in the water. Unfortunately, gun string 3 started auto-firing, and gun strings 1 and 2 were not maintaining pressure. By 22:27 gun strings 1 and 2 were back on board, and at 23:01 gun string 3 was on board too for some click tests.

JD 238 (Sa Aug 26): The wind was coming down to 10 knots, so the weather was now good. Unfortunately, the acoustic array was not easy to get ready for data acquisition. After some tests, gun string 3 was deployed again at 1:42. On gun strings 1 and 2, pressure transducers were fixed, but re-deployment was nonetheless cancelled due to auto-firing on deck. Gun string 1 was redeployed at 7:50, and string 2 was deployed at 9:37. At 11:35 we entered the permitted area again, where we would perform a gun firing test at low pressure on the frontal cluster of string 1. After the test appeared successful, we started a soft ramp-up at 11:52. Though the soft start had to be interrupted twice, it completed by 12:39. As we approached OBS Line 1, we first shot a test line with a fixed shot interval (45 s) by 13:21, and the approach to OBS Line 1 at 150 m shot interval (P1PRE1) by 14:14. The full 36 airgun array of 6600 in³ was working. At 14:31 we started P1POBS1 with shot 1000. By 16:40, gun strings 3 and 4 appeared to be so close that they could tangle, so we considered bringing in string 3 to adjust some ropes to the frontal float. However, by making some adjustments to the speed through the water (below 4.3 knots) we were able to keep the gun strings separate too. The last shot of the day was 1504.

JD 239 (Su Aug 27): We continued to collect refraction data along OBS Line 1 with the full 36-gun acoustic source. We briefly attempted to increase the ship's speed to 4.6 knots, but at 1:43 it became clear that gun string 3 did not hold position well at this higher speed, we settled again on 4.3 knots speed through the water. With the currents, the speed over the ground would often dip below 4 knots. At the lower ship speed it would take hours longer to complete the line, but the longer shot interval (75 s) could also reduce previous shot noise on long-offset refraction data. At 10:14 we lost power to some of the ship's systems for a few minutes. Though we continued shooting, gun GPS was out between shots 1996 and 2005. The first XBT of the project was launched at 14:55, and reached the full depth range of 1830 m. Around 12:00, the currents shifted, and our speed over the ground increased to 5.3 knots, which would give us shorter shot intervals (55 s). At 14:23 an air leak was detected on string 3. Since we now had several problems with string 3, we decided to abort this shot sequence 2P1OBS1, circle back the *Langseth*, and pull string 3 back on deck for repairs. At 15:14, shot 2287 was the last of sequence 2. The first shot of sequence 3, the continuation of OBS Line 1, was named P2OBS1, and it started at 21:52 with shot 2273. The full 6600 in³ acoustic array was in operation. The last shot of the day was 2401.

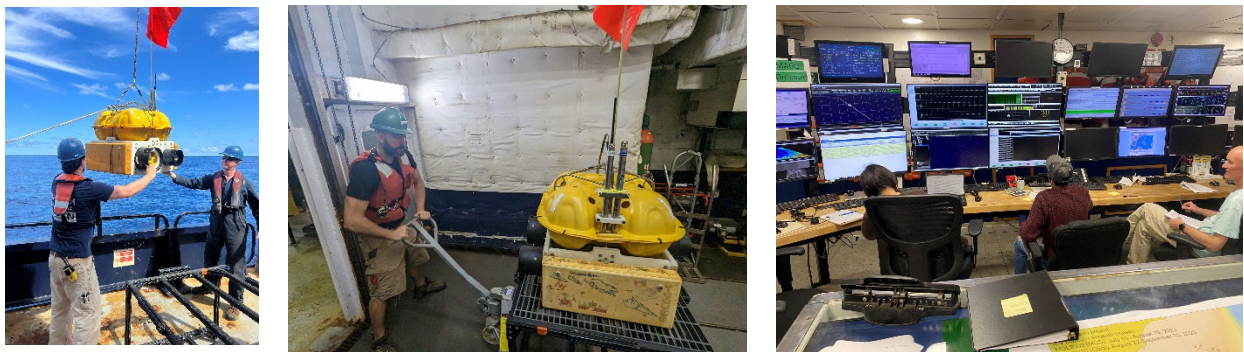


Figure 4.3. A) A Scripps OBS goes over the side. B) Another OBS leaves the dry lab. C) The science party is logging instrument deployment time and location.

JD 240 (Mo Aug 28): We continued shooting OBS Line 1 towards the northwest. At 9:00 we increased our speed through the water slightly to 4.6 knots, which did not appear to affect the acoustic array. A second XBT was launched at 10:45, still in deep water. At 14:58, the compressors were suddenly unable to provide pressure due to fuel filter problem. The engineers switched compressors, but 4 OBS1 shots were lost 3223-3226 were lost, and 5 other shots had lower pressure. We decided that the gap did not warrant a reshoot, so we continued with sequence 3. Shot 3749 was the last shot of the day.

JD 241 (Tu Aug 29): We reached the end of OBS Line 1 on the continental shelf at 4:00 with Shot 3993. The air gun volume had been kept at 6600 in³ on the entire line. After some tests on the acoustic array, recovery of the gun strings started at 4:51, and completed at 7:52. By 8:25 the magnetometer and PAM were

on board too, and the compressors shut down. We proceeded to OBS Site 101 for the first pickup. OBS101 was released and brought on deck at 10:23. After picking up OBS 102, we saw dolphins at the starboard bow at 13:20. OBS 103 required 3 hours of pinging to resurface, but we got it back on deck at 17:02. The next few OBS deployments went smoothly.

JD 242 (We Aug 30): The first OBS recovery of the day was at Site 107, and the instrument was brought on deck at 1:20. OBS 110 took quite some time to release and recover, but came on board at 9:08. OBS recoveries went smoothly until OBS115 came on deck at 19:49. Due to worsening weather conditions with the arrival of tropical storm Idalia, we decided to halt OBS recoveries and set course to the southeast.

JD 243 (Th Aug 31): We reached the southeast end of the line at 08:00. The conditions for OBS recovery at Site 132 were rather poor, with 30-35 knot winds and 10-15 foot seas. Tropical storm Idalia had progressed at a fast pace along the coast of Georgia and the Carolinas, and with hurricane Franklin still near Bermuda, the northern Central Atlantic Ocean had a bad weather forecast for several days to come. We therefore changed plans: When the weather would clear up in the south, we would deploy OBSs on Line 2. Given that we had recovered 15 OBSs from Line 1 already, this was now feasible. Due to poor weather we would start slowly on a southward course at approximately 4 knots. At 23:02 we reached the Bahamas Economic Exclusive Zone, where we turned off the sonars.



Figure 4.4. A) XBT launch. B) D2 OBS from Woods Hole Oceanographic Institution. C) A D2 OBS is brought back on deck.

JD 244 (Fr Sep 1): As we moved southward towards Line 2 we came across some rough seas, but we mostly kept a 5 knot speed. The R/V *Marcus Langseth* left the Bahamas EEZ at 9:36. At 10:28 we reached the first OBS deployment site on Line 2, and OBS 221 was dropped at 11:18. Due to significant swells from the storm to our north, the first few OBS drops were carried out slowly and with care. But as the conditions improved, we were able to deploy the instruments faster. By 21:24 OBSs were installed at sites 221 to 213. We would have continued deploying all OBSs on Line 2, but the captain informed us that we had an emergency on board the ship that required one crew member to be dropped off in Jacksonville. We immediately set course to the west, and made good progress.

JD 245 (Sa Sep 2): By 10:00 we came onto the continental shelf adjacent to Jacksonville. The meet-up time with the Coast Guard was set at 14:30. The source mechanic and one other crew member were transferred from the R/V *Marcus Langseth*. Afterwards we set course to Line 2 to finish OBS deployments. At 23:02 we reached the edge of the continental shelf where we turned the sonars back on.

JD 246 (Su Sep 3): At 2:57 we dropped a SIO OBS at Site 201, the first instrument on the west side of Line 2. The OBS deployments, each time two SIO instruments in a row for one WHOI OBS, went smoothly. OBS 207 was deployed at 9:39. The last instrument on Line 2 was OBS 212, deployed at 15:15. We set course to OBS 116 to retrieve the instruments on the east side of Line 1.

JD 247 (Mo Sep 4): On this day we lost the *Langseth*'s multibeam echosounder (Kongsberg EM122), because two electronic boards burned. Fortunately, our lines had been mapped well during cruise MGL2309. At 5:30 we arrived at Line 1 for recovery of 17 remaining OBSs. We turned off the sonars, and sent the release command for OBS 116, which was recovered at 6:50. OBS 117 to OBS 120 all came on board before 16:00. Around 12:00, the winds quite suddenly dropped from 20 to 2 knots, and it turned out a hot afternoon on the deck. OBS recoveries progressed at a great pace. The instruments released without problems, and the pickup on the surface went fast due to excellent steering at the bridge and well-organized deck teams. OBS 123 was the instrument retrieved on this day at 23:35.

JD 248 (Tu Sep 5): Throughout the day, OBS recoveries went faster than expected. The weather was calm, and the teams were working very well together now on these operations. OBS 130 was recovered at 17:10. Unfortunately, OBS 131 did not respond to any of the enable and release commands. After setting a release command, the OBSIC team waited an hour past the expected surface time, so at 20:35 we moved on to the last OBS. OBS 132 came on deck at 23:17. We then set course to the east end of Line 3 for the last round of OBS deployments.

JD 249 (We Sep 6): We crossed into the Bahamas EEZ at 6:25 on our way to the Line 3 OBS deployments. We came out of the Bahamas waters after 15:00. The Knudsen and multibeam echosounders were still kept off. The first instrument was OBS 318, dropped at 15:53, and the last one of the day was number 311, deployed at 23:33. By this time we were halfway into the line, and the deployments now started to happen faster than planned. Due to some instrument checkout failures for the Woods Hole OBSs, we deployed three SIO OBS for each WHOI OBS.

JD 250 (Th Sep 7): The OBSs on Line 3 were deployed roughly one per hour. For the last instrument 301, which was a SIO OBS dropped at 9:39, Savannah Evans and Cassandra illustrated one of the foam blocks to commemorate cruise MGL2310. The project was not yet over, but the general feeling on the ship was that we were very grateful to have Alan, Dan and Nick on board for all the OBS preparation and deck operations. The PAM and magnetometer were in the water by 10:07. Between 10:40 and 12:52 the four gun strings went out, and we started the soft ramp-up of the acoustic source to start shooting Line 3 at 150 m spacing. At 14:14 the soft start was complete for the entire 6600 in³ acoustic array. We were more than one kilometer south of the projected line, so we quickly maneuvered the *Langseth* on-line and started the line, 20 km west-southwest of the first OBS (301) with Shot Point 5016 at 14:56. Gun 7 of string 3 (60 in³) was disabled at 17:23, but the rest of the acoustic array was in good shape. Unfortunately, the *Langseth* was not registering the magnetometer data, an apparent problem with the port in the recording system. The last shot of the day was 5477.



Figure 4.5. A and B) Floats and air guns on deck. C) A mechanic is servicing the air guns.

JD 251 (Fr Sep 8): The currents were pushing us along, so at 6:54 we reduced our speed through the water to avoid shot spacing closer than 55 seconds. At 8:35 we further reduced STW to 4.3 knots, to keep the gun strings better separated. At approximately 10:00, the recording system was adjusted, so we started logging

the magnetometer data stream again. Later in the day the separation in the gun strings was very good, so at 20:11 we increased the speed through the water to 4.4 knots. At 21:04 we reached the end of OBS Line 3, all of it sequence 4, with shot 6700. Throughout the line we had 35 guns with a volume of 6540 in³. We now started sequence 5, a south to north tie line near the Blake Escarpment, towards OBS Line 2. The shot spacing was again fixed at 150 m. The first shot of Line P1TIE1 was 10015 at 21:28 with the same air-gun volume of 6540 in³. The last shot of the day was 10168.

JD 252 (Sa Sep 9): We continued shooting the tie line P1TIE1 with 35 air guns, and a volume of 6540 in³. The end of the line was reached at 1:35 with shot 10266. The turn portside turn towards OBS Line 2 was just inside our permitted area, west of the border of the Bahamas EEZ along the Blake Escarpment. We started shooting OBS Line 2 from east to west with sequence 6, P1OBS2. The first shot was 12000 at 1:58. At 3:49 we brought the speed through the water up to 4.6 knots through the water, since the gun separation was good. The last shot of the day was 13163.

JD 253 (Su Sep 10): Compressor failure brought an end to sequence 6, the first portion that we shot on OBS Line 2, at 01:56. Since the problem was not resolved in time we needed a soft start to continue with sequence 7, P2OBS2. We started shooting again at 4:10. Unfortunately, at 7:52, gun 4 of string 4 was auto-firing. We examined the situation for a while, but this new problem required us to pick up strings 3 and 4. The line sequence ended at 8:52, and we circled back while the repairs were underway. At 13:50 we came on line OBS2 again with sequence 8, shot 13455 and the full 6600 in³ gun array. At 15:53, gun 2 of string 2 was disabled, and we continued shooting with 35 guns, and a volume of 6240 in³. At 21:23 we reached the end of Line OBS2. The mechanics started to bring in the guns and PAM, which was still underway by 24:00.

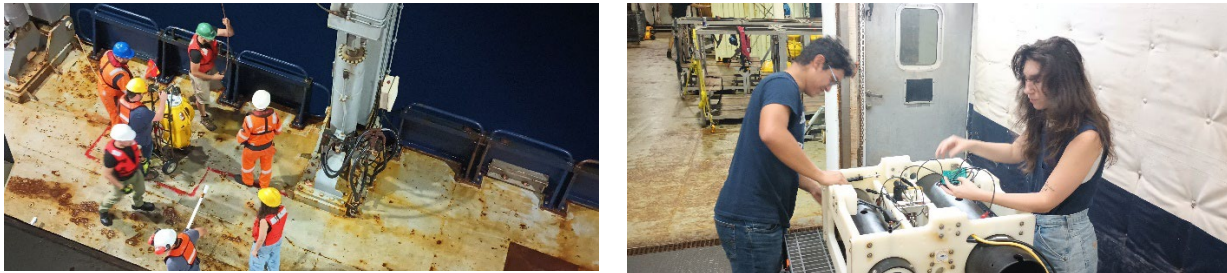


Figure 4.6. A) OBS recovery on deck. B) Instrument check-out.

JD 254 (Mo Sep 11): The last gun string and the magnetometer were recovered at 0:58. The sonars were shut down, and we started recovering OBSs. OBS 201 was on board by 3:34. The second OBS took a long time to release from the seafloor, but it was also recovered by 5:51. For OBS203, a WHOI instrument, we now used a new GPS antenna on the PSO tower, which worked well. The next few OBS recoveries went fast and smooth. The last OBS recovery of the day was OBS 215, at 23:58.

JD 255 (Tu Sep 12): The OBS recoveries along Line 2 progressed quickly. The bridge and the team on the deck were working well together, and the sea state was also good. Hurricane Lee was causing a small, very long-period swell, but it was otherwise calm and quiet. We recovered OBS 221, the last one of the line at 9:11. The transit to the east end of Line 3 was just 2.5 hours, where we continued with picking up OBS 318. By 17:01, OBS 315 was recovered.

JD 256 (We Sep 13): Though the swell was getting worse over time, the OBS recoveries proceeded at a good pace. Occasionally the ship would roll, but the deck team were prepared for it. At site 304 we retrieved the last WHOI OBS at 9:59.

JD 257 (Th Sep 14): We arrived in the port of Charleston around 7:00. The *Langseth* tech team was busy all day preparing the seismic gear for a future cruise, and the OBSIC team was securing the ocean-bottom seismometers for an on-board transit to Woods Hole. In the evening we celebrated a successful cruise MGL2310.

JD 258 (Fr Sep 15): While most of the crew and science party was preparing to leave the Langseth and Charleston behind, College of Charleston professor Steven Jaumé and a group of students took a tour of the vessel at 12:30. The shipboard gravimeter was dispatched to a local benchmark in Charleston for a gravity tie. This was the last data acquisition event of cruise MGL2310.

5. OBS deployments

During cruise MGL2310 we recorded marine seismic refraction data with two different short-period ocean-bottom seismometers: The LCHEAPO OBS from Scripps Institution of Oceanography and the D2 OBS from Woods Hole Oceanographic Institution. The instrument design and characteristics are shown in Appendix A2. The sample rate of all instruments was set at 5 msec (200 Hz). Both instrument types recorded three geophone channels and a hydrophone. The OBSs were equipped with an acoustic release, a flag and strobe light as recovery aids. The SIO OBS was also set up with a radio beacon for recovery, while the WHOI OBS had a GPS. This GPS proved to be effective once the receiving antenna was mounted high on the PSO tower.

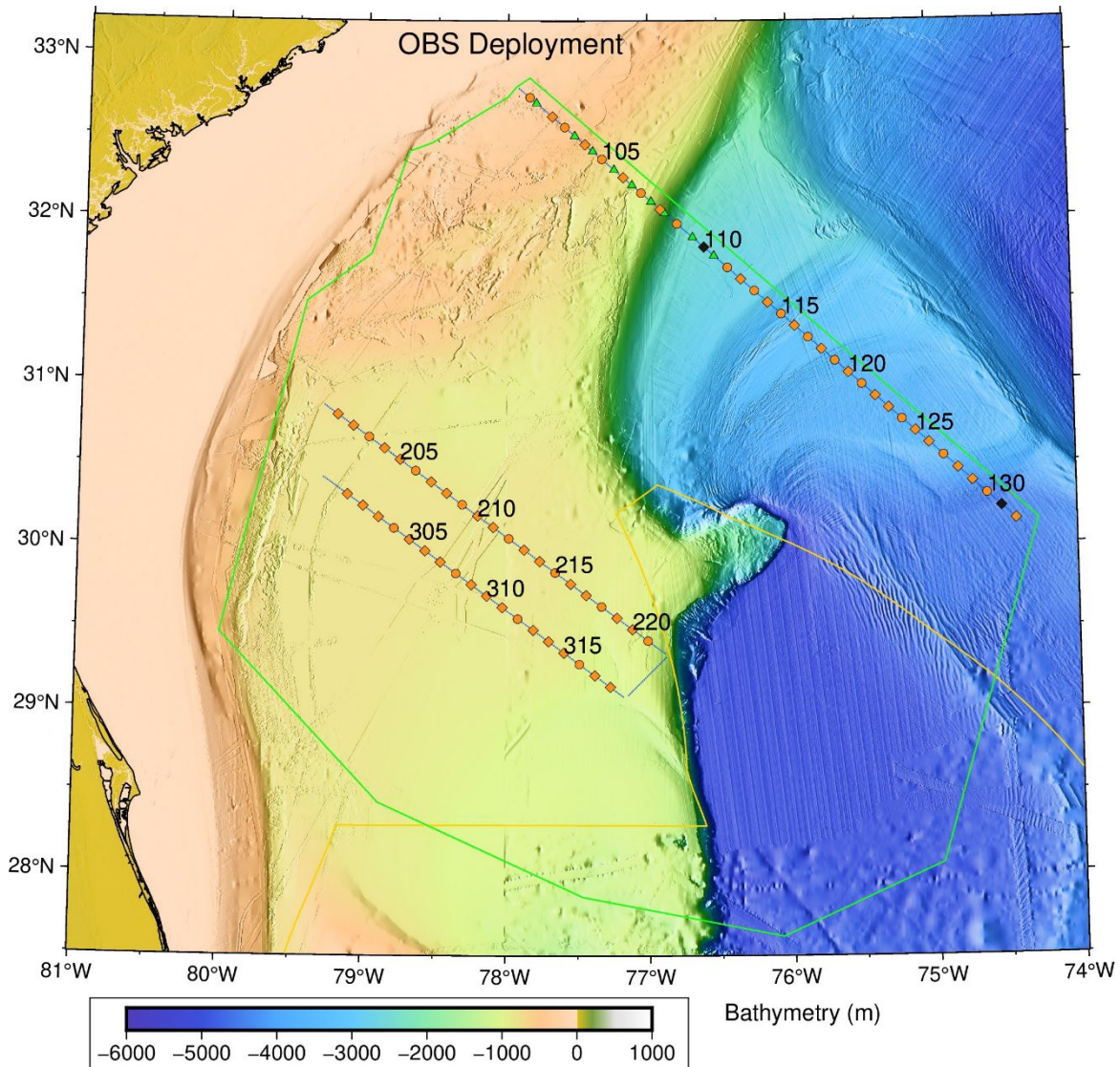


Figure 5.1. Map with instrument sites from cruise MGL2301. Green triangles represent OBS sites from a 1988 seismic refraction study. These OBS records (Holbrook et al., 1994) are available and of high quality. Orange diamonds represent the SIO OBS sites, orange circles the WHOI OBS sites. Note that OBS 101-132 and 201-318 were dropped in two different deployments. The green polygon marks the permitted area, and the orange line is the boundary of the Bahamas EEZ.

The fleet of instruments that was available on board the *Langseth* was used in two deployments. In the first deployment, on August 24 and 25, we dropped 32 instruments on Line 1. This first transect was subsequently shot with the *Langseth* acoustic source. Between September 1 and 7 September 7, 39 instruments were dropped on Line 2 and Line 3 together in a second deployment, after which we shot both Line 2 and Line 3. Since we had more SIO than WHOI OBSs on board, we dropped SIO OBS 46 times, versus 25 WHOI instrument drops (see Table 5.1). We distributed the WHOI OBS sites evenly along each line.

Table 5.1a. First OBS deployment on Line 1.

OBS	TP	ID	Acous	Offset	Date	Time	Lat.	Lon.	Depth	Current	dir.
101	WHOI	D56		19.0	8/24	7:44	32.73857	-77.84477	270	2.2	57
102	SIO	229	166	39.0	8/24	9:09	32.62123	-77.68247	381	2.4	54
103	WHOI	D10		50.0	8/24	10:06	32.55668	-77.59357	381	2.1	57
104	SIO	203	11	68.0	8/24	11:27	32.45077	-77.44843	567	1.5	60
105	WHOI	D04		83.0	8/24	12:43	32.36243	-77.32748	708	0.9	61
106	SIO	234	64	102.0	8/24	14:01	32.24998	-77.17515	822	0.3	194
107	WHOI	D09		118.0	8/24	15:32	32.15550	-77.04699	926	1.2	240
108	SIO	94	73	135.0	8/24	17:02	32.05501	-76.91139	1300	0.5	260
109	WHOI	D90		150.0	8/24	18:34	31.96615	-76.79169	2206	0.3	7
110	SIO	13	39	174.0	8/24	20:08	31.82366	-76.60092	2506	0.6	2
111	WHOI	D29		192.0	8/24	21:42	31.69895	-76.43312	2642	1.1	2
112	SIO	214	103	204.0	8/24	22:38	31.62789	-76.33909	2707	0.5	356
113	WHOI	D26		216.0	8/24	23:37	31.55581	-76.24278	2724	0.8	344
114	SIO	216	003	228.0	8/25	0:34	31.48477	-76.14896	2855	0.8	349
115	WHOI	D55		240.0	8/25	1:37	31.41303	-76.05426	3084	0.9	343
116	SIO	75	122	252.0	8/25	2:40	31.34131	-75.96005	3162	1.0	337
117	WHOI	D06		264.0	8/25	3:45	31.26953	-75.86601	3193	1.2	351
118	SIO	92	101	276.0	8/25	4:50	31.19794	-75.77151	3256	1.2	342
119	WHOI	D64		288.0	8/25	5:49	31.12600	-75.67790	3399	1.1	352
120	SIO	209	90	300.0	8/25	6:48	31.05389	-75.58351	3525	1.1	341
121	WHOI	D34		312.0	8/25	7:47	30.98154	-75.48974	3601	0.8	309
122	SIO	217	24	324.0	8/25	8:44	30.90892	-75.39619	3659	0.7	277
123	SIO	117	47	336.0	8/25	9:34	30.83656	-75.30208	3690	1.0	235
124	WHOI	D25		348.0	8/25	10:26	30.76508	-75.20968	3712	1.0	230
125	SIO	233	107	360.0	8/25	11:18	30.69327	-75.11605	3833	1.0	219
126	SIO	300	50	372.0	8/25	12:17	30.61996	-75.02303	3783	1.0	204
127	WHOI	D28		385.0	8/25	13:20	30.54132	-74.92233	3907	1.7	195
128	SIO	78	40	398.0	8/25	14:22	30.46276	-74.82186	3848	1.2	189
129	SIO	20	59	411.0	8/25	15:20	30.38448	-74.72175	4099	1.0	188
130	WHOI	D14		424.0	8/25	16:21	30.30549	-74.62167	4378	0.7	190
131	SIO	17	69	437.0	8/25	17:21	30.22695	-74.52149	4444	0.3	223
132	SIO	57	007	450.0	8/25	18:20	30.14824	-74.42154	4412	0.1	77

Table 5.1b. Second OBS deployment on Line 2 and Line 3.

OBS	TP	ID	Acous	Offset	Date	Time	dec.lat	dec.lon	Depth	Current	dir.
201	SIO	206	105	1.00	9/3	2:57	30.79779	-79.19389	753	1.1	349
202	SIO	205	28	14.00	9/3	4:02	30.72957	-79.08307	792	0.3	29
203	WHOI	D04		27.00	9/3	5:08	30.66155	-78.97227	806	1.6	19
204	SIO	207	80	40.00	9/3	6:16	30.59336	-78.86216	830	2.1	23
205	SIO	208	117	53.00	9/3	7:21	30.52496	-78.75201	821	1.6	20
206	WHOI	D56		66.00	9/3	8:29	30.45634	-78.64164	812	1.4	15
207	SIO	231	99	79.00	9/3	9:39	30.38816	-78.53209	809	0.9	26
208	SIO	67	31	92.00	9/3	10:46	30.31924	-78.42254	806	0.4	45
209	WHOI	D29		105.00	9/3	12:06	30.25086	-78.31263	803	0.2	134
210	SIO	95	77	118.00	9/3	13:08	30.18151	-78.20335	808	0.7	175
211	SIO	61	57	131.00	9/3	14:12	30.11241	-78.09431	811	1.2	186
212	WHOI	D90		144.00	9/3	15:16	30.04365	-77.98513	817	1.8	125
213	SIO	216	103	157.00	9/1	21:24	29.97493	-77.87620	823	1.5	222
214	SIO	214	3	170.00	9/1	20:14	29.90542	-77.76762	830	1.3	216
215	WHOI	D09		183.00	9/1	19:07	29.83613	-77.65873	845	1.5	202
216	SIO	229	166	196.00	9/1	18:00	29.76659	-77.55022	866	1.3	199
217	SIO	234	0073	209.00	9/1	16:50	29.69739	-77.44195	903	0.7	217
218	WHOI	D26		222.00	9/1	15:41	29.62798	-77.33369	942	0.0	30
219	SIO	234	64	235.00	9/1	14:27	29.55849	-77.22577	916	0.2	10
220	SIO	203	011	248.00	9/1	13:07	29.48907	-77.11768	943	0.5	51
221	WHOI	D55		261.00	9/1	11:18	29.41872	-77.00954	1028	1.0	37
318	SIO	57	07	260.00	9/6	15:53	29.13711	-77.27336	1034	0.7	149
317	SIO	200	130	247.00	9/6	16:52	29.20658	-77.38078	1023	0.5	350
316	WHOI	D28		234.00	9/6	18:07	29.27587	-77.48875	947	0.2	324
315	SIO	75	122	221.00	9/6	19:10	29.34545	-77.59665	900	0.6	233
314	SIO	90	125	208.00	9/6	20:16	29.41496	-77.70430	873	0.2	144
313	SIO	233	107	195.00	9/6	21:18	29.48433	-77.81223	853	1.1	147
312	WHOI	D25		182.00	9/6	22:26	29.55368	-77.92070	832	1.4	180
311	SIO	300	50	169.00	9/6	23:33	29.62299	-78.02909	874	1.3	195
310	SIO	92	101	156.00	9/7	0:35	29.69214	-78.13778	838	1.1	201
309	SIO	117	47	143.00	9/7	1:35	29.76114	-78.24620	835	0.6	207
308	WHOI	D34		130.00	9/7	2:33	29.83015	-78.35501	832	0.6	211
307	SIO	217	24	117.00	9/7	3:33	29.89913	-78.46409	819	0.4	268
306	SIO	209	90	104.00	9/7	4:28	29.96793	-78.57240	809	0.7	337
305	SIO	215	108	91.00	9/7	5:24	30.03661	-78.68176	800	0.9	358
304	WHOI	D06		78.00	9/7	6:25	30.10573	-78.79131	807	0.9	354
303	SIO	78	40	65.00	9/7	7:29	30.17422	-78.90090	809	1.3	359
302	SIO	211	94	52.00	9/7	8:35	30.24237	-79.01069	803	1.3	354
301	SIO	227	78	39.00	9/7	9:40	30.31084	-79.12033	795	0.5	3

The OBS deployments and recoveries proceeded at a good pace throughout the project. After we shot Line 1, we had to improvise the order of these operations due to two storms and a medical evacuation. The recovery of OBSs along Line 1 was interrupted on August 30 by tropical storm Idalia, when instruments 101 to 115

already were on board (see Table 5.2). Since the sea state was slightly better on Line 2 than on Line 1, we then proceeded to drop OBSs 221 to 213 from east to west, until we broke off operations for a medical evacuation on September 1. After the trip to Jacksonville, we deployed OBSs 201-212 on the western half of Line 2 before we recovered the remaining OBSs on the eastern half of Line 1 (OBS 116-132) on September 4 and September 5. Afterwards we dropped all 18 OBSs on Line 3 on September 6 and 7. The shot lines OBS2, OBS3 and TIE (see Section 6) were therefore recorded on OBSs on Line 2 and Line 3. The recovery of OBSs on Line 2 and Line 3 finished up on September 13, before tropical storm Lee impacted our operations. Since the storm was a few hundred miles northeast of us, we mostly experienced a long-wavelength swell. Due to the arrival of this storm we were not able to use the remaining contingency time for science, and we returned to Charleston two days early on September 14.

Table 5.2a. Recovery of OBSs from the first deployment. Status 0 = instrument lost, Status 2 = no data.

OBS	TP	Date	Time	dec.lat	dec.lon	Status
101	WHOI	8/29	10:23	32.74281	-77.84563	1
102	SIO	8/29	12:36	32.63894	-77.68166	1
103	WHOI	8/29	17:02	32.57738	-77.59093	1
104	SIO	8/29	19:34	32.46946	-77.44558	1
105	WHOI	8/29	21:30	32.37783	-77.32287	1
106	SIO	8/29	23:31	32.26517	-77.16740	1
107	WHOI	8/30	1:20	32.16673	-77.03762	1
108	SIO	8/30	3:34	32.05786	-76.89613	1
109	WHOI	8/30	5:44	31.96667	-76.78099	1
110	SIO	8/30	9:08	31.83240	-76.58015	2
111	WHOI	8/30	11:37	31.70474	-76.42878	1
112	SIO	8/30	13:41	31.63551	-76.33802	1
113	WHOI	8/30	15:26	31.56404	-76.24036	1
114	SIO	8/30	17:45	31.49544	-76.15234	1
115	WHOI	8/30	19:49	31.42179	-76.06234	1
116	SIO	9/4	6:50	31.34708	-75.97240	1
117	WHOI	9/4	9:13	31.27543	-75.87853	1
118	SIO	9/4	11:50	31.20494	-75.78506	1
119	WHOI	9/4	13:54	31.13066	-75.68741	1
120	SIO	9/4	16:25	31.05892	-75.59296	1
121	WHOI	9/4	18:43	30.98202	-75.49904	1
122	SIO	9/4	20:59	30.90766	-75.40914	1
123	SIO	9/4	23:35	30.82852	-75.30445	1
124	WHOI	9/5	1:22	30.76301	-75.22352	1
125	SIO	9/5	4:03	30.69177	-75.14992	1
126	SIO	9/5	6:33	30.61935	-75.03784	1
127	WHOI	9/5	8:45	30.54031	-74.93629	1
128	SIO	9/5	11:20	30.46171	-74.84020	1
129	SIO	9/5	14:32	30.38146	-74.74257	1
130	WHOI	9/5	17:10	30.30176	-74.63164	1
131	SIO	9/5				0
132	SIO	9/5	23:17	30.14762	-74.43198	1

Table 5.2b. Statistics of recovery of OBSs from the second deployment on Line 2 and Line 3.

OBS	TP	Date	Time	dec.lat	dec.lon	Status
201	SIO	9/11	3:34	30.81112	-79.18614	1
202	SIO	9/11	5:51	30.73918	-79.07760	1
203	WHOI	9/11	7:18	30.66012	-78.95560	1
204	SIO	9/11	8:38	30.59800	-78.85888	1
205	SIO	9/11	10:09	30.52742	-78.74801	1
206	WHOI	9/11	11:33	30.45742	-78.63774	1
207	SIO	9/11	12:47	30.39015	-78.52784	1
208	SIO	9/11	14:07	30.31872	-78.41874	1
209	WHOI	9/11	15:37	30.24678	-78.30850	1
210	SIO	9/11	17:12	30.17355	-78.20360	1
211	SIO	9/11	18:28	30.10397	-78.09698	1
212	WHOI	9/11	19:39	30.03324	-77.98874	1
213	SIO	9/11	21:08	29.96382	-77.88058	1
214	SIO	9/11	22:35	29.89599	-77.77170	1
215	WHOI	9/11	23:58	29.83219	-77.66114	1
216	SIO	9/12	1:27	29.76477	-77.55234	1
217	SIO	9/12	3:10	29.69905	-77.44576	1
218	WHOI	9/12	4:38	29.63192	-77.33095	1
219	SIO	9/12	6:11	29.56490	-77.22175	1
220	SIO	9/12	7:38	29.49523	-77.11240	1
221	WHOI	9/12	9:11	29.42511	-77.00421	1
318	SIO	9/12	12:13	29.14307	-77.26580	1
317	SIO	9/12	13:46	29.21562	-77.36605	1
316	WHOI	9/12	15:22	29.28069	-77.47625	1
315	SIO	9/12	17:01	29.34499	-77.59194	1
314	SIO	9/12	18:27	29.40992	-77.70447	1
313	SIO	9/12	20:19	29.47744	-77.81458	1
312	WHOI	9/12	21:55	29.54295	-77.92578	1
311	SIO	9/12	23:30	29.61199	-78.03266	1
310	SIO	9/13	1:08	29.67593	-78.14844	1
309	SIO	9/13	2:31	29.75215	-78.25083	1
308	WHOI	9/13	4:07	29.82157	-78.35794	1
307	SIO	9/13	5:40	29.89821	-78.46515	1
306	SIO	9/13	7:00	29.96978	-78.57307	1
305	SIO	9/13	8:22	30.04152	-78.68132	1
304	WHOI	9/13	9:59	30.11703	-78.78631	1
303	SIO	9/13	11:27	30.18383	-78.89588	1
302	SIO	9/13	13:01	30.25116	-79.00544	1
301	SIO	9/13	14:44	30.32255	-79.11049	1

Overall the OBS recoveries went very well. There were a few instruments that required more than one burn command to release from the seafloor. OBS 102 was difficult to release because it was in relatively shallow

water 200 m), but we eventually brought it back on deck. Instrument 110 was recovered without data, and OBS 131 never responded to acoustic enabling or release commands. Many of the other instruments released promptly. The sea state was calm during most of our operations, and instruments that reached the surface were always detected within minutes.



Figure 5.2. Three photographs of OBS preparations from the wet lab, and deployments with the A-frame at the starboard deck of the R/V *Marcus Langseth*.

6. Shot Lines

The marine seismic refraction data on cruise MGL2310 were acquired in two deployments. The first deployment covered OBS Line 1, and the second deployment covered both Line 2 and 3. Our plan was to gather each of these lines with the full acoustic array, 36 guns and a 6600 in³ volume, at a 150 m shot spacing.

Though the mechanics had some difficulty getting the acoustic source ready for Line 1, it was stable and at full capacity (6600 in³) on Line 1. Before the *Langseth* came on to Line 1 we produced a small test line (sequence 1, P1PRE1). The true OBS Line 1 refraction shoot started on August 26 at 14:31 with sequence 2, Shot 1000. On August 27 at 15:14, we broke off this sequence to fix an air leak (last shot 2287). We continued the line with sequence 3, Shot 2273 at 21:52. We therefore have a few shots overlap. The line finished on August 29 at 04:00 with Shot 3993, also with the full 6600 in³ volume.

After recovery of the OBSs on Line 1 and deployment of these instruments on Line 2 and Line 3, the mechanics had a smoother deployment of the air-gun array, which took just four hours this time. We started shooting again on September 7 at 14:57 with sequence 4, shot 5017 on Line 3. Though we started with the full 36-gun, 6600 in³ source, we soon had to disable the 60 in³ gun 7 of string 4 at shot 5163, which reduced our volume to 6540 in³. Line 3 and sequence 4 were completed at 21:04 on September 8 with Shot 6700.

We shot a tie line (Sequence 5, line P1TIE1) to reach Line 2 on the east side. This tie line (shots 10015-10266) was gathered by September 9 by 1:35 with the same 6540 in³ source volume.

Shooting on the final OBS line 3 started on September 9 at 1:58 with the same 6540 in³ gun array (sequence 6) and Shot 12000. This sequence ended with compressor failure at 1:56 on September 10 at shot 13270. Sequence 7 continued OBS Line 3 at 4:10. Unfortunately, this sequence did not last long, since we had an airgun auto-fire, starting 7:52, so we ended sequence 7 at 8:53 on September 10 (Shot 13534). The last shot sequence 8 started at 13:50 with shot 13455 and the full 6600 in³ volume. By 15:36 (Shot 13558) we lost gun 2 of String 2, so we acquired the rest of Line 2 with 6240 in³ source volume. At 21:23 on September 10 we reached the end of Line OBS2.

The fixed shot spacing of 150 meters led to quite variable shot time intervals, dependent on ocean currents. The average ship speed during shooting operations was 4.2 knots. Figure 6.1 shows the progression of the shot numbers over the course of the cruise. In this section we list the basic metrics of the shot sequences that make up the MGL2309 seismic survey (see Table 6.1).

Table 6.1 Shot lines, sequences, gathered during cruise MGL2310.

Deploy	Line	Seq.	Name	SP first	SP last	Jday1	Time1	Lat1	Lon1	Jday2	Time2	Lat2	Lon2
1	PRE	1	1PRE1	104	143	238	13:29	30.053129	-74.358834	238	14:14	30.10417	-74.366066
1	OBS1	2	1OBS1	1000	2287	238	14:32	30.11945	-74.385154	239	15:14	31.28356	-75.883854
1	OBS1	3	2OBS1	2273	3993	239	21:52	31.270986	-75.867359	241	4:00	32.79814	-77.928196
2	OBS3	4	1OBS3	5016	6700	250	14:56	30.416564	-79.292576	251	21:04	29.07625	-77.180537
2	TIE	5	P1TIE1	10015	10266	251	21:28	29.084637	-77.150098	252	1:35	29.32474	-76.876234
2	OBS2	6	P1OBS2	12000	13278	252	1:58	29.345617	-76.896162	253	1:56	30.3567	-78.498289
2	OBS2	7	P2OBS2	13258	13534	253	4:10	30.349873	-78.472953	253	8:52	30.52509	-78.754525
2	OBS2	8	P3OBS2	13455	13901	253	13:50	30.504053	-78.720329	253	21:23	30.85621	-79.287529

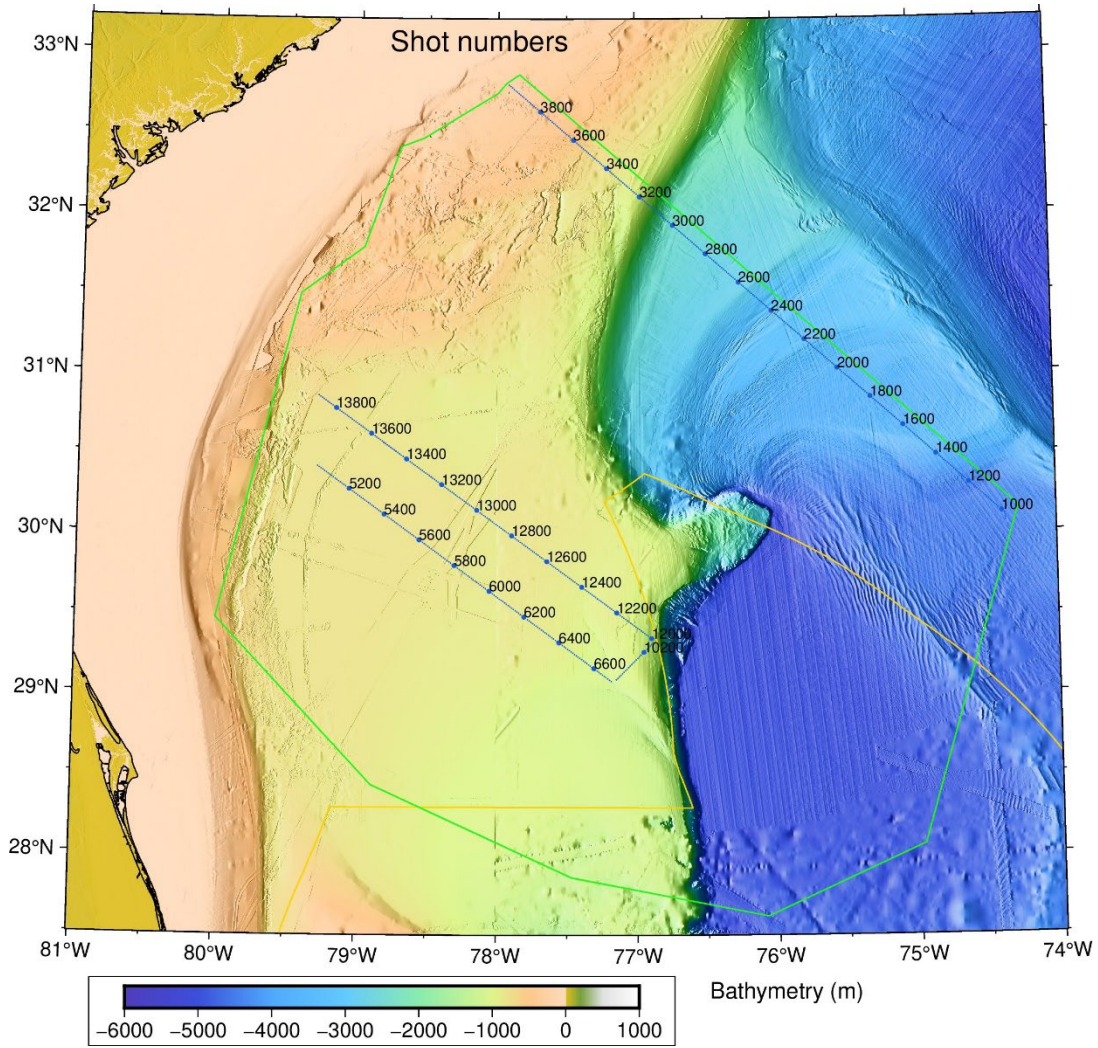


Figure 6.1. Shot lines of cruise MGL2310 annotated by every 200th shot number.

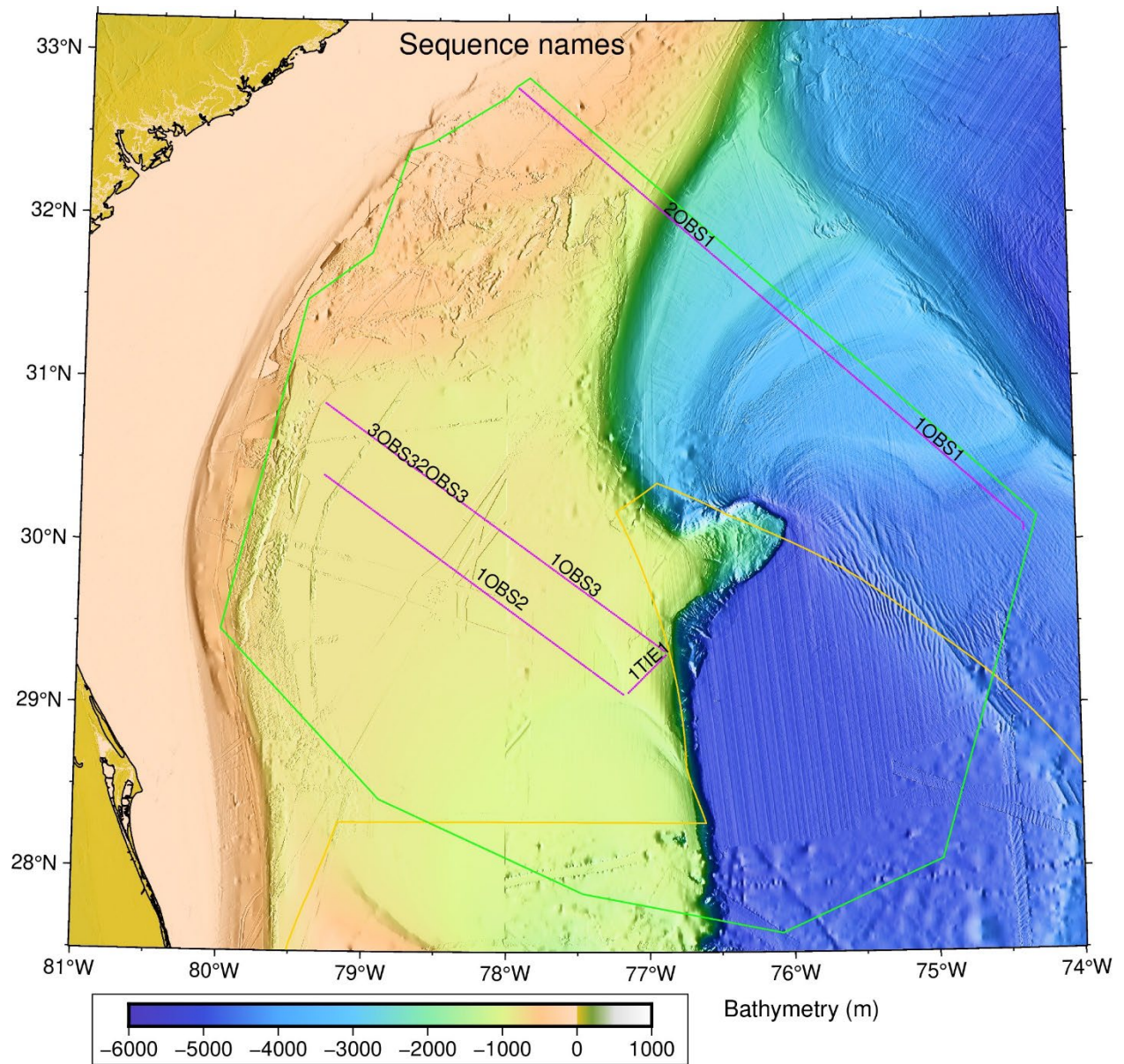


Figure 6.2. Seismic sequence names used during cruise MGL2310.

7. Data redaction.

Before the start of the two Langseth cruises on Blake Plateau, the US Navy requested that the OBS data be screened for sensitive signals related to naval operations during our seismic survey. Those portions of the data would be redacted. The MCS data were not screened, because emissions of the *Langseth* air-gun array would make it too difficult to detect other sound sources. However, the ocean-bottom seismometers recorded in a quiet seafloor environment, often more than a 100 km away from the *Langseth* acoustic source.

Since the WHOI OBSIC team was handling the raw data downloads and the conversion of the time series (in miniSEED) to SEG-Y, we developed an agreement between the Navy and OBSIC. OBSIC was tasked with the secure storage of the raw OBS data on board the R/V *Marcus Langseth*. Neither the PI or students on board would see the OBS data as the instruments came back on board. The Navy received these raw data right after we returned to port, and they committed to screening and redacting the data within 90 days.

Redaction did not go as smoothly as planned. The Navy was able to read the SIO data fine, but the officers had difficulty reading the time stamps on the WHOI Miniseed data, which led to a delay in the process. In the end, only a few sections of WHOI OBS stations 113, 115, 117, 119, 121 and 124 were excised. In February of 2024 the redaction process was completed and the data were returned to us. Figure 7.1 gives an overview of the data coverage and redactions on Line 1.

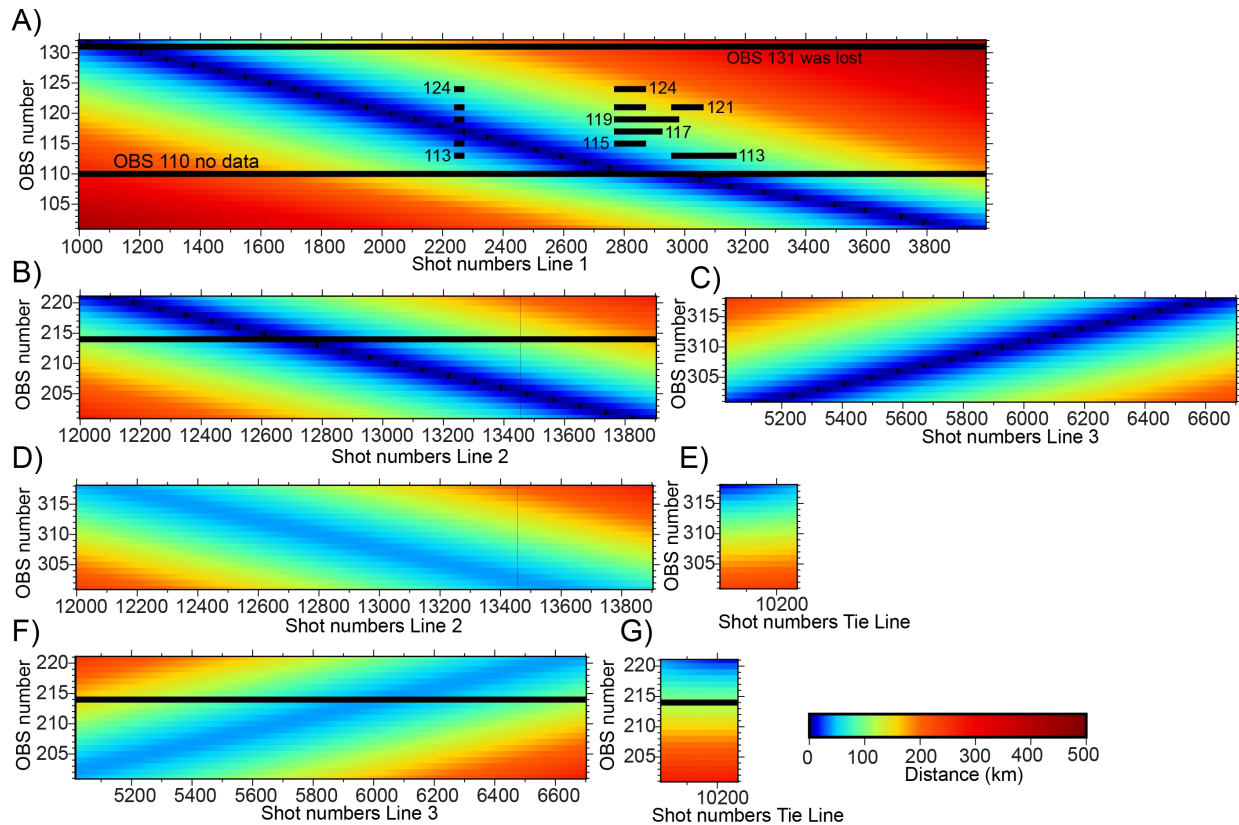


Figure 7.1 Overview of OBS shot number pairs. OBS 110, 131 and 214 did not return data. Other black areas (only on Line 1) represent redacted data. A) Shots and OBSs on Line 1, B) Shots and OBSs on Line 2, C) Shots and OBSs on Line 3, D) Shots from Line 2 recorded on Line 3, E) Shots from the tie line recorded on Line 3, F) Shots from Line 3 recorded on Line 2, G) Shots from tie line recorded on Line 2.

8. OBS Data examples

The seismic refraction experiment on Blake Plateau and the southern Carolina Trough consisted of the deployments of ocean-bottom seismometers, both of which used a combination of SIO and WHOI instruments. Whereas the first array of OBSs on Line 1 only recorded shots from the same line, the second deployment of OBSs on Line 2 and Line 3 also recorded source-receiver pairs between these two lines, as well as shots from the tie line

Deployment 1:

On OBS Line 1 we deployed 32 OBSs, of which 14 came from the WHOI OBSIC fleet and 18 from the SIO fleet (see Table 5.1). These instruments recorded shots at 150 m spacing from the full R/V *Marcus Langseth* acoustic array (Section 6) along Line 1. Due to technical problems and restarts, the shot line is divided in two Orca segments, 2P1OBS1 and 3P2OBS1 (see Table 6.1). The break between 2P1OBS1 and 3P2OBS1 was used for air-gun maintenance, and a small overlap in shots between these records assured continuity. Here we combined these shot segments to produce OBS records along Line 1. Figure 8.1 to 8.4 show example records from four instruments at different water depths. The data quality of the vertical geophone is quite good, sometimes better than the hydrophone channel.

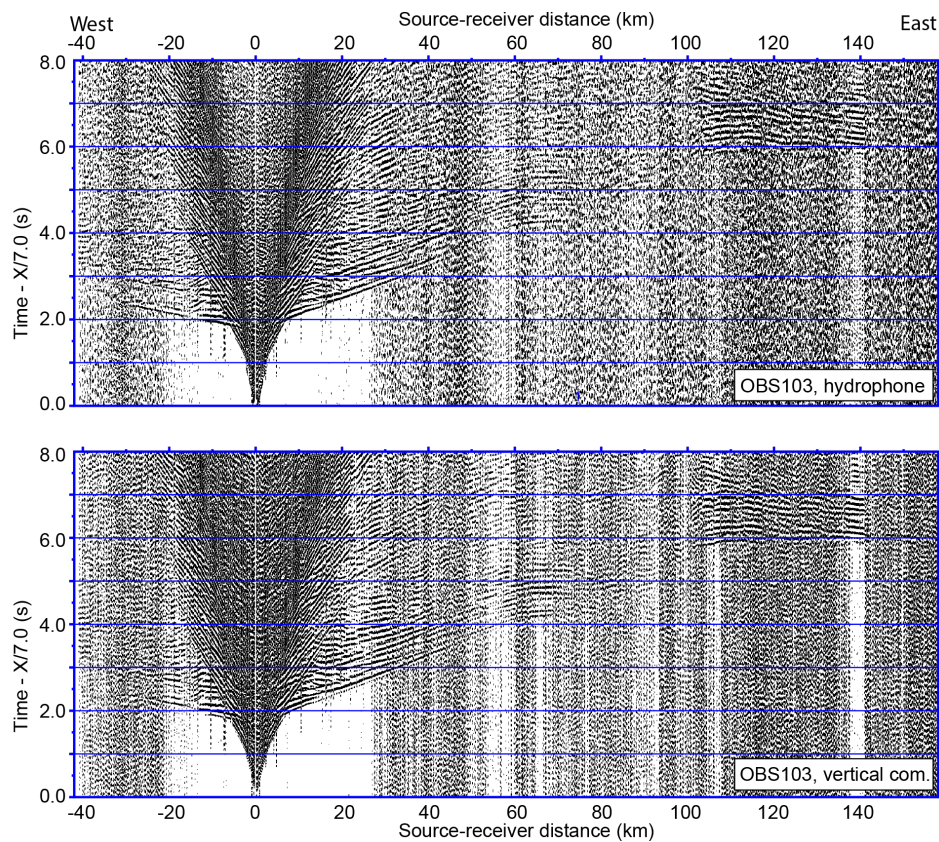


Figure 8.1. Record sections from OBS 103 hydrophone (top) and vertical geophone (bottom) channels. All travel-times reduced by 7 km/s. Wide-angle Moho reflection is visible between 100 and 140 km at 6 seconds.

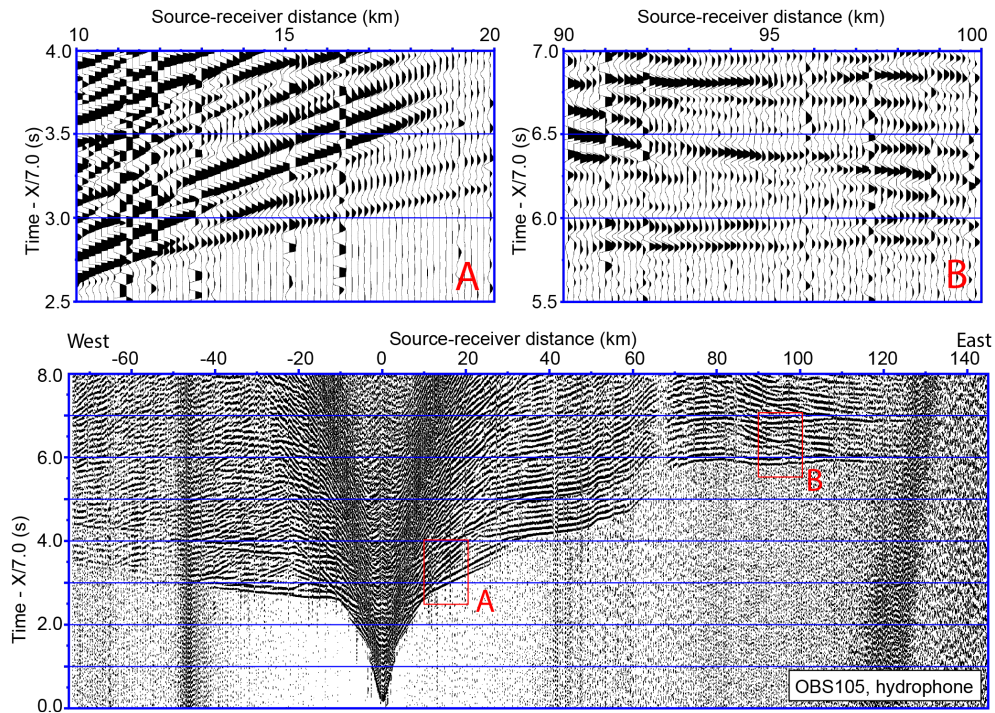


Figure 8.2. Record from OBS 105 that shows refractions turning across the continental shelf break at 70 km. Inset A shows shallow crustal refractions, and inset B shows Moho reflections.

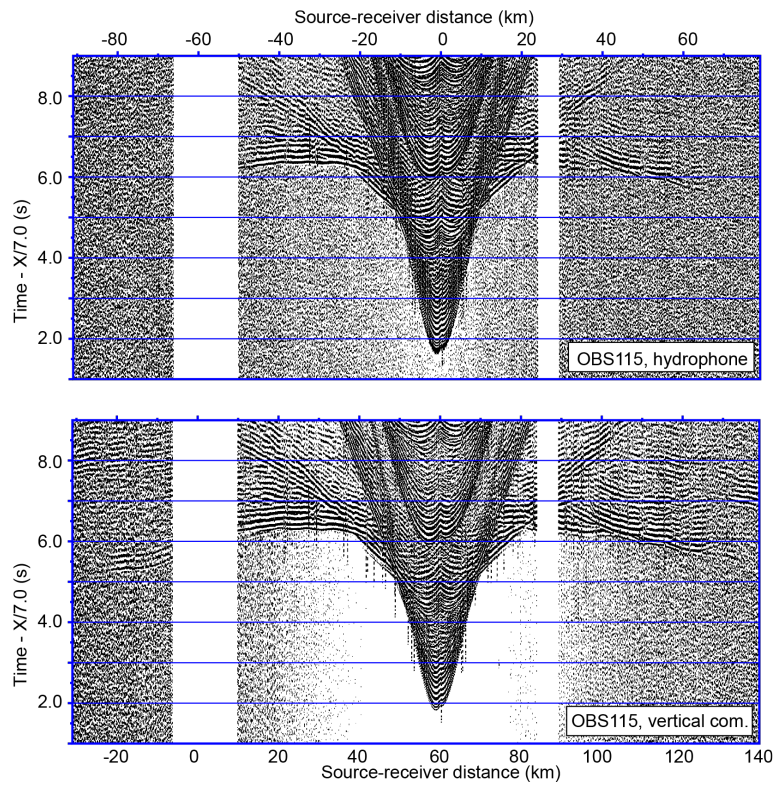
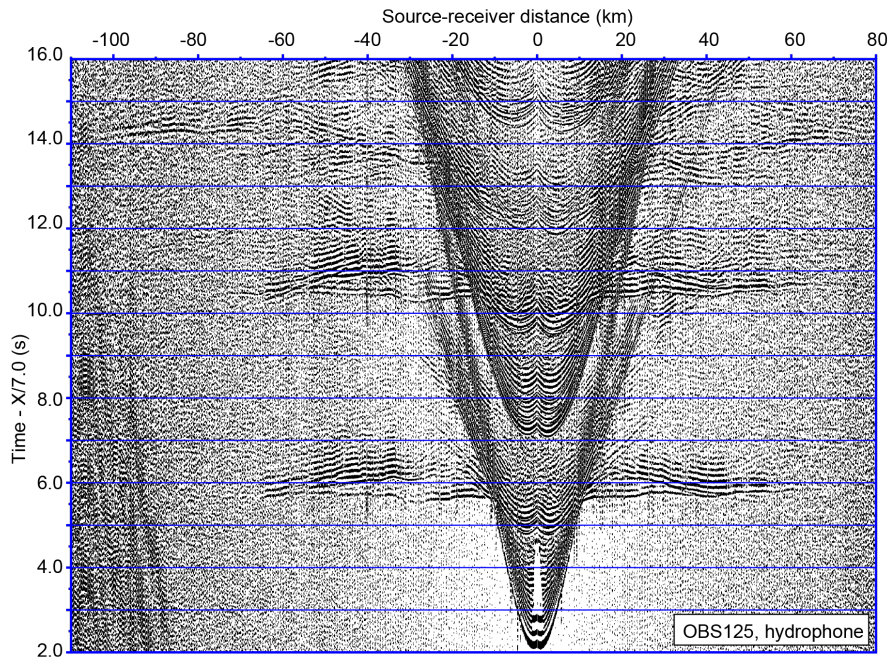


Figure 8.3. OBS records for site 115 were partially redacted. Hydrophone record (top) and vertical component (bottom).



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Figure 8.4 Record for OBS 125 to 16 seconds shows two sets of water multiples. Multiples often show strong refractions to larger offsets than primary arrivals.

Deployment 2:

The second OBS deployment consisted of 28 SIO OBSs and 11 WHOI OBSs, hence there were fewer WHOI instruments available than in the first deployment. These instruments on OBS Line 2 and Line 3 recorded five Orca segments, 4P1OBS3, 5P1TIE1, 6P1OBS2, 7P2OBS2 and 8P3OBS2 (see Table 6.1). While OBS line 3 and the tie line towards Line 2 were shot without problems, we twice serviced the Langseth acoustic array on Line 2.

The OBS data on Blake Plateau are good (Figure 8.5 to 8.9). The hydrophone channel usually records much better data here than the geophone, but there are exceptions. For example, OBS 215 (Figure 8.6) has excellent data on the vertical geophone. On Line 3 the data quality was equally high, and the fan shot data also show useful crustal and mantle seismic refractions at larger offsets.

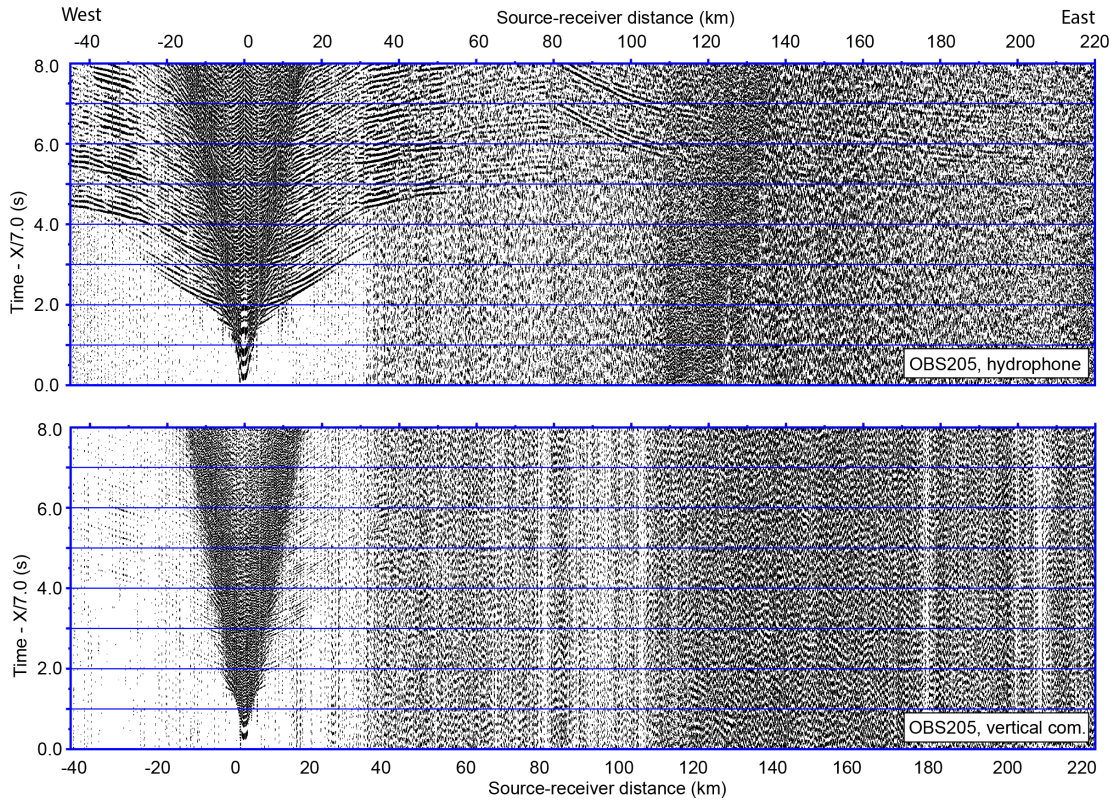


Figure 8.5. Data records from OBS 205, recording shots from line OBS2. Note that the geophone was not well coupled, and the vertical component data (bottom) are poor.

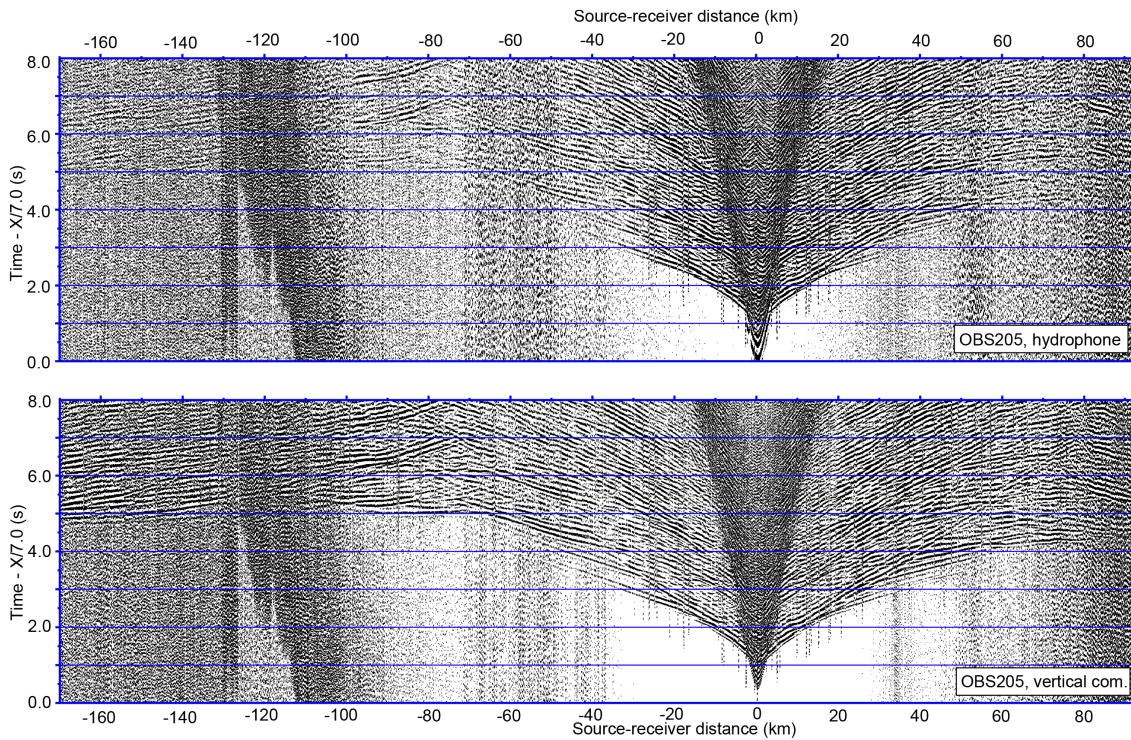


Figure 8.6. Data records from OBS 215, recording shots from line OBS2. Note that the vertical component data are better than the hydrophone shot for this station.

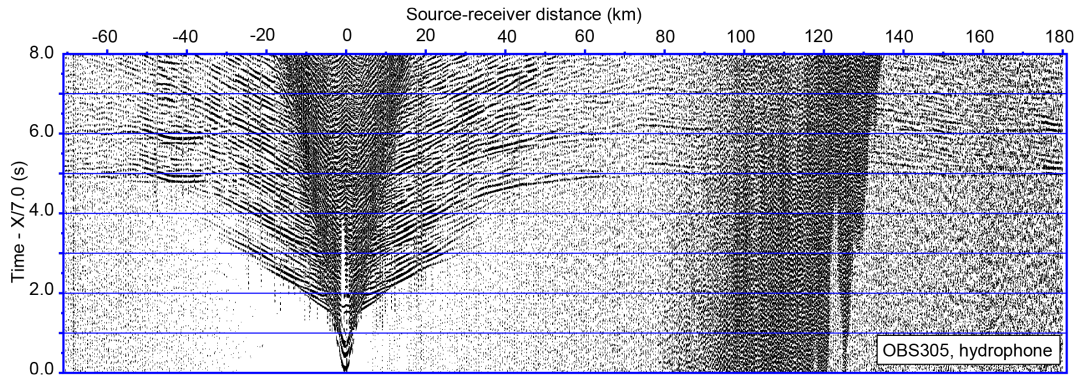


Figure 8.7. OBS 305 seismic refractions from the hydrophone channel.

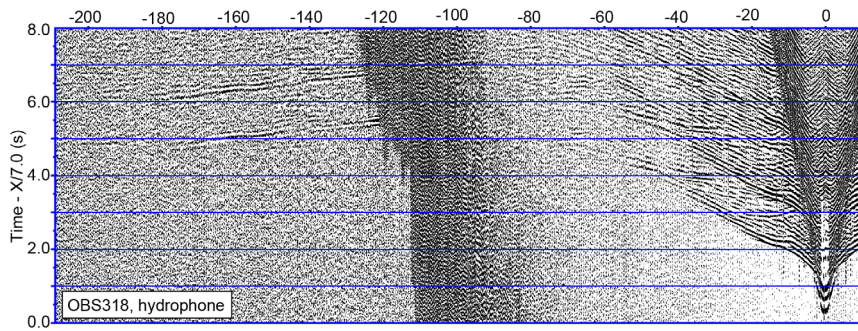


Figure 8.8. OBS 318 recorded shots along the length of Line 3.

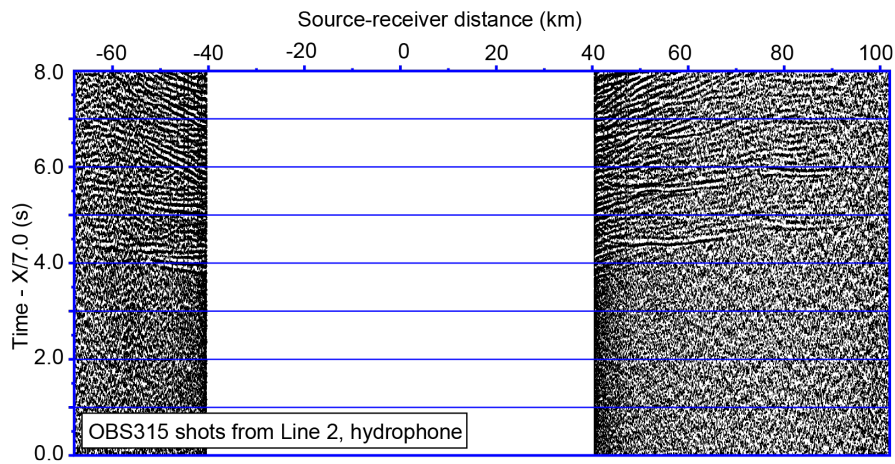


Figure 8.9. An example of OBS refraction data recorded in fan shot geometry. OBS 315 with shots from Line 2.

9. Cruise Participation

The seismic investigation of the Blake Plateau and the Carolina Trough is a collaboration of scientists at the University of Texas at Austin (PIs Harm Van Avendonk and Nathan Bangs) and Lamont-Doherty Earth Observatory PI Anne Bécel). In order to give interested early-career scientists and students from other institutions a chance to participate in the marine seismic cruises, we distributed an advertisement in the wider geophysics and marine geoscience communities. In this advertisement we invited candidates to apply to sail on either the OBS or MCS cruise. When we reviewed the CV and a statement of interest from the candidates, we selected participants based on their training in geophysics, scientific interest in this project, and the potential impact that this sea-going experience may have on their career. Three graduate students and two undergraduate students came on cruise MGL2310 through the call-to-sail program.

During the cruise, these students participated in regular watchstanding duties in the seismic lab. They helped with the deployment and recovery of the OBSs, and monitoring of the acoustic source during seismic shooting. Unfortunately, the new OBS refraction data were not available to the science party due to the navy redaction of these data. For most of these participants this cruise was the first experience at sea. During the cruise we divided the day in three 8-hour watches. This gave us continuity in the seismic lab. On several days we held a science meeting at 13:30 local, where we either discussed a relevant science paper.

At the end of the cruise, the participants shared some impressions:

“The cruise MGL2310 was an enriching research experience for me. The hands-on involvement provided a practical insight into marine research classrooms couldn't match. Unexpectedly, I learned the importance of teamwork and adaptability when unforeseen challenges arise at sea.”

“Participating in this cruise has been an enriching and fun learning experience for me, and it has the potential to impact my future research. Throughout the duration of the cruise, Dr. Van Avendonk led regular discussions centered around literature related to the studied region and the associated research topics, as well as the seismic and gravity data collected during the previous MCS cruise. These discussions have improved my understanding of the structure of rifted margins, the dynamics of the rifting system, and the approaches taken by geoscientists. Furthermore, I gained insights into the methodology of collecting active source OBS data, as well as the challenges and limitations involved in OBS deployment. As a geodynamics modeler, this experience has the potential to inspire me to study the rifting and explore the integration of marine seismic data into my research in the future.”

“This cruise was incredibly useful as a research experience. I learned how a research cruise operates with all of the stages and players, I learned how to use all kinds of equipment, and I made connections and gathered career and life advice from all of the different crews onboard. I gained hands-on experience assembling, disassembling, deploying, and recovering the OBSs with explanations from the OBS techs of all of the pieces and how everything works. The same goes for all kinds of equipment onboard when I followed crew members around, asking questions.”

10. Acknowledgments

We want to thank the captain, officers and crew for hosting the science party on the R/V *Marcus Langseth* for cruise MGL2310. They were very supportive of the research, a few times in challenging weather conditions. We are also grateful to the full team of technicians and mechanics on board for all the hard work on the acoustic array and seismic recording system. The OBSIC team, represented by Alan Gardner, Dan Kot, and UNOLS technician Nick Matthews, did a great job with the instrument deployments and recoveries, which often spanned several days. We also thank the protected species observers for their dedication to life in the waters around us. We would not be able to do our work without you. Last but not least we want to thank the students for their enthusiasm and curiosity for science.

This project was funded by the US National Science Foundation, Marine Geology and Geophysics Program.

Appendices.

Appendix A1. Protected species

The waters offshore the southeastern United States and the Bahamas are home to various species of whales and dolphins, sea turtles, several vulnerable fish species such as sturgeons, and sea birds. As a first measure to minimize the impact of our survey on protected species, we avoid the winter season, when marine mammals migrate through the study area. In addition, we avoided the coastal areas of Georgia and South Carolina with our seismic lines, a sensitive environment with several marine sanctuaries.

During the early planning of the *Langseth* OBS and MCS cruises in 2022, LDEO and NSF prepared an Environmental Assessment (AE) of the project. This AE described the seismic lines that we aimed to gather, the equipment that we would use, the sound levels that we would create in the water column, and the species that may be affected. Subsequently, NSF and LDEO applied for permits to conduct the marine seismic surveys following the process with the Endangered Species Acts (ESA) and Marine Mammal Protection Act (MMPA). Besides the National Marine Fisheries Service (NMFS), the states of Florida, South Carolina and Georgia were also consulted. NMFS issued the Incidental Harassment Authorization (IHA) for both the MGL2309 and MGL2310 cruise on July 10, 2023, well before the start of cruise MGL2309. The monitoring procedures of Protected Species Observers (PSOs) during the seismic cruise, the ramp-up and shutdown procedures for the Langseth's acoustic array, and the animal/vessel strike avoidance measures that were taken during the cruise are all consistent with the conditions stated in the IHA.

We received a permit to gather 950 km of marine seismic refraction data with 150 m shot spacing in an area marked by the green polygon in Figure 3.1B. During cruise MGL2310 we encountered relatively few protected species, and we never shut down for a nearby animal sighting.

In this Appendix we include a copy of the *Finding of No Significant Impact* (FONSI) statement from NSF, which succinctly lists the steps in the permitting process.

**National Science Foundation
Geosciences Directorate
Division of Ocean Sciences
Alexandria, Virginia**

**FINDING OF NO SIGNIFICANT IMPACT (FONSI)
PURSUANT TO THE NATIONAL ENVIRONMENTAL POLICY ACT (NEPA)
AND EXECUTIVE ORDER 12114
AND DECISION DOCUMENT (DD)**

**Marine Geophysical Research by R/V *Marcus G. Langseth*
of the Blake Plateau, Northwest Atlantic Ocean, 2023**

Award: OCE 2112597

Principal Investigators/Institution: Harm Van Avendonk, University of Texas, Austin

Co-Principal Investigator/Institution: Nathan Bangs, University of Texas, Austin

Award: OCE 2112598

Principal Investigator/Institution: Anne Becel, Columbia University, Lamont-Doherty Earth Observatory (LDEO)

Project Title: Rift dynamics during the formation of the Carolina Trough and Blake Plateau

A Final Environmental Assessment/Analysis (Final EA) was prepared for the above noted proposed research project funded by the National Science Foundation (NSF) (Proposed Action). The Proposed Action would involve marine geophysical surveys (or “seismic surveys”) and use of ocean bottom seismometers (OBSs) in the Northwest Atlantic Ocean within International Waters and the U.S. EEZ, but entirely outside of state waters. The Proposed Action would involve the Principal Investigators (PI) noted above, as well as academic participants and technical staff, including other collaborators not funded by NSF. The Proposed Action would involve R/V *Marcus G. Langseth* (*Langseth*) which is owned and operated by Columbia University’s Lamont-Doherty Earth Observatory (LDEO).

The Final EA entitled, “*Final Environmental Assessment/Analysis of Marine Geophysical Research of the Blake Plateau, Northwest Atlantic Ocean*” (Attachment 1) analyzed the potential impacts on the human and natural environment associated with the Proposed Action pursuant to the National Environmental Policy Act (NEPA) and Executive Order 12114, “Environmental Effects Abroad of Major Federal Actions” (EO 12114). The EA tiers to the Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement for Marine Seismic Research Funded by the National Science Foundation or Conducted by the U.S. Geological Survey (June 2011) and Record of Decision (June 2012), referred to herein as PEIS. This Finding of No Significant Impact/Decision Document (FONSI/DD) also incorporates by reference the analyses and conclusions set forth in the Incidental Harassment Authorization (IHA) and Biological Opinion (BiOp)/Incidental Take Statement (ITS) issued by the U.S. National Oceanic and Atmospheric Administration’s National Marine Fisheries Service (NMFS) for this Proposed Action. The conclusions from the Final EA, and other federal regulatory processes, were consistent with the conclusions of the PEIS and were used to inform the Division of Ocean Sciences (OCE) management of potential environmental impacts of the surveys. OCE has reviewed and concurs with the Final EA findings. The Final EA is incorporated into this FONSI/DD by reference as if fully set forth herein.

Project Objectives and Context

The primary goal of the seismic surveys is to investigate the structure and evolution of the rifted margins of the southeastern U.S., including the rift dynamics during the formation of the Carolina Trough and Blake

Plateau. By imaging the sediments and crystalline crust of the margins, the science team would better understand the interaction between tectonic and magmatic processes that led to continental breakup and the onset of seafloor spreading in the central Atlantic Ocean 200 million years ago. The researchers are particularly interested in the stratigraphy of sediments that formed during and after rifting, the degree of crustal stretching at the continental margins, crustal faults that formed during extension of the margin, and the geometry of lava flows that were placed on the crust before the start of seafloor spreading. To achieve the project's goals, the researchers would conduct seismic surveys utilizing the airgun capabilities of R/V *Langseth*, as well as OBSs. Representative seismic survey tracklines shown in Attachment 1, Figure ,1 were revised as clearance to operate within the EEZ of the Bahamas was not obtained. Revised tracklines are depicted below in Figure 1; however, as originally proposed, the tracklines could occur anywhere within the defined survey area (except within the EEZ of the Bahamas). Revisions to the tracklines did not change the anticipated impacts, including marine mammal take estimates, of the Proposed Action. No land-based activities are proposed.

Summary of Proposed Action and Alternatives

The procedures of the Proposed Action would be similar to those used during previous 2-D seismic surveys carried out by NSF and would use conventional seismic methodology. The seismic surveys would involve one source vessel, R/V *Langseth*, which would deploy an array of 36 airguns as an energy source with a total volume of approximately (~)6600 cubic inch (in³). The receiving system would consist of a 15-kilometer (km) hydrophone streamer and ~40 OBSs. The OBSs would be deployed and retrieved twice on different sections of the survey. As the airgun array is towed along the survey lines, the hydrophone streamer would receive the returning acoustic signals. In addition to the operations of the airgun array, other acoustic sources, including a multibeam echosounder (MBES), sub-bottom profiler (SBP), and an Acoustic Doppler Current Profiler (ADCP), would be operated continuously from R/V *Langseth* during the seismic surveys; acoustic pingers would also be used at times during the survey. The proposed seismic surveys would occur in water depths ranging from greater than (>)100–5200 m.

The proposed surveys would take place during summer or fall 2023 for a period of ~61 days, spread between two operational legs, with ~40 days of seismic operations. One leg would include ~32 days of MCS seismic operations and ~4 days of transit time, whereas the other leg would consist of ~8 days of seismic operations with OBSs, ~13 days of OBS deployment and retrieval, and 4 days of transit. Some deviation in the duration of the surveys and ports of call may be required, depending on logistics, weather, COVID-19, etc.; however, seismic survey operations would only occur in the area noted and timeframe allowable under the IHA and other relevant documentation.

Another alternative to conducting the Proposed Action would be the “No Action” alternative (i.e., the proposed research operations would not be conducted). The “No Action” alternative would result in no disturbance to marine species attributable to the Proposed Action, but geological data of scientific value and relevance increasing our understanding of the structure and evolution of the rifted margins of the southeastern U.S., and geohazards of submarine landslides, would not be collected. The purpose and need for the proposed activity would not be met through the “No Action” alternative.

Summary of environmental consequences

The Final EA includes analysis on the affected environment (Chapter III) and the potential effects of the Proposed Action on the environment (Chapter IV). Potential impacts of the Proposed Action on the environment would be primarily a result of the operation of the airgun array. The potential effects of sounds from airguns on marine species, including mammals and sea turtles of particular concern, are described in detail in Attachment 1 (Chapter IV and PEIS Chapters 3 & 4) and might include one or more of the

following: tolerance, masking of natural sounds, behavioral disturbance, and, at least in theory, temporary or permanent hearing impairment, or non-auditory physical or physiological effects. It is unlikely that the Proposed Action would result in any cases of temporary or especially permanent hearing impairment, or any significant non-auditory physical or physiological effects. Some behavioral disturbance is expected if animals are in the general area during seismic operations, but this would be localized, short-term, and involve limited numbers of animals. The potential effects from the other proposed acoustic sources were also considered; however, they would not be likely to have a significant effect on the environment (Attachment 1, Chapter IV; and PEIS Chapter 3). Generally, any bottom disturbances from OBS activities would be anticipated to be minor and temporary; although small OBS anchors would not be retrieved, they would degrade overtime.

The Proposed Action includes an extensive monitoring and mitigation program to minimize potential impacts on the environment. Mitigation efforts include pre-cruise planning activities and operational activities (Attachment 1, Chapters II and IV; and PEIS Section 2.4.1.1). Pre-cruise planning mitigation activities included consideration of energy source optimization/minimization; survey timing (i.e., environmental conditions: seasonal presence of animals and weather); and calculation of mitigation zones.

The operational mitigation program would further minimize potential impacts to marine species that may be present during the conduct of the proposed research to a level of insignificance. As detailed in Attachment 1 (Chapters II and IV), the IHA and BiOp/ITS issued by NMFS, the Proposed Action would include operational monitoring and mitigation measures, such as, but not limited to: visual observations; passive acoustic monitoring; enforcement of exclusion and buffer zones; pre-clearance, ramp-ups, shutdowns of the airguns; monitoring and reporting. The fact that the airgun array, as a result of its design, directs the majority of the energy downward, and less energy laterally, would also be an inherent mitigation measure. The acoustic source would also be powered down (or, if necessary, shut down) in the event Endangered Species Act (ESA)-listed sea turtles and seabirds (diving/foraging) were observed within a designated EZ. Observers (and vessel crew) would monitor for any impacts the acoustic sources may have on fish. Per the IHA, LDEO would also notify NMFS Southeast Regional Office via email the start and end date of seismic operations in the survey area. LDEO would follow additional monitoring and mitigation measures required by the IHA and BiOp for enhanced protections of North Atlantic right whale (e.g., limited timeframes for use of airguns and conducting specific tracklines; submission of daily reports during certain timeframes). LDEO and its contractors are committed to applying these measures in order to minimize any effects on marine mammals, sea turtles, seabirds, and fish, and other potential environmental impacts.

With the planned monitoring and mitigation measures, unavoidable impacts to marine species that could be encountered would be expected to be minimal, and limited to short-term, localized changes in behavior and distribution near the seismic vessel. At most, effects on marine mammals may be interpreted as falling within the U.S. Marine Mammal Protection Act (MMPA) definition of Level B Harassment for those species managed by NMFS. Although NSF calculated predicted distances to the Level A thresholds based on current NMFS Technical Acoustic Guidance¹, per the IHA, NMFS instead established a fixed operational 500 m exclusion zone and 1,000 m buffer zone for the surveys. In the IHA, NMFS also required an extended 1500-m EZ to be established for beaked whales, dwarf and pygmy sperm whales, a large whale with a calf, and groups of six or more large whales encountered during the survey effort. During operations, the IHA requirement (extended 1500-m EZ) would be followed for these special conditions and species. Per the IHA, the shutdown requirement would be waived for small dolphins including *Delphinus*,

¹ 2018 Revision to: Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0). Underwater thresholds for onset of permanent and temporary threshold shifts. Office of Protected Resources, NMFS, Silver Spring, MD.

Lagenodelphis, *Stenella*, *Steno*, and *Tursiops*. Level A takes were requested for the remote possibility of low-level physiological effects; however, because of the characteristics of the Proposed Action and proposed monitoring and mitigation measures, in addition to the general avoidance by marine mammals of loud sounds, Level A takes are considered highly unlikely. The predicted distances for the Level B zones are based on the 160 dB re 1 μ Pa SPL isopleth, per current NMFS approach on Level B harassment.

Mitigation, monitoring, and reporting requirements were incorporated into the Final EA, the FONSI/DD, and/or the LDEO Science Support Plan; protected species observers (PSOs) would take the lead in ensuring compliance with all monitoring and mitigation measures. NMFS included vessel strike avoidance measures in the IHA; however, as noted in the Final EA, R/V *Langseth* (and other vessels in the U.S. Academic Research Fleet) have no history of marine mammal strikes. No long-term or significant effects from the Proposed Action would be expected on individual marine mammals, sea turtles, seabirds, fish, the populations to which they belong, or their habitats.

The results of the cumulative impacts analysis in the PEIS indicated that there would not be any significant cumulative effects to marine resources from the proposed NSF-funded marine seismic research, including the combined use of airguns and other acoustic sources (e.g., multibeam echosounders, etc.). However, the PEIS also stated that cruise-specific cumulative effects analysis would be conducted, “allowing for the identification of other potential activities in the area of the proposed seismic surveys that may result in cumulative impacts to environmental resources.” The potential cumulative effects of the Proposed Action were evaluated in Section 4.1.6 of the Final EA. Due to the location of the Proposed Action, activities in the area around the survey vessel would be anticipated to include other research, military, offshore energy development, vessel traffic, fisheries, and whale watching activities. Although there are a number of shore-accessible SCUBA diving sites off the southeastern U.S. (Final EA, Section 3.8), the proposed activities would occur in water depths >100 m, outside the range for typical recreational SCUBA diving. Most whale watching activities are conducted close to the coast. Given the distance from shore to the survey area, the likely distance from any marine mammal watching activities, and the short and temporary duration of the surveys, it would be unlikely that the marine mammal watching industry would be affected by the Proposed Action. Fisheries activities would not be precluded in the survey area; however, a safe distance would need to be kept from R/V *Langseth* to avoid possible entanglement with the towed airgun array and OBS activities. No fish kills or injuries were observed during any previous NSF-funded seismic survey activities. NSF coordinated the Proposed Action with the US Navy. Any potential conflicts with ocean users would be avoided through Notice to Mariners and direct radio communications during the surveys. Considering the limited time that the planned seismic surveys would take place close to shore, the brief period of operations, and the temporary nature of potential environmental impacts, the proposed project is not expected to have any significant impacts on other activities in the area.

The “No Action” alternative would remove the potential for the limited direct and indirect environmental consequences as described above. However, the “No Action” alternative would preclude important scientific research from going forward that would provide information on the structure and evolution of the rifted margins of the southeastern U.S. and new constraints for examining tsunami hazards associated with submarine landslides. The “No Action” alternative would result in a lost opportunity to obtain important scientific data and knowledge relevant to the geosciences and to society in general. The collaboration, involving academic researchers, students, and collaborators would be lost, as would the opportunity to collect and interpret new data and provide new results to the greater scientific community. Loss of NSF support often represents a significant negative impact to the academic infrastructure, including the professional and academic careers of the researchers, students, ship technicians and crew who are part of the U.S. Academic Research Fleet. The “No Action” alternative would not meet the purpose and need of the Proposed Action.

Coordination with Other Agencies and Processes

Based on discussions with NMFS during MMPA and ESA processes, minor refinements to the information provided in the Draft EA were made. The new information, which was included in the Final EA, did not

alter the overall conclusions of the Draft EA and remained consistent with the PEIS. NSF coordinated with NMFS to complete the Final EA prior to issuance of the IHA and BiOp/ITS.

Compliance with other federal statutes and regulatory processes are summarized below and in further detail in the Final EA, Section 4.1.8.

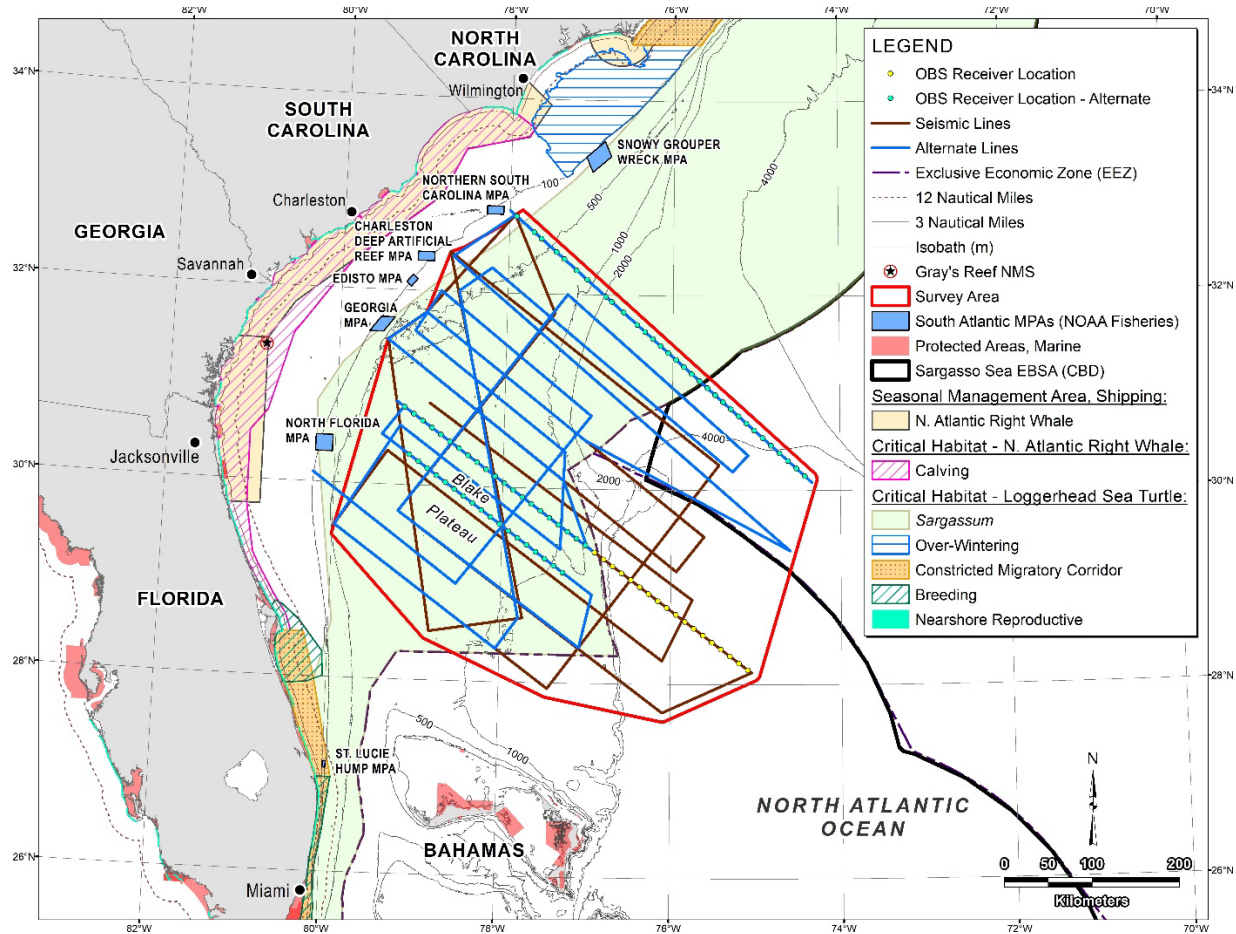


Figure A1-1. Location of the proposed seismic surveys (blue alternate lines), OBS deployments, marine conservation areas, and marine critical habitat in the Northwest Atlantic Ocean. Representative survey tracklines are included in the figure; however, the tracklines could occur anywhere within the survey area (outside of the EEZ of the Bahamas). MPA = marine protected area; NMS = National Marine Sanctuary; EBSA = Ecologically or Biologically Significant Marine Areas.
 CBD = Convention on Biological Diversity.

(a) Endangered Species Act (ESA)

On 17 November 2022, NSF submitted a formal ESA Section 7 consultation request, including the Draft EA, to NMFS for the proposed activity. On 10 July 2023, NMFS issued a BiOp and ITS (Attachment 2).

(b) Marine Mammal Protection Act (MMPA)

On 22 November 2022, on behalf of the action proponents, including NSF, LDEO submitted to NMFS an IHA application pursuant to the U.S. MMPA for “taking by harassment” (disturbance) of small numbers of marine mammals during the proposed seismic surveys. On 7 June 2023, NMFS issued in the Federal Register a notice of intent to issue an IHA for the surveys and a 30-day public comment period. NMFS

issued an IHA for the proposed activity on 10 July 2023 (Attachment 3).

(c) Essential Fish Habitat (EFH) (Magnuson-Stevens Act)

NSF submitted an EFH consultation request on 26 January 2023 to NMFS. On 17 February 2023, NMFS responded noting any effects on EFH from the proposed surveys would be minimal, and accordingly, provided no EFH conservation recommendations for the Proposed Action.

(d) Coastal Zone Management Act (CZMA)

NSF submitted a negative determination pursuant to Subpart C of the CZMA to the State of Georgia on 17 February 2023, and to the State of South Carolina on 3 March 2023. On 6 March, the State of Georgia agreed the proposed action was consistent with the applicable enforceable policies of the Georgia Coastal Management Program and concurred with NSF's negative determination (Appendix E). Although the State of South Carolina confirmed receipt of the negative determination, no further response was received by NSF; therefore, NSF presumed concurrence on 2 May 2023 after 60 days. On 24 January 2023, an email was sent to the State of Florida requesting identification of any applicable enforceable policies; NSF received a response from the State of Florida Department of Environmental Protection on 25 January 2023 noting the state did not select the project for review and the project may proceed (Appendix E).

Conclusion and Decision

NSF has reviewed and concurs with the conclusions of the Final EA (Attachment 1) that implementation of the Proposed Action will not have a significant impact on the environment. Consequently, implementation of the Proposed Action will not have a significant direct, indirect or cumulative impact on the environment within the meaning of NEPA or EO 12114. Because no significant environmental impacts will result from implementing the Proposed Action, an environmental impact statement is not required and will not be prepared. Therefore, no further study under NEPA or EO 12114 is required. As described above, NSF's compliance with the ESA, MMPA, EFH, and CZMA is completed.

In sum, NSF concludes that implementation of the Proposed Action will not result in significant impacts after full consideration of the Final EA; the PEIS; the IHA and BiOp/ITS issued by NMFS; and the entire environmental compliance record. Accordingly, on behalf of NSF, I authorize the issuance of a Finding of No Significant Impact for the Proposed Action, the marine geophysical research and OBSs proposed to be conducted on board Research Vessel *Marcus G. Langseth* in the Northwest Atlantic Ocean, during the effective time period of the IHA, and hereby approve the Proposed Action to commence.



07/11/23

James McManus
Division Director
Division of Ocean Sciences

Date

Attachment 1: Final Environmental Assessment/Analysis of Marine Geophysical Research of the Blake Plateau, Northwest Atlantic Ocean. Attachment 2: NMFS Biological Opinion/Incidental Take Statement Attachment 3: NMFS Incidental Harassment Authorization

Appendix A2. Ocean-bottom seismometers

Description WHOI D2 OBS:

The WHOI D2 ocean-bottom seismograph is a compact, lightweight system, which allows recording of three components of ground motion and one pressure channel at sample rates up to 200 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 lbs in air.

The upper glass ball (17" diameter) contains a Quanterra signal-processing unit (Q330), a Quanterra data recording unit (Baler 14) containing a 64 GB solid state drive and an Ethernet hub, an EdgeTech acoustic release board, GPS antenna, recovery aids, and custom electronics. A Seascan clock located on a circuit board provides reasonably stable time for the duration of the deployment. Recovery aids include four LED flashers and a LoRa transmitter which sends GPS coordinates to a base station on the ship at approximately 900 MHz. The Q330 includes a low-power analog-to-digital converter with 140 dB dynamic range, digital filters, clock, and 8 megabytes of RAM. Engineering data and the four seismic channels are continuously digitized to RAM, and intermittently logged to the solid-state drive in miniSEED format. For this experiment we used a sample rate on all seismic channels of 200Hz. In the lower glass ball (12" diameter) are battery packs comprised of lithium cells that supply power separately to the Q330, the recovery aids, and to the EdgeTech release board. An external Ethernet connection can be used to change and program the operating software and to recover data from the hard drive.

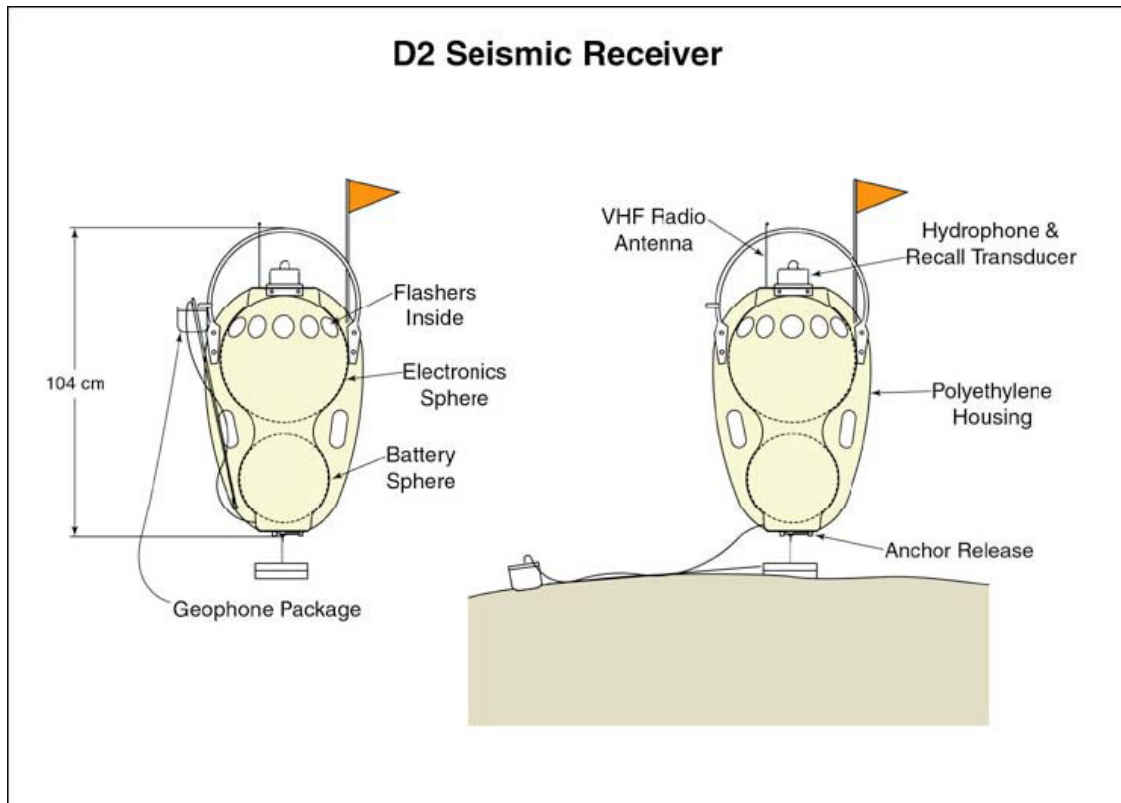


Figure A2.1. Schematic drawing of a D2 four-component ocean-bottom seismometer from WHOI.

The external plastic case provides protection for the glass balls and structural rigidity. A free-flooded-ring ceramic acoustic transducer is attached to the upper cover of the case. Next to the transducer is a HighTech model HTI-90-U hydrophone. Three orthogonally mounted 4.5 Hz geophones are mounted in a

5" diameter (5.5" high) titanium case, 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. A bail on the seismometer case is hooked to the top of a 23" long fiberglass deployment arm. The bottom of the arm is attached to the base of the plastic housing by a hinge. The top of the arm is attached to the plastic housing by a galvanic link that dissolves in seawater after 2 to 6 hours. When the link dissolves, gravity carries the sensor can out and away from the D2. The sensor can slip from the end of the arm, which is then pulled up and away from the can by a bungee cord.

The D2 has ~25 lb of buoyancy. A 55 lbs steel plate anchor (6"x15"x2") keeps the D2 on the ocean floor, attached to the D2 by a 9" length of stainless steel wire rope. A 2" diameter ring at the end of the wire rope is held to the D2 by a lever arm on the bottom of the D2. 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 from the ship to the EdgeTech transponder. When the burn wire is severed, the lever arm swings down, releasing the ring, wire rope, and anchor, allowing the D2 to return to the surface.

The LCHEAPO short-period ocean bottom seismometer of SIO

LC4x4 OBS System Description

The LC4x4-SP is an ocean-bottom instrument designed for use in seismic experiments that use either passive sources (e.g., earthquakes) or active sources (e.g. seismic air-gun surveys) to generate signals. The general characteristics of the Low-Cost Hardware for Earth Applications and Physical Oceanography (LCHEAPO) instruments include:

- 24-bit analog-to-digital converter
- precision time base
- large capacity solid-state memory
- EdgeTech independent acoustics
- 3-axis 4.5 Hz geophone (active/microseismicity)
- hydrophone (active/microseismicity)

A frame composed primarily of polyethylene holds the instrument together. Tubes in the frame are used to hold pressure cases for the acoustics package and for the data logger itself. A float assembly is attached to the frame (yellow hardhats) and includes brackets for mounting a flag, radio, and a strobe light to aid in locating the instrument on the sea surface for recovery. For scale, the dimension of the SP (short-period) unit is roughly 1 meter cubed.

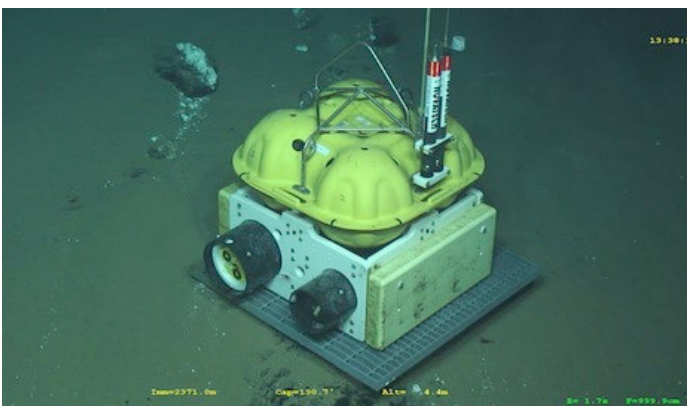


Figure A2.2. A) A LCHEAPO four-component short-period OBS on the seafloor. B) Instruments stacked on the back deck of the R/V *New Horizon*.

The acoustic release transponder package includes the electronics for operating the burn wire release assembly, which is mounted in the bottom center of the frame and connects the instrument to an anchor that consists principally of a large piece of steel grating (~1 square meter). The data logger pressure case contains all the electronics required to digitize the sensor outputs and record the data on compact flash card storage. For the SP (short-period) unit the seismometer is housed in its own pressure case and the hydrophone is encapsulated in neoprene, both of which are mounted in the center of the frame. All configurations can store enough primary cell lithium batteries for deployment durations exceeding 1 year.

LC4x4 short-period OBS detail

The SIO short-period/active-source instruments feature a 4-component (3-axis geophone and hydrophone) system designed to be compact and easy to use for experiments requiring large numbers of instruments and/or rapid response. Characteristics of the LC2000 short-period OBS instruments are listed in Table 1. With dual teams checking out data logger electronics and assembling the anchor-frame-float modules, instruments can be prepared for deployment within 15-20 minutes. A concise checklist is used for each instrument deployment that records critical deployment parameters such as position, time, recording window, sample rates, and clock drift measurements. Complete turnaround can be accomplished within 45 minutes to an hour. This ease of use and set-up is vitally important in large-scale, multi-deployment experiments where ship time is limited.

Upon recovery, data offload can be done quickly and efficiently on the boat after the instrument is on deck. Raw data is transferred from CF cards to an external storage device giving a working backup of all data. Continuous time series data for all channels is then converted to mSEED format. All A/D time delays and oscillator drift corrections are applied to the data during this data conversion procedure. SQLite database files are also produced outlining detailed information of all deployments parameters (lat/long locations, drift corrections, A/D delay, instrument serial and component numbers, etc.).

Table A2.1: Characteristics of the SIO OBS.

Physical Design	One 7" diameter, 31" long Al cylinder holds data logger system and main battery housing. A 4.5" diameter, 19" long Al cylinder contains EdgeTech acoustic release system. Pressure cases, sensors, and 12" glass ball floats are housed in a modular frame assembly. For broadband configuration an additional 31" Al pressure case is used to house batteries. Separate batteries power the acoustic release.
Data Logger	LC4x4 24-bit A/D. Dynamic range at 31.25 Hz is 130 dB and at 250 Hz is 124 dB. The 4x4 design will include the new Cirrus/Crystal chip with programmable sample rates from 4 KHz to 1 Hz.
Active Sensors	Each LC4x4 includes a 4.5 Hz, 3-component Sercel L-28 geophone housed in its own pressure vessel, and mounted on a two-axis gimbal system that allows the seismometer to level itself regardless of the tilt of the pressure housing. Optionally a Sercel L-22 2-Hz vertical component seismometer can be accommodated.
Clock	Seascan low-power, digitally-temperature-compensated (DTCXO), precision time base. Drift rate is $1:3-5 \times 10^{-8}$ (~3-5 ms/day before correction and <0.1 s/yr after correction)
Pressure Sensors	Active/Microseismicity: HiTech HTI-90-U hydrophone with internal preamp. Bandwidth (-3 dB) is 50 mHz - 15 kHz. Passive: Differential Pressure Gauge (DPG) with flat response from 10 mHz - 10 Hz.
Release	EdgeTech acoustic communication (customized layout for each group) with burn wire release

Appendix A3. Performance of air-gun array

Line OBS1

Sequence 1: 1PRE1

- Started 8/26/2023, 13:29.
- Shots 104-143. 36 guns, 6600 in³.
- Test line, completed on 8/26/2023, 14:14.

Sequence 2: 1OBS1:

- Started 8/26, 14:32.
- Shots 1001-2287. 36 guns, 6600 in³.
- Ended with air leak, string 3, gun 1. On 8/27/2023, 15:14.

Sequence 3: 2OBS1

- Started line on 8/27/2023, 21:52.
- Shots 2273-3993. 36 guns, 6600 in³.
- Compressor problem, shots 3223-3226 missing, 3219-3222 low pressure.
- Completed Line OBS1 on 8/29/2023 at 04:00.

Line OBS3

Sequence 4: 1OBS3

- Started line on 9/7/2023, 14:56.
- Shots 5016-5162. 36 guns, 6600 in³. String 3, gun 7 disabled after shot 5162.
- Shots 5163-6700. 35 guns, 6540 in³.
- Completed Line OBS3 on 9/8/2023, 21:04.

Line TIE

Sequence 5: 1TIE1

- Started line on 9/8/2023, 21:28.
- Shots 10015-10266. 35 guns, 6540 in³.
- Completed Line TIE on 9/9/2023, 1:35.

Line OBS2

Sequence 6: 1OBS2

- Started line on 9/9/2023, 01:58.
- Shots 12000-13163. 35 guns, 6540 in³. string 3, gun 7 disabled
- Compressor problems 13164-13278.
- End of line due to compressor issue. 9/10/2023, 2:09

Sequence 7: 2OBS2

- Started the line on 9/10/2023, 04:10.
- Shots 13258-13480. 35 guns, 6540 in³. string 3, gun 7 disabled
- Shots 13481-13534. String 4, gun 4 auto-firing, 180 in³.
- End of line due to auto-firing. 9/10/2023, 7:51

Sequence 8: 3OBS2

- Started the line on 9/10/2023, 13:50.
- Shots 13455-13557. 36 guns, 6600 in³. String 2, gun 2 disabled after shot 13557.
- Shots 13558-13901, completed Line OBS2 on 9/10/2023, 21:23.

Appendix A4. Serial data

During surveys, the R/V *Marcus Langseth* continuously records navigation, weather data, oceanographic and geophysical data. The serial data streams are made available continuously to the science party. LDEO science tech Gilles Guerin maintained a file in csv format where these data streams were merged at 10 seconds and one-minute intervals. These files are named MGL2309_serial_data_1min.csv and MGL2309_10sec.csv, respectively. We used this record extensively to track our progress, to process gravity and magnetic field data, and to update our data acquisition maps.

Data fields in merged serial data are: Julian Day, Date, Time (UTC), Latitude, Longitude, Ship Heading, Ship Speed, Wind Speed, Wind Direction, Depth, Magnetic Field Magnitude, Gravity, Sea Temperature, Salinity, Sound Velocity, Air Temperature, Speed through Water, Course over Ground, Air Pressure,

Below we summarize the format of various time series data sets that we used during cruise MGL2309, and that form the basis of the merged serial data output. This is not a complete list of all time series and data types that are made available

Navigation.

CNAV 3050 outputs data in NMEA 0183 compatible format at a 1-second interval. This includes the GPVTG (GPS velocity, track made good and ground speed data) and GPGGA (Global Positioning System fix data).

File format : MGL-cnav.y***d**

*\$GPVTG, xxx.x, T, M, m.mm, N, n.nn, K*hh*

xxx.x course over the ground COG). Degrees from true North.

T Flag course relative to North

M Degrees from magnetic North.

m.mm SOG, nautical miles per hour, knots.

N Flag that speed is in knots.

n.nn SOG in km/h.

K Flag speed in km/h.

*\$GPGGA, hhmmss.ss, ddm. mmmmm, a, ddm. mmmmm, a, x, xx, x.x, xx.xx, M, xx.xx, M, x.x, xyy*hh*

hhmmss.ss UTC time of position

ddm. mmmmm Latitude

a Flag N/S

ddm. mmmmm Longitude

a Flag E/W

x Flag GPS quality (0=bad)

xx Number of satellites

POS/MV Position and Heading

POS/MV outputs data using the NMEA 0183 format at rates of up to fifty sentences per second. The following seven different sentence formats are available.

\$INGGA-Global System Position Fix Data

\$INHDT-Heading - True data

\$INVTG-Course over ground and Ground speed data

\$INGST-GPS pseudorange noise statistics

\$PRDID-Attitude data

\$INZDA-Time and date.

File format : MGL-posmv.y***d**

*\$INGGA, hhmmss.sss, llll.llll, a, yyyy.yyyy, b, t, nn, v.v, x.x, M,,c.c,rrrr*hh*
hhmmss.sss UTC time of position
llll.llll Latitude
a Flag North or South
yyyy.yyyy Longitude
b Flag East or West
t GPS quality factor
nn Number of satellites in fix

*\$INHDT, x.x, T*hh*
x.x True vessel heading in vessel frame (degrees)

*\$INVTG, x.x, T, M, n.n, N, k.k, K*hh*
x.x True vessel track in frame (degrees)
n.n Speed (knots)

*\$INZDA, hhmmss.ss, DD, MM, YYYY,, *hh*
hhmmss.ss GPS time
DD Day of month
MM Month
YYYY Year

Bathymetry.

The center beam depth is extracted from the Kongsberg EM122 multibeam data.

File format: MGL---bath02.y****d***

*bath02 2015:233:00:14:27.1279 \$KIDPT,4840.83,5.60,12000.0*73*
bath02 yyyy:ddd:hh:mm:ss.ssss \$KIDPT,xxxx.xx,z.zz,rrrr.r##*
xxxx.xx Seafloor bottom depth from transducer face.

Magnetics.

The G-822 Cesium Marine Magnetometer converts the cesium Larmor signal (70 kHz to 350 kHz) into magnetic field strength in nano-Tesla (20,000 nT to 100,000 nT) by using a CM-221 counter module.

File name: MGL---mag01.y****d***

mag012015:114:00:17:32.7965 \$ 49034.313,0781,0876
mag01yyyy:ddd:hh:mm:ss.ssss \$ xxxxx.xxx,aaaa,bbbb
xxxx.xxx Magnetic Field Strength (nano Teslas)

Gravity.

Gravity data are recorded continuously on the R/V *Marcus Langseth* with a Bell Aerospace BGM-3 gravimeter. Gravity measurements are logged as counts at a 1 second interval in the raw serial data. There is no manual on the Langseth for the conversion of raw gravity counts to SI units.

File format: MGL-vc01.y****.d***

vc01 2015:234:00:00:53.7862 04:024326 00
vc01 yyyy:ddd:hh:mm:ss.ssss xx:yyyyyy ff
xx Output frequency
yyyyyy Raw gravity counts

Water temperature and salinity

The Thermosalinograph data from the Seabird Electronics SBE-45 integrated temperature and conductivity unit is output in the following sentence formats that includes the Seabird SBE-38 Remote Temperature Sensor located at the Uncontaminated Seawater System intake in the bow of the RV *Marcus G. Langseth*.

File format: *MGL---tsgraw.y****d****

tsgraw 2015:234:00:04:28.6392 t1=27.7779, c1= 5.75784, s=36.1196, sv=1541.693, t2=27.6301
tsgraw yyyy:ddd:hh:mm:ss.ssss t1= tt.tttt, c1=cc.ccccc, s= ss.ssss, sv=vvvv.vvv, t2=tt.tttt

<i>t1</i>	Temperature from SBE 45 – TSG
<i>c1</i>	Conductivity (S/m)
<i>s</i>	Inferred salinity (psu)
<i>sv</i>	Inferred acoustic wavespeed (m/s)

Weather

The meteorological data from the Vaisala WXT-520 integrated weather station includes wind speed and direction, air temperature, humidity, pressure, and precipitation.

File format: *MGL-vaisala1.y****.d****

\$WIXDR,A,105,D,0,A,105,D,1,A,105,D,2,S,3.7,N,0,S,3.8,N,1,S,3.9,N,2,C,27.2,C,0,C,28.4,C,1,H,70.5,P,0,
*P,1 013.5,H,0,V,0.00,M,0,Z,0,s,0,R,0.0,M,0,V,0.0,M,1,Z,0,s,1,R,0.0,M,1,R,1.7,M,2,R,0.0,M,3*6D*
\$WIXDR,A,xxx,D,0,A,xxx,D,1,A,xxx,D,2,S,x.x,N,0,S,x.x,N,1,S,x.x,N,2,C,xx.x,C,0,C,xx.x,C,1,H,xx.x,P,0,P,x
*x xx.x,H,0,V,x.xx,M,0,Z,0,s,0,R,x.x,M,0,V,x.x,M,1,Z,0,s,1,R,x.x,M,1,R,x.x,M,2,R,x.x,M,3*6D*

<i>x.x</i> (following second S):	Average wind speed (knots)
<i>xx.x</i> (following C):	Temperature (°C).

Appendix A5. Multibeam Bathymetry and Knudsen 3.5 KHz acquisition

Multibeam data acquisition: Bathymetric data acquisition was performed using a Kongsberg EM-122 multibeam echosounder system (Figure A4.1), with control and monitoring facilitated by the Kongsberg SIS (Seafloor Information System) acquisition software on board the R/V *Marcus Langseth*. The system comprises hull-mounted transducer arrays, including a transmit unit ($150^\circ \times 1^\circ$) positioned along the ship's central axis, emitting signals at a frequency of 12.0 kHz. The receive unit ($1^\circ \times 30^\circ$) is located aft of the transmit unit, oriented athwart-ships.

Multibeam data acquisition was used during cruise MGL2310. However, we turned off the sonars during the recovery of ocean-bottom seismometers, so we would not interfere with signals to and from the acoustic release. In addition, we lost the multibeam on September 4, when two circuit boards burned. Fortunately, the three OBS lines were well surveyed during cruise MGL2309.



Figure A4.1. Kongsberg EM122 transmit (EM122 Tx) and receiver (EM122 Rx).

Knudsen 3.5 kHz deata acquisition

The Knudsen sub-bottom imaging system was active during much of the cruise. During OBS recoveries the subbottom profiler was shut off to avoid interference with the acoustic releases. We also shut down the Knudsen system in the Extended Economic Zone of the Bahamas, but we recorded data in US and international waters. The incoming data were stored in segy, kea and keb formats in the raw data folder of cruise MGL2310. The Knudsen data show very shallow sediment structure along our track lines. The 3.5 kHz data did not play a role in the objectives of the marine seismic cruise, but they may be valuable to other scientists that want to integrate them with the seismic reflection profiles and bathymetric data from cruise MGL2309.

Appendix A6. Gravity and magnetics

On board the R/V *Marcus Langseth* we gathered continuous gravity data with the Bell Aerospace BGM-3 gravimeter. The raw data were stored with a 1.0 s rate in the serial data files MGL-vc01.y****d*** (for formats, see Appendix A7). Towed magnetic data were gathered during seismic data acquisition on the R/V *Marcus Langseth* with a Geometrics G-882 Cesium marine magnetometer. These data were stored at a 0.1 s rate in the serial data files MGL-mag01.y****d***. Both data streams were also concatenated in the merged serial data streams at 10 s and one-minute intervals.

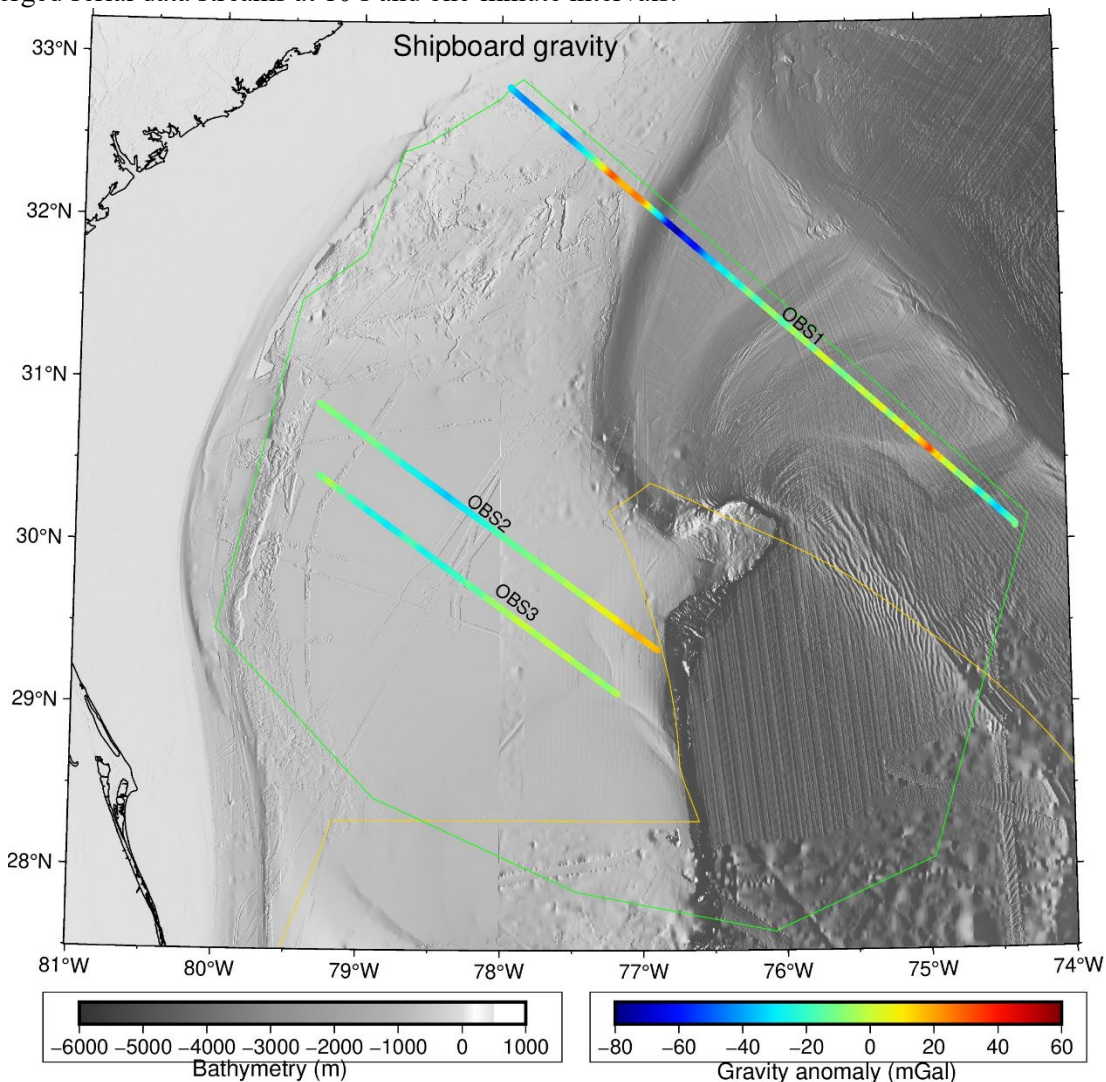


Figure A6.1. Processed gravity profiles along the three OBS Lines.

Corrections and Filtering

During cruise MGL2309 we used the *MGL2309_serial_data_1min.csv* merged serial file to extract the time series for bathymetry, gravity, and magnetics data, but also the ship's latitude and heading. The gravity, magnetics, and bathymetry time series had a few gaps.

To remove high-frequency noise we applied a Gaussian filter to the gravity data in the time domain with a 2-hour length. Next, we applied a Eotvos correction, using the ship's speed and heading, and calculated

gravity anomalies by subtracting the International Gravity Formula (IGF). The international gravity formula (Eq. 1) and Eotvos effect (Eq. 2) were calculated for all latitudes in our survey area.

$$IG(\varnothing) = 978032.7 (1 + 0.0053024 \sin^2(\varnothing) - 0.0000058 \sin^2(2\varnothing)) \text{ mGal} \quad (1)$$

$$Et = 7.5038 \times sp \times \sin(hd) \times \cos(\varnothing) + 0.004154 \times sp \quad (2)$$

Here \varnothing is the latitude in decimal degrees, **sp** is the ship's speed in knots per second (Kts), and **hd** is the ship's heading in degrees. The corrected free-air gravity anomaly was then calculated using Eq. 3.

$$\text{Free - air gravity anomaly} = \text{measured gravity} - IG + Et \quad (3)$$

For the Langseth's shipboard magnetic data, we subtracted the International Geomagnetic Reference Field (IGRF) to obtain magnetic anomalies. The magnetic anomaly was then calculated through Eq. 4

$$\text{Magnetic anomaly} = \text{measured intensity} - \text{total intensity} \quad (4)$$

Results

We gathered gravity and magnetic data on all three OBS transects (Figure A5.1). Gravity measurements were made continuously between Port Canaveral and Charleston. The seaward portion of Line 2 was important, because we did not get reliable shipboard gravity data here during cruise MGL2309. The magnetometer was deployed during OBS shooting. However, the magnetometer failed halfway during the last OBS line shoot.

We compare the shipboard bathymetry (Appendix A5), gravity (Figure A6.1) and magnetic (Figure A6.2) data gathered along the three MGL2310 OBS lines with global compilations. For bathymetry we use the Global Multi-Resolution Topography (GMRT) grid, version 4.1; the magnetic data we compare with the Earth Magnetic Anomaly Grid, 2-arc minute resolution (EMAG2, version 3) (Meyer et al., 2017); gridded gravity data are from Cryo-Sat-2 and Jason-1 (Sandwell et al., 2014).

Our profiles (Figure A6.3) show consistent misfit patterns between the shipboard gravity, magnetic and bathymetry data and gridded data. The bathymetry data fit very well. The shipboard gravity data generally fits the Sandwell et al. (2014) compilation well too. The shipboard magnetic data show much more pronounced magnetic anomalies than in the gridded data. For example, we found a much larger negative Brunswick anomaly (-500-300 nT), and a more positive magnetic anomaly at the eastern Blake Plateau (150-200 nT).

References for Appendix A6.

Meyer, B., Chulliat, A., & Saltus, R. (2017). Derivation and Error Analysis of the Earth Magnetic Anomaly Grid at 2 arc min Resolution Version 3 (EMAG2v3): EMAG2 version 3. *Geochemistry, Geophysics, Geosystems*, 18(12), 4522–4537. <https://doi.org/10.1002/2017GC007280>

Sandwell, D. T., Müller, R. D., Smith, W. H. F., Garcia, E., & Francis, R. (2014). New global marine gravity model from CryoSat-2 and Jason-1 reveals buried tectonic structure. *Science*, 346, 65–67. <https://doi.org/10.1126/science.1258213>

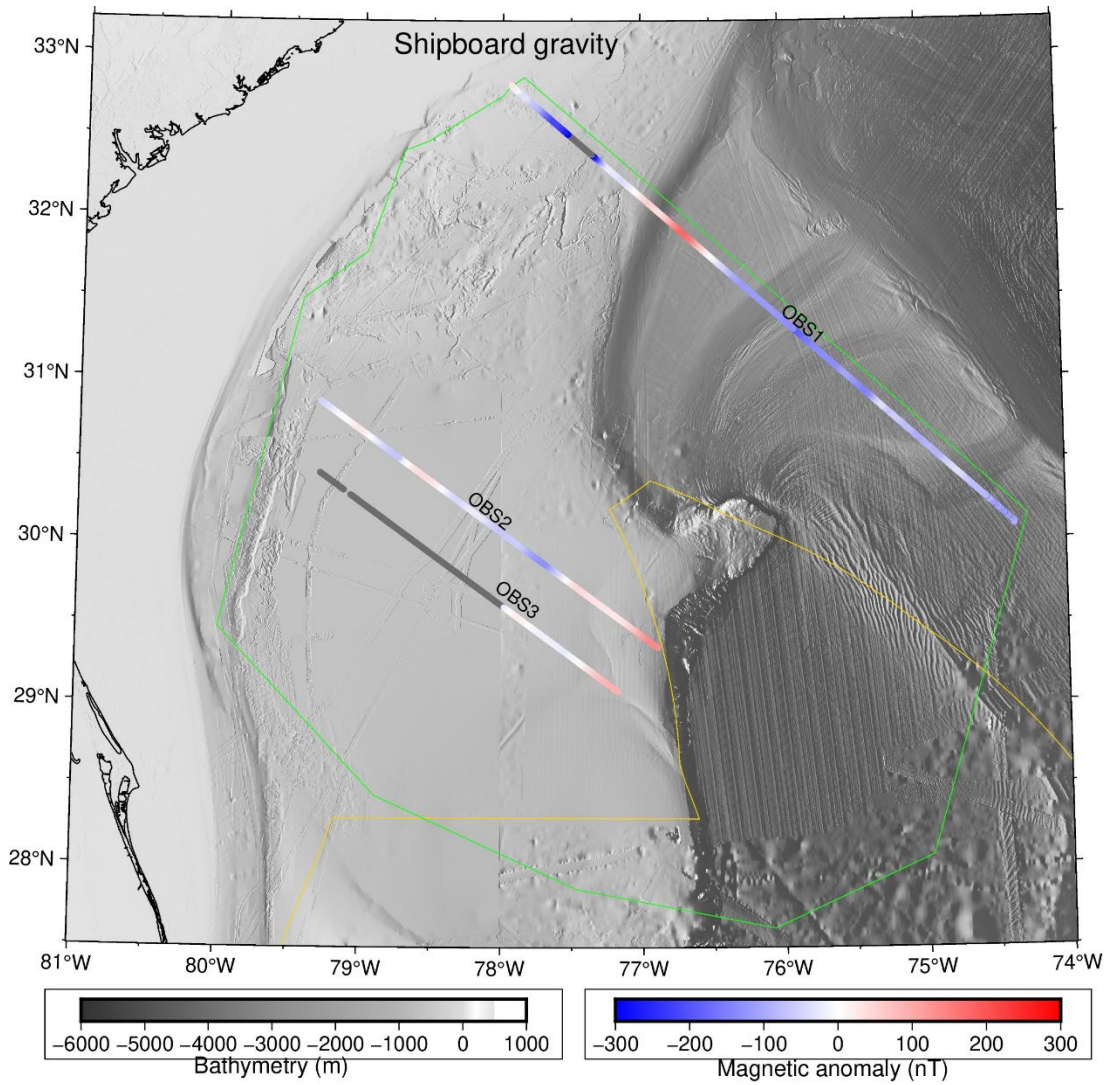


Figure A6.2. Processed magnetic profiles along the three OBS Lines. The magnetometer failed during seismic shooting on line OBS3

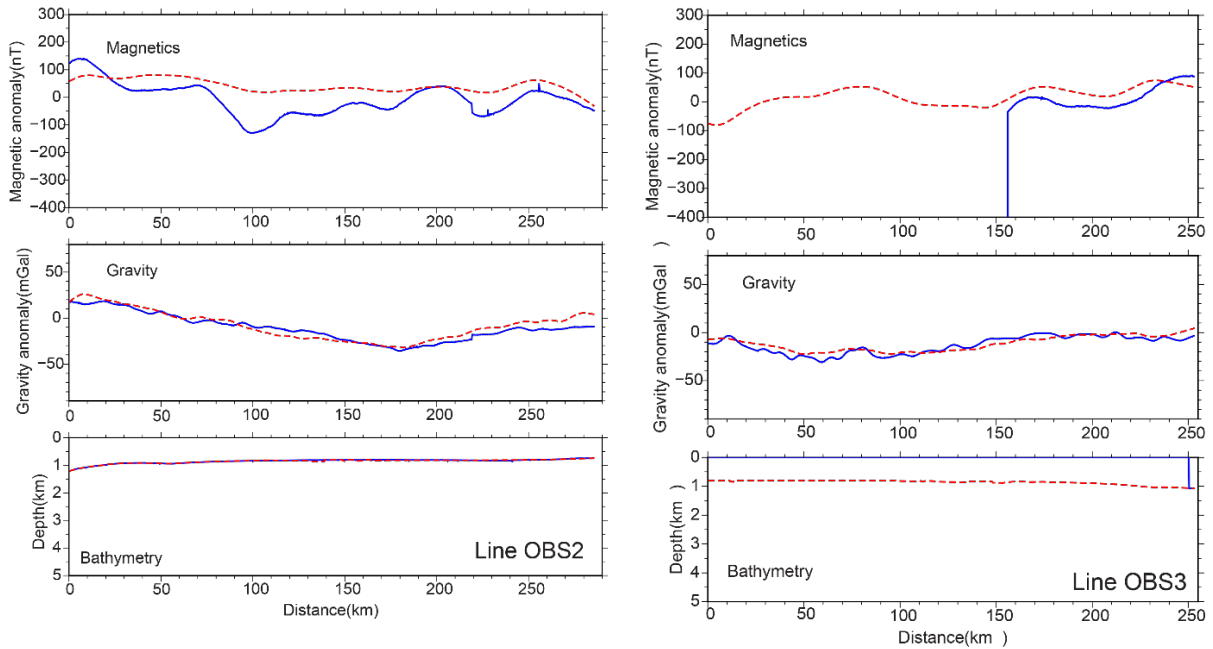
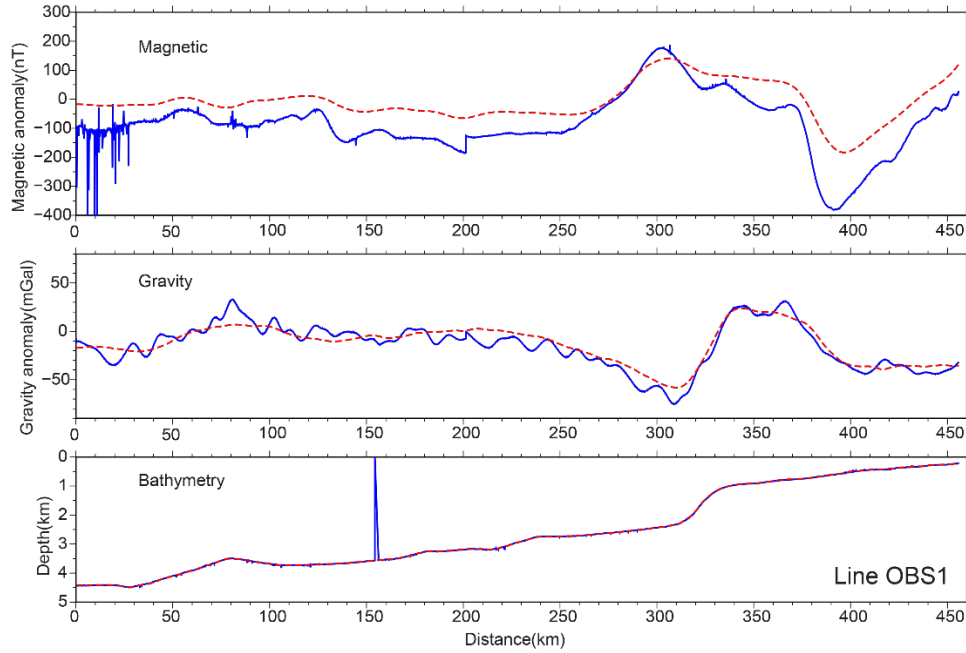


Figure A6.3. Three transects of magnetic anomaly, free-air gravity anomaly and bathymetry acquired during acquisition of OBS seismic lines 1, 2, and 3. The blue curves are shipboard data, and the red curves are extracted from global compilations for comparison.

Appendix A7. Expendable Bathythermographs (XBT)

During cruise MGL2310, the water temperature and salinity versus depth were measured with XBT's (T-5 and T-7). The speed of sound in water can be estimated from these properties, which aids seismic data analysis and multibeam bathymetry mapping (see Appendix A5). Along with temperature and salinity, also resistivity is measured. The two probe models (Figure A7.1), T-5 and T-7, have the same vertical data recording resolution of 65 cm but are used under different sea water depth and ship speed. T-5 is used during slower ship transit (5 knots) in deep ocean, and can collect data down to a maximum depth of 1830 m. Instead, T-7 is the most appropriate in shallow water (760 m maximum) and faster ship transits (10 knots). The XBT's were dropped on average once per day, at various points in the survey area but often in water less than 1000 m deep. We anticipated that acoustic wave speed would be most variable on the continental shelf and slope.

Because the probe falls through the water at a known rate, the depth of the probe can be inferred from the time of launch. It is then possible to plot temperature as a function of depth to create a temperature profile of the water which plays an important role in multibeam mapping operations. The speed at which sound travels changes as the density of water varies through the water column. Temperature and salinity are the two main variables that affect the density of seawater.

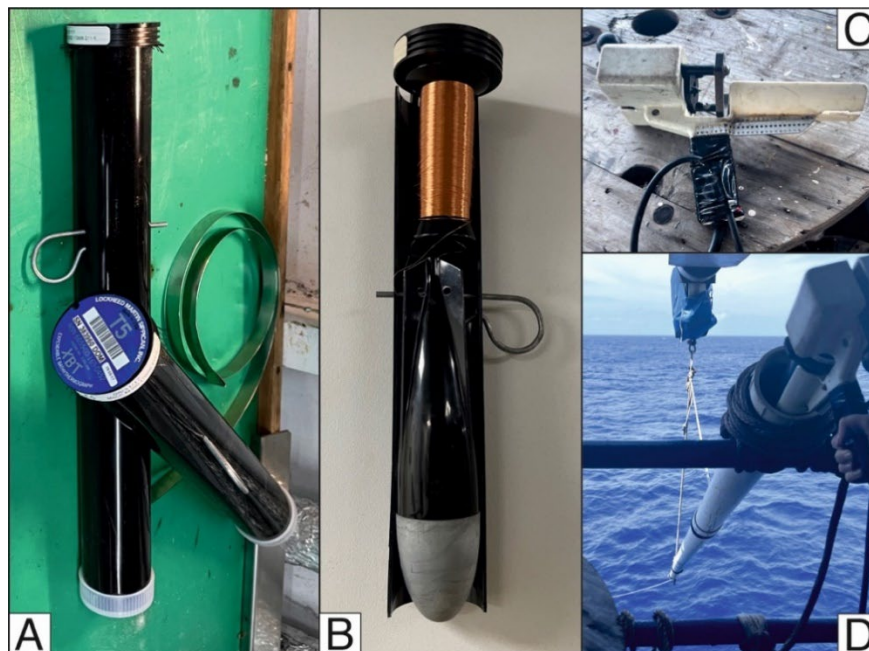


Figure A7.1. A) Example of T-5 probes. B) Internal structure of the probe showing the canister wire spool (copper wire) to the top and the thermistor to the bottom. C) Gun used to load and deploy the probe. D) Picture of the launching tube located on the streamer deck (port side) at 15 m above sea level.

During cruise MGL2310, 7 XBT drops were carried out. The general XBT drop distribution, line position, weather, and currents conditions were checked before every launch along with the seafloor depth. The position of the streamer and air gun line with respect to the currents (and thus, the deployment location on the port) deserves particular attention because the currents can drive the probe toward the instruments, compromising the data collection.

The details of the XBT deployments can be found in Table A7.1. Figure A7.2 shows the sound velocity (at 6.1 meters below the surface) and the location of XBT drops. The seven sound profiles are generally consistent, though profile #3 deviates, likely because of its location in the gulf stream (Figure A7.3).

Table A7.1. Location and time of the XBT deployments.

XBT	Type	Date	Time	Lat.	Lon.
1	T5	27-Aug	14:45	31.31886	-75.9123
2	T5	28-Aug	10:43	31.91661	-76.7244
3	T5	28-Aug	22:06	32.48333	-77.4932
4	T7	7-Sep	20:09	30.18908	-78.9253
5	T5	8-Sep	17:45	29.21994	-77.4018
6	T7	9-Sep	9:53	29.6936	-77.4357
7	T5	10-Sep	0:44	30.30448	-78.4004

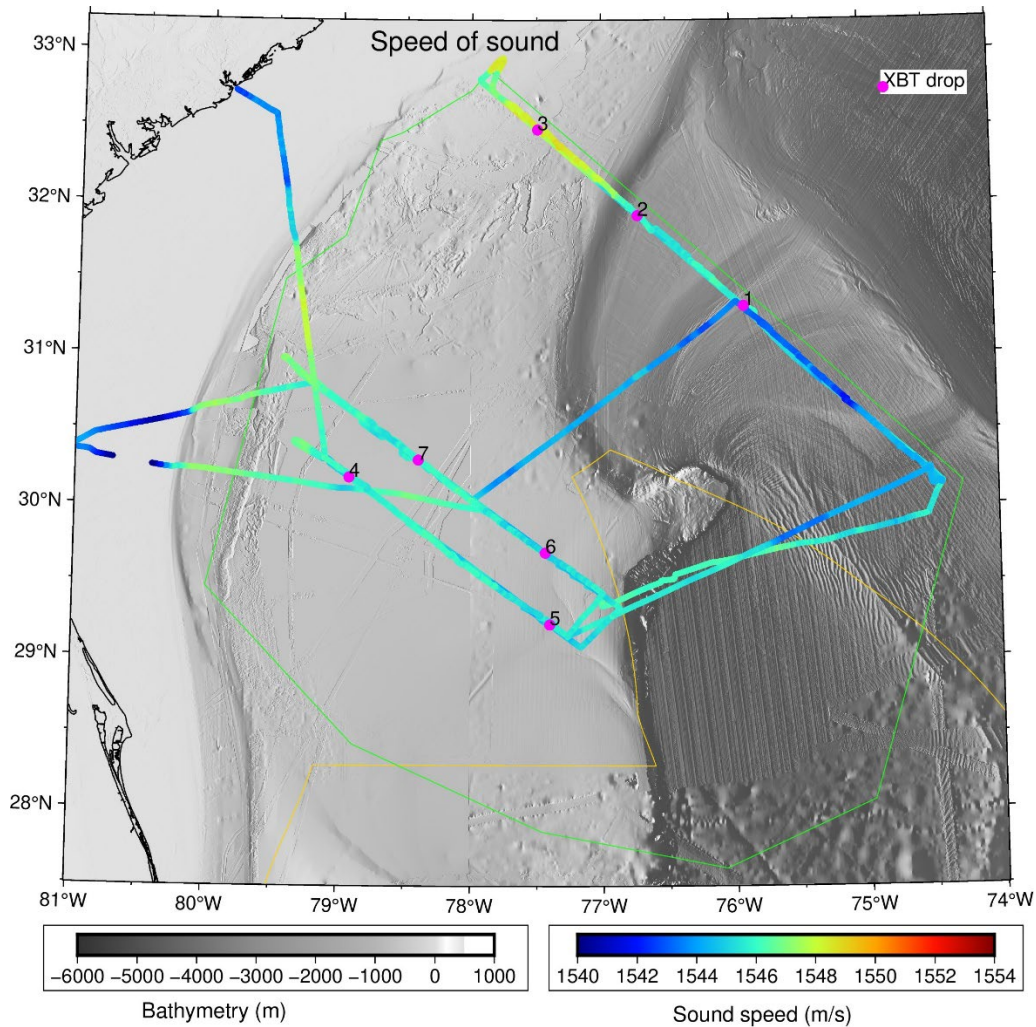


Figure A7.2 Shipboard measurements of acoustic wavespeed at 6 m depth. XBT drop locations in purple.

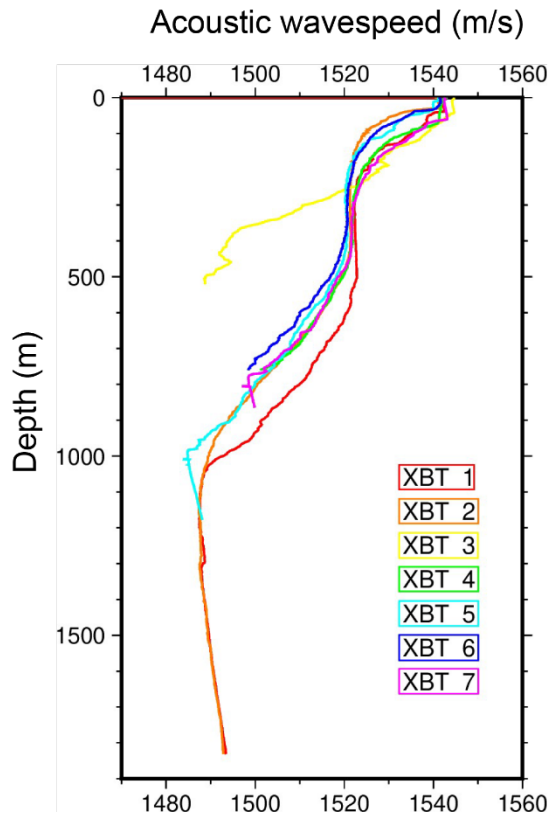


Figure A7.3. XBT profiles of speed of sound

Appendix A8. Weather

The acquisition of marine seismic refraction data, including OBS operations and shooting, requires fairly calm seas. Cruise MGL2310 took place offshore the southeastern United States between August 23 and September 14, 2023, around the usual peak of the hurricane season. Hurricane Idalia forced us to stop operations for a couple of days, while hurricane Lee led us to end the cruise a day sooner than planned. In Figure A8.1 we show the development of hurricane Idalia, before it arrived in the Atlantic. The shipboard measurements of air temperature and wind speed are shown in Figure A8.2.

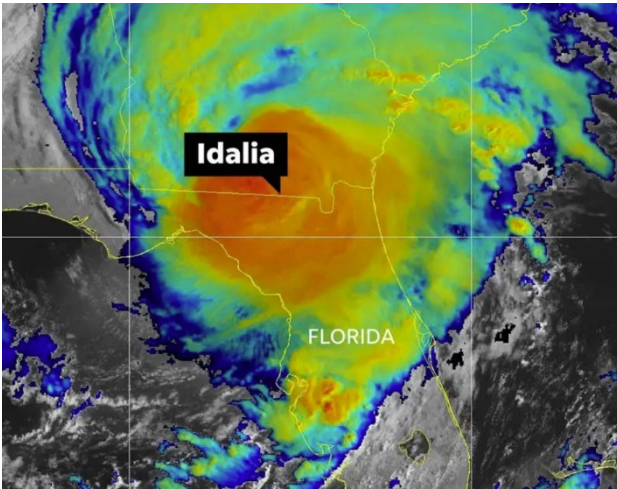


Figure A8.1. Weather map of August 30, 2023. Idalia formed off Yucatan, and crossed Florida into the Atlantic Ocean, where it forced us to hold OBS operations..

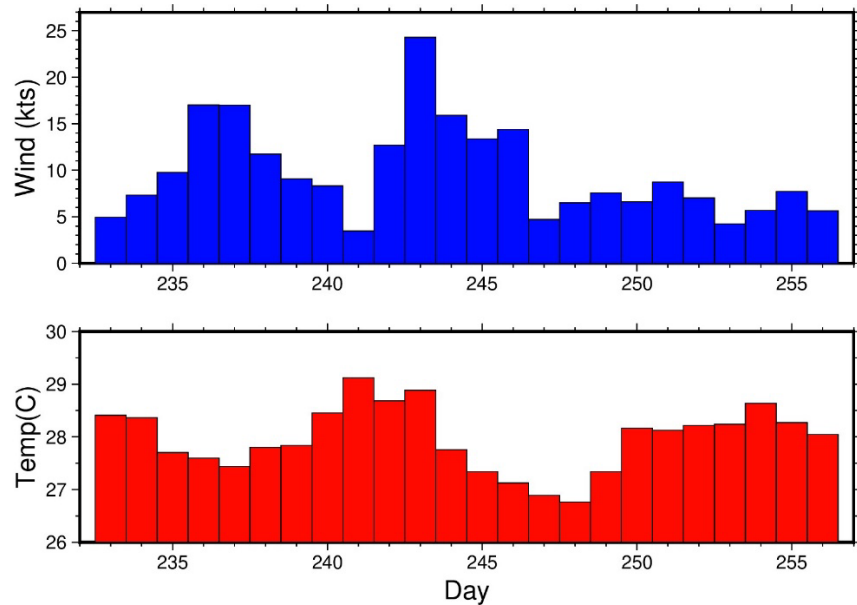
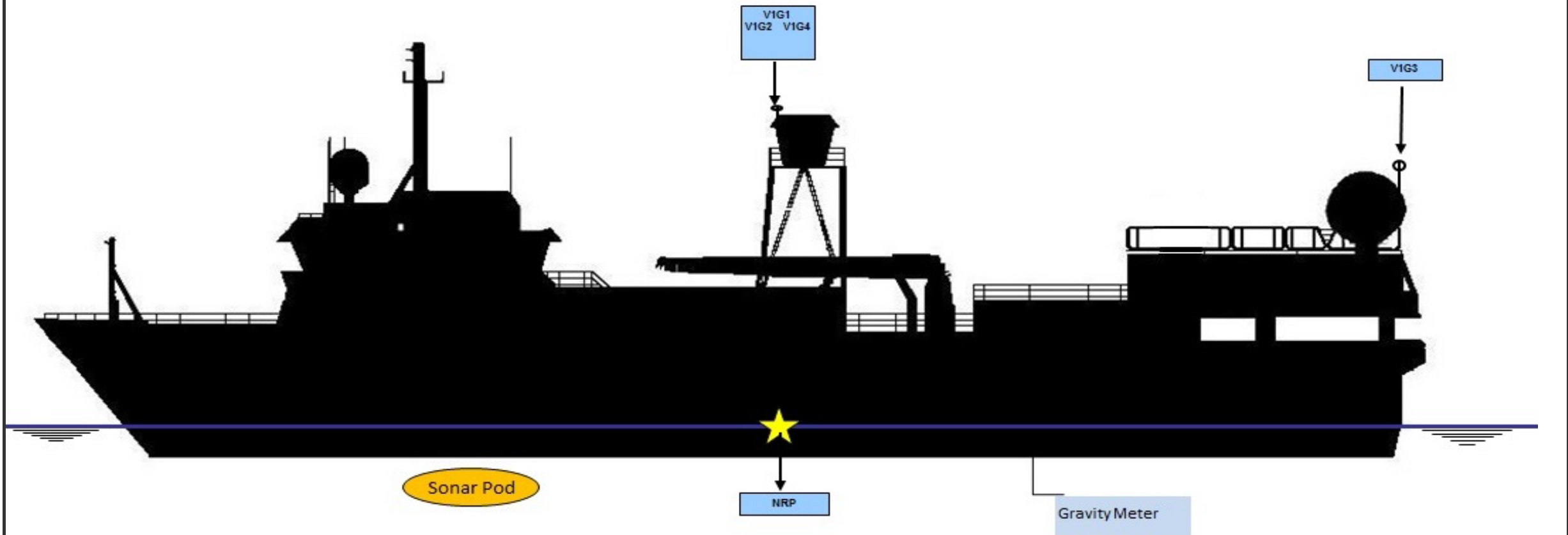


Figure A8.2. Daily variation in temperature and wind speed during cruise MGL2310.

Appendix A9. Diagrams of seismic data acquisition

The towing configuration of the shipboard GPS and acoustic source.

R/V Marcus G. Langseth - Vessel Sensor Offsets



Negative values are above water line
All measurements in meters



			STBD/PORT (X)	FORE/AFT (Y)	UP/DOWN (Z)
NRP	NAVIGATION REFERENCE POINT		0.00	0.00	0.00
V1G1	SeaPath 330	Orca	-1.33	-1.25	-16.90
V1G2	C-Nav3050 MMO Tower	Orca	-0.09	0.00	-16.90
V1G3	C-Nav3050 Stern	Orca	-1.95	-31.83	-14.50
V1G4	Pos MV	Orca	2.39	12.75	-16.90
	PosMV Output position is IMU mounted in stbd drylab				
V1R1	PosNet		-1.30	-0.02	-16.90
Sonar Pod	EM122 Knudsen ADCP		0.00	20.20	7.49
	EM122 Center Beam offset (in Spectra)				
			0.00	13.4	7.49
MRU	Seapath MRU		2.39	12.75	-4.30
BGM	Bell Gravity Meter		0.00	-13.10	1.10

