Cruise report EN-546, R/V *Endeavor*

Short-period OBS deployment and recovery for the Eastern North America (ENAM) Community Seismic Experiment (CSE)

Departure on September 12, 2014, from North Kingstown, Rhode Island.

Arrival on October 9, 2014, in North Kingstown, Rhode Island.

Co-chief scientists:

Harm Van Avendonk and Brandon Dugan

Content:

Participant list

R/V Endeavor crew:

E. McMunn	Captain
S. Post-Maher	Chief Mate
C. Armanetti	Second Mate
T. Varney	Chief Engineer
K. Rethorn	Engineer
P. Quigley	Engineer
C. Bean	AB/deck
C. Wroblewski	AB/deck
E. Irons	AB/deck
S. Sisson	Boatswain
M. Duffy	Steward
M. Brennan	Steward assistant
W. Fanning	Marine Technician

Science Party:

Harm Van Avendonk	UTIG	Co-chief scientist
Brandon Dugan	Rice University	Co-chief scientist
Ernest Aaron	SIO	OBS technician
Mark Gibaud	SIO	OBS technician
Peter Lemmond	WHOI	OBS technician
David DuBois	WHOI	OBS technician
Jennifer Harding	UTIG	Graduate student
Dylan Meyer	UTIG	Graduate student
Kathryn Volk	U. Michigan	Graduate student
Afshin Aghayan	Oklahoma State	Graduate student
Pamela Moyer	U. New Hampshire	Graduate student
Gary Linkevich	Rice University	Graduate student

Science background

Rifting between eastern North America and northwest Africa in the Mesozoic was accompanied by stretching of the continental lithosphere in a direction that was generally perpendicular to the Appalachian terranes (Figure 1). Strata in deep sedimentary basins of the eastern United States, which generally thicken towards the present-day coast, record extension of the continental crust from the Middle Triassic to Early Jurassic. Besides these sediments, the basin infill includes basalt flows that may be related to the short-lived Central-Atlantic Magmatic Province (CAMP) at the Triassic/Jurassic boundary, or they may have been generated by mantle decompression and melting during continental breakup in the Early Jurassic. The deep crustal structure beneath the present-day shelf and deeper margin can give further insight in these rifting processes. The East Coast Magnetic Anomaly (ECMA) and Blake Spur Magnetic Anomaly (BSMA) are two very prominent magnetic lineations that parallel the eastern seaboard of the United States (Figure 1). Such magnetic anomalies are generally assumed to be evidence of voluminous synrift magmatism. Indeed, early academic offshore seismic studies have provided evidence that ECMA coincides with seaward-dipping reflections (SDRs) and a thick high-velocity lower crust that is consistent with magmatic underplating. On the other hand, the nature of the BSMA, which lies roughly 200 km offshore, is not yet well understood. In general, the more seaward magnetic lineations represent younger oceanic crust. However, it is possible that the BSMA also formed during continental breakup, and that its eastern location was the result of an eastward jump of the incipient Mid-Atlantic Ridge. That scenario would explain the notable asymmetry with the northwest African margin, where magnetic anomalies are much less prominent.

The post-rift evolution of the margin of the eastern U.S. was dominated by cooling and subsidence. As a result, a thick layer of sediment covers the coastal plain and the continental shelf. Scientists have used bathymetric data, backscatter data, and high-resolution seismic reflection data to show that Quaternary landslide deposits cover a significant area of continental slope, which suggests that such catastrophic events pose a significant geohazard for the coastal population. Geological factors that may control the occurrence of landslides are the strength of margin sediments and the presence and stability of gas hydrates. Further studies of the shallow structure of the margin of the eastern U.S. can give important insight in the stability of the sediments on the continental shelf and slope.

The U.S. scientific community chose the Eastern North America Margin (ENAM) as an ideal place to study continental breakup and the evolution of rifted margins through the NSF-funded GeoPRISMS program. At a workshop at Lehigh University in October 2011, the scientific community evaluated a few corridors along the east coast as possible targets for geological, geochemical and geophysical investigations. In the summer of 2012, a large team of U.S. investigators submitted a proposal to NSF to acquire seismic data on the margin in the vicinity of Cape Hatteras as part of a community experiment. Between the Carolina Trough to the south and Baltimore Canyon Trough to the north there appears to be some along-strike complexity that can be investigated with a 3-D geophysical data set. This area is also known for some prominent landslides. The proposal was funded in 2013, after which a logistical plan was developed to gather such data across the shoreline (Figure 2). Additional feedback from the scientific community has led to minor changes to the final experiment plan.

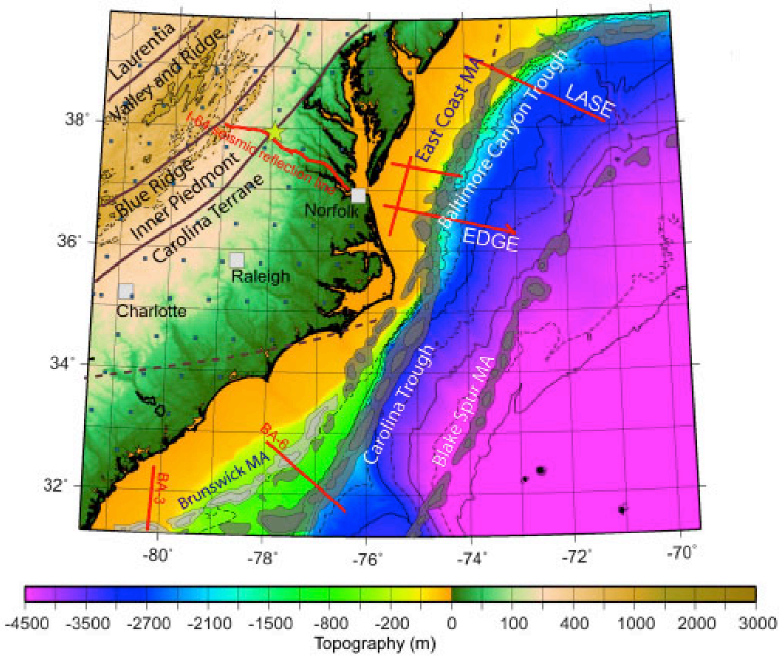

Figure 1. Major structural boundaries in the eastern United States. Gray lines onshore approximate the edges of Appalachian terranes. Gray zones offshore show the major magnetic anomalies. The red lines mark existing regional seismic reflection/refraction transects. The yellow star shows the epicenter of the 2011 Mineral, Virginia earthquake. Small green squares represent seismometers of the EarthScope Transportable Array.

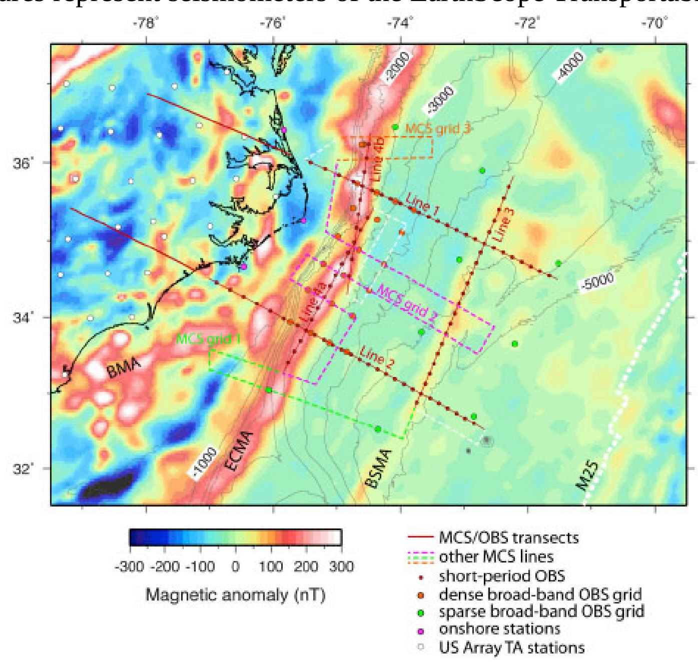

Figure 2. Instrument layout and transects of the ENAM Community Seismic Experiment with some modifications adopted in December 2013. Some additional changes were made in the MCS coverage during data acquisition in September and October 2014.

ENAM data acquisition and distribution plan

The ENAM Community Seismic Experiment (CSE) consists of different components (Figure 2). Together they provide coverage across the shoreline, and over a range of length scales that are appropriate for investigations of shallow sedimentary features and crustal and mantle structure.

Marine active-source seismic data: One of the key objectives of the community experiment was to acquire marine seismic reflection and refraction data offshore North Carolina and Virginia along more than 5000 km of profiles in September and October 2014. The seismic source and 2-D multichannel seismic recording capability of the R/V *Marcus Langseth* were essential in this effort. In addition, seismic waves generated by the *Langseth's* source were recorded on short-period ocean bottom seismometers (OBSs) deployed from the R/V *Endeavor* at 94 locations along four offshore transects.

Onshore active-source seismic refraction data: A temporary array of 80 seismometers, which were onshore in North Carolina and Virginia in September and October 2014, recorded airgun shots from the R/V *Marcus Langseth*. We also plan to acquire active-source seismic refraction data onshore in the summer of 2015 along three profiles. Data from these two efforts will provide an onshore continuation of the marine active-source seismic profiles, which can provide information on the structure of the crust before it stretched and of rifting structures onshore.

Deployment of broadband seismometers: Broadband seismometers will record distant earthquakes for one year (April 2014 to April 2015). Three seismometers are deployed onshore on the Outer Banks, North Carolina, and thirty seismometers are deployed on the seafloor offshore North Carolina. Together with the EarthScope USArray seismometers onshore, these data will enable continuous imaging of the North American lithosphere across the shoreline.

Data distribution: All the data acquired during the ENAM CSE are open to public access. The broadband seismic data and land seismic data will be distributed through the IRIS Data Management Center (www.iris.edu/ds/nodes/dmc). The marine seismic reflection and refraction data will be distributed through the marine seismic data portals at Lamont-Doherty Earth Observatory (LDEO) (www.marine-geo.org/portals/seismic) and the University of Texas Institute for Geophysics (UTIG) (www.ig.utexas.edu/sdc). Though the data will be made available as early as possible, the ENAM principal investigators are also committed to provide quality control and any information on the geophysical field campaigns that are pertinent to this data set.

Seismic data processing workshops: A marine seismic reflection processing workshop will be held at LDEO in the summer of 2015 to involve young scientists and students in the U.S. community in the processing and interpretation of the marine seismic reflection data. A similar workshop will subsequently be held at UTIG to engage young scientists in the analysis of marine seismic refraction data.

Short-period OBS

In the ENAM CSE we used four-component, short-period ocean-bottom seismometers from the U.S. Ocean-Bottom Seismometer Instrument Pool (OBSIP) to acquire marine seismic refraction data. Twenty-four of these instruments and one spare were supplied by the OBSIP instrument center at Scripps Institution of Oceanography (SIO), and twenty-three OBSs plus three spares were contributed by Woods Hole Oceanographic Institution (WHOI). Each of these 47 instruments were deployed twice to cover a total of four marine seismic transects (Figure 2). In our experiment design we assume that the quality and characteristics of the data recorded by these two instrument designs is very similar. Each of the four ENAM marine seismic transects therefore employed a mix of the WHOI and SIO instruments. On the EN-546 cruise, two SIO technicians (Ernest Aaron and Mark Gibaud) and two WHOI technicians (Peter Lemmond and David DuBois) participated to ensure the success of the marine seismic refraction component of the ENAM study. They prepared the OBSs, carried out the deck operations with the assistance of other members of the science party and crew of the R/V *Endeavor*, and they downloaded raw data after instrument recovery. The SIO and WHOI teams provided SEG-Y data to the science party during and at the end of the cruise.

Description SIO LC4X4 Short-Period OBS

The Institute of Geophysics and Planetary Physics at Scripps Institution of Oceanography (IGPP/SIO) in conjunction with the Ocean Bottom Seismology Instrument Pool (OBSIP) provided 24 (plus one spare) short period LC4X4s for this experiment. The sensors used on the SP-OBS are an L28 gimbaled 3-component geophone and a hydrophone from Sercel. Each instrument is comprised of a 100-pound anchor, a four ball McLane glass float assembly on which the lifting bail is attached, two syntactic foam blocks for additional floatation to aid positive buoyancy, a polyethylene (HDPE) frame holding the sensors, an acoustic release transponder, an LC4X4 data logger, and a central mechanical release system (Figure 3).

The SP-OBS float and frame components are typically stored separately in a custom rack system, and are assembled and tested prior to deployment on a raised preparation platform, which is secured to the deck. The complete instrument weighs approximately 300 pounds in air. The anchor is a 100-pound iron grate held to the base of the poly frame by a single 2” oval quick-link when the release mechanism is cocked and secured. When the anchor is released for recovery, the four

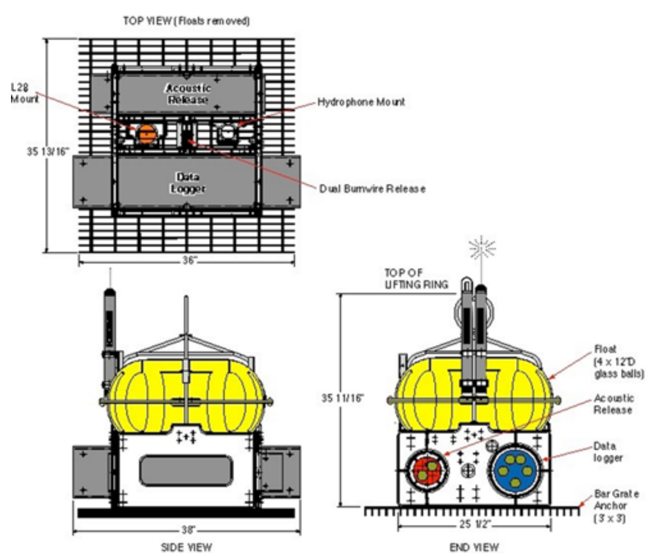

Figure 3. Layout of SIO short-period OBS

12” glass spherical floats, as well as the syntactic foam blocks provide sufficient buoyancy to lift the instrument at about 45 m/min to the sea surface. To increase visibility at the surface, an orange flag on a 48” fiberglass-resin staff is attached to the side of the lift bale along with a Novatech low-pressure activated strobe-beacon and radio. The radio provides one-second pulses every two-seconds at 160.725 MHz.

The acoustic release transponder developed in conjunction with ORE/EdgeTech is comprised of a main circuit board, an SIO-developed battery array, and an ITC-3013 transducer manufactured by International Transducer Corp. These are all installed in and on a 4-5/8” aluminum pressure case. All SIO transponders are interrogated at 11kHz and respond at 13kHz. Alkaline batteries provide 18 volts power for the burn, 12 volts power for the transponder, and 9 volts power for the circuit board logic. The release mechanism includes two double wire burn elements. When fresh, two battery strings are combined to provide the 18 volts to burn one of two release wires in an average of 7 minutes for water depths encountered during this experiment.

Description WHOI D2 OBS

The WHOI model D2 ocean-bottom seismometer is a compact, relatively lightweight system, which allows recording of three components of ground motion and one acoustic channel at sample rates up to 250 Hz. The D2 is comprised of two glass balls containing electronics and batteries enclosed within a rigid plastic housing (Figure 4). The system stands 39” high and weighs approximately 115 lb in air.

The upper glass ball (17” diameter) contains a Quanterra signal-processing unit (Q330), a Quanterra 20 Gbyte hard drive containing an ethernet hub, an EdgeTech acoustic release board, GPS antennae, recovery aids, and custom electronics. A Seascan clock is located on a system control board and is accessible via a serial ASCII current loop. Recovery aids include four flashers and a programmable VHF radio with a minimum range at sealevel of ~2 nmi. The radio transmits at 154.585 MHz. The VHF antennae is attached to the inside surface of the glass ball. The Q330 includes operating software, a low-power analog-to-digital converter with 140 dB dynamic range, digital filters, clock, and 8 Mbytes of buffer memory. Engineering data and four channels of signal are continuously recorded and intermittently logged via an ethernet connection onto the disk drive in miniSEED format. For this experiment we used a sample rate on all data channels of 200Hz. In the lower glass ball (10” diameter) are battery packs comprised of both alkaline and lithium cells that supply power separately to the Q330 and hard drive, the recovery electronics board and aids, and to the EdgeTech release board used for acoustic ranging and supplying a current to the anchor release burn-wire. Ethernet connections can be used to change and program the operating software and to recover data from the hard drive.

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

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

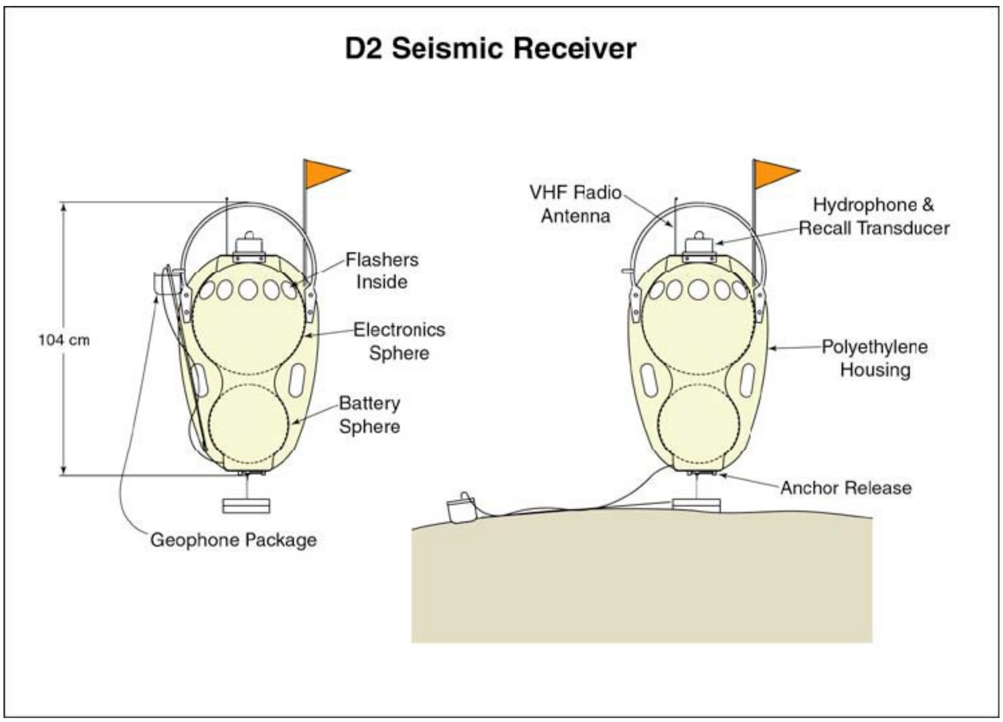

Figure 4. Schematic layout of the WHOI D2 OBS.

Coordination with R/V *Marcus Langseth*

The marine active-source component of the ENAM CSE was a carefully designed two-ship experiment. The acoustic array of the R/V *Marcus Langseth* was used for both OBS and MCS shooting. While the seismic vessel towed an 8 km-long streamer, the R/V *Endeavor* did all the OBS deployments and recoveries. The R/V *Marcus Langseth* was originally scheduled to depart from Norfolk on September 15, 2014. However, due to delays in the previous cruise, the ENAM science party, led by Donna Shillington, Matthew Hornbach and Anne Bécel, did not board the R/V *Marcus Langseth* until the morning of September 15. On the morning of September 16, the R/V *Marcus Langseth* left the dock in Norfolk and steamed towards the seaward end of Line 2 (Figure 2).

Line 2:

Most of the OBSs along this line were deployed when the R/V *Marcus Langseth* was still in transit from Norfolk, VA. The R/V *Marcus Langseth* deployed the streamer and source array late on September 17, and started shooting Line 2 from east to west at 01:38 EDT on September 18 (261/05:38 UTC). The R/V *Endeavor* deployed the last instrument, OBS 201, on line 2 at 23:00 EDT on September 17. The R/V *Endeavor* subsequently traveled to the east end of Line 2 for OBS recovery. Recovery of OBSs started on line 2 at 01:37 EDT on September 19 after the R/V *Marcus Langseth* had advanced 180 km landward of OBS 225. The R/V *Endeavor* waited to pick up OBS 2404 just over three hours before the passing of the R/V *Marcus Langseth*, which was shooting MCS data on this line from west to east. By day 264/18:08 UTC (September 21) OBS 2404 was successfully recovered. The R/V *Marcus Langseth* completed shooting Line 2 OBS at 11:00 on September 20 (263/15:00 UTC). OBS recovery continued along Line 2, ending with OBS 201 at 04:41 EDT on September 22. The R/V *Marcus Langseth* shot Line 2 MCS between 263/22:00 and 266/0:00.

Line 3:

All of the OBSs along Line 3 were deployed from north to south from 258/10:30 UTC to 259/10:57 UTC. Therefore all Line 3 OBSs were deployed before the R/V *Marcus Langseth* left Norfolk, VA. The seismic vessel shot this line with OBS shot spacing from 266/15:15 UTC to 268/12:58 UTC (11:15 EDT September 23 to 08:58 EDT September 25) from south to north. The science team on the R/V *Endeavor* recovered the OBSs from south to north between 267/22:20 UTC and 270/14:29 UTC. As the OBS pickup was in progress, the R/V *Marcus Langseth* was shooting MCS data in the southward direction. At OBS 312 the R/V *Endeavor* let the R/V *Marcus Langseth* and its streamer pass before this instrument was recovered at 269/12:42 UTC.

Line 4:

We deployed OBS Line 4 immediately after recovery of OBSs along Line 2. OBSs along Line 4 were deployed from south to north from 265/17:01 UTC to 266/20:05 UTC, which coincided with the time that the R/V *Marcus Langseth* finished shooting MCS Line 2 and had started shooting OBS Line 3. Upon completion of OBS deployments, we transited to the south end of OBS Line 3. The R/V *Marcus Langseth* started shooting OBS Line 4a from its south end at 272/22:15 UTC and completed shooting Line 4b at 275/21:20 UTC. Before starting recovery of OBSs on Line 4, the R/V *Endeavor* held position and waited until the R/V *Marcus Langseth* had shot OBS Line 4a and part of OBS 4b to facilitate maximum data records on the OBSs on Line 4a. The R/V *Endeavor* started recovering OBSs along Lines 4a and 4b with OBS 401 at 275/12:21 UTC. At OBS 409, the R/V *Endeavor* paused OBS recoveries again, such that the instruments of Line 4a and Line 4b that lie ~100 km south of Line 1 would record airgun shots from this east-west transect. All Line 4a and 4b OBSs, with the exception of OBS 419, were recovered by 278/08:19 UTC.

Line 1:

The OBSs on Line 1 were deployed over the course of 36 hours between 270/23:41 UTC (OBS 125) and 272/ 0:31 UTC (OBS 100). OBS 100 and OBS 101 were a SIO and WHOI OBS deployed in the same approximate location. For the R/V *Marcus Langseth* this line was the last major OBS/MCS transect of the ENAM project. The R/V *Marcus Langseth* started OBS shots on Line 1 at 276/06:06 UTC and completed OBS shots on Line 1 at 278/03:43 UTC. The R/V *Marcus Langseth* then began shooting MCS Line 1 at 278/06:43 UTC, which finished at 280/22:02 UTC.

Cruise narrative

September 10: Most of the science party of cruise EN-546 arrived during the day and evening of September 9. By September 10, the team was complete. Though we stayed in a hotel near Quonset Point, RI, we made visits to the *Endeavor* in the SENESCO dock, during which we prepared the science lab and moved personal effects into staterooms. The WHOI OBS team installed portable van on deck, and SIO OBSs were strapped directly to the deck around the WHOI van. All instruments were therefore stationed close to the knuckle crane on the starboard side, and close to the entrance of the main science lab of the R/V *Endeavor*.

September 11: Soon after lunch we held a general science meeting, which was attended by the science party, both OBS teams, and the marine technician, William Fanning. There were also three additional members of the WHOI personnel who had helped to install the WHOI equipment on the R/V *Endeavor*, but would not participate in the cruise. The chief scientists explained the goals of the ENAM study. For an hour we discussed the time that should be allotted in our schedule for various OBS deployment and recovery activities. The Gulf Stream would likely be a factor to consider in the positioning of many of the OBSs, though the more landward and seaward instruments should not be affected by it. In the evening we enjoyed a last dinner on shore, and settled on board again for the night.

September 12: At 11:00 AM local time (EDT), the R/V *Endeavor* left the SENESCO dock at Quonset Point in excellent weather. We had a considerable transit ahead of us, but at 11.5-12.0 knots we made very good time. During this time we adjusted to the ship motion, and we refined our cruise plan.

September 13: The first task during the cruise was to conduct a 1 km by 1 km survey with the 3.5/12 kHz Knudsen echo sounders centered on OBS sites 104, 105, and 419, which lie inside an essential fish habitat - habitat area of particular concern (EFH-HAPC) off Cape Hatteras. Each survey pattern consists of six 1 km-long lines that we recorded at 4-5 knots. These surveys help us confirm that the OBSs will be placed on sedimented seafloor, rather than hard seafloor where corals might be present. We started the survey of OBS 104 at 19:30 EDT.

September 14: We finished the last 3.5/12 kHz Knudsen survey at approximately 03:45 EDT. We immediately set course for the rosette test site, 165 nautical miles to the east in 4700 m deep water. We had a ship safety drill around 10:30 EDT where the science party mustered in the science lab in life vests. We provided the OBS deployment and recovery plan to the OBS teams so they were aware of whose instrument would be deployed at each station, the order of deployment, and the order of recovery. We arrived on site and started the rosette test for the SIO acoustic system at 18:00 EDT. The rosette test confirmed communication with all systems at 4000 m water depth and was completed at 21:15 EDT. We then began the 90 nautical mile transit to the north end of Line 3 where OBS deployment will begin.

September 15: OBS deployments began today, starting at the north end of Line 3 at OBS 321, and we would continue dropping instruments to the south. The transit of the R/V *Endeavor* to site 321 was completed by 6:00 EDT. This area lies east of the Gulf Stream, and our ADCP indicated that the current was around 0.5 knots. We therefore decided not to survey these first instruments at the seafloor. For site 321 we chose a WHOI OBS, which was handled by the noon-midnight shift. After ranging to the descending OBS, we disabled its acoustic release at a depth of ~500 m. At site 320 we deployed an SIO OBS, which was handled by the midnight-noon shift. OBS 320 was deployed by the midnight-noon shift at 11:54 UTC. The first two deployments therefore helped us train both shifts of the science party, and we obtained a good impression of the workflow for both instrument types. OBSs 319-315 were all WHOI OBSs and were deployed by 22:59 UTC. At times there were heavy showers, but it was also quite warm (27˚C), and it did not affect the operation. The coordination between the bridge, OBS team and science lab quickly became a familiar routine.

September 16: The remainder of the OBS deployments on Line 3 went quickly, such that we started our transit from OBS 301 to OBS 225 at 14:30 UTC. The weather was great at this time. By this time, tropical system Edouard had been upgraded to a Category 3 hurricane a few hundred miles ESE from us, but this storm would not affect the sea state in our work area for another two days. OBSs 225-222 were WHOI OBSs and were deployed by 18:30 UTC. Each instrument was ranged during initial descent to a depth of ~500 m, after which we disabled its acoustic release. OBSs 221-217 were all SIO OBSs and were deployed by 260/00:15 UTC. Before the deployment of OBS 216, a WHOI OBS, we noted an increase in current as we were approaching the Gulf Stream. OBS 216 was deployed at 260/01:11 UTC and then was surveyed at the seafloor. The survey was successfully completed at 260/03:41 UTC. Weather was calm most of the day with a few small rain showers.

September 17: The science team and technicians were working efficiently and cleanly today. OBSs 215-213 were WHOI OBSs and were deployed by 06:52 UTC. Each WHOI instrument was ranged briefly and then disabled before moving to the next site. OBSs 212-208 were SIO OBSs and were deployed by 11:30 UTC. OBS 208 was successfully surveyed in to evaluate the effects of the Gulf Stream on SIO OBSs. OBSs 2404 and 207-205 were WHOI OBSs and were deployed by 21:31 UTC. OBSs 207 and 206 were successfully surveyed in as we were tracking the influence of the Gulf Stream. OBSs 204-201 were SIO OBSs and were deployed by 261/03:01 UTC. The deployment locations for OBSs 211, 210, 207, 206, and 205 were slightly modified based on the Gulf Stream current to deploy upstream of the proposed locations so the OBSs landed near the proposed locations after drift during deployment. OBS 202 was relocated 200 m from the proposed location to provide a 350 m buffer from a shipwreck. Weather conditions were favorable all day; partly sunny with a few short showers.

September 18: After completing OBS deployments we began transiting to OBS 210 for a survey that will give us its location on the seafloor. We gathered depth readings from the 12 kHz Knudsen system, which will give us a bathymetry profile of Line 2. The R/V *Marcus Langseth* can use this information when it operates the streamer in shallow water. During the deployment of OBS 210 and OBS 211 we had noticed strong and unusual currents, so we considered it useful to directly determine their position on the seafloor. When we reached these SIO instruments, we did a small survey to relocate them, which was all finished by 15:25 UTC. Subsequently we cruised further along Line 2, on our way toward the R/V *Marcus Langseth*, which was shooting its seismic array for OBS refraction data acquisition towards the west. We passed the R/V *Marcus Langseth* at 16:45 EDT and then continued to OBS 225. At OBS 225 we started a rosette test at 1000 m water depth at 22:42 EDT.

September 19: The recovery of OBSs started with OBS 225 on the east end of Line 2 at 05:37 UTC. At this time the R/V *Marcus Langseth* had covered 180 km of the refraction shoot along Line 2. This WHOI OBS did not respond well to acoustic commands from the ship after its release from the seafloor, but it surfaced in normal time, and it was recovered at 07:37 UTC. We were able to track OBS 224 by ranging on its way to the surface. Nonetheless, the recovery of this instrument was much more problematic, because it surfaced at dawn (06:22 EDT or 10:22 UTC) without a working radio beacon. From the R/V *Endeavor*, OBS 224 could barely be noticed, as it was right beneath the rising sun at 0.5 nautical miles. By 12:22 UTC it was on board, and we proceeded down Line 2. The following OBS recoveries went much smoother and faster, as both the ship's crew and OBS teams settled in the routine. By midnight we had also retrieved OBS 223, OBS 222, OBS 221, and OBS 220, and OBS 219 was on its way to the surface. It was a windy day with consistent winds of 15-20 knots. Seas were also rougher than the past few days but did not interfere with deck operations.

September 20: We continued to make good progress with OBS recoveries. In the morning hours we received an update that the R/V *Marcus Langseth* was shooting about 233 km to the west of us on Line 2, which was enough for us to continue picking up instruments at this rate. The team worked effectively all day facilitating the recovery of OBS 219 (04:18 UTC) through OBS 211 (264/02:58 UTC). Even with increasing sea state during the day, the team was efficient with recoveries, keeping us ahead of schedule. It was an overcast day with periods of rain and winds were consistently 25-30 knots.

September 21: On Sunday morning before sunrise the storm depression reached its peak. The recovery of OBS 211 and OBS 210 were a bit challenging because the OBS at the surface was just periodically in sight due to the high waves. Once we closed in on these two SIO instruments, we brought them on deck without problems. Before sunrise the sea suddenly calmed down, and the recovery of OBS 209 and OBS 208 were relatively easy. We arrived on site to pick up OBS 2404 just over three hours before the passing of the R/V *Marcus Langseth*, which was shooting MCS data on Line 2 from west to east. We decided to wait with the release of this WHOI OBS until the seismic vessel and its streamer had cleared the area. By 18:08 UTC OBS 2404 was successfully recovered. At lunch time we had a birthday celebration for graduate student Afshin Aghayan. Later in the day, we picked up OBS 207 to OBS 204. By this time we reached the continental shelf, and recoveries here were fast due to the fact that we needed to wait just minutes after the release command was sent for the instruments to surface.

September 22: The recovery of OBS 203 and OBS 202 was hindered to some degree by the presence of a warship nearby, but we continued to make good progress. OBS 201 was the last instrument to come on board at 08:41 UTC. By 09:04 UTC the deck was secure for an 8-hour transit to the south end of Line 4 for a deployment of the OBSs that we had just recovered. As we downloaded and analyzed the data from the SIO OBSs that had been stationed on the shelf portion of Line 2 (OBS 201 to OBS 204) we noticed that the hydrophone channel of these instruments did not record good data. It was unclear whether this problem stemmed from the instruments, or whether the shallow environment contributed to the high noise levels. After the transit we deployed OBS 401 to OBS 409 by day 266, 03:36 UTC. In the early afternoon the seas were calm, and it was sunny and warm outside.

September 23: The deployment of OBS 410 to OBS 420 proceeded quickly, even though the combination of wind, waves, and Gulf Stream current made a very choppy ride. The deck operations were wet, but without problems. To adjust for the 3 knot current we dropped the OBSs about 0.4 nautical miles upstream. The deployment of OBS 421 to OBS 422 proceeded with choppy seas, but the current had decreased so these instruments were deployed 250 m upstream. Deployment of OBSs along Line 4 were completed at 20:05 UTC. After the deck was secure we started to transit to the south portion of Line 3 (OBS 301). It was an overcast and cool day. Winds slowly picked up during the day reaching 25 knots in the evening.

September 24: The day started during our transit to the OBS 301. We arrived on site by 14:30 EDT and the ship's crew performed winch rewind on winch #1. After completion of the winch rewind, we began recovery of OBS along Line 3. We recovered OBS 301 and OBS 302 by 268/02:02 UTC. OBS 303 was enabled at 268/02:58 UTC and was rising from the seafloor when the day ended. Most of the day had calm seas and warm temperatures. Sea state picked up and became choppy around 22:15 EDT and there were some short, intense rain showers.

September 25: We continued recovering OBSs along Line 3 today. OBS 303, OBS 304, and OBS 305 were recovered by 10:22 UTC. We had planned to survey OBS 306, but upon arrival (11:31 UTC) we enabled the OBS but then had communication problems. Due to the time cost of establishing communication (approximately 2 hours), we decided not to survey in this OBS. After changing the location of the R/V *Endeavor* relative to the instrument on the seafloor, stable communication was established, OBS 306 was released from the seafloor at 13:56 UTC and was recovered at 15:31 UTC. We established good connection with OBS 307 upon arrival and surveyed in the site. OBS 307 was then released from the seafloor and recovered at 18:50 UTC. OBS 308 was recovered by 21:18 UTC. OBS 309 had similar communication issues as OBS 306; we enabled it quickly but then had difficulty communicating with it and could not get a confirmed release command. We worked on ship location to get good communication with the OBS. After about 30 minutes we received confirmation of our release command, and OBS 309 was recovered on deck at 269/00:59 UTC. OBS 310 was enabled and the release command was confirmed. We had trouble (no communication) during the initial ranging after release, but communication was re-established and confirmed a successful release. OBS 310 was recovered on deck at 269/03:20 UTC. Sea state was calm for most of the day. Skies were overcast. The day was dry other than short intervals of heavy rain in the late evening.

September 26: In the early hours we recovered OBS 311 without a problem. As the R/V *Endeavor* traveled north on Line 3 to pick up more OBSs, the R/V *Marcus Langseth* was shooting MCS data in the opposite direction. When we reached OBS 312, the seismic vessel was just three hours away from us to the north. We briefly enabled this SIO instrument to make sure that it was in good working order, but we waited four hours to let the R/V *Marcus Langseth* and its 8 km-long streamer pass before we proceeded to release OBS 312 from the seafloor. By 12:42 UTC the OBS was on deck, and we continued our journey to the north. The rest of the day continued with smooth recoveries of OBSs 313-317; the last of which was recovered at 270/02:40 UTC. The day ended as we sent the release command to OBS 318. It was a calm, partly cloudy day.

September 27: The science team on the R/V *Endeavor* completed the retrieval of OBSs that had been deployed on Line 3 for approximately two weeks, from OBS 318 at 05:35 UTC to OBS 321 at 14:29 UTC. Over this time the seas were building, but it was still relatively calm. At 14:40 UTC we started our transit to site OBS 125. We arrived at the east end of Line 1 and began OBS deployments with OBS 125 at 23:38 UTC and continued through OBS 121 at 271/03:37. Seas were moderate today with some larger swells, but they did not alter operations. Temperatures were comfortable and it was partly sunny.

September 28: The day consisted of finishing OBS deployments along Line 1. OBS deployments for OBS 120 through OBS 102 were completed by 23:32 UTC. There was just a four-hour interruption at OBS 210 when the R/V *Endeavor* let a larger vessel pass. The work otherwise progressed quickly. For station OBS 101, which is in 35 m water, we decided to deploy two OBSs to assess OBS performance in shallow water, shelf environments. OBS 101 was an SIO instrument and OBS 100 was a WHOI instrument and OBS 101 was an SIO instrument. Deployments along Line 1 were completed by 272/00:45 UTC. We then started the transit to the south end of Line 4. Seas were mostly calm, winds were around 10-15 kts, and it was partly sunny.

September 29: We completed the transit to the south end of Line 4 at 12:35 EDT. Before beginning OBS recoveries, we had to wait on the R/V *Marcus Langseth* to allow adequate shot coverage on Line 4a/4b. Over the course of 17 days at sea, the R/V *Endeavor* and its science team had consistently gained time on its schedule in the ENAM two-ship active-source seismic experiment. On the other hand, the R/V *Marcus Langseth* had experienced a delay in their departure, and strong currents often required that the 8 km-long streamer be towed at 3 knots or less during portions of the ENAM cruise. At this time, all OBSs were already deployed for the second time. All we could do now was wait until the seismic vessel made enough progress on Line 4 for us to start the recovery of some of the OBSs on this transect. After evaluating the R/V *Marcus Langseth* schedule and the time required to recover all the Line 4 and Line 1 OBSs, we decided to wait on the R/V *Marcus Langseth* until approximately 17:00 EDT on October 2. This would provide significant shot coverage on Line 4 OBS stations and would allow the R/V *Endeavor* to return to port on time. The science crew put the top cover on the rosette and secured it on deck, making it ready for transport at the end of the cruise.

September 30: As it was clear that we were now waiting for the R/V *Marcus Langseth* to make progress shooting Lines 4a and 4b, we moved to a site south of Cape Lookout, near OBS 202 to hold position. Since SIO still had a spare OBS, we decided to use it for a test deployment at site OBS 202 (called OBS 500) that would also record R/V *Marcus Langseth* shots on Line 4a. OBS 500 was deployed at 12:42 UTC. The seas were calm. The weather was cool in the morning and warm during the day, which was mostly sunny.

October 1: We were still waiting on the R/V *Marcus Langseth* to make the transit from Line 4a and start shooting on Line 4b. While we were waiting we completed two OBS tasks. We recovered OBS 500 (same site as OBS 202) at 15:02 UTC. We then performed deployed and recovered another OBS in 29 m water, near OBS site 202. This deployment and recovery was an evaluation of the release mechanism in shallow, warm water. No data were recorded and the test took approximately 1 hr from deployment to recovery. The WHOI team created SEG-Y files of their OBS data from Lines 2 and 3, and provided them to the science party. The day was calm and sunny.

October 2: The R/V *Marcus Langseth* was making good progress along Line 4b and was 300+ km from OBS 401 by 12:00 UTC, so the R/V *Endeavor* started recovering OBSs along Line 4a with OBS 401. OBS 401 provided a little difficulty for recovery as it surfaced to the east over 1 nmi from the ship and was difficult to spot in the sunlight. OBS 401 was successfully recovered at 13:50 UTC. The recoveries of OBS 402-406 were straightforward and were completed by 276/03:48 UTC. It was a pleasant, sunny day. The sea state was a bit higher than the past few days as we moved back into the Gulf Stream; this did not affect operations.

October 3: The R/V *Endeavor* started the day recovering OBS 407 and OBS 408, which were recovered by 08:26 UTC. At this time the R/V *Marcus Langseth* had started OBS shots on Line 1, and the R/V *Endeavor* went into standby. The standby was to allow additional OBS shots on Line 1 to provide 3D data coverage by recording Line 1 shots on Line 1 and Line 4a/4b OBSs. By 20:00 UTC, the R/V *Marcus Langseth* had made sufficient progress along Line 1 so the R/V *Endeavor* resumed operations by surveying in OBS 409 and then recovering it (21:57 UTC). We then recovered OBSs 410 and 411 by 277/03:01 UTC. OBS 411 surfaced with a non-functioning light, but we recovered it without any lost time using slant ranges, the OBS's radio, and the ship's spotlight. We took a short break at lunch to celebrate graduate student Kate Volk's birthday.

October 4: OBS 412 surfaced without a working radio, and the currents prolonged the recovery. Afterwards, the retrieval of OBSs on Line 4 progressed steadily with the recoveries of OBS 413, OBS 414, and OBS 415. After the transit to OBS 416, we halted operations for 50 minutes to give the R/V *Marcus Langseth* some additional time to proceed along Line 1 increasing the offsets recorded on the remaining Line 4 OBSs. OBS 416 was recovered without issue. OBS 417 was recovered on schedule, even though the radio was not working at the surface. The recovery of OBS 418 went smoothly. OBS 419 was problematic. Upon arriving at site OBS 419, we were unable to establish communication with the instrument. We started searching the area to establish communication and also continually monitored the surface. After ~5 hrs, with OBS 419 not communicating and no indication of it at the surface, we transited to OBS 420 and planned to return to OBS 419 after recovering OBS 104 or OBS 105 on the Line 1 profile. OBS 420 was recovered as planned. The sea state was rough as winds approached 30 knots at times during the day.

October 5: The recovery of OBS 421 and OBS 422 happened without problems despite the stormy conditions. By 278/08:47 UTC we started the transit to the west end of Line 1. Here we recovered both the WHOI OBS (100) and SIO OBS (101) in shallow water by 13:33 UTC. OBS 102, OBS 103, and OBS 104 were recovered without any problems, however nearby ship traffic slightly slowed down recovery of OBS 102 and OBS 104. After OBS 104 (18:16 UTC) we transited back to OBS 419 to re-attempt recovery. We started trying to release OBS 419 approximately 2.2 nmi from the site at 19:42 UTC. Once we arrived at the drop location, we continued to send release and burn commands, but received no response. At 20:46 UTC we lowered a release beacon into the water that sent release commands every 2 min. The beacon was lowered to 1900 m wire out by 21:22. We continued release commands from the beacon while drifting near the drop location until 22:11 and then started recovering the beacon. After recovering the beacon we stayed on station for 1 hr monitoring for the OBS radio or a visual. No communication or visual was made, so we transited to OBS 105. OBS 105 and OBS 106 were retrieved successfully by 279/03:46 UTC. The seas and winds calmed through the morning and were then pleasant. Temperatures were cooler only reaching about 70^{o}F.

October 6: OBS 107, OBS 108, and OBS 109 were recovered as planned. We slowed our transit to OBS 110 by diverting off Line 1 to allow the R/V *Marcus Langseth* to pass as it was shooting MCS Line 1 from west to east. OBS 111, OBS 112, OBS 113, and OBS 114 were all recovered quickly and without incident. OBS 115 required two burn cycles to release from the seafloor and then was recovered without incident. Recovery of OBS 116 went smoothly and was the last operation of the day. Operations were helped by good weather. It was a beautiful day with calm seas, mild wind, and pleasant temperatures.

October 7: It was a day full of OBS recoveries, and marked the last day of OBS recoveries. We successfully recovered OBSs 117-125 between 280/05:29 UTC and 281/02:20 UTC. Most of the recoveries went smoothly and as planned. The recoveries of OBS 118 and OBS 123 required two burn cycles before they released from the seafloor, but then were recovered as planned. Recoveries were helped by good weather – calm seas, mild winds, and pleasant temperatures. We also received complete shot logs for the OBS and MCS lines that were acquired while the OBSs were on the seafloor. The OBS technicians started using these data to make SEG-Y files for all shot-OBS pairs.

October 8: Just after midnight we started our 40-hour transit back to Rhode Island. For a while the winds picked up, which led to a few rolls of the ship. The packing of all OBS gear for demobilization nonetheless went forward without issues.

October 9: As we approached Narragansett Bay from the south, we made copies of the SEG-Y and miniSEED data provided by the WHOI and SIO OBSIP teams, as well as the underway data from the R/V *Endeavor*. At 3:00 PM EDT we returned to the SENESCO dock of North Kingstown, RI. That evening we had our first dinner on shore with a few beers.

October 10: Shortly after breakfast we offloaded the OBS gear of the SIO team, followed immediately by the WHOI van at 9:30 AM EDT. By early afternoon trucks for the both the WHOI and SIO gear were loaded up and on their way back to the OBSIP facilities. The science party then gathered their personal items, and arranged plans for the trip home.

Seafloor surveys

The proposed locations for OBSs 104, 105, and 419 are within essential fish habitats - habitat areas of particular concern (EFH-HAPC) off Cape Hatteras, so we conducted 3.5/12 kHz echosounder surveys around the proposed sites. The surveys were conducted to image the seafloor conditions and confirm that the OBS locations were located in soft, sedimented locations and not on hardgrounds which could be coral habitats. To accomplish this a grid of ~6 km was collected over each site providing at least 0.5 km coverage from the proposed location (Figure 5).

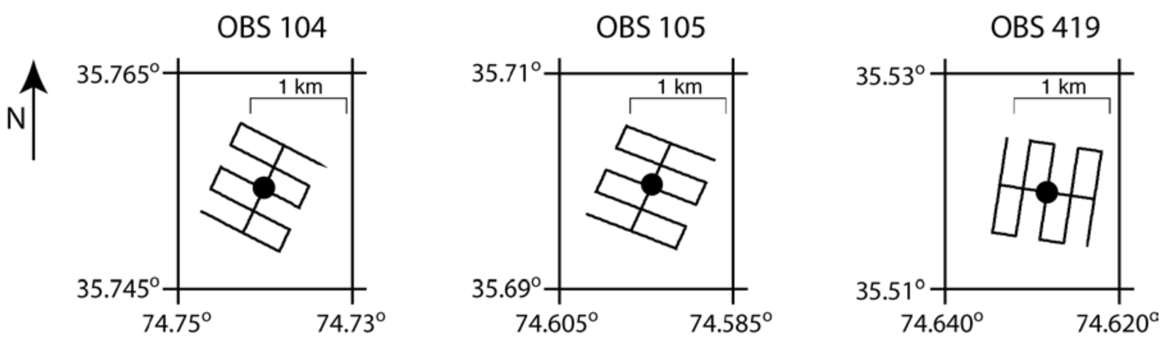

Figure 5. Planned survey grids over proposed sites for OBS 104, OBS 105, and OBS 419. Proposed OBS locations (solid black dots) are the center of the surveys which extend 500 m away from the sites.

The general strategy was to have one watchstander looking at echosounder data in real-time and another observer logging operations. We were watching for four key characteristics in the echosounder data: (1) seafloor reflection in the 12 kHz data; (2) layering in the 3.5 kHz data; (3) no/low reflectivity in the 3.5 kHz data; or (4) high surface reflectivity in the 3.5 kHz data with significant attenuation below. The 12kHz data helped indentify the bathymetry across the survey regions. Layering or low/no reflectivity in the 3.5 kHz data is indicative of soft sediments allowing 3.5 kHz penetration (layering) or soft sediments of low velocity and density (low/no reflectivity) indicative of recent sedimentation. High 3.5 kHz surface reflectivity underlain by blanking is indicative of a hardground.

Survey for OBS 104

The seafloor survey for OBS 104 collected chirp data centered on the proposed OBS location (Figure 6). Water depths ranged from 850 m to 1140 m (Figure 7). The 12 kHz data showed a consistent seafloor response (Figure 7 bottom) with no indication of any hard seafloor. The 3.5 kHz data were dominated by low reflectivity, but did show some regions of layered sediments (e.g., around trace 2100) (Figure 7 top). Based on the consistent response in the 12 kHz and the presence of low reflectivity or layering in the 3.5 kHz data, we do not interpret any hard seafloor in the survey region, which extends greater than 500 m from the proposed location of OBS 104.

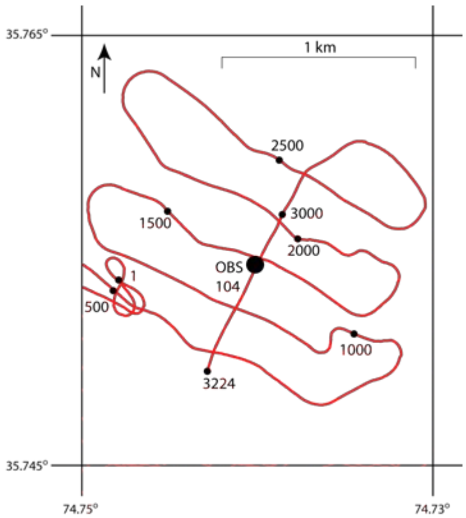

Figure 6. Track map for seafloor environmental survey over proposed location for OBS 104 (red line). Proposed OBS site is large black dot. Small, numbered dots are chirp trace numbers.

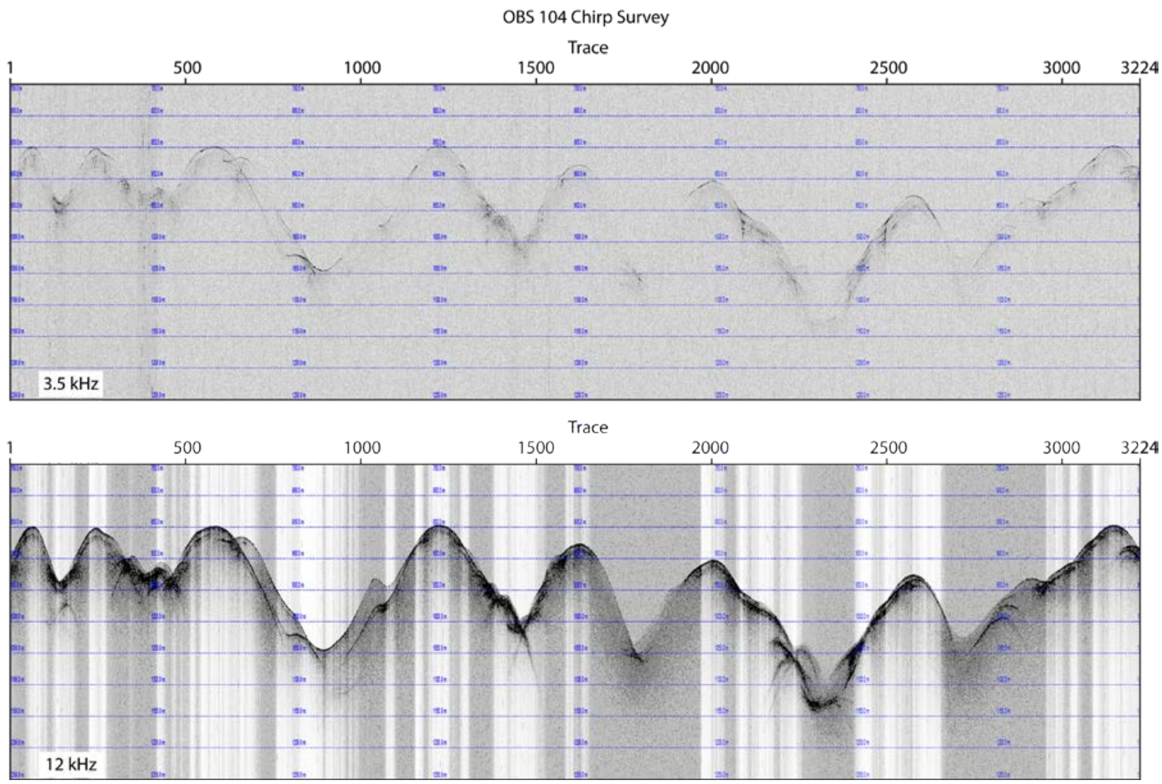

Figure 7. Raw 3.5kHz (top) and 12kHz chirp survey for OBS 104. Track map for survey is located in Figure 6. Depth scale is constant from 750-1250 m water depth across the profiles.

Survey for OBS 105

The seafloor survey for OBS 105 collected chirp data centered around the proposed OBS location (Figure 8). Water depths ranged from 1625 m to 2090 m (Figure 9). All data collected in this region show very low reflectivity. This is likely the result of rougher sea state during acquisition and a soft seafloor. The 12 kHz data showed an inconsistent seafloor response, at times no response is interpreted (Figure 9 bottom). The 3.5 kHz data were dominated by very low-to-no reflectivity (Figure 9 top). Based on the low-to-no reflectivity in the 12 kHz and the 3.5 kHz data, we do not interpret any hardgrounds in the survey region, which extends greater than 500 m from the proposed location of OBS 105.

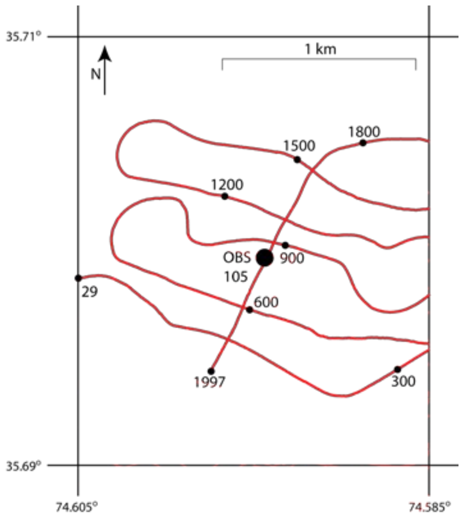

Figure 8. Track map for seafloor environmental survey over proposed location for OBS 105 (red line). Proposed OBS site is large black dot. Small, numbered dots are chirp trace numbers.

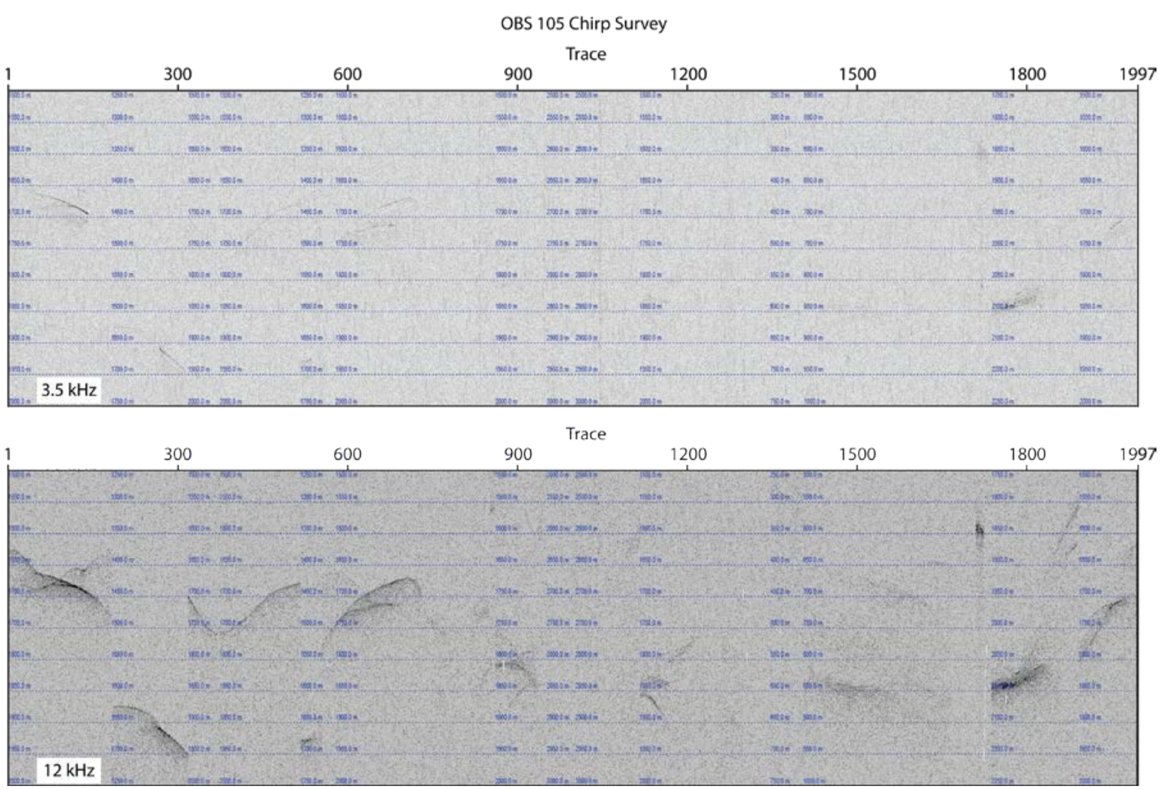

Figure 9. Raw 3.5kHz (top) and 12kHz chirp survey for OBS 105. Trackmap for survey is located in Figure 8. Depth scale varies along the profile (blue lines) based on changes in water depth and dynamic chirp scale adjustments.

Survey for OBS 419

The seafloor survey for OBS 419 collected chirp data centered around the proposed OBS location (Figure 10). Water depths ranged from 1925 m to 2075 m (Figure 11). Most of the data in this survey show low reflectivity, but there are some normal seafloor responses in the 12 kHz data. Similar to the survey for OBS 105, rougher sea state during acquisition and a soft seafloor are likely the cause for the lack of reflectivity in much of the survey. The 12 kHz data showed an inconsistent seafloor response, at times no response is interpreted, but a few bathymetric lows show a consistent seafloor response (Figure 11 bottom). The 3.5 kHz data were dominated by very low-to-no reflectivity, but do show a low reflectivity response and subtle layering where the 12 kHz data are good (Figure 11 top). Based on the low-to-no reflectivity in the 3.5 kHz data, we do not interpret any hardgrounds in the survey region, which extends greater than 500 m from the proposed location of OBS 419.

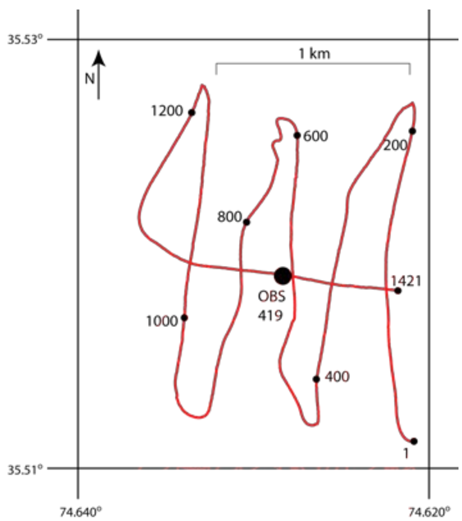

Figure 10. Track map for seafloor environmental survey over proposed location for OBS 419 (red line). Proposed OBS site is large black dot. Small, numbered dots are chirp trace numbers.

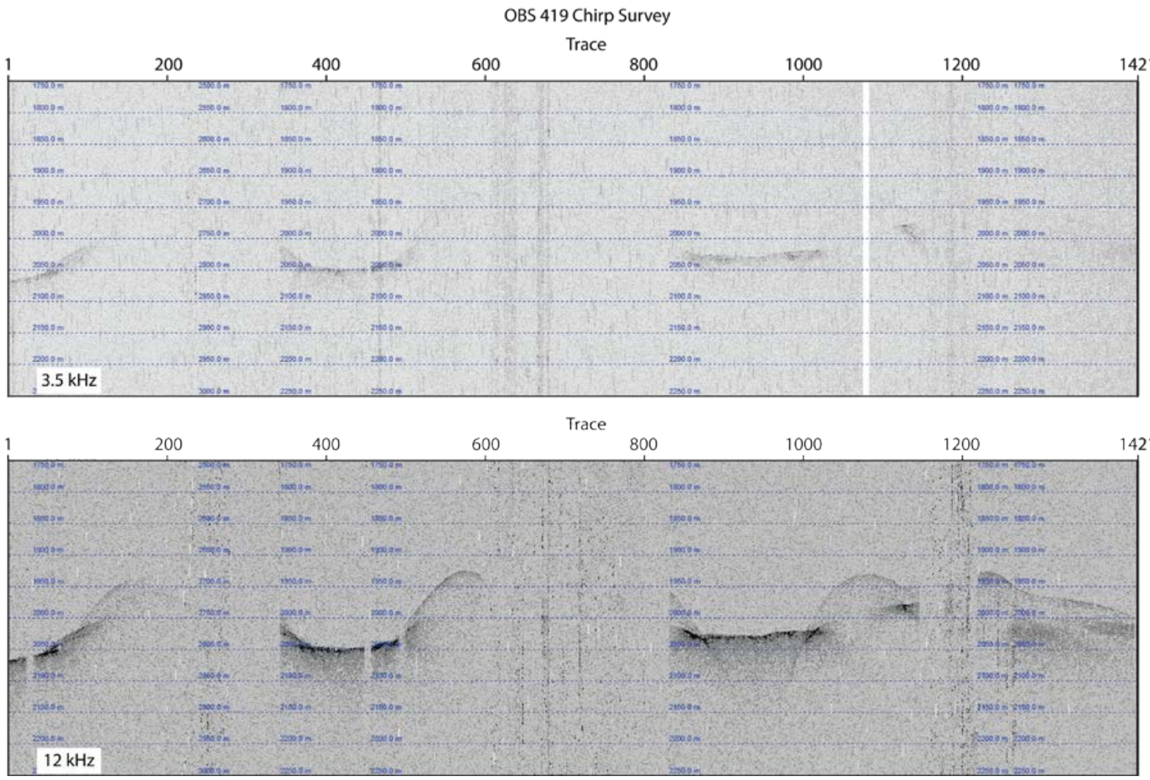

Figure 11. Raw 3.5kHz (top) and 12kHz chirp survey for OBS 419. Trackmap for survey is located in Figure 10. Depth scale varies along the profile (blue lines) based on changes in water depth and dynamic chirp scale adjustments.

OBS deployment and recovery

In the design of the ENAM active-source program, short-period OBSs from the SIO and WHOI OBSIP teams were spaced 10 km to 25 km apart along four major transects (Figure 2). Line 4 consists of two subsets (Line 4a and 4b) that cross each other at a narrow angle offshore Cape Hatteras. To allow each of the two OBSIP groups to design a daily work and sleep schedule around the OBS operations, we grouped the OBS sites in sets of three, four, or five instruments that were assigned to either WHOI or SIO.

We experienced generally favorable weather conditions during the OBS deployments and recoveries. One other factor that we considered during OBS deployments was the Gulf Stream current (Figure 12), which could drift instruments up to 1.0 km from the drop site to their seafloor location. In areas where surface currents exceeded 2 knots, we often deployed OBSs some distance from their desired location, with the expectation that the OBSs would descend to the planned instrument location.

In Table 1 to Table 4, we list the time and location of OBS deployment and recovery for each of the ENAM transects, together with surface currents during these operations. In Table 5 we show the OBS coordinates in the few cases where we conducted an acoustic survey to find the precise location on the seafloor. Table 6 summarizes the timing and orientation of each of the R/V *Marcus Langseth* shot lines. A comparison with the OBS shipboard operations (Table 1 to 4) clarifies which of these airgun shots were recorded by the short-period OBS array.

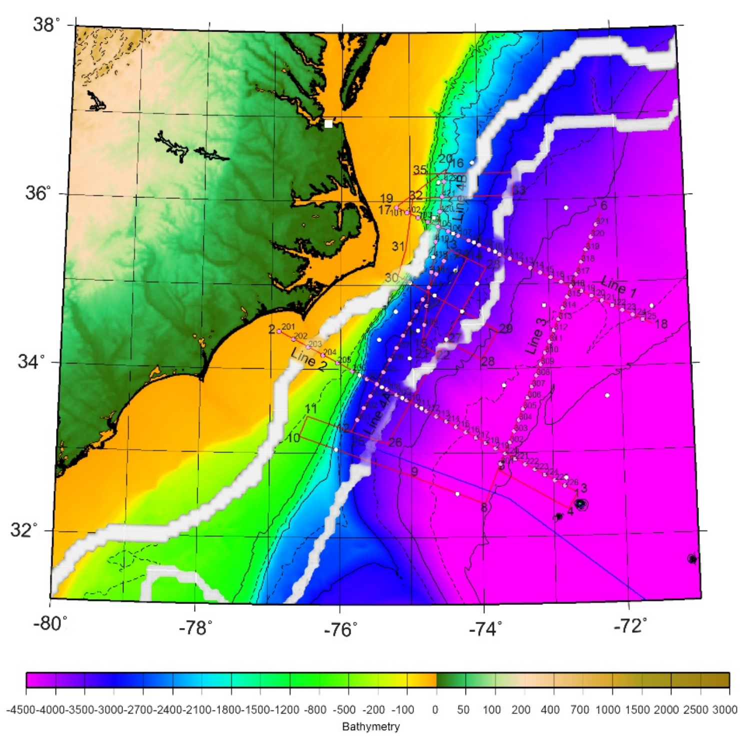

Figure 12. Forecast of the boundaries of the Gulf Stream on September 12, 2014, superimposed on the cruise plan.

Weather

The weather started out very favorable for the EN-546 cruise. The calm seas certainly helped us finish the first OBS deployment on Lines 3 and 2 roughly half a day faster than originally planned. Hurricane Edouard could have posed a threat as it rapidly approached us on September 15 and 16, but afterwards it veered off to the northeast (Figure 13). It did significantly affect the working conditions for the R/V *Endeavor* but did not delay our overall operations. We also encountered two other weather systems that created rough seas and periods of intense rainfall. The first was from September 20 to September 21 when barometric pressure dropped from ~1020 mbars to ~1000 mbars and winds were near 40 knots. The second occurred on October 4 when barometric pressure dropped from ~1018 mbars to ~1000 mbars and winds were near 35 knots. Each of these events made rough sea conditions that made spotting OBSs at the surface more difficult, and at times made approaching and hooking the OBSs harder than normal. Overall, however, weather conditions were fantastic with smooth seas (less than 5 m) and mild winds (less than 20 knots, and often 10-15 knots). These conditions allowed us to continually stay ahead of schedule on our OBS deployments and our OBS recoveries.

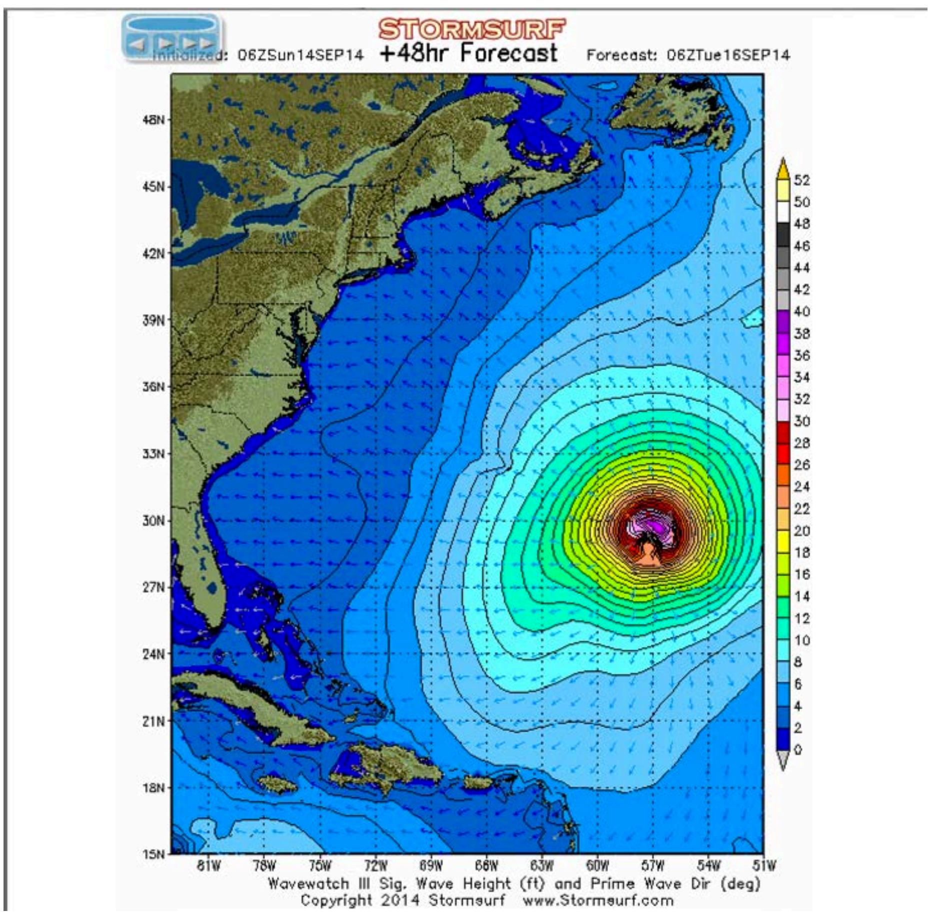

Figure 13. Closest approach of Hurricane Edouard to the ENAM area, on September 16.

Table 1a. Deployment statistics of OBSs on Line 1.

OBS	Type	Deployment		Latitude (N)		Longitude (W)				
		Julian day	Time	Deg.	minutes	Deg.	minutes	Depth	Current	Azimuth
100	WHOI	272	0:31	35	55.497	75	11.624	35	0.4	310
101	SIO	272	0:45	35	55.557	75	11.495	35	0.3	334
102	WHOI	271	23:32	35	52.096	75	2.536	40	0.3	326
103	WHOI	271	22:07	35	48.454	74	52.857	96	0.1	51
104	WHOI	271	21:16	35	45.281	74	44.39	878	0.8	31
105	SIO	271	20:23	35	41.574	74	35.987	1604	2.6	32
106	SIO	271	19:13	35	38.292	74	26.968	2368	1.7	34
107	SOI	271	18:09	35	34.997	74	18.007	2614	1.2	29
108	WHOI	271	17:17	35	31.655	74	9.029	2829	1.2	17
109	WHOI	271	16:27	35	28.307	74	0.114	3036	1.1	358
110	WHOI	271	15:08	35	25.173	73	51.162	3271	1.1	8
111	WHOI	271	14:15	35	21.736	73	42.28	3427	0.9	352
112	SIO	271	13:17	35	18.301	73	33.463	3601	0.8	323
113	SIO	271	12:19	35	14.844	73	24.58	3776	0.3	4
114	SIO	271	11:17	35	11.414	73	15.762	3940	0.4	68
115	WHOI	271	10:10	35	7.985	73	6.964	4080	0.6	74
116	WHOI	271	9:14	35	4.528	72	58.155	4190	0.5	83
117	WHOI	271	8:16	35	1.044	72	49.35	4265	0.7	95
118	WHOI	271	7:18	34	57.544	72	40.586	4340	0.7	124
119	SIO	271	5:55	34	54.010	72	31.838	4397	0.9	122
120	SIO	271	4:49	34	50.474	72	23.126	4442	0.5	119
121	SIO	271	3:37	34	46.930	72	14.448	4447	0.5	115
122	WHOI	271	2:41	34	43.375	72	0.7291667	4433	0.4	70
123	WHOI	271	1:44	34	39.795	71	57.049	4388	0.4	90
124	WHOI	271	0:42	34	36.205	71	48.381	4416	0.3	41
125	WHOI	270	23:41	34	32.606	71	39.757	4491	0.1	82

Table 1b. Recovery statistics of OBSs on Line 1.

OBS	Type	Recovery		Latitude (N)		Longitude (W)				
		Julian day	Time	Deg.		Deg.		Depth	Current	Azimuth
100	WHOI	278	13:00	35	55.267	75	11.507	34	0.8	155
101	SIO	278	13:33	35	55.422	75	11.442	35	0.5	160
102	WHOI	278	15:05	35	51.911	75	2.619	40	0.7	188
103	WHOI	278	16:46	35	48.492	74	52.784	87	0.5	69
104	WHOI	278	18:16	35	45.43	74	44.296	975	0.8	19
105	SIO	279	1:45	35	42.545	74	35.113	1683	2.7	31
106	SIO	279	3:46	35	39.232	74	26.249	2387	2.8	30
107	SOI	279	5:58	35	35.901	74	17.288	2607	2.4	34
108	WHOI	279	8:00	35	32.33	74	8.437	2815	1.7	33
109	WHOI	279	10:05	35	29.175	73	59.68	3037	1	32
110	WHOI	279	12:40	35	25.673	73	50.85	3281	0.3	317
111	WHOI	279	15:15	35	22.187	73	41.972	3419	0.4	4
112	SIO	279	17:33	35	18.86	73	33.001	3594	0.7	35
113	SIO	279	19:56	35	15.21	73	24.266	3760	0.8	44
114	SIO	279	22:19	35	11.613	73	15.717	3931	0.4	47
115	WHOI	280	0:54	35	7.975	73	7.019	4065	0.2	37
116	WHOI	280	3:12	35	4.447	72	58.24	4185	0.6	178
117	WHOI	280	5:29	35	0.902	72	49.736	4264	0.9	215
118	WHOI	280	8:10	34	57.501	72	41.087	4334	0.5	250
119	SIO	280	10:50	34	53.848	72	31.411	4398	0.4	302
120	SIO	280	13:27	34	50.299	72	23.843	4442	0.2	309
121	SIO	280	16:15	34	46.885	72	15.176	4448	0.1	266
122	WHOI	280	18:36	34	43.274	72	6.277	4436	0.7	185
123	WHOI	280	21:05	34	39.58	71	57.658	4392	0.7	227
124	WHOI	280	23:34	34	35.863	71	49.109	4432	0.5	195
125	WHOI	281	2:20	34	32.328	71	40.425	4490	0.3	248

Table 2a. Deployment statistics of OBSs on Line 2.

OBS	Type	Deployment		Latitude (N)		Longitude (W)				
		Julian day	Time	Deg.	minutes	Deg.	minutes	Depth	Current	Azimuth
201	SIO	261	3:01	34	26.943	76	53.294	26	0.3	291
202	SIO	261	1:41	34	21.416	76	40.449	28	0.4	285
203	SIO	261	0:21	34	15.903	76	27.853	33	0.2	213
204	SIO	260	22:58	34	10.323	76	15.2	43	0.2	243
205	WHOI	260	21:31	34	4.577	76	2.649	381	1.7	38
206	WHOI	260	19:11	33	58.845	75	50.124	840	2.5	33
207	WHOI	260	15:32	33	52.876	75	37.712	2972	1.8	32
2404	WHOI	260	14:16	33	49.666	75	28.823	3044	1.2	32
208	SIO	260	11:30	33	45.858	75	20.478	3203	0.5	45
209	SIO	260	10:38	33	42.048	75	11.995	3381	0.2	160
210	SIO	260	9:45	33	38.493	75	3.314	3562	1.1	212
211	SIO	260	8:50	33	34.642	74	54.885	3717	1	220
212	SIO	260	7:53	33	30.410	74	46.859	3897	0.8	180
213	WHOI	260	6:52	33	26.603	74	38.405	4068	0.9	172
214	WHOI	260	5:52	33	22.733	74	30.064	4243	0.6	187
215	WHOI	260	4:44	33	18.884	74	21.64	4379	0.9	153
216	WHOI	260	1:11	33	15.021	74	13.342	4485	0.8	135
217	SIO	260	0:15	33	11.121	74	5.014	4572	0.7	102
218	SIO	259	23:21	33	7.180	73	56.672	4682	0.5	99
219	SIO	259	21:55	33	3.294	73	48.371	4770	0.5	86
220	SIO	259	20:51	32	59.466	73	40.259	4893	0.4	77
221	SIO	259	19:50	32	55.535	73	31.935	4993	0.4	90
222	WHOI	259	18:30	32	50.651	73	21.594	5073	0.3	74
223	WHOI	259	17:18	32	45.714	73	11.255	5134	0.2	53
224	WHOI	259	15:57	32	40.802	73	0.934	5197	0.4	6
225	WHOI	259	14:41	32	35.866	72	50.61		0.3	21
500	SIO	273	12:42	34	20.190	76	41.219	28	0.3	342

Table 2b. Recovery statistics of OBSs on Line 2.

OBS	Type	Recovery		Latitude (N)		Longitude (W)				
		Julian day	Time	Deg.		Deg.		Depth	Current	Azimuth
201	SIO	265	8:40	34	27.029	76	53.246	25	0.1	243
202	SIO	265	6:42	34	21.427	76	40.419	27	0.2	222
203	SIO	265	5:00	34	15.804	76	27.645	31	0.2	131
204	SIO	265	2:50	34	10.173	76	15.118	43	0.5	218
205	WHOI	265	1:02	34	4.91	76	2.551	388	1.5	343
206	WHOI	264	23:15	34	0.124	75	49.827	873	3.5	359
207	WHOI	264	20:53	33	54.266	75	37.125	2974	2.7	1
2404	WHOI	264	18:08	33	50.415	75	28.186	3057	2	29
208	SIO	264	11:35	33	45.938	75	19.942	3117	1.7	50
209	SIO	264	8:56	33	41.986	75	11.756	3386	0.2	116
210	SIO	264	5:35	33	37.983	75	3.462	3561	0.4	105
211	SIO	264	2:58	33	33.791	74	55.462	3741	0.8	204
212	SIO	263	23:49	33	29.446	74	47.178	3896	1.8	188
213	WHOI	263	21:04	33	25.642	74	38.553	4071	1.8	182
214	WHOI	263	18:30	33	21.96	74	29.992	4241	0.9	165
215	WHOI	263	15:55	33	18.142	74	21.476	4368	1	140
216	WHOI	263	13:16	33	14.429	74	13.055	4480	0.6	105
217	SIO	263	10:32	33	10.604	74	4.555	4576	0.8	90
218	SIO	263	7:20	33	6.881	73	56.216	4718	0.6	91
219	SIO	263	4:18	33	3.268	73	47.771	4768	0.9	69
220	SIO	263	0:58	32	59.579	73	39.745	4907	0.6	46
221	SIO	262	21:30	32	55.725	73	31.439	5106	0.6	60
222	WHOI	262	18:14	32	50.936	73	21.301		0.3	314
223	WHOI	262	15:06	32	45.873	73	11.167	5133	0.2	257
224	WHOI	262	12:20	32	40.776	73	0.91	5196	0.5	23
225	WHOI	262	7:37	32	35.955	72	50.543	4793?	0.1	65
500	SIO	274	15:01	34	20.139	76	41.34	29	0.2	221

Table 3a. Deployment statistics of OBSs on Line 3.

OBS	Type	Deployment		Latitude (N)		Longitude (W)				
		Julian day	Time	Deg.	minutes	Deg.	minutes	Depth	Current	Azimuth
301	SIO	259	10:27	32	52.207	73	44.261	4857	0.4	113
302	SIO	259	8:47	33	7.395	73	36.336	4864	0.7	52
303	SIO	259	7:49	33	15.318	73	32.399	4793	0.4	42
304	SIO	259	6:46	33	23.262	73	28.471	4743	0.7	12
305	SIO	259	5:47	33	31.156	73	24.513	4695	0.8	355
306	WHOI	259	4:43	33	39.082	73	20.562	4659	0.7	331
307	WHOI	259	3:34	33	46.994	73	16.597	4701	0.9	341
308	WHOI	259	2:27	33	54.902	73	12.622	4646	1.1	329
309	WHOI	259	1:18	34	2.823	73	8.638	4515	1.2	332
310	WHOI	259	2:09	34	10.720	73	4.6	4453	1.1	342
311	SIO	258	22:59	34	18.699	73	0.689	4439	1.1	341
312	SIO	258	21:49	34	26.572	72	56.532	4502	0.5	336
313	SIO	258	20:27	34	34.472	72	52.494	4497	0.8	11
314	SIO	258	19:28	34	42.344	72	48.344	4404	0.6	21
315	WHOI	258	18:06	34	50.236	72	44.411	4343	0.2	345
316	WHOI	258	16:02	34	57.509	72	40.549	4333	0	77
317	WHOI	258	14:58	35	6.288	72	36.078	4313	0.1	270
318	WHOI	258	13:55	35	14.990	72	31.48	4007?	0.3	270
319	WHOI	258	12:52	35	23.705	72	26.835	4225	0.7	137
320	SIO	258	11:54	35	32.480	72	22.27	4170	0.3	154
321	WHOI	258	10:30	35	41.023	72	17.658	4078	0.2	324

Table 3b. Recovery statistics of OBSs on Line 3.

OBS	Type	Recovery		Latitude (N)		Longitude (W)				
		Julian day	Time	Deg.		Deg.		Depth	Current	Azimuth
301	SIO	267	22:20	32	52.619	73	43.95	4858	0.8	336
302	SIO	268	2:02	33	8.065	73	35.835	4854	0.7	9
303	SIO	268	4:47	33	15.784	73	32.311	4780	0.8	19
304	SIO	268	7:32	33	23.833	73	28.686	4731	1	349
305	SIO	268	10:22	33	31.768	73	24.918	4697	1.2	10
306	WHOI	268	15:31	33	39.616	73	21.148		0.2	356
307	WHOI	268	18:50	33	47.443	73	17.237	4744	0.7	281
308	WHOI	268	21:18	33	55.401	73	13.313	4563	0.8	290
309	WHOI	269	0:58	34	3.693	73	9.672	4493	1.4	315
310	WHOI	269	3:19	34	10.964	73	5.004	4452	1.6	325
311	SIO	269	5:56	34	18.927	73	0.916	4437	1.2	342
312	SIO	269	12:42	34	26.557	72	56.771	4502	0.4	91
313	SIO	269	15:21	34	34.383	72	52.568	4489	0.7	156
314	SIO	269	18:01	34	42.125	72	48.452	4405	0.7	217
315	WHOI	269	20:47	34	50.061	72	44.554	4334	0.7	231
316	WHOI	269	23:26	34	57.389	72	40.748	4334	0.6	265
317	WHOI	270	2:39	35	6.256	72	36.132	4320	0.7	81
318	WHOI	270	5:35	35	14.865	72	31.505	4270?	0.5	110
319	WHOI	270	8:27	35	23.32	72	27.026	4235	0.4	118
320	SIO	270	11:25	35	32.105	72	22.665	4685?	0.1	178
321	WHOI	270	14:29	35	40.969	72	18.372	4084	0.5	280

Table 4a. Deployment statistics of OBSs on Line 4.

OBS	Type	Deployment		Latitude (N)		Longitude (W)				
		Julian day	Time	Deg.	minutes	Deg.	minutes	Depth	Current	Azimuth
401	SIO	265	17:01	33	23.872	75	50.033	2900	2.9	59
402	SIO	265	18:16	33	34.035	75	43.526	3012	3.6	47
403	SIO	265	19:25	33	44.239	75	37.434	3073	3.7	35
404	SIO	265	20:34	33	54.011	75	31.083	2999	3.7	19
405	SIO	265	21:33	34	4.068	75	24.737	2967	2.9	6
406	WHOI	265	22:34	34	14.115	75	18.26	3024	2.4	7
407	WHOI	265	23:31	34	24.256	75	11.862	2979	2	21
408	WHOI	266	0:28	34	33.790	75	5.764	2904	2	32
409	WHOI	266	3:36	34	37.002	74	47.168	3140	1.2	42
410	SIO	266	5:01	34	43.111	74	58.318	2884	2.3	31
411	SIO	266	6:39	34	48.393	74	45.409	2973	2.1	47
412	SIO	266	7:56	34	52.611	74	53.74	2850	2.5	46
413	SIO	266	9:15	35	0.029	74	43.466	2420?	2.8	44
414	SIO	266	10:20	35	2.030	74	47.659	2735	2.9	46
415	WHOI	266	11:34	35	11.861	74	41.27	2605	3.2	44
416	WHOI	266	12:33	35	19.866	74	35.961		3.6	40
417	WHOI	266	13:18	35	22.092	74	39.411	2248	2.9	35
418	WHOI	266	14:14	35	27.936	74	30.814	2290	3.1	34
419	SIO	266	15:08	35	31.732	74	37.564	2216	2.5	31
420	SIO	266	17:16	35	52.489	74	33.67	1925	1.9	32
421	SIO	266	18:33	36	3.172	74	31.769	1810	1.2	28
422	SIO	266	20:05	36	14.679	74	29.659	1631	0.6	29

Table 4b. Recovery statistics of OBSs on Line 4. OBS 419 was lost.

OBS	Type	Recovery		Latitude (N)		Longitude (W)				
		Julian day	Time	Deg.		Deg.		Depth	Current	Azimuth
401	SIO	275	13:50	33	24.413	75	48.445	2873	2.2	48
402	SIO	275	16:26	33	34.86	75	42.073	3005	2.5	52
403	SIO	275	19:03	33	45.382	75	36.103	3120	2.3	54
404	SIO	275	21:38	33	55.045	75	30.208	3003	2	50
405	SIO	276	0:08	34	5.002	75	23.376	2892	2.6	51
406	WHOI	276	3:47	34	14.644	75	17.576	3034	2.5	42
407	WHOI	276	6:07	34	24.842	75	11.275	2979	2.3	27
408	WHOI	276	8:25	34	34.555	75	5.328	2857	2.3	10
409	WHOI	276	21:57	34	38.383	74	46.602	3156	2.1	11
410	SIO	277	0:27	34	43.892	74	59.573	2887	2.4	4
411	SIO	277	3:01	34	49.802	74	44.859	2809	2.4	13
412	SIO	277	5:10	34	53.552	74	53.533	2872	2.2	1
413	SIO	277	7:52	35	1.92	74	42.732	2825	2.2	14
414	SIO	277	9:44	35	3.124	74	47.234	2715	2.3	14
415	WHOI	277	11:54	35	13.098	74	40.655	2596	2.5	31
416	WHOI	277	14:53	35	21.002	74	34.99	2430	2.9	41
417	WHOI	277	16:29	35	22.945	74	38.53	2271	2.8	38
418	WHOI	277	18:11	35	28.562	74	30.166	2295	2.8	43
419	SIO									
420	SIO	278	3:02	35	52.553	74	32.412	1940	2.3	72
421	SIO	278	5:41	36	2.767	74	31.664	1881	0.8	138
422	SIO	278	8:19	36	14.302	74	29.777	1618	1.4	215

Table 5. Relocated OBS locations on Lines 2, 3, and 4 based on ranging.

OBS	Type	Latitude (N)		Longitude (W)		
		Deg.	minutes	Deg.	minutes	Depth
206	WHOI	33	59.136	75	49.782	864
207	WHOI	33	53.332	75	37.2588	2977
208	SIO	33	45.775	75	20.229	3203
210	SIO	33	38.178	75	3.336	3553
211	SIO	33	34.326	74	54.924	3717
216	WHOI	33	14.663	74	13.227	4494
408	WHOI	34	34.110	75	5.3989	2907
409	WHOI	34	37.3904	74	46.8161	3156
307	WHOI	33	47.182	73	17.005	4744

Shot lines of the R/V Marcus Langseth

The short-period OBS array of the ENAM project recorded air-gun shots from regional lines covered by the R/V *Marcus Langseth* (Figure 2). Some of these lines were acquired strictly for multichannel seismic (MCS) reflection imaging, with a shot spacing of 50 m. However, the main transects of the ENAM active-source experiment were shot twice, for MCS and OBS imaging, where the OBS shot spacing was 200 m. In Table 6 we list the OBS and MCS lines that were shot by the seismic vessel over the time that the short-period OBSs were recording on the seafloor.

Table 6. Start and end points of each of the R/V *Marcus Langseth* lines that were shot during the EN-546 short-period OBS deployments.

Line		First shot					Last shot				
Name	Code	Number	Latitude	Longitude	Date	Time	Number	Latitude	Longitude	Date	Time
OBS01A	18	1014	35.917444	-75.173994	10/3/14	6:03:20	2057	35.018144	-72.833716	10/4/14	9:25:43
OBS01B	19	2030	35.034260	-72.898179	10/4/14	12:14:31	2649	34.487986	-71.528396	10/5/14	3:45:11
OBS002	27	970	32.479868	-72.599602	9/18/14	4:55:57	2983	34.444005	-76.871894	9/20/14	14:57:06
OBS003	37	993	32.781428	-73.785599	9/23/14	15:10:17	2625	35.827563	-72.219103	9/25/14	10:10:14
OBS04A	47	992	33.274027	-75.910180	9/29/14	22:14:43	2220	35.475159	-74.503753	9/30/14	19:58:22
OBS04B	48	1024	34.333321	-74.834020	10/2/14	1:26:35	2022	36.336152	-74.477763	10/2/14	20:58:57
MCS01	10	941	34.475466	-71.498576	10/5/14	6:17:20	6087	35.488132	-74.033881	10/6/14	12:13:18
MCS01A	11	5910	35.452969	-73.946547	10/6/14	17:11:01	7787	35.810352	-74.885381	10/7/14	4:55:24
MCS01B	12	7666	35.787095	-74.824851	10/7/14	18:07:40	8349	35.915965	-75.168166	10/7/14	22:02:58
MCS002	20	1029	34.455063	-76.897650	9/20/14	17:26:21	9598	32.601464	-72.850386	9/23/14	0:36:25
MCS003	30	971	35.840361	-72.211680	9/25/14	12:58:57	8395	32.762583	-73.794746	9/27/14	11:21:29
MCS031	31	1257	32.690281	-73.828457	9/27/14	12:38:47	2138	32.321772	-74.002307	9/27/14	17:42:34
MCS032	32	1111	32.325266	-74.062317	9/27/14	18:25:10	4033	32.838443	-75.495497	9/28/14	11:14:45
MCS033	33	1022	32.842574	-75.506546	9/28/14	11:24:02	2817	32.997493	-75.950000	9/28/14	17:34:30
MCS034	34	1020	32.998248	-75.953534	9/28/14	17:38:11	4430	33.256940	-76.813854	9/29/14	14:02:53
MCS035	35	1158	33.202811	-76.789185	9/29/14	15:23:46	2705	33.220424	-76.167267	9/29/14	20:03:15
MCS041	41	1111	35.469440	-74.437817	9/30/14	20:55:07	2200	35.231510	-73.914038	10/1/14	04:36:53
MCS042	42	1045	35.204396	-73.904921	10/1/14	5:01:22	3618	34.196189	-74.598920	10/1/14	21:39:51

OBS data figures

Towards the end of the EN-546 cruise on the R/V *Endeavor*, the SIO and WHOI OBS teams assembled SEG-Y files for the wide-angle seismic data, using shot tables that were sent to us by colleagues on the R/V *Marcus Langseth* (Table 6). The quality of these seismic refraction data is generally good but varies between seismic stations, presumably due to differences in the local geology and a few different noise factors. Since the purpose of this cruise report is to document the operations on the R/V *Endeavor*, we show just one OBS record with four channels for an OBS from WHOI (Figure 14) and for an OBS from SIO (Figure 15) Both these records are from the shots of line OBS002. This cruise report will therefore be followed by a comprehensive data report that provides a better overview of volume and quality of the ENAM OBS refraction data set.

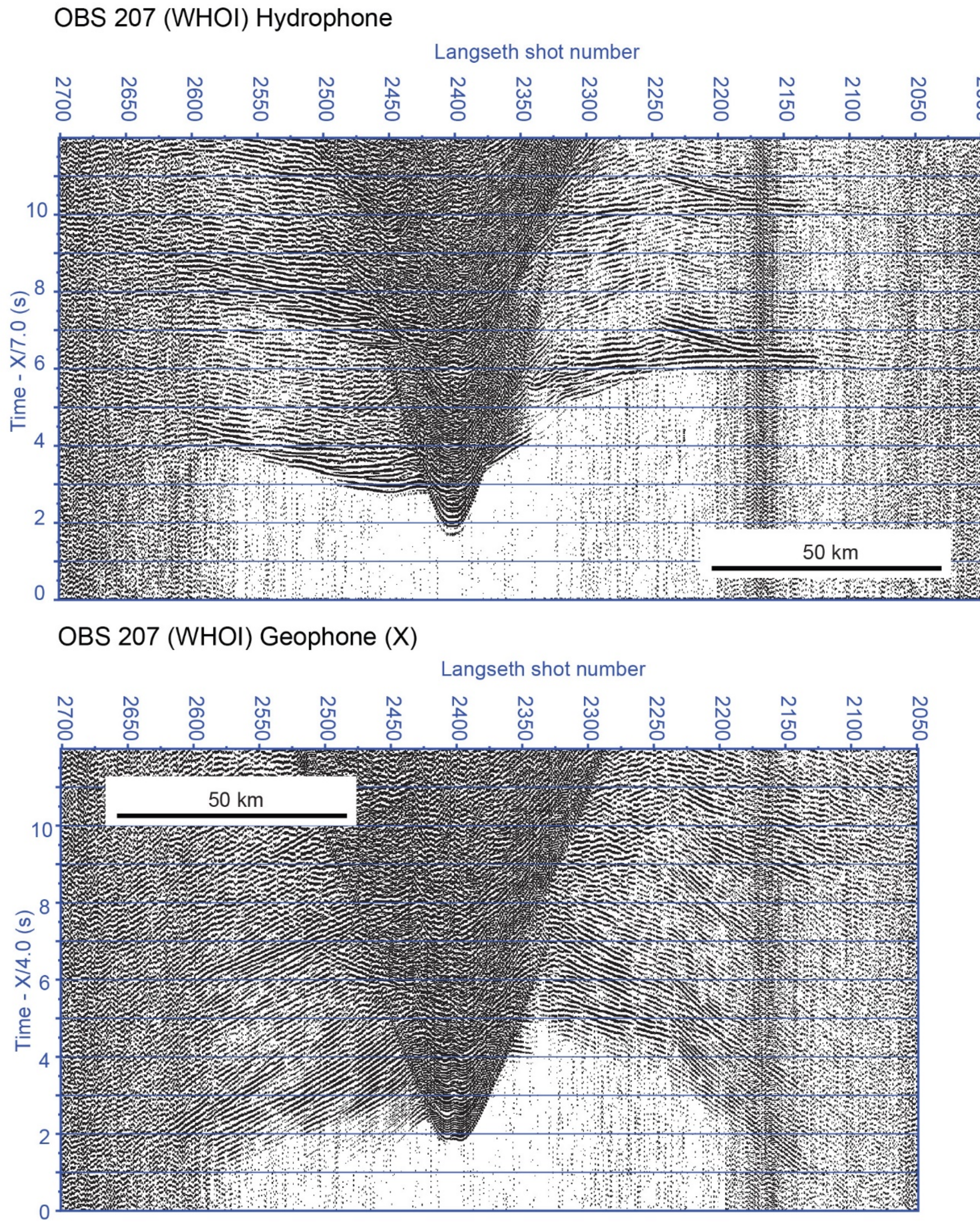

Figure 14a. Shot line OBS002 record sections of OBS 207. This was an instrument from the WHOI OBSIP group. Top: Hydrophone channel. Bottom: Horizontal channel (2).

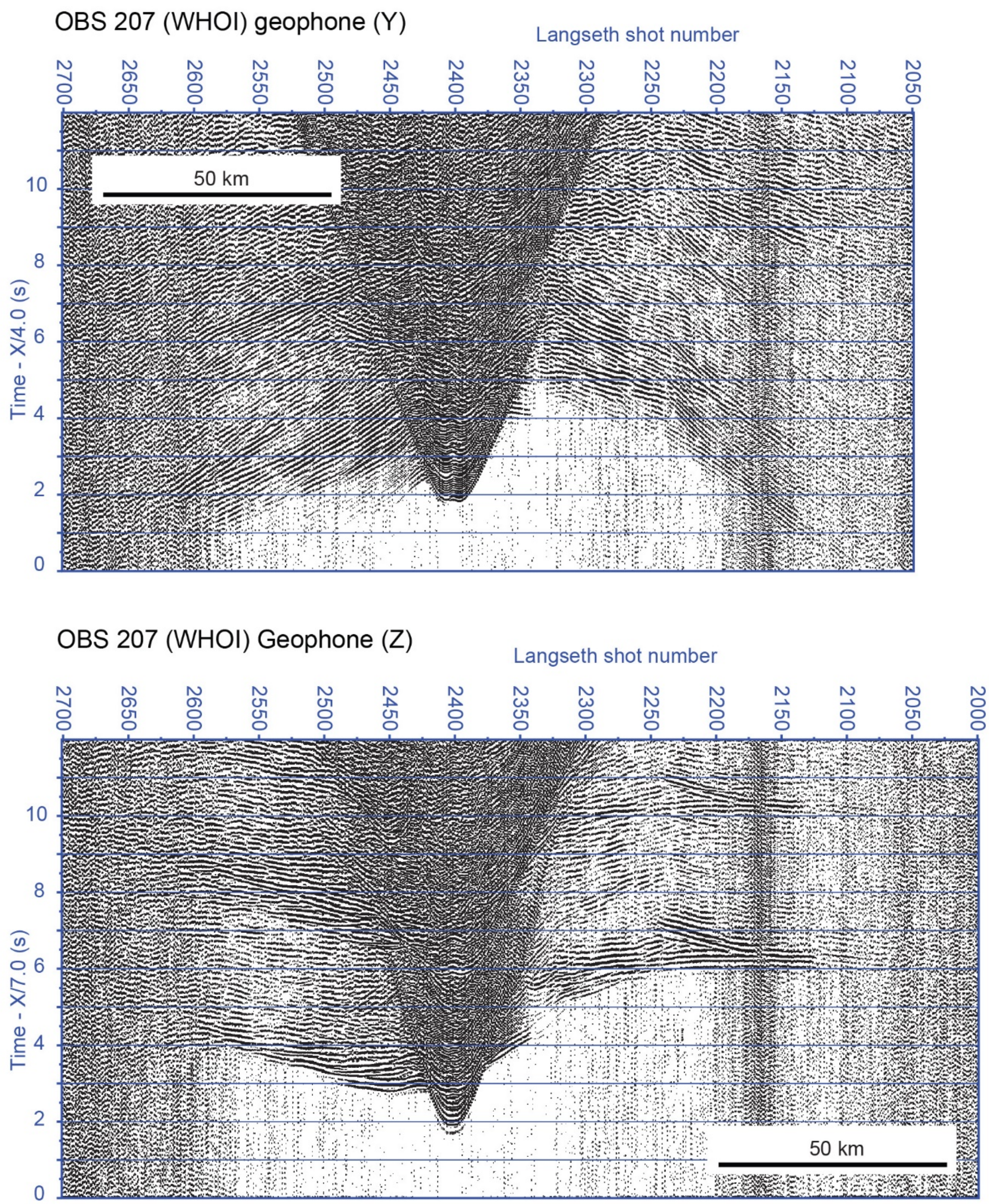

Figure 14b. Shot line OBS002 record sections of OBS 207. This was an instrument from the WHOI OBSIP group. Top: Horizontal channel (3). Bottom: Vertical channel.

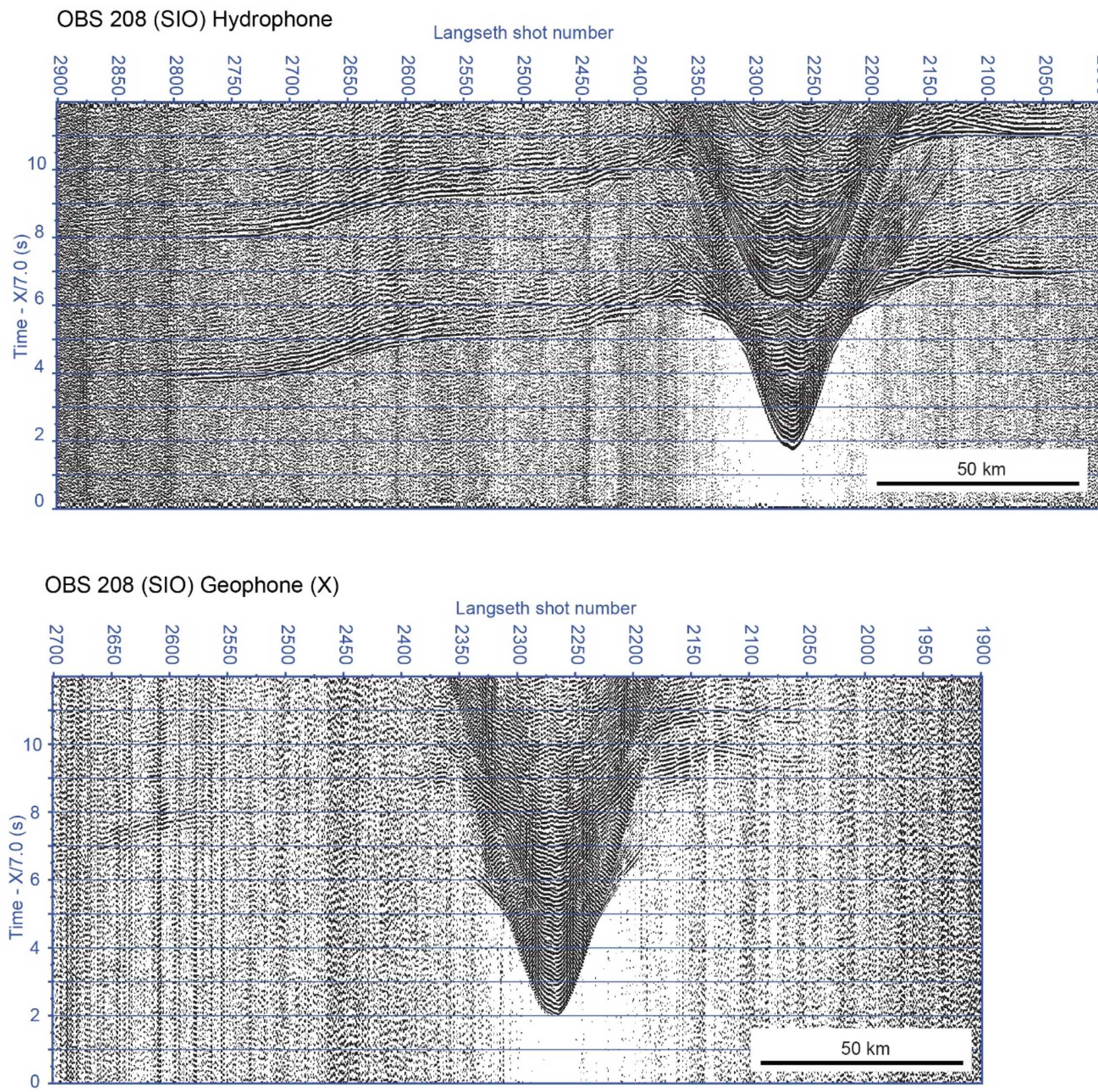

Figure 15a. Shot line OBS002 record sections of OBS 208. This was an instrument from the SIO OBSIP group. Top: Hydrophone channel. Bottom: Horizontal channel (X).

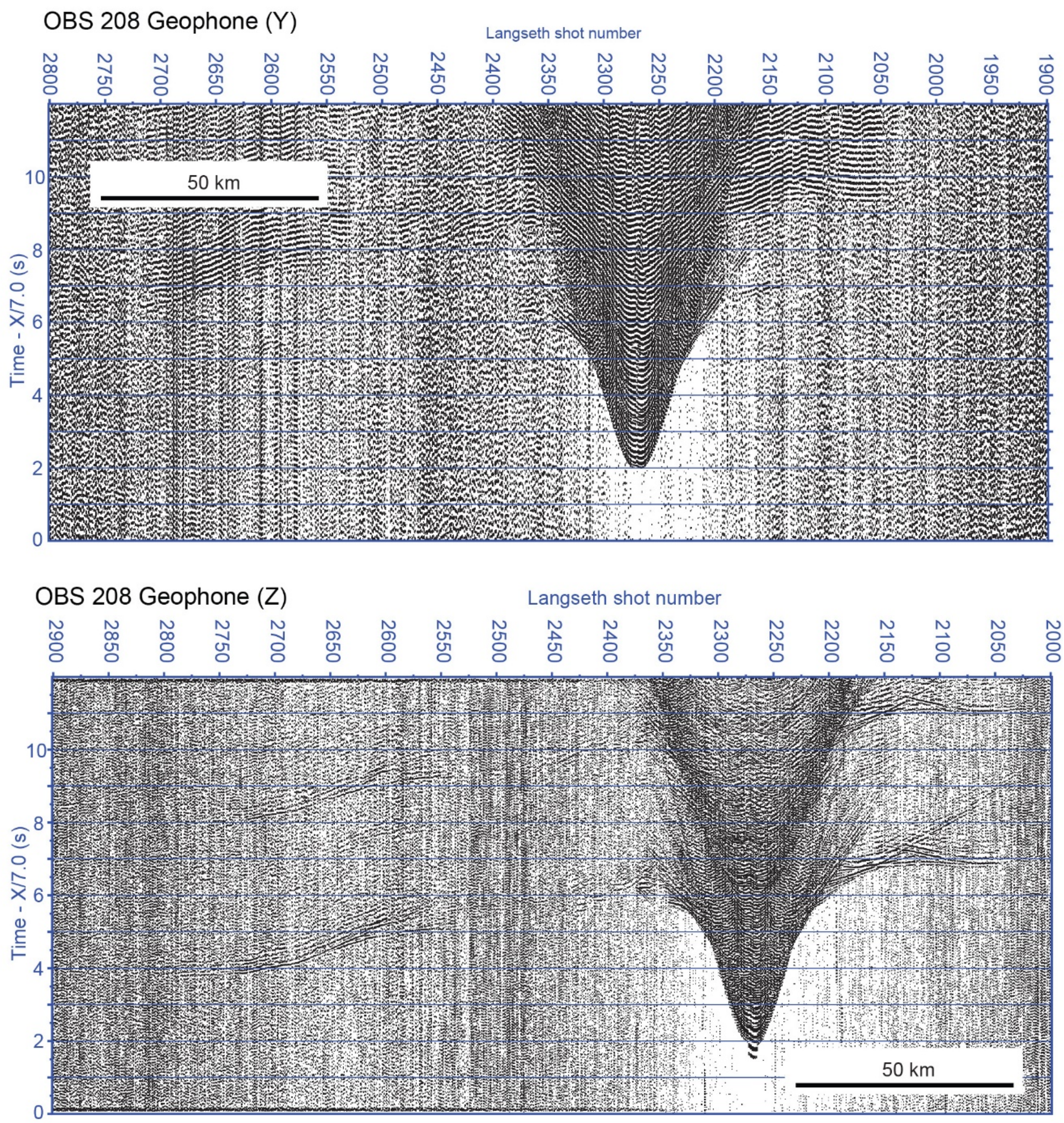

Figure 15b. Shot line OBS002 record sections of OBS 208. This was an instrument from the SIO OBSIP group. Top: Horizontal channel (Y). Bottom: Vertical geophone channel.