Cruise report: GUlf of Mexico Basin Opening (GUMBO)

An OBS seismic refraction study, conducted from October to December 2010 in the northern Gulf of Mexico with the M/V *Iron Cat*.

Chief Scientists:
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University of Texas Institute for Geophysics.

Vessel:
M/V *Iron Cat*, Reservoir Geophysical.

Departure: Sunday October 24, 2010. Amelia Louisiana.
Return: December 6, 2010. Amelia, Louisiana.

December 24, 2010.

Page index.

1. Participants

Johnny Buzbe	RG	Captain	
James Scanlan	RG	Second Captain	
Robin Mareno	RG	Third Captain	11/5 – 12/6
Larry Guillary	RG	Engineer	
Darwin Robertson	RG	Engineer	
Steven Sheely	RG	AB	
Elvin Ruiz	RG	AB	
Ben Bennett	RG	Party Chief	
Todd Meyer	RG	Shift leader Mechanic	
Michael Coufal	RG	Shift leader Mechanic	10/24 – 11/5
Brad Bennington	RG	Shift leader Mechanic	11/5 – 12/6
Riley Hall	RG	Mechanic / Electronic Technician	
Jaffery Reiger	RG	Mechanic / Welder	
Dwayne Fontenot	RG	Electronic Technician	
James Borden	RG	Electronic Technician	
Stephen Anderson	RG	Compressor Technician	
David Thibodeaux	RG	Compressor Technician	10/24 – 11/5
Slade Henry	RG	Compressor Technician	11/5 – 11/22
Josh LeClerc	NCS	Navigator (lead)	
Mitch Scoggins	NCS	Navigator	
Jennifer Scott	DESCO	Marine Mammal Observer (lead)	
Meghan Pieray	DESCO	Marine Mammal Observer	
Greg Sagmeister	DESCO	Marine Mammal Observer	
Richard Mathous	Trinity	Cook	
Jarred Sherry	Trinity	Galley Hand	
Harm Van Avendonk	UT	Chief Scientist	
Gail Christeson	UT	Chief Scientist	
Steffen Saustrup	UT	Scientist	
Drew Eddy	UT	Scientist	
Anatoly Mironov	UT	OBS engineer	
John Gerboc	UT	OBS engineer	10/24 - 11/13
Oleksy Tsyganok	Geopro	OBS engineer	
Yuriy Malykh	Geopro	OBS engineer	
Stephan Marienfeld	Geopro	OBS technician	

2. Basic objectives

The Gulf of Mexico is a relatively small oceanic basin that formed by rifting between the continental blocks of North America and Yucatan in the Middle to Late Jurassic (165 Ma ago). It is currently unknown how much the margins of the continents stretched and thinned before they separated. After the breakup, seafloor spreading formed volcanic crust in at least part of the central Gulf of Mexico. However, in the Early Cretaceous (140 Ma ago) opening between North America and Yucatan stopped. Since then, subsidence and sedimentation have shaped the Gulf margin that we see today.

Currently we only have potential field data and a handful of seismic refraction records to image beneath the top of basement in the Gulf of Mexico. As a result, we do not know how the continental crust of North America tapers towards the central Gulf, and where precisely the transition from continental to oceanic crust can be found. Because of the lack of constraints on the basement, we also do not understand the early depositional setting in which the salt formations developed. A new, comprehensive study of the basement in the Gulf of Mexico would give us insight in the mechanics of continental breakup, and in the role of rift architecture on the post-rift structural development of this margin.

We can image the crustal structure of the Gulf of Mexico by recording seismic waves over offsets of roughly 10 km to 100 km. The larger the source-receiver distance, the deeper the seismic waves will turn in the Earth. To get good lateral resolution in such a seismic image, we must record air-gun shots on an array of seismometers with an internal spacing on the order of 10-20 km.

To understand the opening of the Gulf of Mexico we acquired four long-offset seismic refraction lines on the northern (U.S.) margin. The M/V *Iron Cat* provides a powerful airgun source that is recorded on the seafloor by four-component ocean-bottom seismometers (OBS's) from the University of Texas Institute for Geophysics in Austin (UTIG) and Geopro GmbH, Hamburg.

The four seismic refraction lines all cross the margin from the shallow water near the coast to the deepwater near the U.S.A.-Mexico maritime border. From west to east they can be briefly described as follows:

Line 1, offshore Texas, between Matagorda Island and Alamino Canyon. 307 km.
Line 2, offshore Louisiana, between Vermillion and Sigsbee Escarpment. 396 km.
Line 3, offshore Florida, from Pensacola across de Soto Canyon. 522 km.
Line 4, offshore Florida, Gainesville (Florida) line, from Gainesville to Florida Plain. 546 km.

Despite decades of seismic exploration in the Gulf of Mexico, its deep crustal structure is not yet imaged in much detail. The acquisition of deeply penetration OBS seismic refraction data will help provide new insights in the evolution of the Gulf of Mexico.

3. Ship schedule

Before the start of the project we made a tentative ship schedule based on a variety of parameters for the OBS and sound source operations. These parameters were largely based on previous experience of the UTIG OBS group. Since we were conducting the first seismic refraction study on the M/V *Iron Cat*, we allocated more than 7 days of ship contingency time to our planned ship schedule. Our total amount of operation time for the project was 45 days, which would not include long delays due to port calls, major storm systems, and major ship failure. In the end, we gathered all four seismic transects in 43 days, including 4 port calls and some additional down-time at sea.

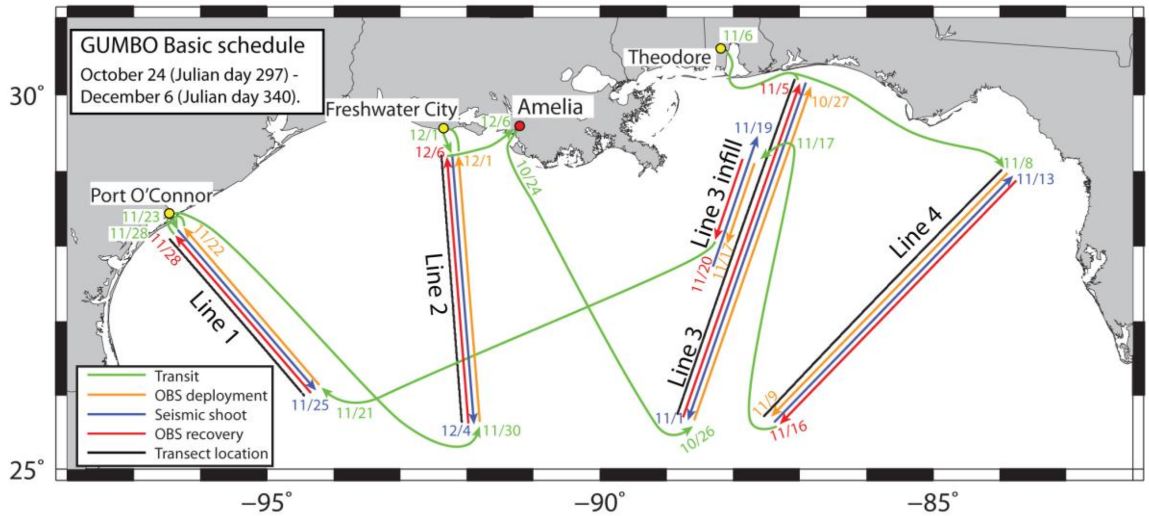


Figure 3.1. Basic schedule of the M/V Iron Cat in the Fall of 2010. Amelia was the start and end port, while Theodore, Port O'Connor, and Freshwater City were brief supply stops. The colored dates on the map indicate the end of each activity (see colors in legend).

Since we were able to meet all our goals in the available ship time, we consider our pre-cruise planning fully adequate. In our fastest predicted ship schedule we would have finished the GUMBO project in 37.5 operation days. We did not meet this schedule by several days for a number of reasons:

1) Although we had assumed that a shooting speed of 4.5 knots may be feasible, the condition of the air compressors rarely allowed us to shoot faster than 4.2 knots, and sometimes no faster than 3.0 knots.
2) We experienced quite a few air leaks in our sound source, which often required us to circle back and re-shoot part of seismic line. This procedure would cost us regularly between 4 and 6 hours.
3) The deployment and recovery of the air-gun array was more difficult than we had expected, costing quite a few additional hours, particularly in poor weather conditions.
4) As we were approaching the winter season, a few northerlies slowed down or halted our operation for a few hours or a full day.
5) Since we had a poor data return in the middle section of line 3, we decided to reshoot part of this transect.

We gained back some of the above time losses during other operations:

1) Both our OBS recoveries and deployments went faster than expected. The crane operations went smoothly, and we did not spend much time searching for OBS's on the sea surface.

2) Our transit speed often approached 11 knots, whereas 10 knots was the transit speed used in our calculations.

We gathered the OBS data along our four transects in the following order (Figure 3.1): Between October 26 and November 5 we laid 45 OBS's on Line 3, produced air-gun shots along the transect, and picked up the instruments. Between November 8 and November 16 we similarly acquired line 4. Between November 17 and November 20 we gathered more OBS data on Line 3, the so-called "Line 3 Infill". Subsequently, we acquired Line 1 between November 21 and November 28. Last, we did Line 2 between November 30 and December 6. The order in which we acquired these transects (3,4,1, and 2) was based on our science priorities. The direction in which we shot the transects was chosen just to minimize transit time.

4. Sound source operations on the M/V *Iron Cat*

During our cruise the R/V *Iron Cat* was equipped with an air gun array composed of 5 strings.The configuration of guns 1 to12 was identical in each string, each giving us a total of 1800 cubic inches in volume. From back to front, the air-gun capacity for each string was as follows: 1) 100, 2) 100, 3) 150, 4) 150, 5) 300, 6) 300, 7) 150, 8) 150, 9) 100, 10) 100, 11) 100, 12) 100. The air-gun arrays were suspended from linear flotation systems for each array string. Guns were towed over/under with 1-m vertical separation at 9 and 10 m. The air-gun controller system was the Real Time Systems RTS Big Shot. The compressor system included 8 Price AirMaster 2000 PSI inline diesel-driven air compressors. Each compressor nominally has 200-250 CFM capacity and furnishes air supply to a common distribution system and the air-gun arrays.

Navigation of the sound source was provided by NCS SubSea. Base GPS positions were determined using a differentially corrected C-Nav GPS receiver, and center of source (airgun array) was positioned using a calculated layback from the vessel. NCS SubSea initiated a trigger to the gun controller; shot confirmation from the Real Time Systems Bigshot gun controller was sent to a Novatel GPS receiver which determined the exact time of the shot. Upon completion of each profile, two files were generated: source data containing shot number, shot time, and shot coordinates; and gun data containing shot number, volume, and pressure. Navigation was also provided for OBS deployment and recovery positions assuming a position near the port side of the OBS lab where operations took place.

Seismic operations were supervised by Party Chief Ben Bennett. Prior to leaving port, Bennett informed the chief scientists that based on a recent test cruise he estimated that deployment and recovery of the air-gun strings would take about 2 hours, and that profiling speed should not exceed 3.7 knots. Actual deployment and recovery of the air-gun strings vastly exceeded 2 hours, slowed in part by air leaks and problems with the hydraulic winches. However, we did find that profiling speeds of 4.0-4.5 knots could usually be achieved when firing 3 air-gun strings.

Profile	Deployment Time (to start of ramp up)	Recovery Time
3	11.0 hours	4.0 hours
4	5.5 hours	7.0 hours
3 infill	5.5 hours	4.5 hours
1	3.5 hours	5.0 hours
2	5.5 hours	3.5 hours

Initial plans were to shoot with all 5 air-gun strings at a volume of 9000 cubic inches and pressure of 2000 psi. However, it was immediately apparent that the compressors could not maintain a working pressure at this volume and that many were failing. After a second failed attempt we started shooting GUMBO Line 3 with 3 air-gun strings (5400 cubic inches. It became clear that three air-gun strings produced the volume for which the compressors could maintain adequate pressure, especially after a sea water cooling system for the compressors was installed. Numerous air leaks meant that parts of profile 3 were shot with only 2 air-gun strings; all subsequent profiles were shot with 3 air-gun strings. There were 9 stoppages in shooting during acquisition of the seismic profiles. Compressor failure caused 2 stoppages each on profile 3 and profile 4; air leaks with inability to maintain firing on 3 strings caused 2 stoppages on profile 3 and 1 stoppage on profile 4; and ship generator failure caused 1 stoppage each on profile 3 infill and profile 1. The general progress of seismic shooting on each GUMBO transect over the course of the project is shown in Figure 4.1.

Profile	Line Length	Number of Shots	Acquisition Time	Avg. Shots Per Day	Number of Stoppages	Mean Volume	Mean Pressure
3	522 km	3473	4.5 days	772	4	4726	1980
4	507 km	3382	3.5 days	966	3	5289	1994
3 infill	201 km	1338	1.2 days	1115	1	5373	1984
1	307 km	2028	2.0 days	1014	1	5201	1997
2	396 km	2643	2.1 days	1259	0	5220	2015

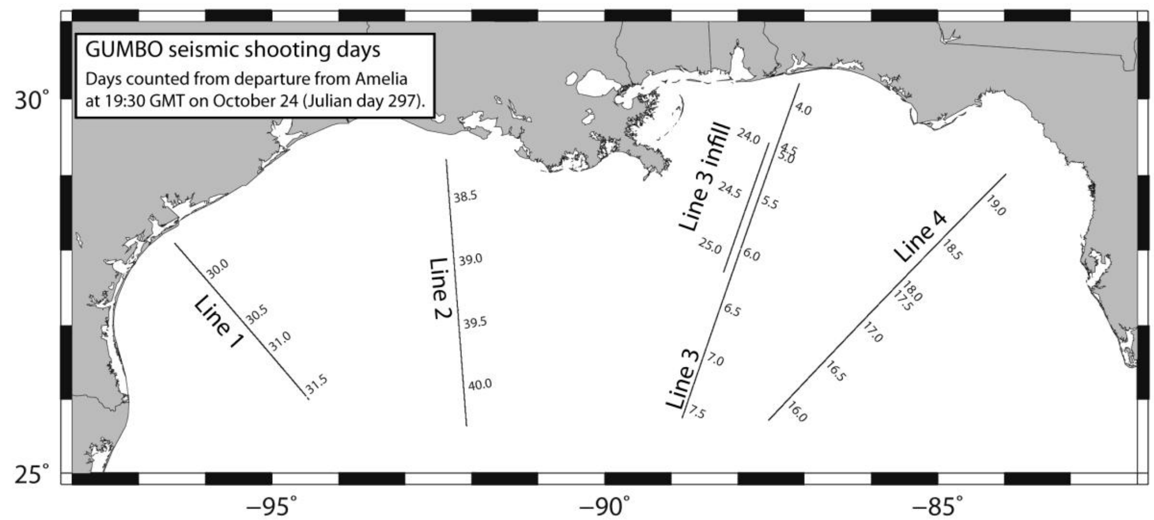


Figure 4.1. Progress of seismic shooting (annotated as days) along the four GUMBO transects.

5. OBS operations on the M/V Iron Cat

Ocean bottom seismometers (OBSs) were deployed along each profile to record long-offset seismic refraction and reflection data. The OBSs were manufactured by GeoPro GmbH, Hamburg, Germany. Each OBS consists of a 17” glass sphere enclosed in a plastic hard-hat housing. Inside the glass sphere is a 3-component geophone, batteries, seismic recorder, radio beacon, acoustic release system, and light. On the outside of the sphere are a transducer, hydrophone, radio antenna, and flag. Instruments have 120 dB dynamic range, a 24 A/D converter, and variable sampling rate. Approximately 1/3 of the OBSs were owned and operated by UTIG, and the remaining instruments were owned and operated by GeoPro. The UTIG and GeoPro instruments used the SEDIS-V and SEDIS VI seismic recorders, respectively.

The UTIG instruments were prepared by Anatoliy Mironov, with the assistance of Gail Christeson, Drew Eddy, John Gerboc, Steffen Saustrup, and Harm van Avendonk. The GeoPro instruments were prepared by Oleksy Tsyganok and Yuriy Malykh, with the assistance of Stephan Marienfeld.

Deployments were made from the top deck using a crane and a quick release. Deployments were carried out by a team of 3: a crane operator and the 2 watchstanders on duty (either Harm and Drew or Gail and Steffen). During deployment along profile 2 gale force winds shut down the use of the crane, and deployments were instead done by hand. This required about 6 people: 3 on the top deck lifting the instrument and lowering it down by pully and rope to the lower deck, and 3 on the lower deck to position the OBS away from the hull and release the instrument using the quick release. A total of 166 instruments were deployed during the project.

Recoveries started with a release command to the OBS via a transducer lowered into the water while the ship engines were not running. For several instruments communications were only established after moving the ship to different positions surrounding the deployment location. We were able to communicate with 165 of the 166 deployed OBSs (OBS 337 was the exception). Once communications were established we would send a release command, and then measure ranges to the instrument. We would know that the instrument had released from the seafloor when the ranges started to decrease; 3 instruments from profile 3 and 4 instruments from profile 1 remained on the seafloor hours after release command and were abandoned. Instruments rose from the seafloor at different rates based on configuration. Slower rise times were found for UTIG instruments on profile 3 that included an external radio beacon and for GeoPro instruments on profile 2 that included extra batteries in the lower sphere; average rise time for all instruments was approximately 45 m/min.

Upon surfacing we would visually locate the instrument by use of the red flag (day) or light (night). Some instruments were located using the assistance of the radio beacon. Difficulties did arise when some instruments surfaced sideways or upside down, but we were eventually able to locate all instruments that released from the seafloor. Recovery of OBSs was accomplished using a boat hook from the port side of the lower deck. Initially this required multiple passes of the ship as Johnny and Jim learned to use the wind and currents to push the instrument towards the port-side recovery location; however, by the last two profiles recoveries were usually accomplished within 5-10 minutes of instruments surfacing. 2 instruments were crushed under the stern as the ship pitched during 6-8 foot seas on profile 3. After recovery the OBS was lifted by crane to the top deck, except on profile 1 where the lifting was done by hand using rope and a pully owing to the inadvertent loss of the lube oil supply which meant that hydraulics could not be used. A total of 156 instruments were recovered during the project.

Instruments were then given a fresh water rinse, clock drifts were measured, and data were downloaded. The spheres of the UTIG instruments had to be opened for clock drift measurements; the GeoPro instruments include a gps unit and drift measurements could be made without sphere opening. A drawback to not opening the sphere was that the backup timed release was not immediately deactivated; this resulted in radio beacons going off on deck via timed release which interefered with using the radios for locating surfacing instruments.

Prior to the cruise historical timing parameters were used to estimate time length of OBS operations: ship transit speed of 10 knots, 20 minutes per deployment and 25 minutes per recovery for ship maneuvering and speed changes, release wire burn time of 10 minutes, and instrument rise time rates of 45 m/min.

Instrument deployments were 12 hours faster than initially estimated on Profile 3, and hence we adjusted timing parameters for the remainder of the program for a ship transit speed of 10.5 knots and a deployment time per instrument of 10 minutes. Deployments along profile 4, profile 3 infill, and profile 1 were 1-4 hours faster than time estimates using these revised parameters. The exception was profile 2, where deployments were 6 hours slower than the time estimates owing to the poor weather conditions during much of the deployment.

Recoveries on profile 3 were 7 hours slower than initially estimated despite the observation that release wire burn times averaged about 5 minutes rather than 10 minutes. Reasons for the slower recoveries included poor weather conditions, a learning curve on how best to maneuver the ship during recoveries, and a transit of several hours during an attempt to recover OBS 337 on timed release. Recoveries on profile 4 were 4 hours faster than estimated and we thus adjusted timing parameters for the remainder of the program for a release wire burn time of 5 minutes and a recovery time per instrument of 20 minutes. Recoveries along profile 3 infill and profile 2 were within 1 hour of these revised time estimates despite some poor weather conditions on profile 2. Recoveries on profile 1 were 25 hours slower than expected because of a shutdown of operations during high sea state, and additional delays incurred transiting back to stuck instruments to check whether they remained on the seafloor.

6. Daily log of GUMBO project October 24 - December 6, 2010.

Sunday October 24 (day 1): In the days before the ship's departure we arranged our OBS lab on the upper back deck (Figure 6.2), which was conveniently divided in a workspace for the Geopro and UTIG teams. After we finished filling the sand bags for OBS drop weights (Figure 6.1), we were ready for the cruise. The crew of the Iron Cat was still busy making some last adjustments at the gun deck, but these preparations finished around noon. We left the port of Amelia in the early afternoon (19:30 GMT), a full day earlier than scheduled. From the dock in Amelia we made it to the Gulf of Mexico in five hours, from where we turned southeast to the seaward end of Gumbo Line 3.

Figure 6.1. Drew Eddy and John Gerboc in front of our completed pile of sand and gravel bags, which would be used for OBS drop weights during the cruise. Sand bags (black) were used offshore Florida, and gravel bags elsewhere.

Figure 6.2. Central and starboard sections of the OBS lab. GeoPro engineers prepared their instruments in the port section; UTIG engineers in the starboard section. The central section was used for data processing and navigation.

Monday October 25 (day 2): We had a long transit to the first OBS drop site on line 3. During this time we were busy preparing 45 OBS's for our first seismic refraction line. The instruments were all programmed with the same start and end recording time, and a back-up release time that increased from south to north, in case the acoustic releases would not work. We set back the release time 12 hours and 15% from our assumed schedule, so they would not surface before our seismic shoot was completed. While these preparations were in progress, we did a test deployment and recovery of an OBS on the Louisiana shelf to see if our sand bag design and our crane procedures would work. Our large black cotton bag, which can hold about 36 kg of regular sand, was developed to meet permit requirements on the Florida shelf, and it appeared to work fine. The test was also a helpful practice of our quick release during deployment, and of the boat hooks for OBS recoveries at the lower deck. We had initially planned to recover OBS's with a net, but the aluminum base frame of the OBS's made it difficult to hoist the instruments over the railing with a net. We used boat hooks to snag the rope loop on top of the OBS's. The same boat hooks could be used to lift the instruments vertically from the water, along the ship's hull, over the railing. Given the short length of the rope from the crane, we decided that no additional tag lines were necessary to stabilize the instrument during deployment. We would use one tag line during recovery.

Tuesday October 26 (day 3): We arrived at Site 345 at 04:23 GMT for our first of 45 OBS drops, with 12 km spacing between neighboring instruments, starting at the south end of Line 3. The weather here was mostly calm, and quite hot (80s) in the day time, but much cooler (50s) at night. Although weather conditions gradually deteriorated, we deployed OBS 345 to 318 by 24:00 GMT (Figure 6.3). The Iron Cat only needed to stop for 5 or 10 minutes between drop sites for a deployment, and the ship's speed between drops was usually more than 10 knots. Most OBS's were already sitting fully prepared with sandbags on the back deck, so we were not in danger of falling behind with our preparations. The first and last set of 15 OBS's were from Geopro, and the middle 15 from UTIG. This deployment scheme would allow the two OBS teams to take a long rest between deployment operations.

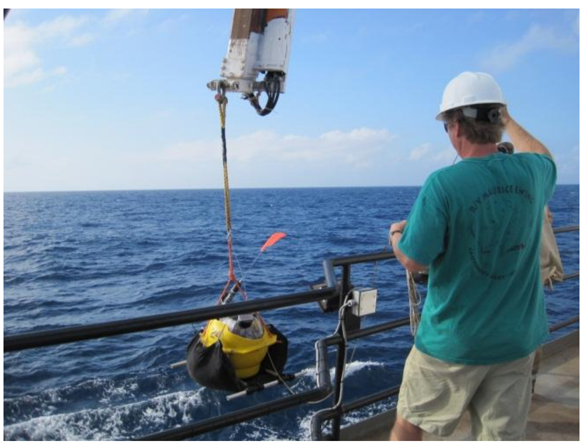


Figure 6.3. Deployment of an OBS from the upper deck. Black bag containing sand is released from OBS via burn wire upon command during recovery operations.

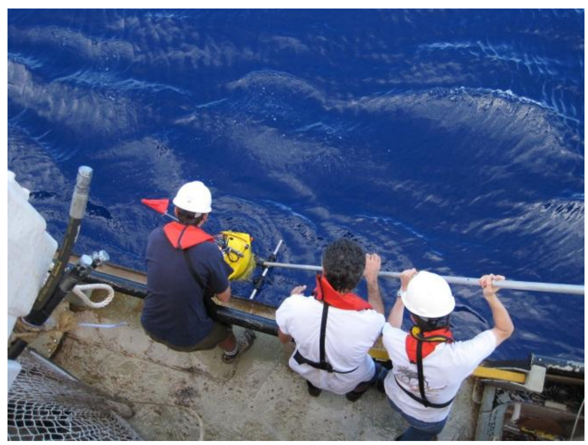


Figure 6.4. Recovery of an OBS from the lower deck using a boat hook. The crane is then used to lift the OBS to the upper deck.

Wednesday October 27 (day 4): We dropped the rest of the instruments for GUMBO Line 3 at sites 317 to 301 by 11:09 GMT. The repeated practice made the procedure easier for us and the crane operators. The quick release would not work well if the release wire twisted around the crane hook or OBS flag during operations. A careful arrangement of the rope and quick-release line on deck would avoid that problem, so the OBS deployment became effortless over time. After the OBS array was in place, the gunners would need the next 11 hours to deploy five air-gun strings (Figure 6.5) in the water and they start test firing at 22:50 GMT. Our objective for the next few days was to deliver 4478 air-gun shots at 150 meter spacing.

Thursday October 28 (day 5): At 02:15 GMT we fired our first shot on GUMBO Line 3 with five air-gun strings. Unfortunately, we immediately had problems with the air compressors, which started overheating, and then failing. We therefore could not keep enough pressure on the air-gun array, and our first attempt to shoot the refraction line was terminated at 09:25 GMT. A second attempt on Line 3 with the same objective to shoot five air-gun strings, starting at 12:27 GMT, had the same result. Given the lack of air volume, we next planned to shoot with just three air-gun strings, which seemed within the capabilities of the air compressors. The first shot (number 1001) was fired at 17:09 GMT. A new problem that only now became apparent was that the air hoses to the guns would break regularly. The resultant air leaks would quickly take one full air-gun string out of operation. By 21:19 GMT, we would be shooting with just one air-gun string. Since we considered the air volume of one gun string much too low for our project, we turned the vessel back to the north to reshoot part of the line, so we would not have a gap in our data. During the loop the air-gun crew was given some time to repair their equipment and bring air-gun strings back in operation. Over the duration of the acquisition of this and other seismic lines, we would circle back if the seismic air-gun array did not have sufficient volume or air pressure. Such a loop could take between 0.5 and 2 hours depending on currents and sea state.

Friday October 29 (day 6): After we looped back for air-gun repairs, we came on Line 3 again at 03:26 GMT with shot 1218, firing three air-gun strings. The air compressors could keep up with our seismic shoot if the ship's speed was occasionally reduced to 3.0 to 3.5 knots to avoid overheating. Fortunately, the compressor technicians managed to improve the sea water cooling of the compressors, which made it possible for us to acquire seismic data with 3 air-gun strings, or 5400 cubic inches, at speeds up to 4.2 knots over significant lengths of our seismic line. Unfortunately, the air hoses continued to spring leaks, which disabled one air-gun string after another. While our goal was to shoot the seismic line with at least three air-gun strings, we had to settle for two strings for part of the line, and we had to turn around and reshoot portions to avoid having just one working air-gun string in the water. As a result, we only reached shot 1740 by 24:00 GMT, where we had to circle back once more on GUMBO Line 3 to reshoot a piece of the seismic transect.

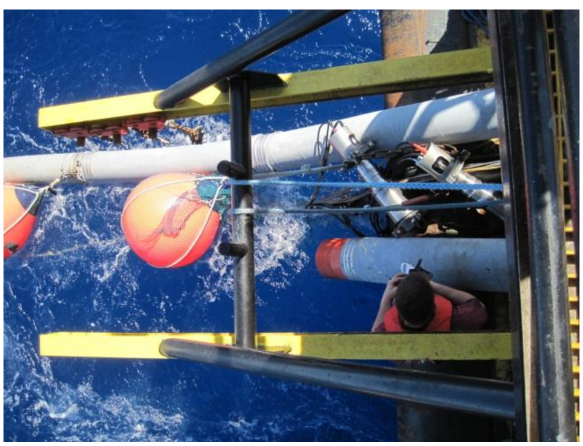


Figure 6.5. Deploying an air gun string over the stern of the M/V *Iron Cat*.

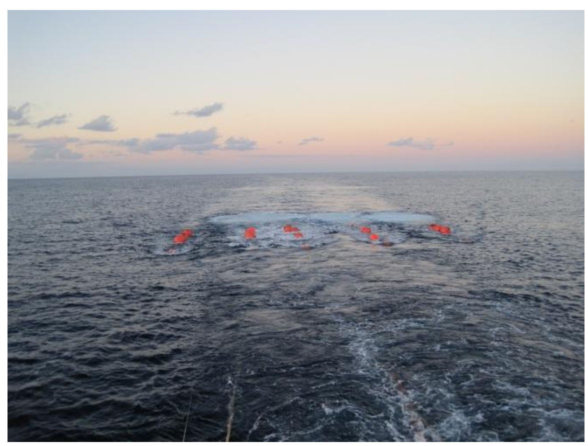


Figure 6.6. Shooting three of five air gun strings towed by the M/V *Iron Cat*.

Saturday October 30 (day 7): At 01:54 GMT we came back on Line 3 at shot 1714. By this time the weather was getting quite rough. Due to the fact that we had following seas we were able to maintain a course in which the ship would not roll much. On the other hand, 4 to 6-foot waves would frequently damage the air hoses. As the waves washed on the gun deck, the crew could not keep up with the repairs. Clearly, the air hoses, or the fitting of air hoses onto the air guns, were not robust enough to handle even a moderate sea state. This is a problem the crew would eventually solve towards the end of Line 3. By 18:58 GMT the winch on air-gun string 2 had a hydraulic problem, which made it difficult to get the equipment on board for repair. While the hydraulic problem was being addressed, the Iron Cat kept shooting on gun strings 3, 4, and 5. By 24:00 GMT we reached shot 2725 at 27.995N.

Sunday October 31 (day 8): As we steamed into the deepwater section of GUMBO Line 3, the problems with the air-gun array seemed to reach a status quo: Every few hours we sprang a leak in an air-gun string that required repairs. By pulling in the air guns and fixing them, the crew was able to keep mostly three, but sometimes just two air-gun strings firing. The ship slowed down to approximately 2.5 knots for the retrieval and redeployment of air-gun strings. We would otherwise maintain a shooting speed of 4.0 to 4.2 knots, which was the rate at which the compressors were able to produce sufficient air volume. By 24:00 GMT we reached shot 3824 at 26.590N (Figure 6.6).

Monday November 1 (day 9): As we started shooting the last portion of GUMBO Line 3, the problems with the air-gun winch hydraulics became worse. As a result, air-gun strings 1 and 2 were very difficult to get back on deck for repairs. Fortunately, air-gun strings 3, 4, and 5 kept firing until we reached the end of the seismic transect. By this time, the air-gun crew discovered that a looser fit of the air hoses on the air guns would cause far fewer air leaks. It later showed that this new approach would make the acquisition of GUMBO Lines 1,2, and 4 much easier, because we never needed to bring in the gun strings as often as during the acquisition of the first two thirds of Line 3. Near the end of Line 3, the compressors were again having problems with overheating, but by slowing the ship down we were able to get enough air pressure and finish the line. At 14:09 GMT the last shot 4478 of Line 3 was fired on line 3, after which the gunners started to pull in the air-gun array. By 18:40 we started recovery of the OBS's on Line 3 from the south to the north (Figure 6.4). Given that the water depth at the south end was more than 3000 meters, the recovery time for each instrument here included up to 70 minutes of rise time in the water. In addition, both captains of the Iron Cat had to steer the vessel very precisely, such that a surfaced OBS would float along the port side, where the OBS team would bring it in by boat hook. The OBS recovery would take more or less half an hour, depending on our skills, the sea state, current, and perhaps a bit of luck. By 24:00 GMT we had the first two instruments, OBS 345 and 344 back on deck.

Figure 6.7. Captain Johnny Buzbe worked the noon to midnight shift.

Figure 6.8. Captain Jim Scanlan had the helm at the midnight to noon shift.

Tuesday November 2 (day 10): We continued with the recovery of OBS's from Geopro from south to north along GUMBO Line 3. Although we were successful with instruments from sites 343 to 339, OBS 338 appeared stuck at the seafloor. Our acoustic communication with the OBS was good, so we obtained the range between the OBS and the ship. The OBS would also respond well to the acoustic release command, but the range to the ship (a depth of 2598 meters) remained the same. After 1.5 hours of sending acoustic release commands we abandoned OBS 338. Possibly, the release wire did not burn, the sandbag did not fall away from the OBS base frame, or the instrument was stuck on a muddy seafloor. Unfortunately, we also lost neighboring instrument 337, although the circumstances were different. We never established acoustic communications with OBS 337, and after 1.5 hours of trying we considered it lost. We would later return to find out if OBS 337 would pop up on its time release, but we did not see it on the surface. At this time we considered OBS 337 and 338 to be lost. We also had some difficulty with acoustic communication to OBS 336, but by repositioning the ship in a few different locations near the OBS drop site we were able to send a successful release command. We recovered instruments up to OBS 334 by 24:00 GMT.

Wednesday November 3 (day 11): The recovery of OBS's on GUMBO Line 3 continued with the instrument deployed on site 333. We initially had trouble releasing this OBS from the seafloor, but by repositioning the ship a few times around the drop location we managed to get a successful release command to OBS 333. Instruments 332 and 331 were recovered without such problems. OBS 330, the first UTIG OBS that we planned to recover from Line 3, responded well to our acoustic release command, but it remained stuck on the seafloor in the same sense as we had seen with OBS 338. We abandoned OBS 330 after waiting almost 2 hours for its ascent from the seafloor. OBS's 329 to 324 all came back, but the weather and the sea state were getting worse, making recovery from the lower deck on the port side more difficult. OBS 323 released from the seafloor, but as we tried to recover it in rough seas, the glass sphere was crushed under the stern as the ship pitched in the waves. By this time we encountered waves mostly between 6 and 8 feet, but occasionally of 10 feet (Figure 6.9 and 6.10). The OBS team that snagged our instruments from the port side lower deck got wet a few times, but they were rarely hit directly by an incoming wave. We were relatively lucky in the sense that the orientation of Line 3 steered us precisely into the seas.

Figure 6.9. OBS prior to recovery in 6-8 foot seas.

Figure 6.10. Lifting an OBS from lower to upper deck after recovery.

Thursday November 4 (day 12): OBS's 322 and 321 were brought back safely on deck but OBS 320 did not rise from the seafloor, even though the acoustic release command went through successfully. We waited 1.5 hours for the instrument to rise, but in the end we abandoned it. Subsequently, OBS 319 was recovered quickly, but 318 also appeared to be stuck on the seafloor. Despite good acoustic communications, we could not get the instrument to rise from the seafloor. After we abandoned OBS 318, we initially had the same problem with OBS 317. However, this OBS started to rise 45 minutes after our release command, and we recovered it. Now knowing that these OBS's could eventually rise long after our release command, we returned to OBS 318 to see if it was still on the seafloor. To our surprise, our acoustic ranging showed that it was halfway up in the water column, so it must freed itself 4 hours after our acoustic release command. OBS 318 was recovered, and we did not encounter other problems with OBS recovery that day. By 24:00 GMT we had picked up OBS 312.

Friday November 5 (day 13): As we approached the north end of GUMBO Line 3, the stormy weather was only gradually subsiding. The recovery of OBS's 311 to 301 therefore appeared to go more smoothly, although OBS 306 was once again crushed by the hull at the port side stern as the ship pitched during the recovery. OBS 301, the last OBS of Line 3, was back on deck by 15:00 GMT. The problems that we encountered with the compressors and the hydraulic winches of the air-gun array required that we proceed to port for repairs and additional parts. In addition, we were already running out of food, which indicated that we would need a few more supply stops later in the project. Although we were closer to Panama City, Reservoir Geophysical chose to use the docks of Theodore, Alabama, for our port call. From our last OBS recovery, the transit to Theodore was six hours to the northwest.

Saturday November 6 (day 14): We spent a day in port in Theodore for maintenance and re-supply. Many of us took a taxi to nearby Mobile to spend the evening off the ship, or the next morning to Tillmans Corner to shop for personal goods. J.D. Beeman and Jerry Warren of Reservoir Geophysical visited the ship to discuss our experience so far. Unfortunately, two Reservoir Geophysical crew members resigned during this port call, but we left the dock with three new people to replace them. While the refraction shoot and OBS recovery had both been difficult, we were able to see that many instruments recorded great data, with *PmP* and *Pn* arrivals over more than 100 km. However, several instruments (mostly UTIG) recorded no data. Combined with the lost instruments this resulted in a gap of 60 km with no data in the key geologic region near the transition from thick to thin crust. We later discovered an additonal problem in that several of the GeoPro instruments recorded data with very strong electronic noise. At this stage, we started making preparations for the acquisition of GUMBO Line 4, but we also made a tentative plan to reshoot the central portion of Line 3 after the completion of Line 4, if it would fit in our schedule.

Sunday November 7 (day 15): We departed the dock of Theodore at 3:00 GMT for a long transit back to the landward end of GUMBO Line 4. Our original plan was to deploy 45 OBS's at 12 km spacing on this profile. However, we lost 6 OBS's on Line 3, and we did not have enough spare instruments to replace all of them. We therefore cut OBS positions 401 and 445 from our deployment schedule, so we had an array of 43 OBS's with 12 km spacing available for Line 4. We used the long transit time to replace batteries and prepare instruments for deployment. Instead of grouping the OBS's in large series from either Geopro or UTIG, as we did on Line 3, we now staggered our OBS's such that we would drop a UTIG OBS after each two Geopro instruments. By the time that we approached the first drop location we already had more than two thirds of the instruments ready on the back deck.

Monday November 8 (day 16): The first OBS on line 4, at site 402, was deployed at 02:39 GMT. The cold front that had hampered the recovery of OBS's on Line 3 had dropped the temperatures into the low 40s for a day, but the weather was now calm, and perfect for our project. The deployments therefore went even faster than on Line 3, and by 24:00 GMT we had dropped all instruments up to OBS 434 on the seafloor. One notable problem that we found out around the deployment of OBS 413 was that John Gerboc had developed an infection on one of his toes. Although we considered a rescue charter to bring John back on shore to nearby St Petersburg to see a doctor, we decided that simple treatment on board the ship would be sufficient. John mainly received medical help and advice from the galley cook Richard Mathous and captain Jim Scanlan (Figure 6.8), both of whom had first aid training.

Figure 6.11. Captain Jim Scanlan and navigator Josh LeClerc. The navigators not only provided precise positions for shots, but also for OBS deployments and recoveries.

Figure 6.12. Navigator Mitch Scoggins. Mitch worked the midnight to noon shift, and Josh worked the noon to midnight shift.

Tuesday November 9 (day 17): The remaining OBS deployments 435 to 444 went without effort, and by 6:36 GMT our OBS array was installed on the seafloor. Air-gun deployment and testing started at 11:46 GMT. The deployment of air-guns went slower than expected, because air-gun string 1 sprang a leak right off the stern. The appearance of dolphins added to the delay, but only for an hour or so. The first shot (number 1073) on GUMBO Line 4 was fired at 18:16 GMT. With gun strings 2, 3, and 4 firing, we reached shot 1317 at 25.961N by 24:00 GMT.

Figure 6.13. Dolphins sighted during the deployment of air gun strings. We would not start the seismic source until at least half an hour after we last observed the dolphins.

Figure 6.14. Dolphins enjoying the waters near the *Iron Cat*.

Wednesday November 10 (day 18): As we continued shooting of GUMBO Line 4, the three middle gun strings kept performing, but we had to vary our speed between 3.6 and 4.0 knots to prevent the compressors from overheating. Finally, by 14:30 GMT, at shot 1993, we encountered problems with the compressors that required us shut down the air-gun array, circle back and resume shooting. Fortunately, this episode took not much more than an hour. Occasionally we had to drop the ship's speed back to 3.0 knots, but we reached shot 2408 at 27.031N by 24:00 GMT.

Thursday November 11 (day 19): While air-gun strings 2,3, and 4 had been shooting very consistently on GUMBO Line 4 thus far, string 3 developed an air leak at 00:03 GMT, so we brought gun string 5 on line to replace it. At 04:02, gun string 3 was deployed again. However, at 05:33 GMT, after shot 2614, failure of the compressors required us to circle back and reshoot a portion of our seismic line. During this time, gun string 5 was brought back on deck. At 06:57 we came back on our line with shot 2604. Shooting with gun strings 2, 3, and 4 continued until 15:08 GMT (shot 2972), when air-gun strings 3,4, and 5 all needed to be repaired, and the compressors were shut down. This large failure required a longer break, but by 24:00 GMT we were ready again for seismic shooting.

Friday November 12 (day 20): The Iron Cat completed its long turn back to GUMBO Line 4 with shot 2970 at 0:07 GMT. We continued to shoot gun strings 2, 3, and 4, mostly at speeds between 3.7 and 4.3 knots. At 08:51 GMT, around shot 3401, the weather started to deteriorate, but the air-gun array and compressors would hold up fine all day. At 8:30 local time (14:30 GMT), John Gerboc reported that he had another infection, this time on a finger of his right hand. In a matter of an hour the infection got worse, so captain Jim Scanlan and chief scientist Harm Van Avendonk made plans for John's evacuation. We approached the landward end of our line, but at the nearby Florida coast between Panama City and St Petersburg there is no suitable port for the Iron Cat. We therefore chartered a small tow boat from the fishing port of Steinhatchee to meet us at the end of our seismic line on Saturday morning. John's further evacuation to a hospital would be handled by SOS International. We reached shot 4150 at 28.720N by 24:00 GMT.

Saturday November 13 (day 21): At 05:37 GMT shot 4454 was the last one of GUMBO Line 4. At 07:22 GMT the air-gun crew was pulling in the seismic gear as we continued steaming northeast towards Steinhatchee. At 12:49 GMT the air guns were all recovered. At this point we expected to meet the tow boat for John Gerboc's evacuation, but due to the rough weather this small vessel was staying just outside their home port. We continued towards land, and the boat-to boat transfer of John Gerboc took place at 13:48 GMT in rough seas. John Gerboc would be transported to a hospital in Gainesville, from which he was released later that week. As the weather was improving, we started recovery of OBS's on GUMBO Line 4 on the Florida shelf at 15:04 GMT with OBS 402. During the retrieval of OBS 407, the starboard engine of the *Iron Cat* failed, which slowed the recovery of the next several instruments. By 24:00 GMT we had all instruments up to OBS 409 on board.

Sunday November 14 (day 22): We continued the recovery of OBS's on Line 4 offshore Florida. OBS 410 and 411 were still picked up with just one working engine on the Iron Cat, but by 03:00 GMT this problem was solved. Next, we had to cope with the fact that we had great difficulty sending and receiving acoustic commands to OBS 413 to OBS 418, but eventually we got them all on board. All these instruments were in shallow water approaching the Florida shelf break, so perhaps the thermocline or similar layering in the water affected our acoustic communications. In deeper water we had no such problems, and by 24:00 GMT we had recovered all instruments up to OBS 423.

Monday November 15 (day 23): As we cruised along Line 4 into the deeper Gulf of Mexico, the OBS rise times would increase significantly. A more surprising problem that we now encountered was the fact that many OBS's would now float sideways or upside-down after they surfaced. At night this would make some of the instruments difficult to see, but with the help of the radio's and systematic searches we were able to retrieve OBS 434 by 24:00 GMT.

Tuesday November 16 (day 24): We completed the OBS recovery on GUMBO Line 4 with OBS 435 to OBS 444. This last instrument came on board at 19:51 GMT. We had not lost any OBS in the acquisition of this seismic refraction line, and the first SEGY data that we cut from the UTIG instruments on the shelf and in deeper water looked fantastic, with seismic arrivals over distances exceeding 200 km. Since we had also gained a day on our overall schedule during the shooting and OBS pick-up on Line 4, we decided that we should spend a few days of ship time to improve our coverage on the critical, central part of Line 3. We would redeploy 9 instruments on sites where we either lost OBS's or acquired no data or just very poor data. The rest of the day we were in transit to site 323 on GUMBO Line 3.

Figure 6.15. John Gerboc and Anatoliy Mironov programming an OBS.

Figure 6.16. GeoPro personnel working on OBS instruments.

Wednesday November 17 (day 25): Since our OBS recovery on Line 4 had stretched over several days, we had time to refurbish some of these instruments for the next deployment. We used 5 Geopro and 4 UTIG instruments in a staggered deployment schedule for the Line 3 infill shoot. These OBS's would reoccupy sites 323 to 319, 317, 315, 313, and 312. Once we arrived at site 323, the OBS's were rapidly deployed between 09:00 and 15:52 GMT. At 16:38 GMT, air guns were going back out for the infill shoot on Line 3 towards the south. During the deployment, air-gun string 2 developed a leak, so it was already pulled back in when we started ramping up the air-gun array with strings 1, 3, and 4. We started shooting at 22:38 GMT on Line 3 with shot 1640, quite far up on the continental slope, to get long offsets from this section of the transect. By 23:02 GMT, gun string 2 was back in the water. By 24:00 GMT we had reached shot number 2700 at 29.3025N.

Thursday November 18 (day 26): Seismic shooting of the infill on Line 3 was humming along well, with speeds between 3.3 and 4.3 knots, until the ship had a power outage at 09:30 GMT. We slowed down to 2.6 knots for half an hour, but we continued shooting. The air-gun crew fixed string 1 along the way, and we had the full array deployed by 15:25 GMT, although we would only fire the guns from strings 2, 3 and 4. The OBS teams already started to prepare OBS's for GUMBO Line 1 during the infill shoot on Line 3. By 24:00 GMT we reached shot 2830 at 27.860N.

Friday November 19 (day 27): The shooting of the infill on GUMBO Line 3 proceeded with speeds between 4.0 and 4.2 knots in calm weather. However, at 01:10 GMT, near shot 2889, the gun trigger stopped working, so circled back on the line. This maneuver took place in just half an hour. By 03:23 we reached the last shot (number 2977) of the infill on Line 3, at 27.672N. By 08:34 the air guns were all on board. We transited to site 323 for the first OBS recovery. OBS 323 was quickly picked up at 10:03, and all following OBS's were similarly easy to get back on board, although some of them were again floating sideways. By 24:00 GMT we had only OBS 312 left to pick up.

Figure 6.17. Steffen Saustrup with a blackfin tuna. **Figure 6.18.** Steffen cooking his catch.

Saturday November 20 (day 28): After we retrieved OBS 312 from the infill on Line 3 at 01:30 GMT, we started a long transit from the eastern to the western Gulf of Mexico. Most OBS's for Line 1 were already prepared, and we were making plans with Jay Pulliam for the timing of this transect, since air-gun shots from the Iron Cat would now also be recorded on an array of "Texan" short-period land recorders. A power surge at approximately 09:00 GMT burned some of the lights in our lab, in the wheelhouse, and at the gun deck, but no major equipment damage came of this. The highlight of the transit was when Steffen Saustrup caught a blackfin tuna which he barbequed and shared with the crew.

Sunday November 21 (day 29): After a very smooth transit, with excellent weather, we arrived at the first OBS drop site on GUMBO Line 1. By that time almost all OBS's were programmed for recording (Figure 6.15), so we expected little delay. We had arranged for a port call in Port O'Connor after the OBS deployment to get a food order on board, and the seismic shoot with on-land recording was scheduled afterwards for Tuesday and Wednesday. Since we discovered that 8 of the Geopro OBS's recorded data with electronic noise on both line 3 and line 4, we did not use these on GUMBO Line 1. The Geopro and UTIG OBS drop sites were staggered, with either one or two Geopro OBS's between the UTIG instruments. OBS 132 at the seaward end was the first instrument deployed at 14:36 GMT. Due to good weather and favorable currents, we deployed 18 of the 32 instruments of this line by 24:00 GMT.

Monday November 22 (day 30): We continued the deployment of OBS's on GUMBO Line 1 from south to north towards Matagorda Island (Figure 6.19 and 6.20). Although the wind picked up during the deployment of the last few OBS's on Line 1, all instruments were installed on this seismic refraction line by 07:42 GMT. We set course for Port O'Connor to get new supplies, which required a 3.5 hour transit. Many of us took the opportunity to shop for some personal items, or to explore Port O'Connor. Later that day we met with Jay Pulliam, Ian Norton, and the rest of the land station deployment team to discuss the timing of the seismic shoot and their instrument retrieval. With Thanksgiving coming up, they had limited access to some of their sites on Matagorda Island and Falcon Point Ranch near the town of Seadrift, but Jay had planned the logistics well.

Figure 6.19. The OBS fleet programmed on the back deck. They would be ready for deployment after they are mounted on a sand bag (right).

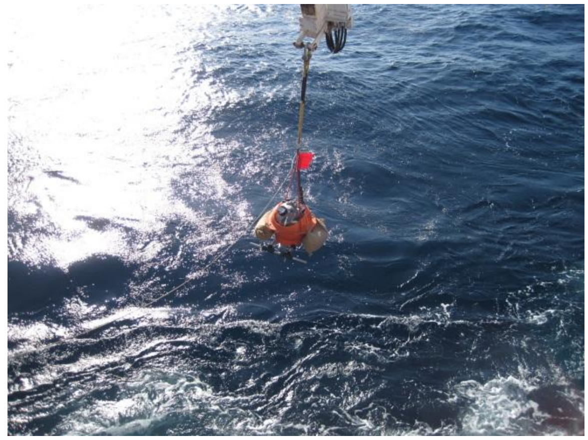


Figure 6.20. Deployment of an OBS with gravel bags as drop weights.

Tuesday November 23 (day 31): At 7:03 GMT we left the dock in Port O'Connor with fuel, food and water for the rest of the project. By 08:16 we were in open water, and by 09:54 GMT we were at the north end of GUMBO line 1 for air-gun deployment. The first three gun strings (1, 2, and 3) were out by 13:39, and at 14:52 GMT we started shooting the line with shot 3047. Since we had originally planned to acquire the line from south to north, we were now counting down the shot numbers from the north. All five air-gun strings were in the water by 20:08 GMT, after which we would mostly shoot the three middle air-gun strings (2, 3, and 4). By 24:00 GMT we had reached shot number 2613 at 27.656N.

Wednesday November 24 (day 32): The shooting of GUMBO Line 1 progressed well. We gained some time on our schedule, because the ship often went faster than 4 knots due to favorable seas and wave direction. However, the weather forecasts predicted stormy weather for Thursday and Friday, so we were eager to acquire as much data while the weather was adequate for shooting. By 10:00 GMT we informed Jay Pulliam that we would probably have shot 200 km on Line 1 by 16:00 GMT, at which time the land seismic stations could be picked up for data downloads. Although we had certainly acquired enough data on the Texans by that time, it took us much longer than predicted to get to the 200 km mark on our profile. At 16:08 GMT, a prolonged power outage silenced our compressors for a few minutes, so we lost quite a few shots in a row. As we circled back to reshoot this part of Line 1, a half-hour visit of three dolphins at the bow delayed our ramp-up. We took the opportunity to fix a tow rope on air-gun string 2, and string 3 was brought back on deck for repair. We resumed shooting the seismic line by 19:19 GMT with air-gun strings 1, 2, and 4. Due to the worsening sea state we did not re-deploy string 3. By 24:00 GMT we had reached shot 1667 at 26.686N.

Thursday November 25 (day 33): The acquisition of GUMBO Line 1 proceeded steadily, though we slowed down to 3.5 or 3.7 knots to allow the compressors to make sufficient air. At 13:10 GMT we had a large compressor failure that caused us to miss shots 1046 to 1028, but we decided not to circle the ship back to acquire these. The last shot of Line 1 (number 1001) was fired at 14:48 GMT, at 26.000N. The recovery of air guns started at 14:59 (Figure 6.21), and was accompanied by a few power outages. By 20:19 all air-guns were back on deck. We had lost as many as seven air-gun floats in rough weather during the air-gun recovery, but we tracked down two of the floats and brought them back on board. During the air-gun recovery one of the crew members must have left an oil valve open by accident, so we were almost out of oil already again. We planned for another quick stop in Port O'Connor after the OBS pick-up on Line 1. After a short transit to Site 132 we recovered the first OBS of the profile at 23:14 GMT. Through the operations, the cooks made us a great Thanksgiving lunch and dinner that lasted us into Friday.

Figure 6.21. Air gun string recovery in rough weather.

Figure 6.22. Deploying an air gun string.

Friday November 26 (day 34): The recovery of OBS's on GUMBO Line 1 started out well. OBS 131 to 126 were brought back on deck between 01:26 GMT and 09:25, although that last instrument was floating sideways during recovery. Unfortunately, both OBS 125 and 124 did not release from the seafloor, even though we had good acoustic communication with these instruments. We waited 2 hours at each OBS to see if it would break loose. We returned to each OBS a couple more times. We visited OBS 123, had good communications, but decided not to release it because of worsening sea conditions. We returned to OBS 124 to find that we could not communicate with it any more at approximately 17:00 GMT. Either it had finally released after 4 hours and floated away, or acoustic signal had worsened due to the deteriorating weather. When we subsequently checked on OBS 125 once again, we found that it was still on the seafloor and responding to our acoustic signals, more than 5 hours after we had sent it our acoustic release command. Unfortunately, we were unable to get OBS 125 off the seafloor. At this time a cold front was approaching, making it impossible to continue with OBS recoveries at 18:27 GMT. As 9-12 foot seas and 40 knot winds descended on us, we passed the time with a few big screen movies in the OBS lab while the ship ran weather patterns.

Saturday November 27 (day 35): At 08:29 GMT the storm had subsided enough that we resumed the recovery of OBS's in a northward direction. We recovered OBS's 123 to 120 without difficulty, but instrument 119 was again stuck on the seafloor, despite good acoustic communications. We picked up OBS 118 and returned to OBS 119. The OBS was still on the seafloor and it would not release from the seafloor. By 24:00 GMT we recovered all instruments to OBS 115.

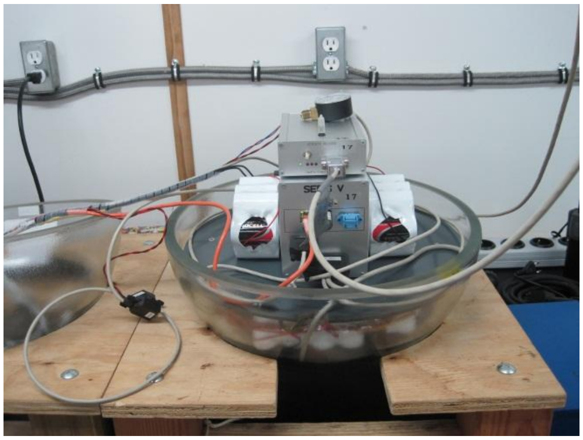


Figure 6.23. Open OBS sphere. Visible are batteries, the Sedis-V computer, and the acoustic release unit.

Figure 6.24. Glass shards peeling off recovered OBS. This OBS may have hit the hull during an earlier recovery in rough weather, causing stress to the sphere.

Sunday November 28 (day 36): We retrieved most of the remaining OBS's without difficulty, except for the instrumernt at site 107. Although our acoustic communication was good, the instrument would not lift from the seafloor. We tried for 1.5 hours, picked up OBS 106 and 105, and returned once again to site 107 to find that this OBS was still on the seafloor after 5.5 hours. We therefore abandoned it and continued to recover OBS's at the landward end of Line 1. Communications with the OBS's in shallow water was somewhat more difficult, but we were able to release all these by maneuvering the ship to a few different locations around each deployment site to ping to the OBS's. At 18:04 we finished the recovery with OBS 101. We made a quick transit to Port O'Connor to pick up more oil for the M/V Iron Cat. Our initial plan was to wait with OBS deployments on GUMBO Line 2 (offshore Louisiana) until the next storm would pass. However, since the weather forecast improved slightly, we decided to head back into the central Gulf of Mexico for OBS deployment on line 2, despite the impending storm. At 22:00 GMT we left Port O'Connor and set course for the south end of Line 2.

Monday November 29 (day 37): The long transit to the south end of GUMBO Line 2 (26 hours), gave us time to prepare and program OBS's. We originally planned to deploy 38 instruments on this last transect, but given the loss of 4 Geopro OBS's on the last line, and a problem with the A/D converter on our instrument 15, we had to settle for 37 OBS's on our last transect. We were now heading straight into a new storm with 25 knot winds from the south. We knew that the next day the winds would turn to the north, after which the storm would become even stronger. With this forecast in mind, we decided to set the OBS pop-up release times more conservatively than during our other deployments. Instead of the usual 15% of the operation time plus 12 hours, we now added an additional 36 hours of contingency to the self-timed OBS releases, just for the storm.

Tuesday November 30 (day 38): After we completed our transit, OBS 238 is the first instrument deployed on GUMBO Line 2 at 7:25 GMT. The wind and sea state make it difficult to keep the OBS from swinging on the crane, but we get plenty of help from crew members to get our instruments safely over the side of the ship. As the wind switched to the north we had a few hours of calm seas, but by 14:18 GMT the storm front arrived with heavy rain during the deployment of OBS 226. At this time we accidentally switched OBS 224 and OBS 225 on deck, so our original instrument preparation and deployment notes do not have the correct instrument ID's. At 15:24 the rain was accompanied by strong winds, and the seas started to build gradually. With some extra help from the air-gun crew we were able to get the instruments safely over the side of the ship without swinging too much. However, during the deployment of OBS 221 the waves (to 12 feet) and the wind had increased so much that we could not use the crane anymore, as the shaking and rolling of the vessel would apply too much torque on this heavy equipment. We tried a few methods to deploy the OBS's with just manpower. With OBS 220 and OBS 219 we tried to slide the instruments off a plank from the port side gun deck into the waves. However, in this manner the OBS's hit the water with too much lateral momentum, so we preferred to lower the instruments with a pulley from the upper deck. Two people would lift the instruments with sand bags over the railing of the upper deck, while a third person would control the descent with a rope that was looped around the railing three times. At the lower deck, two other people would place a release line on the OBS. As we lifted the OBS over the railing of the lower deck with the same rope and pulley from the upper deck, a third person from the lower deck would push the OBS away from the hull of the ship with a boat hook. Once the OBS was in the water, we would pull the release line. This latter method required a lot of people to handle the OBS's, but we considered it safe. OBS 218 was deployed in this manner at 23:21 GMT.

Figure 6.25. Front view of the M/V *Iron Cat*, operated by Reservoir Geophysical.

Figure 6.26. Stern of the M/V *Iron Cat*. Air gun arrays are visible on the lower deck; containers on the top deck provided storage space, the OBS lab, and living quarters.

Wednesday December 1 (day 39): As we slowly (3 to 5 knots) made our way north into the northerly storm, we deployed OBS's 217 to 204 by hand with a pulley from the upper deck. This method was physically tiring, but we had plenty of people available, and a shift change during the night brought some relief in the operation. By the first day light (around 12:00 GMT) the storm was still unrelenting even though we were now approaching shore, but by sunrise the wind and the sea suddenly came to rest. Starting with OBS 203 at 13:52 GMT, we deployed the last 3 OBS's by crane again. At 14:58 GMT OBS 201 was the last instrument deployed for our project. We now set course for Freshwater City, Louisiana, to pick up fuel filters. Until a few days ago the ship had plenty of fuel filters, but due to a water leak in the fuel supply, the ship used all its fuel filters over a 24-hour period. In the meantime, the air-gun crew would work to convert air-gun strings 4 and 5, which were significantly damaged, together into one working air-gun string. At 20:30 GMT the Iron Cat left Freshwater City again, and at 23:07 GMT we were in water deep enough to deploy the first air-gun string.

Thursday December 2 (day 40): After the deployment of air-gun strings 1, 2, and 3, we attempted to start the seismic line at 01:33 GMT, but air-gun string 3 had to be pulled back with an air leak, so string 4 was now going to be deployed. During the deployment of string 4, its air manifold was completely destroyed, so string 4 had to be brought back on the gun deck, and string 3 had to be repaired and re-deployed at 04:07 GMT. At 04:44 GMT we finally came on GUMBO Line 2 with shot number 1001. The weather was very calm, and the forecast for the rest of the project was very good. Due to favorable currents we kept our speed mostly at 4.2 knots, occasionally dropping below 4.0 knots. At 06:25 GMT we deviated slightly from our seismic transect for an oil platform. At 07:19 GMT, near shot number 1139, one of the gunners discovered that all the shots thus far had been timed with a setting for Bolt air guns, instead of sleeve air guns. This problem was instantly corrected, and we decided not to circle back to reshoot the start of Line 2. At 13:04 GMT, air-gun string 4 was finally fixed and deployed as a spare. At 14:44 GMT we entered a maze of oil platforms that required some more deviations from the Line 2 transect. At 15:34 GMT, we experienced a significant power outage, but we did not miss shots. Our speed was relatively high at 4.2 to 4.4 knots. At 20:46 GMT we noticed that our effective air-gun volume was quite low (4600 cubic inches) despite the fact that we were shooting with three air-gun strings. We therefore started to shoot with some guns from string 4/5 as well by 22:27 GMT, which brought the air-gun volume back to 5450 cubic inches. By 24:00 GMT we had reached shot 2003.

Figure 6.27. Gail Christeson with OBS fleet prior to deployment.

Figure 6.28. Todd Meyer giving the last OBS to be deployed on the project some extra attention.

Friday December 3 (day 41): The acquisition of GUMBO Line 2 went along smoothly. We continued to shoot guns from all 4 air-gun strings to keep up enough volume. At 08:46 GMT we moved about 400 m off our transect to avoid an oil rig. At 13:24 GMT we saw two sperm whales at approximately 2 km off the port side. Since they were outside our safety radius, the marine mammal observers did not break off our seismic operation. By 24:00 GMT we reached shot 3250.

Saturday December 4 (day 42): At 05:08 GMT, the navigation team on the bridge noted another volume drop at shot 3518. At 05:17 GMT (shot 3525), our air volume was down to 4850 cubic inches. The air-gun crew wanted to bring in string 3 and fire strings 1,2, and 4/5 at 5150 cubic inches. However, the use of the hydraulic winches caused electrical power problems, and we decided to finish the line with 4850 cubic inches. At 07:34 GMT, shot 3643 was the last one fired on GUMBO Line 2 and the entire project. At 08:07, the ship turned north for the recovery of air-gun string 4/5. At 10:00 GMT, string 2 was on board, and by 11:33 GMT, all air-guns were recovered. We immediately proceeded with OBS pick-up on Line 2. The first OBS, number 238, was difficult to find, but we located it with our hand-held radio, and it was recovered at 14:12 GMT. With OBS 236 we were initially unable to get acoustic communication, but by deploying the shipboard transducer at different azimuths and distances up to 700 m from the OBS deployment site, we were eventually able to release the instrument from the seafloor, and bring it back on board. By 24:00 GMT we had recovered all OBS's between 238 and 234.

Figure 6.29. Science party.

Front row: Yuriy Malykh, Stephan Marienfeld, Oleksy Tsyganok, Gail Christeson.

Back row: Drew Eddy, Anatoliy Mironov, Harm Van Avendonk, Steffen Saustrup.

Sunday December 5 (day 43): Although the recovery of OBS's on GUMBO Line 3 went very well in general, we had great difficulty with OBS 325. The acoustic communication with this instrument was very sporadic, so we re-positioned the ship many times to find the best location for an acoustic release. During this time, we managed to get a few ranges to the OBS, which showed us that the instrument was still there. Only after 4.5 hours were we able to send a successful release command, from 700 m northeast of the deployment site.

Monday December 6 (day 44): The weather was quire rough, windy, and cold, but with the end of the project in sight we labored hard to get the remaining OBS's on the landward side of GUMBO Line 2 back on board. Instrument 215 was difficult to recover, because we had to re-position the ship a few times to get good acoustic communication, but we got it back. All other OBS's were retrieved without a problem. By 14:35 GMT we brought OBS 201, the last instrument, back on board, and set course for the Reservoir Geophysical dock in Amelia. We had not lost a single OBS on GUMBO Line 2, which made a very happy conclusion to the project.

Figure 6.30. Science party and crew of the M/V *Iron Cat* upon completion of the GUMBO project in Amelia, LA.

7. Weather

Although the cruise took place fairly late in the year (October 25 to December 6), we initially encountered mild to warm temperatures on the water (80s in the day, 50s at night). The storm of November 5 (at north end of Line 3) suddenly brought much cooler temperatures (low 40s). The last storm of December 5 (north end of Line 2) brought even colder weather (high 30s). Overall the temperatures were very comfortable, and the occasional low temperatures did not have a negative impact on our operations.

The wind speed and height of sea waves were much more critical for our operations. Waves over 10 feet would wash over the gun deck, which would delay the deployment and recovery of the source array. Seas over 12 feet would make it unsafe for us to use the cranes during OBS deployment and recovery. A high sea state would also make it more difficult to spot our OBS's on the sea surface during recovery. As we described in the daily log, storms caused a few 12-hour or 24-hour delays when they overlapped with our operations (Figure 7.1).

Although we received regular weather forecasts over the radio, the exact timing of cold fronts sweeping through the Gulf region was not sufficient to help with the our planning and OBS programming for each transect. The OBS recovery for Line 3 took place during a storm, which we could not avoid due to the fact that the instruments were just 6 hours away from their time release.

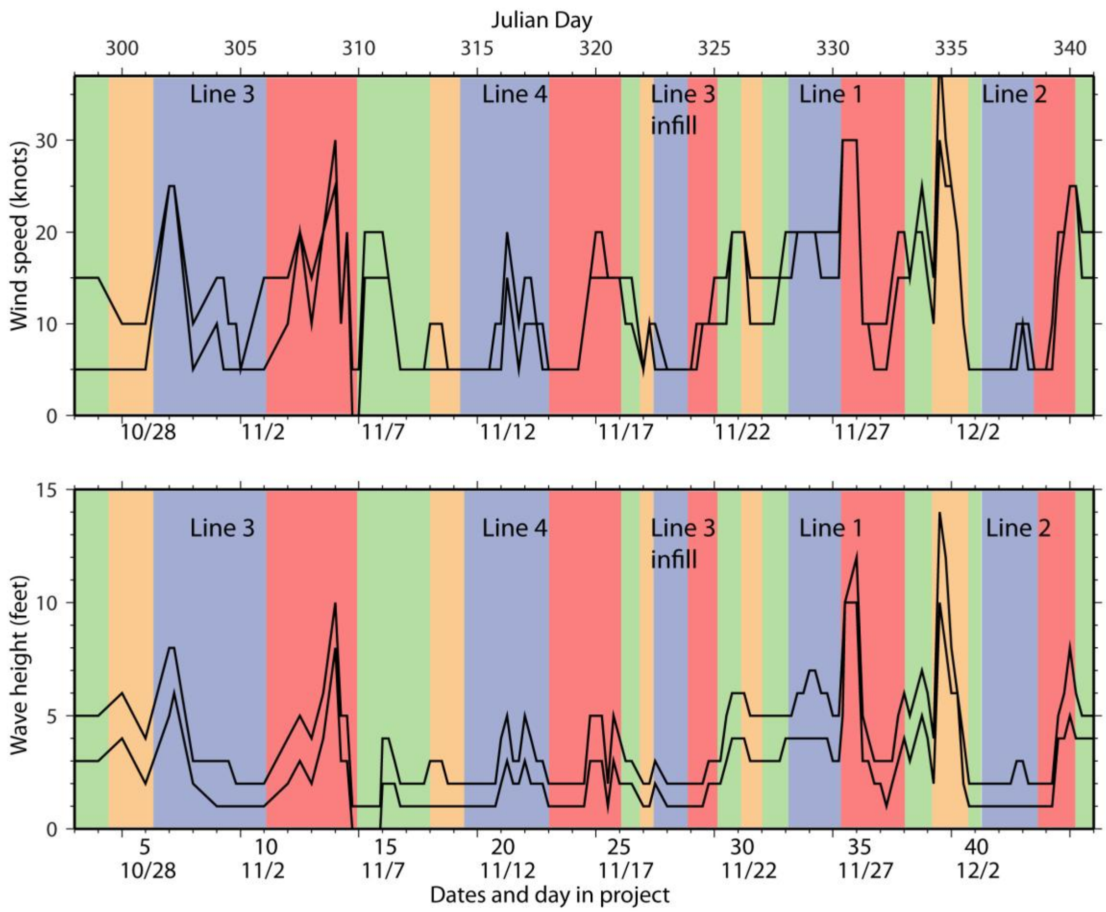


Figure 7.1. Sea state (wave height) and wind speed over the duration of the project. The two black curves indicate a low and a high estimate. The color panels represent our basic activities, similar to the color coding of Figure 3.1: Green = transit, orange = OBS deployment, violet = seismic shooting, red = OBS recovery.

8. Shot timing

Shots were triggered by NCS SubSea which initiated a trigger signal to the gun controller; the trigger signals were also recorded in the OBS lab. As a test to estimate whether there were any delays between the trigger and the actual shot time we deployed a hydrophone over the side of the ship and ran both the trigger signal and the hydrophone signal through an oscilloscope. The measured time between the trigger and shot as recorded by the hydrophone was 33-36 ms. The estimated distance between the hydrophone position and the center of the gun array was 46 m. With a water velocity of 1500 m/s we would expect it would take 31 ms to travel from the gun array to the hydrophone. Hence, we estimate a shot delay of 2-5 ms between trigger and actual shot, which is within the 5 ms sampling interval of the OBSs.

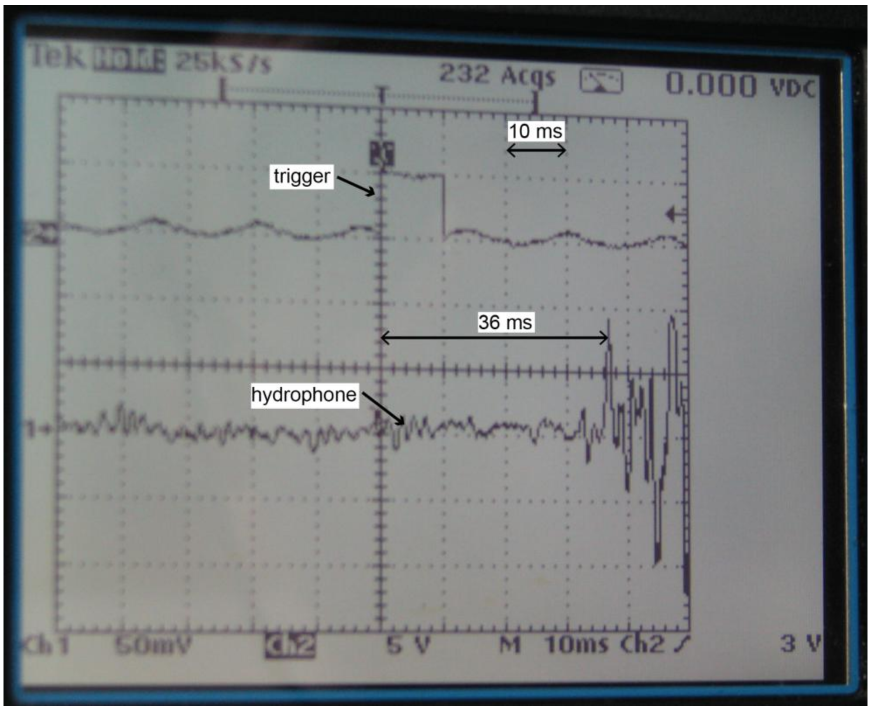


Figure 8.1. Oscilloscope screen displaying shot trigger and actual shot recorded by a hydrophone deployed over the side of the *Iron Cat* near the OBS lab.

9. Some data concerns

Instrument Noise on Geopro OBS's

After deployment of instruments on profile 4, Oleksy Tsyganok discovered that 6 instruments deployed on profile 3 had instrument noise that strongly obscured actual arrivals on the geophone components; no signal was recorded on the hydrophone component. Unfortunately these instruments had also been deployed on profile 4. Oleksy diagnosed the problem as an incorrect setting of the hydrophone preamp. Examples are shown for OBS 315, OBS 409, and OBS 435. Because the noise was coherent across the geophone components, Oleksy did find some improvement in signal by subtracting a horizontal component from the vertical component (Figure 9.1 and 9.2). This results in visible arrivals out to 15-20 km (OBS 315) or as much as 30-50 km (OBS 409 and OBS 435). By comparison, the position at OBS 315 was reoccupied during infill shooting of profile 3, and these data show clear arrivals out to offsets of 70-100 km. The hydrophone pre-amp setting was changed on these instruments and no further occurrence of this type of instrument noise was observed.

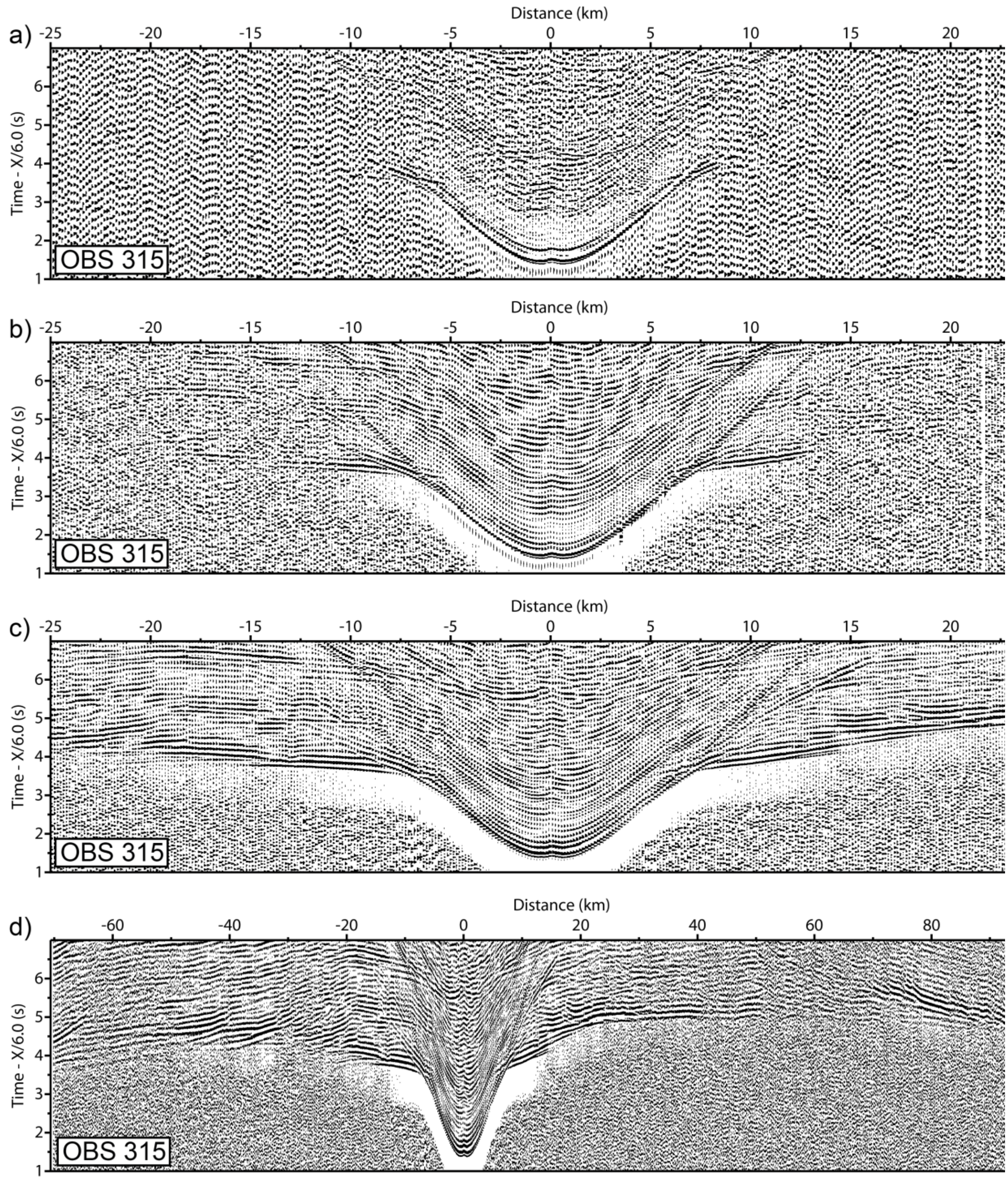


Figure 9.1. a) Instrument noise observed on vertical channel of OBS 315. b) OBS 315 vertical after subtraction of channel 2 horizontal component. c) OBS 315 vertical from the infill shooting. d) OBS 315 vertical from the infill shooting displaying clear arrivals out to long distances.

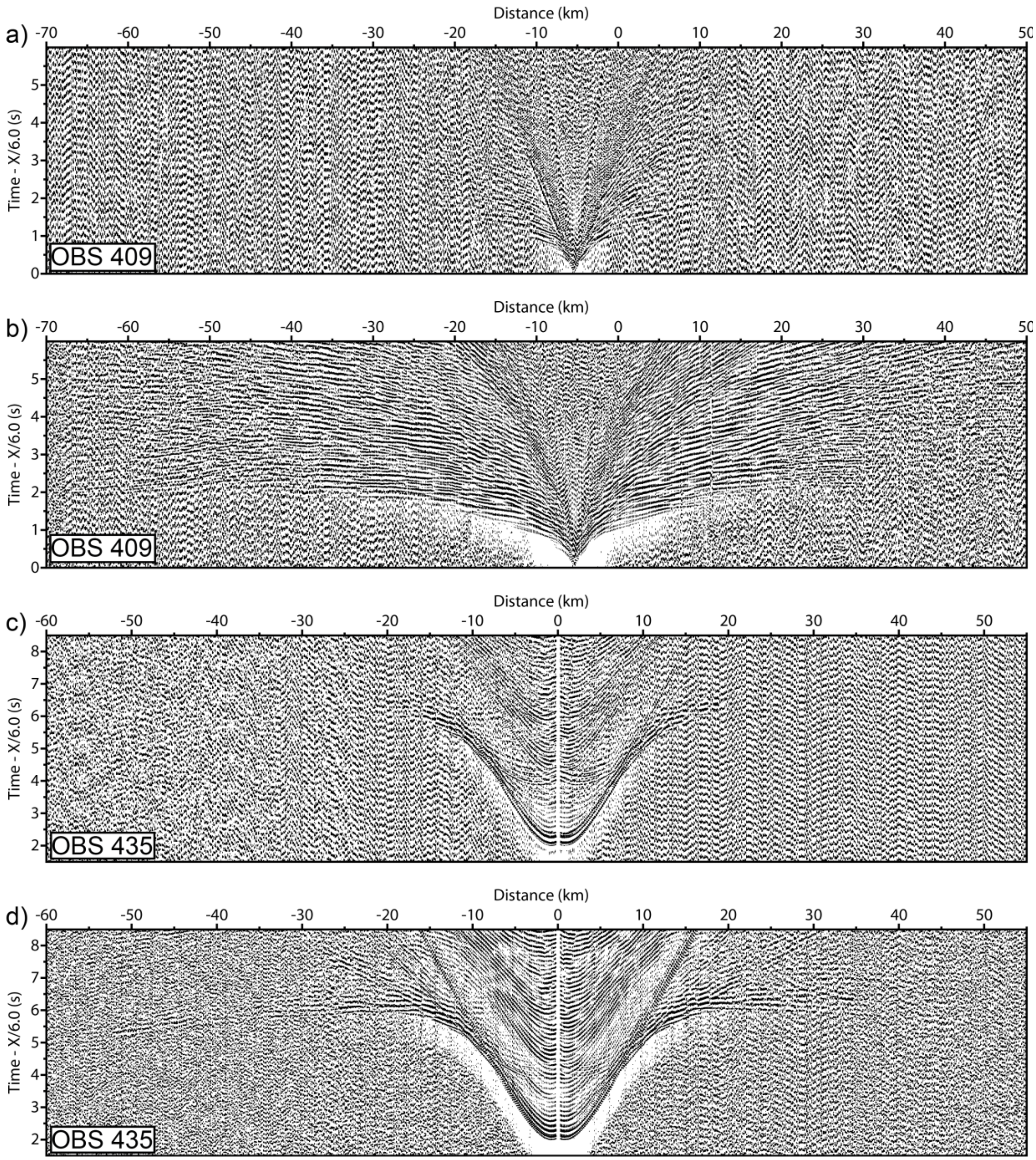


Figure 9.2. a) Instrument noise observed on vertical component of OBS 409. b) Vertical channel of OBS 409 after subtraction of channel 2 horizontal component. c) Instrument noise observed on vertical component of OBS 435. d) Vertical component of OBS 435 after subtraction of channel 2 horizontal component.

Gun Controller Settings, Shots 1001-1139, Profile 2

At the start of Line 2, the air-gun crew reported a small error in the shot timing that did not warrant a reshoot of the first portion of this transect: Shots 1001-1138 on Line 2 were shot with the gun controller set for Bolt air guns instead of the sleeve guns used by the *Iron Cat*. However, there does not appear to be any clear change in source signal recorded by the OBSs because of this error (Figure 9.3). Examples are shown for OBS 201 and OBS 202, the 2 closest instruments to these shots.

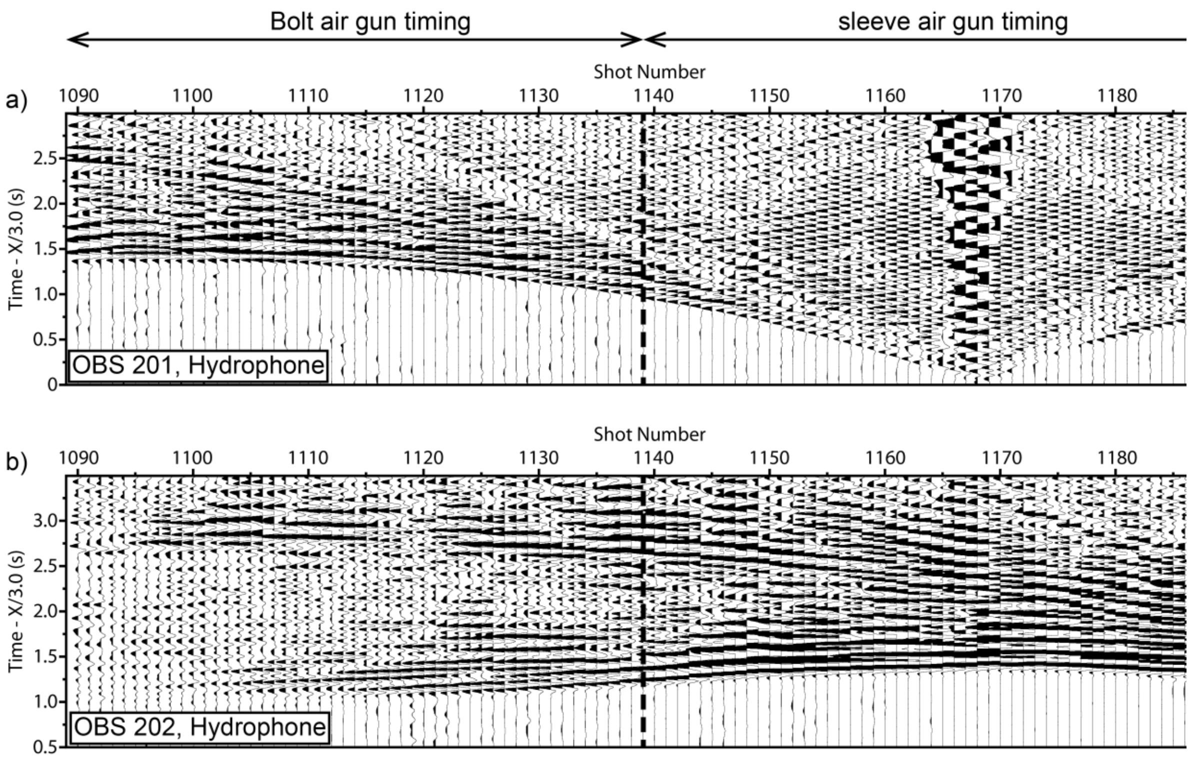


Figure 9.3. Hydrophone data for a) OBS 201 and b) OBS 202 for shots 1090-1190. Shots 1001-1138 were shot with the controller set for Bolt air gun timing instead of sleeve air gun timing.

10. Volume of seismic source

The M/V *Iron Cat* was equipped with 8 air compressors that were together nominally capable of supplying enough air to shoot an air-gun array with a volume of 9000 cubic inches at 2000 psi with a shot interval of 40 to 60 s. Since our project design assumed a 150 m shot spacing, a 60 second shot interval would be sufficient for ship speeds up to 4.5 knots. With this capacity we would be able to shoot all 5 air-gun strings of the M/V Iron cat for the duration of our project. However, we quickly discovered at the start of our operations that the compressors could not meet these specifications, so we had to settle for a smaller air-gun volume (see section 4).

The state of the air compressors generally allowed us to keep 3 air-gun strings shooting. During times that the compressors started to overheat, the pressure might drop below 1900 psi. We would temporarily lower the ship’s speed (typically from approximately 4 knots to 3 knots), to increase the shot interval from approximately 75 to 100 seconds. The longer intervals would then allow the compressors to catch up with their air supply.

Besides the compressor problems, we also had difficulties with the air-gun strings themselves, which would fail occasionally due to air leaks. This problem was quite severe initially during the acquisition of Line 3. Fortunately, the source crew was able to improve the fitting of air hoses to the air guns, so we had a more stable volume of the air-gun array during the rest of the project (Figure 10.1).

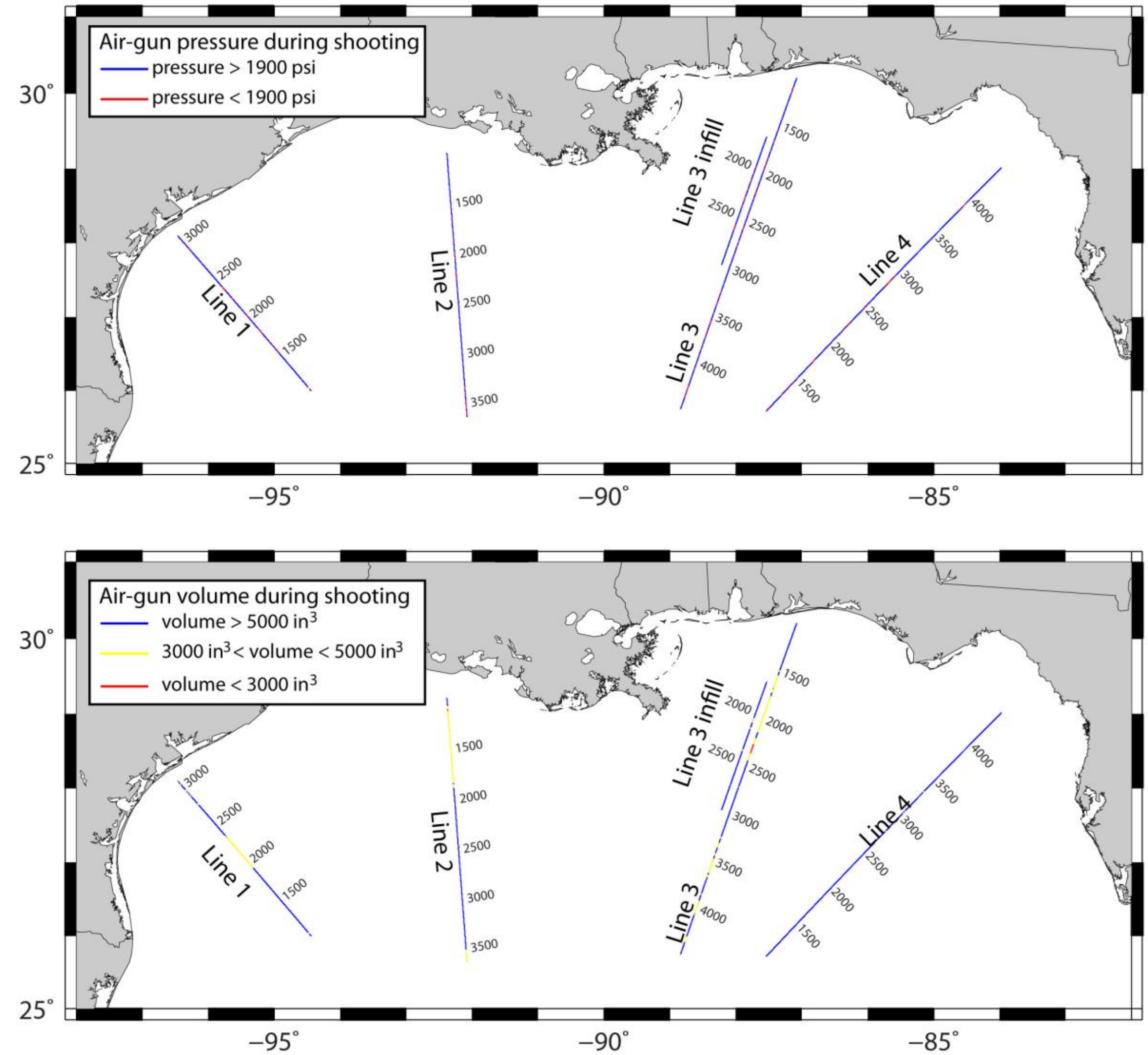


Figure 10.1. Variation in air-gun pressure (top) and total air-gun volume (bottom) over the course of the GUMBO project. Shots are annotated on each transect. The location of Line 3 Infill is offset from Line 3 to show variations in source array performance.

Data comparison for 3 and 5 air-gun strings

Since we acquired most of the OBS data for our project with 3 instead of 5 air-gun strings, we were interested to find out if this reduction of air volume affects the amplitude of seismic refractions recorded on our OBS's.

At the end of GUMBO Line 3 infill shooting the weather was calm, 6 generators were working, and all strings were operational and deployed. Party Chief Ben Bennett decided to turn the ship on a reciprocal course and do a test firing all 5 air-gun strings for about 15 shots. The resulting data displayed for OBS 322 surprisingly do not show a clear improvement in signal with the larger source. An additional, longer test of 4 airgun strings was planned for the end of profile 1 but could not be conducted because of weather conditions.

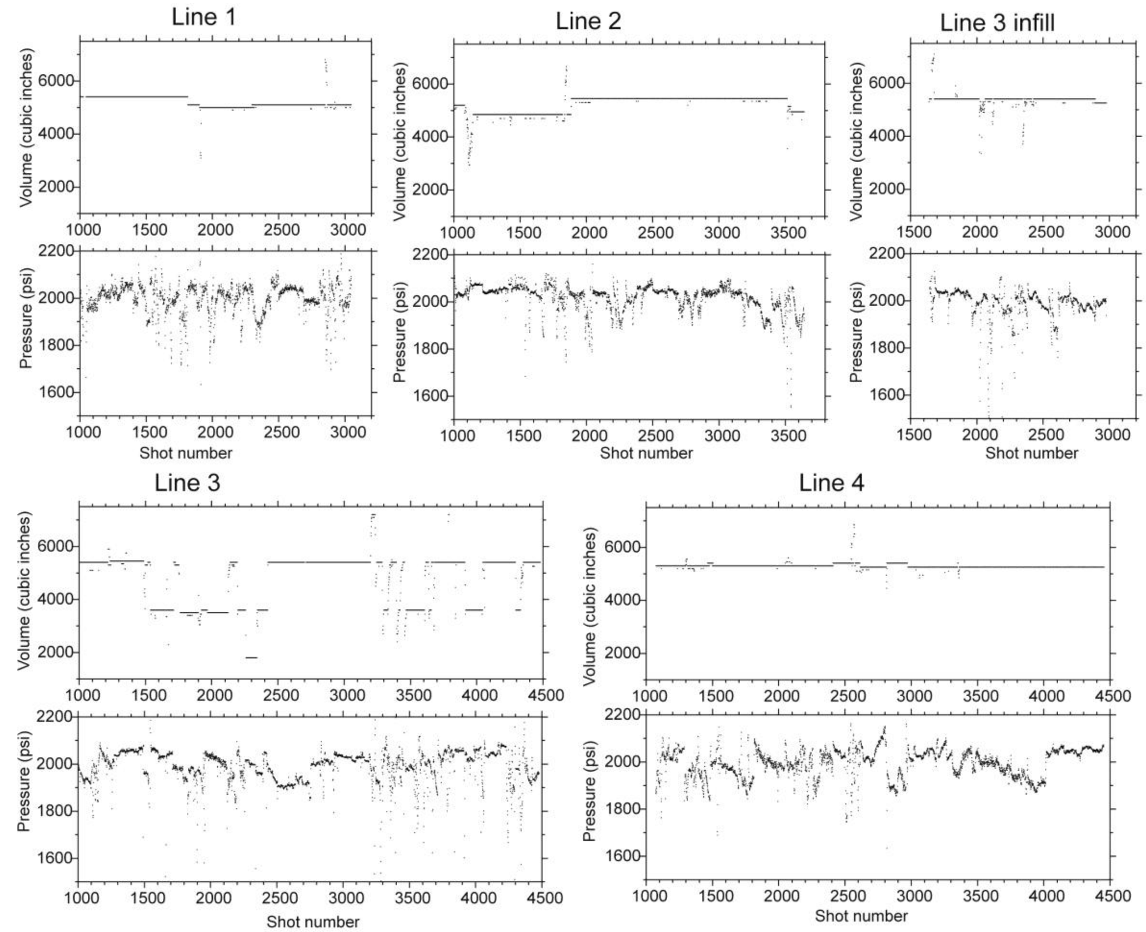


Figure 10.2. Profile of gun volume and gun pressure along each of the GUMBO transects.

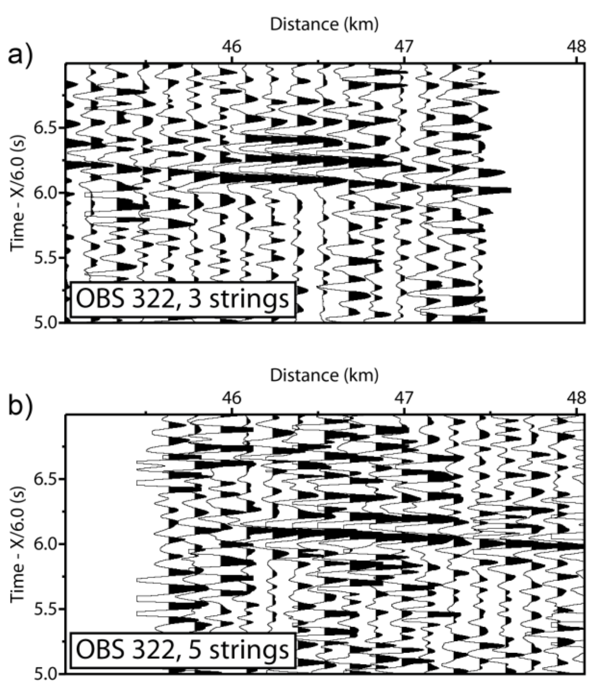


Figure 10.3. a) Vertical channel of OBS 322 for shots 2961-2977 of Profile 3 infill. These shots had a gun volume of 5250 cubic inches and were generated by 3 airgun strings. b) Vertical channel of OBS 322 for shots 2965-2981 shot on a reciprocal profile with 5 airgun strings.

Data comparison for 2 and 3 air-gun strings

While our goal was to shoot all profiles with 3 airgun strings, portions of GUMBO Line 3 were shot with only 2 air-gun strings owing to numerous air leaks. In the resulting data there is sometimes a clear decrease in signal quality corresponding to the decrease in source volume, while at other times there are not.

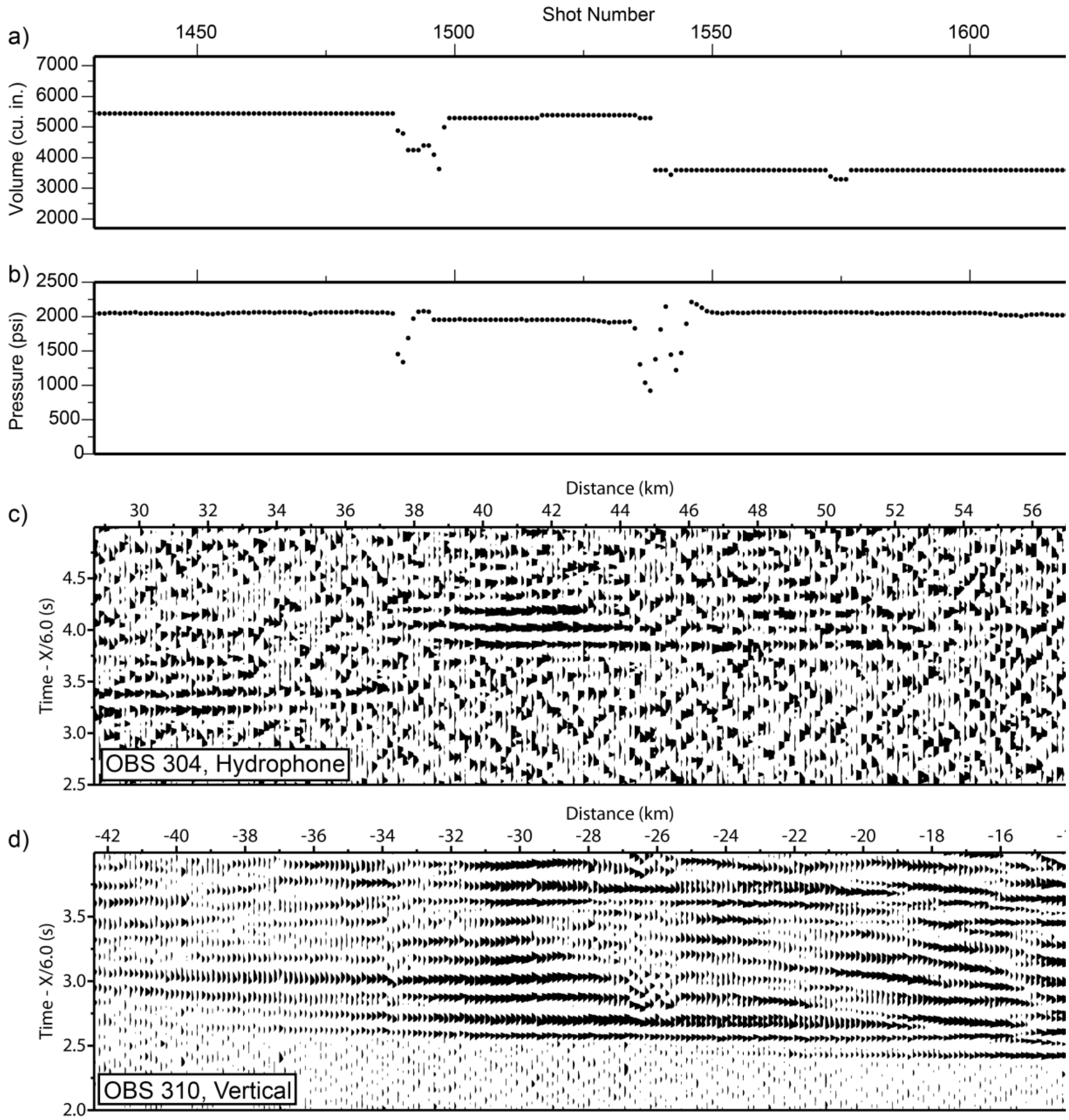


Figure 10.4. a) Source volume, shots 1430-1630 of Profile 3. Air leaks resulted in a decrease to firing on 2 airgun strings at shot 1535. b) Compressor pressure, shots 1430-1630 of Profile 3. c) OBS 304 hydrophone channel, shots 1430-1630 of Profile 3. d) OBS 310 vertical channel, shots 1430-1630 of Profile 3. Note clear decrease in signal amplitude corresponding to decrease in source volume for OBS 304 but not for OBS 310. The amplitudes of the seismograms have been range scaled by a factor of $R^{1.0}$, where R is the distance of the shot from the receiver.

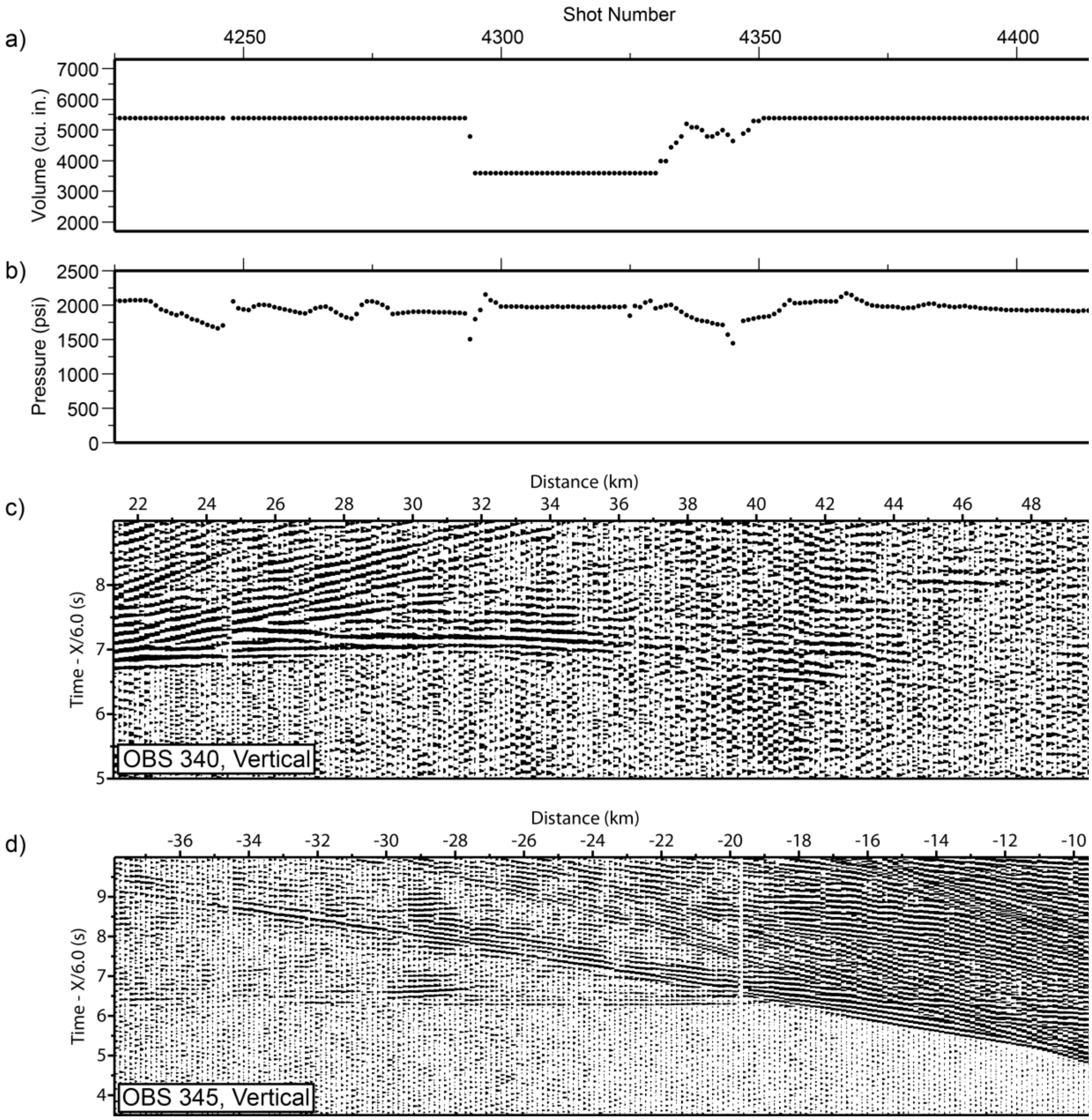


Figure 10.5. a) Source volume, shots 4225-4425 of Profile 3. Air leaks resulted in a decrease to firing on 2 airgun strings at shot 4295 with return to 3 airgun strings at shot 4349. b) Compressor pressure, shots 4225-4425 of Profile 3. c) OBS 340 vertical channel, shots 4225-4425 of Profile 3. d) OBS 345 vertical channel, shots 4225-4425 of Profile 3. There is not a clear change in signal amplitude corresponding to the decrease in source volume. The amplitudes of the seismograms have been range scaled by a factor of $R^{1.0}$, where R is the distance of the shot from the receiver.

11. OBS locations and deployment duration

Over the entire GUMBO project we made 166 OBS deployments. Of these instrument drops, 58 were performed by the UTIG team, and 108 were done by the Geopro team. The time and location of each OBS drop and recovery were carefully marked by the two navigators on the bridge. In figure 11.1a we show the distribution of Geopro and UTIG OBS's on the survey map.

The recovery of OBS's was generally successful, but over the course of the project we lost 10 instruments. Two instruments were crushed during recovery, 7 OBS's remained stuck on the seafloor, and one instrument never communicated, and did not come back on a time release. For details, see Section 6 (Daily Log).

Of the 156 recovered OBS's, 18 did not record data (Figure 11.1b). In some cases the same OBS did not record data on more than one deployment, in which case we may have a defect in the electronics. On quite a few occasions, an OBS did not record data on just one of our transects, but recorded well on all other deployments. Here we suspect problems with the flash memory cards, or a loose connector in the OBS. On Line 3 and 4, some of the Geopro OBS's had a problem with electronic noise from the hydrophone channel (see Section 8). This problem was solved by changing the gain on the hydrophone.

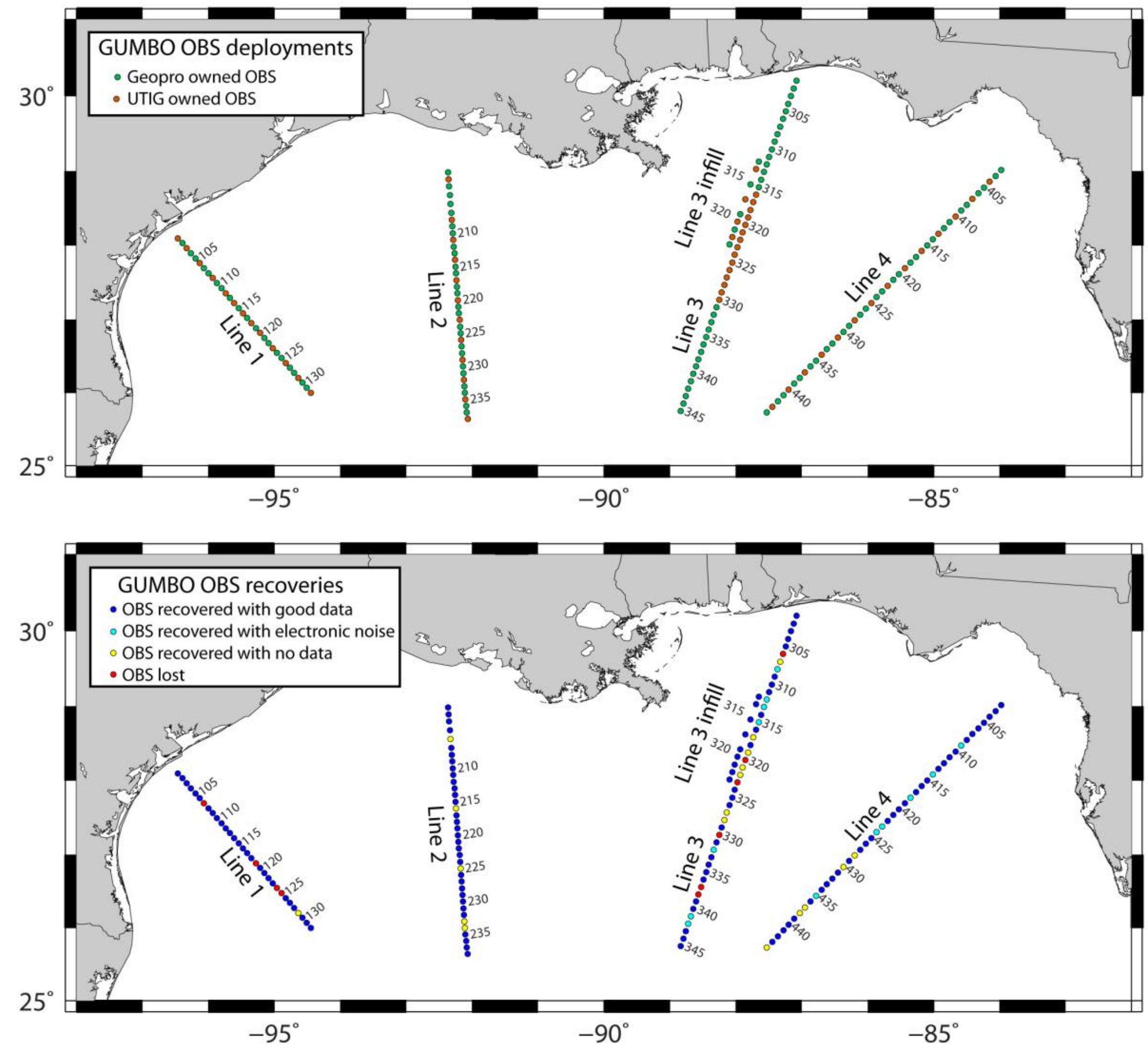


Figure 11.1. Top: The OBS sites colored by institution: Green = Geopro, orange = UTIG. Every fifth instrument is annotated. The sites of Line 3 Infill are offset from their true location on Line 3. Bottom: OBS sites are color coded by recovery status.

We list the location and time of the deployment and recovery of all OBS's for all seismic transects. The color coding in these tables is consistent with Figure 11.1: Dark blue = OBS recovered with good data. Light blue = OBS data with electronic noise. Yellow = OBS without data. Red = OBS and data lost.

OBS deployment and recovery GUMBO LIne 1

OBS	Deployment					Recovery				
	Latitude	Longitude	Date		Time	Latitude	Longitude			
101	28.09878	-96.46154	11	22	7:42	28.09856	-96.46196	11	28	18:04
102	28.03156	-96.39463	11	22	7:10	28.03207	-96.39501	11	28	17:00
103	27.964	-96.32856	11	22	6:38	27.96425	-96.33955	11	28	16:18
104	27.89676	-96.26291	11	22	6:05	27.89673	-96.26393	11	28	15:32
105	27.82981	-96.19635	11	22	5:32	27.83026	-96.19717	11	28	12:06
106	27.76195	-96.13042	11	22	4:59	27.76319	-96.1306	11	28	11:22
107	27.69428	-96.06473	11	22	4:27	27.69428	-96.06473	11	28	8:44
108	27.62714	-95.99873	11	22	3:54	27.62504	-95.99907	11	28	8:08
109	27.56007	-95.93252	11	22	3:22	27.56174	-95.93323	11	28	7:20
110	27.4923	-95.86736	11	22	2:49	27.4933	-95.86815	11	28	6:30
111	27.42468	-95.80196	11	22	2:06	27.42542	-95.80223	11	28	5:19
112	27.35694	-95.73628	11	22	1:32	27.35637	-95.73671	11	28	4:08
113	27.28964	-95.67086	11	22	0:59	27.28875	-95.67305	11	28	1:32
114	27.22194	-95.60481	11	22	0:25	27.22107	-95.60536	11	28	0:32
115	27.15388	-95.5402	11	21	23:52	27.1531	-95.54135	11	27	23:30
116	27.08661	-95.47511	11	21	23:19	27.0854	-95.47674	11	27	22:23
117	27.01934	-95.40956	11	21	22:46	27.01735	-95.41186	11	27	21:06
118	26.95128	-95.3448	11	21	22:12	26.94913	-95.34667	11	27	17:41
119	26.88367	-95.27956	11	21	21:39	26.88367	-95.27956	11	27	14:36
120	26.8155	-95.21531	11	21	21:06	26.81548	-95.21531	11	27	13:49
121	26.74771	-95.1505	11	21	20:32	26.74604	-95.15212	11	27	12:11
122	26.68007	-95.0856	11	21	19:59	26.67836	-95.0884	11	27	10:40
123	26.61214	-95.02067	11	21	19:27	26.61064	-95.02434	11	27	9:12
124	26.54449	-94.95642	11	21	19:53	26.54449	-94.95642	11	26	13:02
125	26.47627	-94.89182	11	21	18:17	26.47627	-94.89182	11	26	10:08
126	26.40854	-94.82731	11	21	17:43	26.4067	-94.83195	11	26	9:25
127	26.3402	-94.76308	11	21	17:12	26.33796	-94.76936	11	26	7:58
128	26.27201	-94.69844	11	21	16:42	26.27178	-94.70386	11	26	6:35
129	26.20443	-94.63449	11	21	16:10	26.20524	-94.64067	11	26	5:08
130	26.13639	-94.57065	11	21	15:40	26.13849	-94.57632	11	26	3:07
131	26.06817	-94.50632	11	21	15:03	26.07067	-94.51243	11	26	1:26
132	26.00004	-94.44233	11	21	14:36	26.00293	-94.44473	11	25	23:14

OBS deployment and recovery GUMBO LIne 2

OBS	Deployment					Recovery				
	Latitude	Longitude				Latitude	Longitude			
201	28.97973	-92.36194	12	1	14:58	28.97981	-92.36333	12	6	14:35
202	28.88872	-92.35372	12	1	14:26	28.88908	-92.35747	12	6	13:54
203	28.79545	-92.34535	12	1	13:52	28.79847	-92.34921	12	6	13:04
204	28.67846	-92.33548	12	1	12:48	28.67823	-92.33659	12	6	12:02
206	28.55765	-92.32440	12	1	12:00	28.55573	-92.32746	12	6	11:04
207	28.43740	-92.31473	12	1	11:00	28.43665	-92.31547	12	6	9:52
208	28.34655	-92.30617	12	1	10:00	28.34635	-92.30778	12	6	9:08
209	28.25654	-92.29812	12	1	8:56	28.25595	-92.30024	12	6	8:18
210	28.16617	-92.29051	12	1	7:56	28.16472	-92.25090	12	6	7:26
211	28.07580	-92.28229	12	1	7:06	28.07543	-92.28259	12	6	6:38
212	27.98633	-92.27542	12	1	6:08	27.98520	-92.27558	12	6	5:45
213	27.89527	-92.26621	12	1	4:58	27.89425	-92.26578	12	6	4:46
214	27.80509	-92.25916	12	1	3:54	27.80435	-92.25916	12	6	3:49
215	27.71527	-92.25133	12	1	2:55	27.71431	-92.25216	12	6	2:49
216	27.62430	-92.24321	12	1	1:50	27.62398	-92.24381	12	6	1:38
217	27.53350	-92.23642	12	1	0:43	27.53277	-92.23548	12	6	0:33
218	27.44434	-92.22864	11	30	23:21	27.44387	-92.22970	12	5	23:26
219	27.35377	-92.22012	11	30	22:10	27.35202	-92.22004	12	5	22:22
220	27.26335	-92.21246	11	30	20:51	27.26276	-92.21338	12	5	21:24
221	27.17152	-92.20512	11	30	19:32	27.17082	-92.20670	12	5	20:11
222	27.08300	-92.19730	11	30	17:02	27.08142	-92.19654	12	5	19:04
223	26.99276	-92.18941	11	30	16:04	26.99167	-92.19074	12	5	17:56
224	26.90281	-92.18178	11	30	15:24	26.90047	-92.18311	12	5	16:54
225	26.81253	-92.17404	11	30	14:50	26.81204	-92.17312	12	5	11:28
226	26.72231	-92.16635	11	30	14:18	26.72068	-92.16476	12	5	10:20
227	26.63208	-92.15884	11	30	13:45	26.62962	-92.15596	12	5	9:02
228	26.54236	-92.15113	11	30	13:10	26.53990	-92.14774	12	5	7:52
229	26.45140	-92.14344	11	30	12:36	26.44863	-92.14091	12	5	6:18
230	26.36152	-92.13595	11	30	12:02	26.35897	-92.13471	12	5	4:55
231	26.26861	-92.12698	11	30	11:28	26.26895	-92.12655	12	5	3:19
232	26.18039	-92.12053	11	30	10:52	26.17959	-92.11946	12	5	1:46
233	26.09062	-92.11306	11	30	10:16	26.08916	-92.11211	12	5	0:25
234	25.99993	-92.10546	11	30	9:42	25.99966	-92.10403	12	4	22:58
235	25.90962	-92.09887	11	30	9:10	25.90962	-92.09845	12	4	21:16
236	25.81953	-92.09075	11	30	8:35	25.81794	-92.08782	12	4	19:34
237	25.72915	-92.08309	11	30	8:02	25.72751	-92.08120	12	4	15:55
238	25.63927	-92.04599	11	30	7:25	25.63746	-92.07523	12	4	14:12

OBS deployment and recovery GUMBO Line 3

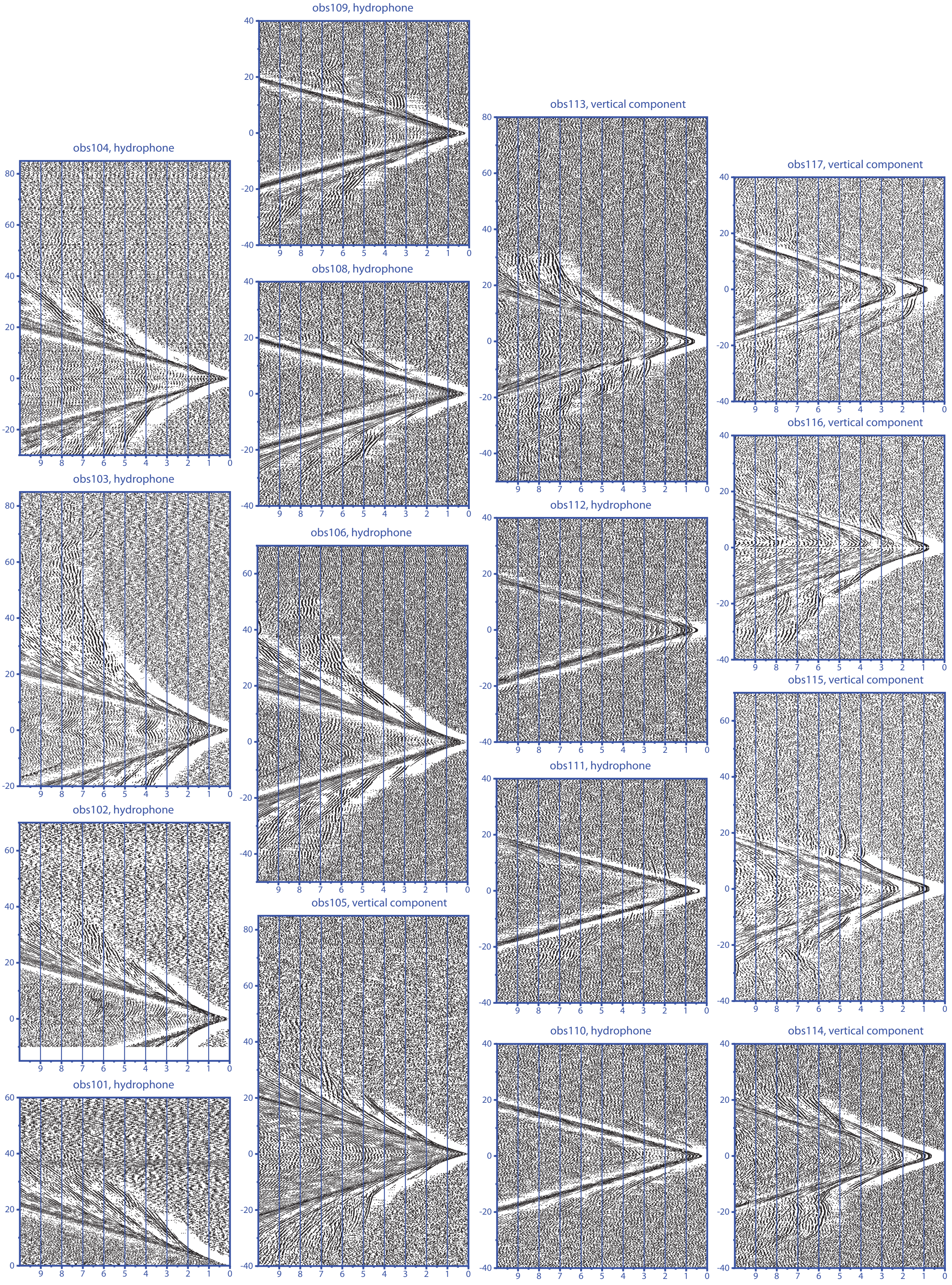
OBS	Deployment					Recovery				
	Latitude	Longitude	Date		Time	Latitude	Longitude	Date		Time
301	30.19313	-87.07782	10	27	11:09	30.19100	-87.07683	11	5	15:00
302	30.09244	-87.11975	10	27	10:19	30.09202	-87.11824	11	5	13:58
303	29.99148	-87.16113	10	27	9:38	29.99087	-87.16068	11	5	13:01
304	29.89050	-87.20288	10	27	8:56	29.88733	-87.20028	11	5	12:11
305	29.78971	-87.24378	10	27	8:17	29.78903	-87.23937	11	5	11:05
306	29.68936	-87.28514	10	27	7:39	29.68936	-87.28514	11	5	10:15
307	29.58855	-87.32600	10	27	7:01	29.58719	-87.32513	11	5	8:55
308	29.48763	-87.36670	10	27	6:22	29.48700	-87.36422	11	5	7:42
309	29.38722	-87.40858	10	27	5:45	29.38586	-87.40836	11	5	5:56
310	29.28615	-87.45097	10	27	5:06	29.28359	-87.45058	11	5	3:51
311	29.18598	-87.49116	10	27	4:26	29.18457	-87.49005	11	5	1:45
312	29.08479	-87.53106	10	27	3:47	29.08430	-87.52918	11	4	23:28
313	28.98394	-87.57187	10	27	3:01	28.98304	-87.57263	11	4	21:33
314	28.88326	-87.61243	10	27	2:15	28.88346	-87.61426	11	4	19:30
315	28.78225	-87.65282	10	27	1:29	28.78217	-87.65479	11	4	17:17
316	28.68168	-87.69394	10	27	0:49	28.68152	-87.69495	11	4	15:15
317	28.58047	-87.73408	10	27	0:08	28.58298	-87.73487	11	4	11:45
318	28.47991	-87.77450	10	26	23:24	28.47192	-87.77543	11	4	12:55
319	28.37882	-87.81448	10	26	22:43	28.37979	-87.81533	11	4	7:14
320	28.27823	-87.85432	10	26	21:58	28.27823	-87.85432	11	4	3:45
321	28.17674	-87.89472	10	26	21:19	28.17517	-87.89496	11	4	2:54
322	28.07611	-87.93433	10	26	20:40	28.07545	-87.93445	11	4	0:47
323	27.97535	-87.97446	10	26	19:57	27.97535	-87.97446	11	3	21:24
324	27.87420	-88.01426	10	26	19:17	27.87513	-88.01284	11	3	20:42
325	27.77328	-88.05439	10	26	18:29	27.77520	-88.05462	11	3	18:32
326	27.67237	-88.09364	10	26	17:42	27.68191	-88.09420	11	3	16:29
327	27.57183	-88.13343	10	26	17:04	27.57920	-88.13464	11	3	13:56
328	27.47029	-88.17261	10	26	16:25	27.47331	-88.17209	11	3	11:38
329	27.36878	-88.21214	10	26	15:45	27.36968	-88.21351	11	3	9:42
330	27.26832	-88.25185	10	26	14:57	27.26832	-88.25185	11	3	6:01
331	27.16769	-88.29134	10	26	14:01	27.16831	-88.29170	11	3	5:16
332	27.06664	-88.33062	10	26	13:24	27.06246	-88.33396	11	3	3:15
333	26.96564	-88.36990	10	26	12:45	26.96222	-88.37300	11	3	0:46
334	26.86470	-88.40903	10	26	12:06	26.86218	-88.41201	11	2	22:37
335	26.76337	-88.44796	10	26	11:14	26.76138	-88.45119	11	2	16:48
336	26.66214	-88.48604	10	26	10:36	26.66011	-88.48802	11	2	15:02
337	26.56142	-88.52464	10	26	9:58	26.56142	-88.52464	11	2	12:30
338	26.46001	-88.56477	10	26	9:21	26.46001	-88.56477	11	2	10:32
339	26.35914	-88.60297	10	26	8:39	26.35793	-88.59931	11	2	9:49
340	26.25797	-88.64302	10	26	8:01	26.26093	-88.64448	11	2	7:11
341	26.15635	-88.68078	10	26	7:25	26.15674	-88.67701	11	2	4:54
342	26.05538	-88.71923	10	26	6:42	26.05548	-88.71729	11	2	2:28
343	25.95451	-88.75784	10	26	6:02	25.95501	-88.75799	11	2	0:23
344	25.85438	-88.79529	10	26	5:16	25.85517	-88.29456	11	1	22:19
345	25.75228	-88.83438	10	26	4:23	25.75184	-88.83041	11	1	20:06

OBS deployment and recovery GUMBO Line 3 infill

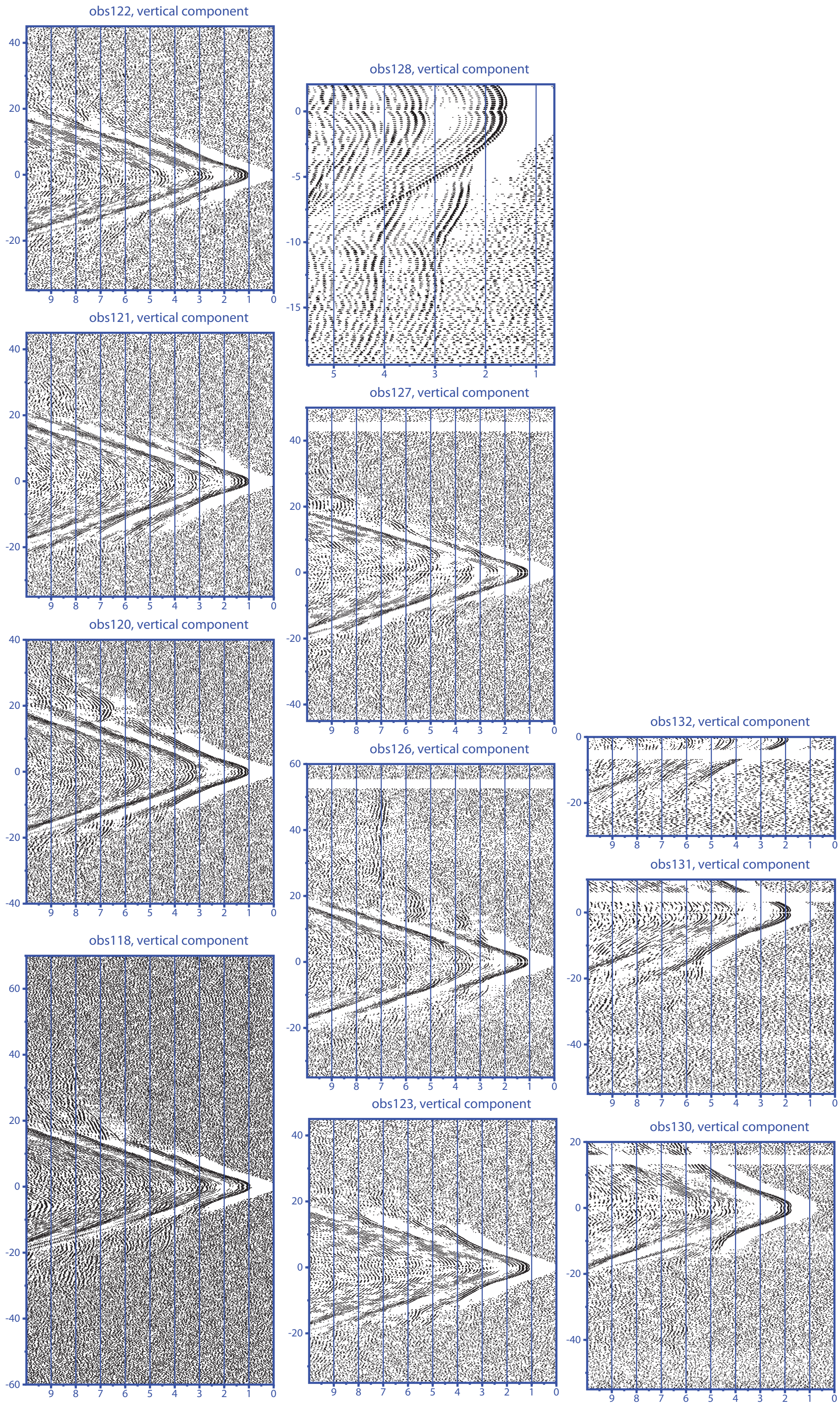
OBS	Deployment					Recovery				
	Latitude	Longitude	Date		Time	Latitude	Longitude	Date		Time
312	29.08508	-87.53165	11	17	15:52	29.08649	-87.59332	11	20	1:30
313	28.98456	-87.57231	11	17	15:15	28.98662	-87.57264	11	19	23:39
315	28.78223	-87.65304	11	17	14:00	28.78459	-87.65189	11	19	21:30
317	28.58067	-87.73372	11	17	12:48	28.58246	-87.73346	11	19	19:18
319	28.37884	-87.81406	11	17	11:36	28.38289	-87.81646	11	19	17:10
320	28.27799	-87.85407	11	17	11:00	28.28299	-87.85726	11	19	15:34
321	28.17738	-87.89486	11	17	10:22	28.18188	-87.89498	11	19	13:41
322	28.07611	-87.93432	11	17	9:40	28.07922	-87.93555	11	19	12:00
323	27.97530	-87.97466	11	17	9:00	27.97738	-87.97794	11	19	10:03

OBS deployment and recovery GUMBO Line 4

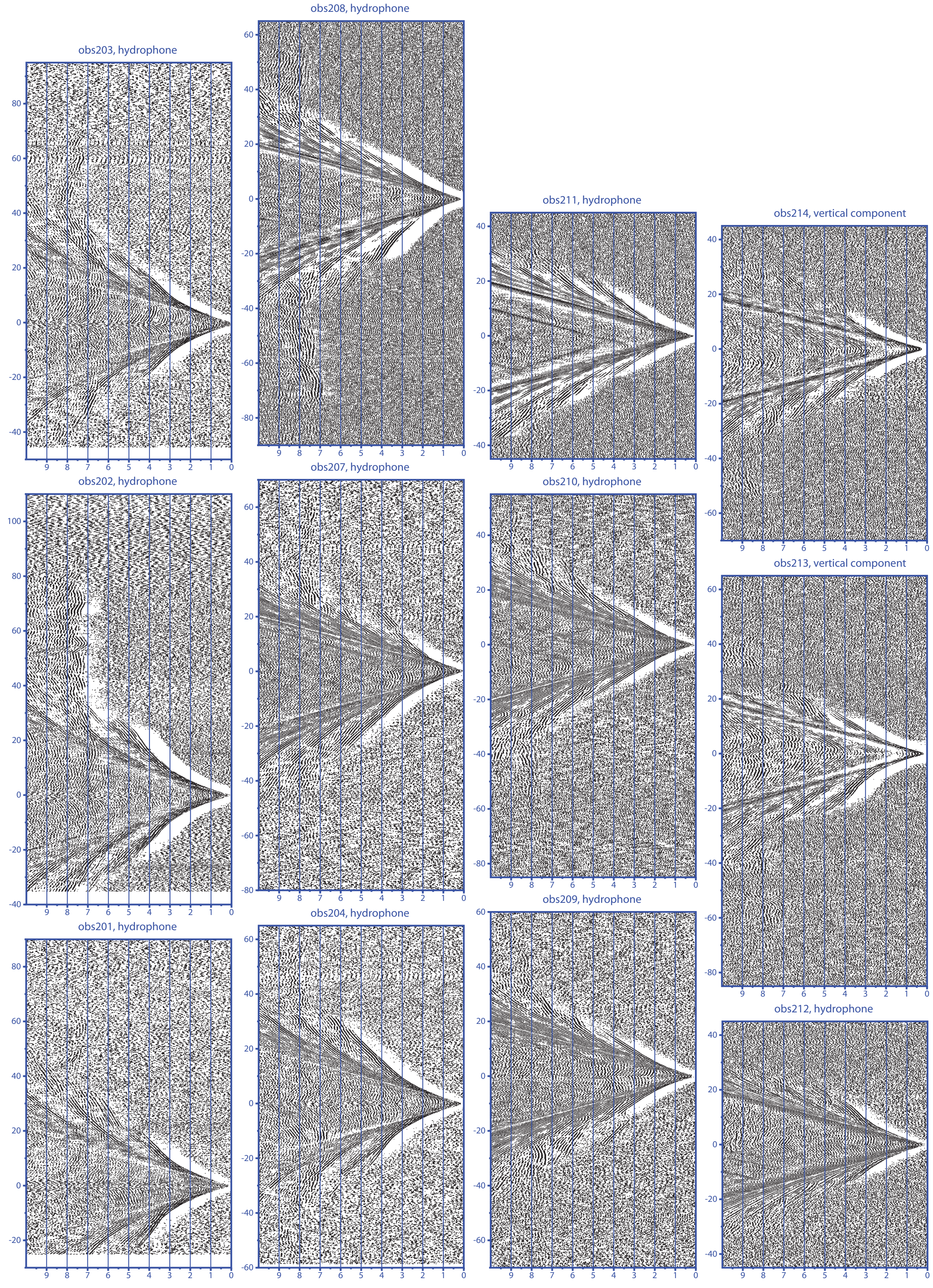
OBS	Deployment					Recovery				
	Latitude	Longitude	Date		Time	Latitude	Longitude	Date		Time
402	29.01004	-83.97468	11	8	2:39	29.01024	-83.97474	11	13	15:07
403	28.93308	-84.06102	11	8	3:23	28.93343	-84.06159	11	13	16:18
404	28.85573	-84.14833	11	8	4:05	28.85578	-84.14966	11	13	17:15
405	28.77900	-84.23491	11	8	4:47	28.77902	-84.23516	11	13	18:04
406	28.70116	-84.32170	11	8	5:30	28.70117	-84.32185	11	13	18:53
407	28.62405	-84.40903	11	8	6:12	28.62435	-84.40886	11	13	19:52
408	28.54651	-84.49469	11	8	6:51	28.54641	-84.49461	11	13	21:39
409	28.46948	-84.58113	11	8	7:27	28.46979	-84.58161	11	13	23:15
410	28.39220	-84.66715	11	8	8:05	28.39167	-84.66703	11	14	0:41
411	28.31464	-84.75364	11	8	8:40	28.31374	-84.75385	11	14	1:59
412	28.23676	-84.83876	11	8	9:16	28.23637	-84.83894	11	14	3:00
413	28.15979	-84.92491	11	8	9:53	28.15907	-84.92941	11	14	4:16
414	28.08166	-85.01102	11	8	10:32	28.08094	-85.01195	11	14	5:19
415	28.00433	-85.09617	11	8	11:09	28.00424	-85.09751	11	14	8:51
416	27.92671	-85.18209	11	8	11:47	27.92668	-85.18340	11	14	10:01
417	27.84859	-85.26705	11	8	12:25	27.84894	-85.26653	11	14	11:44
418	27.77069	-85.35230	11	8	13:04	27.77054	-85.35237	11	14	13:52
419	27.69305	-85.43724	11	8	13:50	27.69312	-85.43795	11	14	14:55
420	27.61485	-85.52235	11	8	14:32	27.61624	-85.52274	11	14	16:08
421	27.53664	-85.60730	11	8	15:14	27.53820	-85.60738	11	14	18:22
422	27.45861	-85.69217	11	8	15:55	27.45895	-85.69181	11	14	20:27
423	27.38057	-85.77688	11	8	16:34	27.38102	-85.77930	11	14	22:19
424	27.30246	-85.86134	11	8	17:13	27.30407	-85.86473	11	15	0:19
425	27.22389	-85.94553	11	8	17:50	27.22524	-85.95236	11	15	2:41
426	27.14571	-86.02944	11	8	18:35	27.14684	-86.03646	11	15	4:33
427	27.06771	-86.11413	11	8	19:13	27.06941	-86.12433	11	15	6:22
428	26.98948	-86.19803	11	8	19:54	26.99008	-86.21062	11	15	8:23
429	26.91081	-86.28166	11	8	20:37	26.91093	-86.30381	11	15	11:14
430	26.83202	-86.36547	11	8	21:19	26.83208	-86.37758	11	15	13:08
431	26.75384	-86.44890	11	8	21:57	26.75071	-86.45452	11	15	15:10
432	26.67485	-86.53217	11	8	22:35	26.66733	-86.53763	11	15	17:36
433	26.59613	-86.61632	11	8	23:14	26.58867	-86.61796	11	15	19:52
434	26.51790	-86.69913	11	8	23:51	26.50946	-86.69980	11	15	21:57
435	26.43882	-86.78204	11	9	0:29	26.43297	-86.78416	11	16	1:01
436	26.36041	-86.86565	11	9	1:09	26.35351	-86.86940	11	16	2:51
437	26.28122	-86.94769	11	9	1:46	26.27624	-86.95114	11	16	4:50
438	26.20228	-87.03099	11	9	2:25	26.19667	-87.03631	11	16	6:47
439	26.12367	-87.11368	11	9	3:05	26.12091	-87.12256	11	16	8:42
440	26.04440	-87.19645	11	9	3:48	26.04171	-87.20023	11	16	10:37
441	25.96553	-87.27887	11	9	4:31	25.96346	-87.28359	11	16	12:35
442	25.88703	-87.36099	11	9	5:14	25.88445	-87.36281	11	16	15:00
443	25.80780	-87.44337	11	9	5:55	25.80600	-87.44354	11	16	17:14
444	25.72869	-87.52605	11	9	6:36	25.72653	-87.52224	11	16	19:51



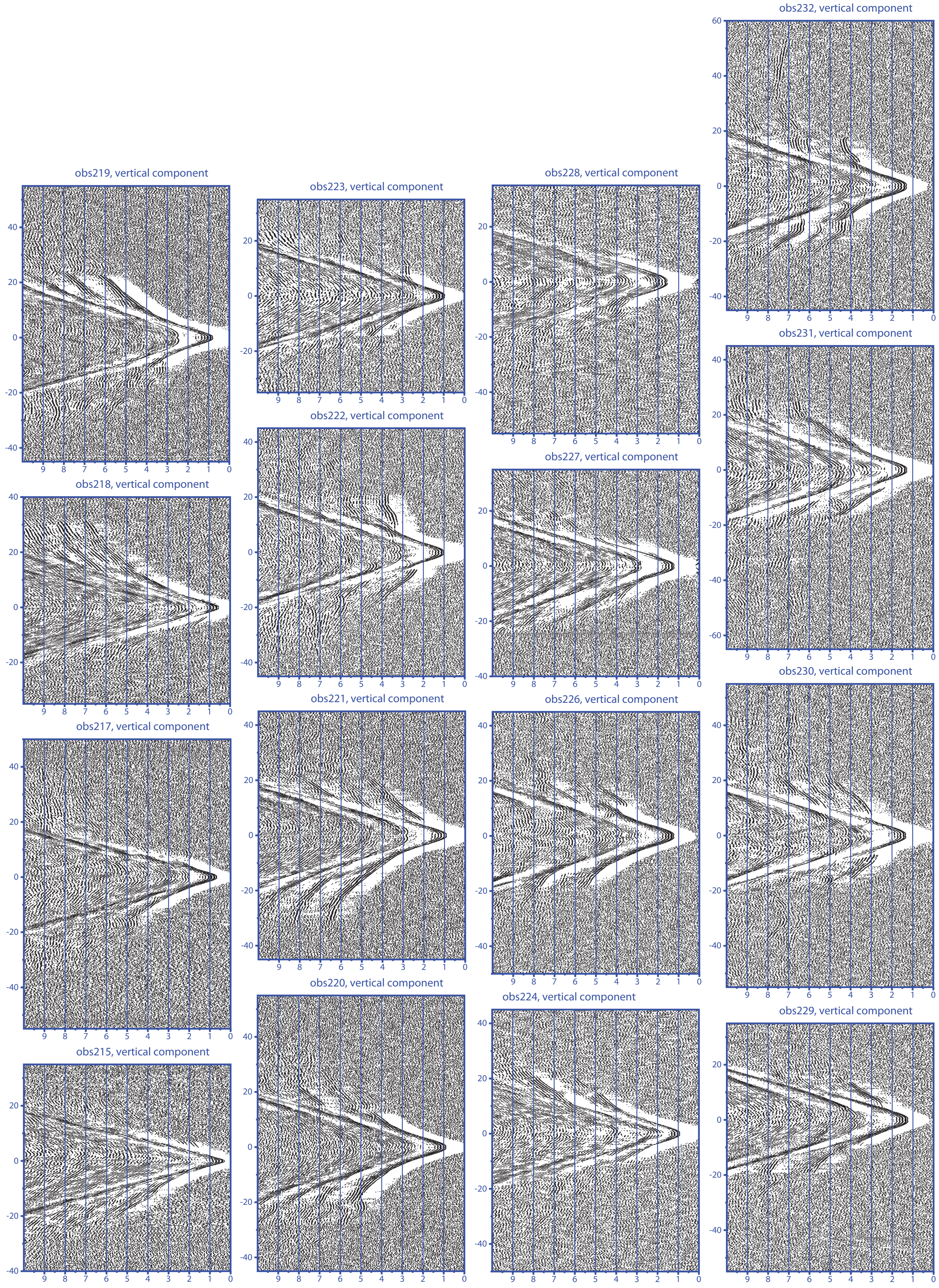
12. Data plots, GUMBO Line 1. OBS 101 to OBS 117. All figures are shown at the same scale, with 6 km/s reduction velocity.



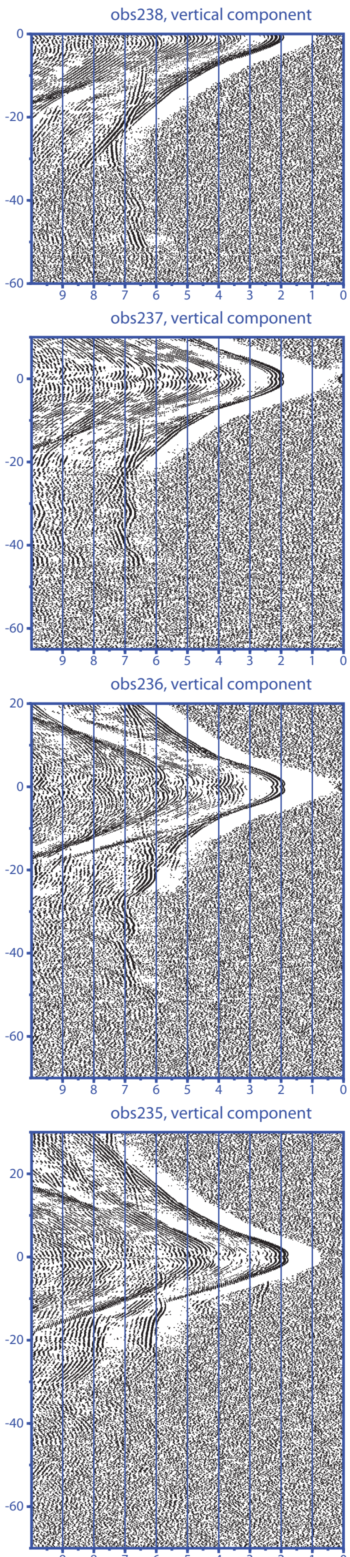
Data plots, GUMBO Line 1. OBS 118 to OBS 132.



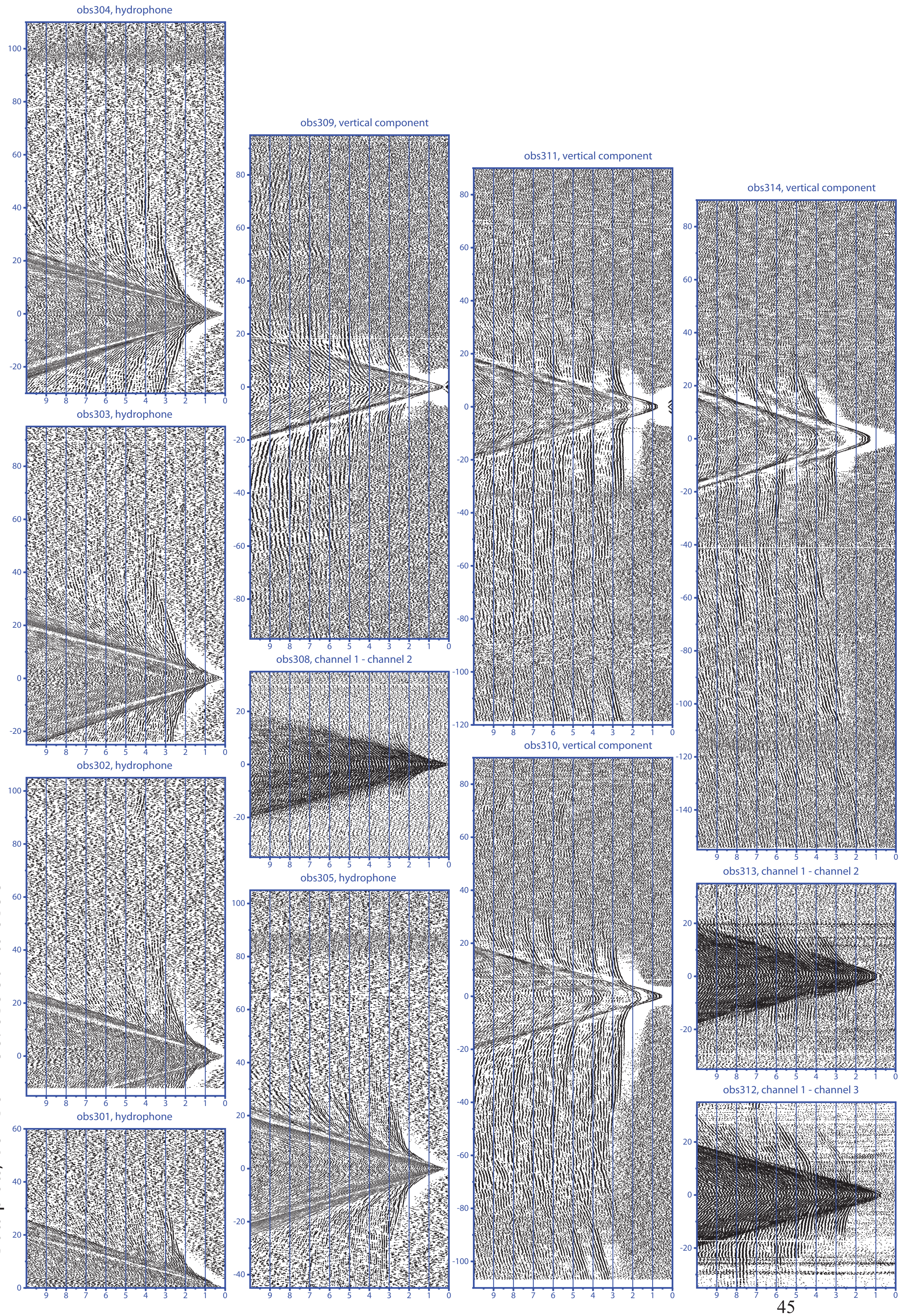
Data plots, GUMBO Line 2. OBS 201 to OBS 214.



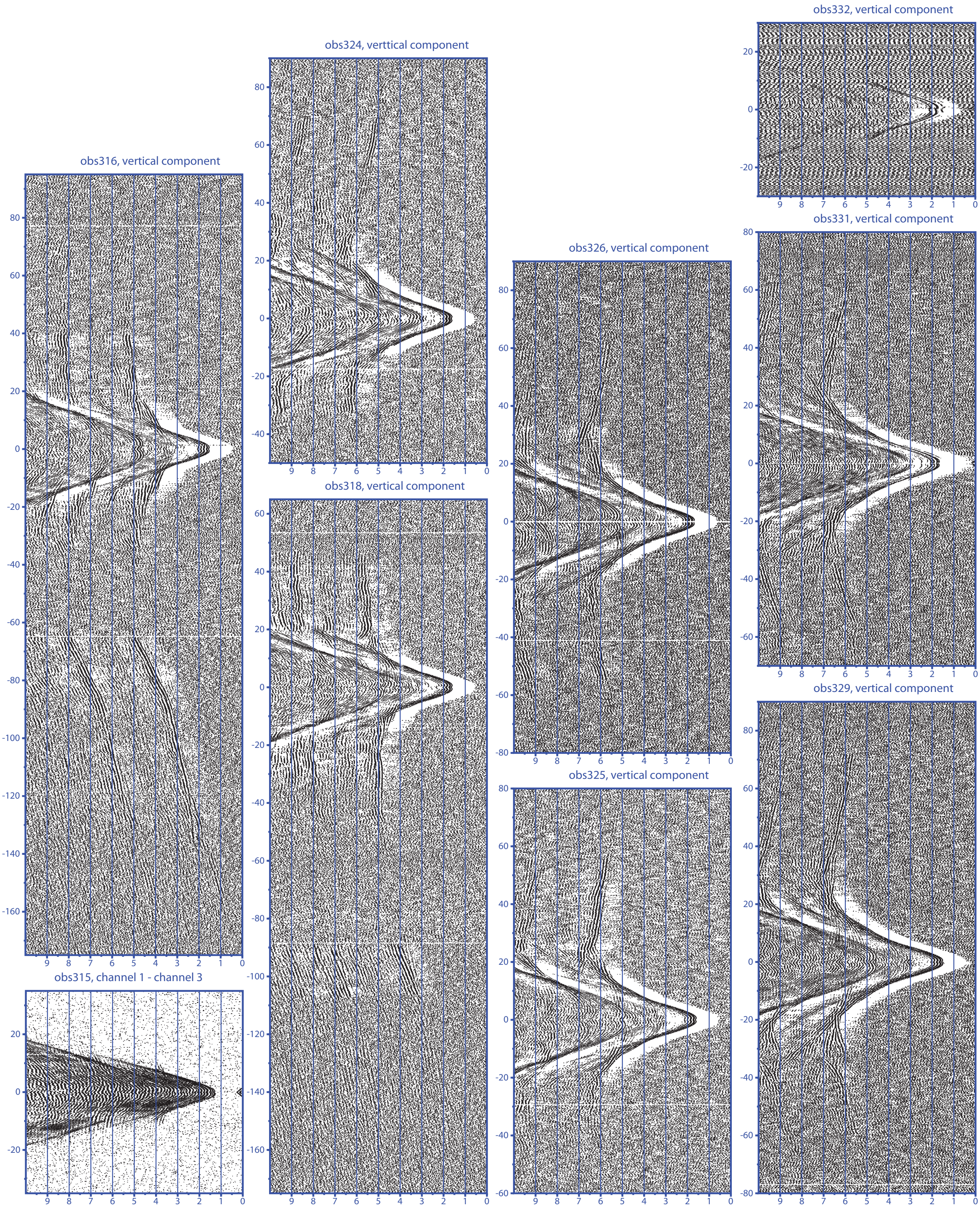
Data plots, GUMBO Line 2. OBS 215 to OBS 232.



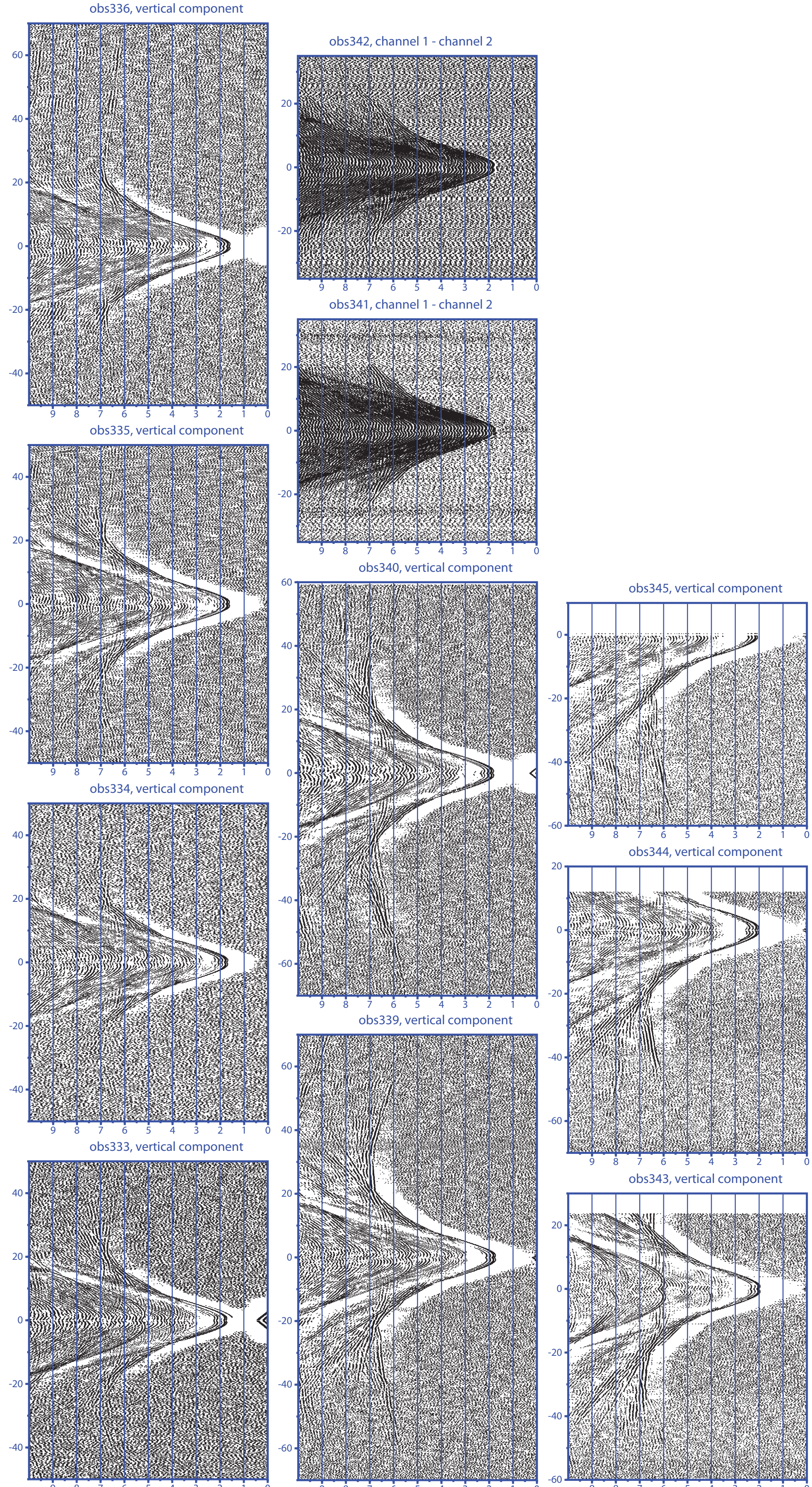
Data plots, GUMBO Line 2. OBS 235 to OBS 238.



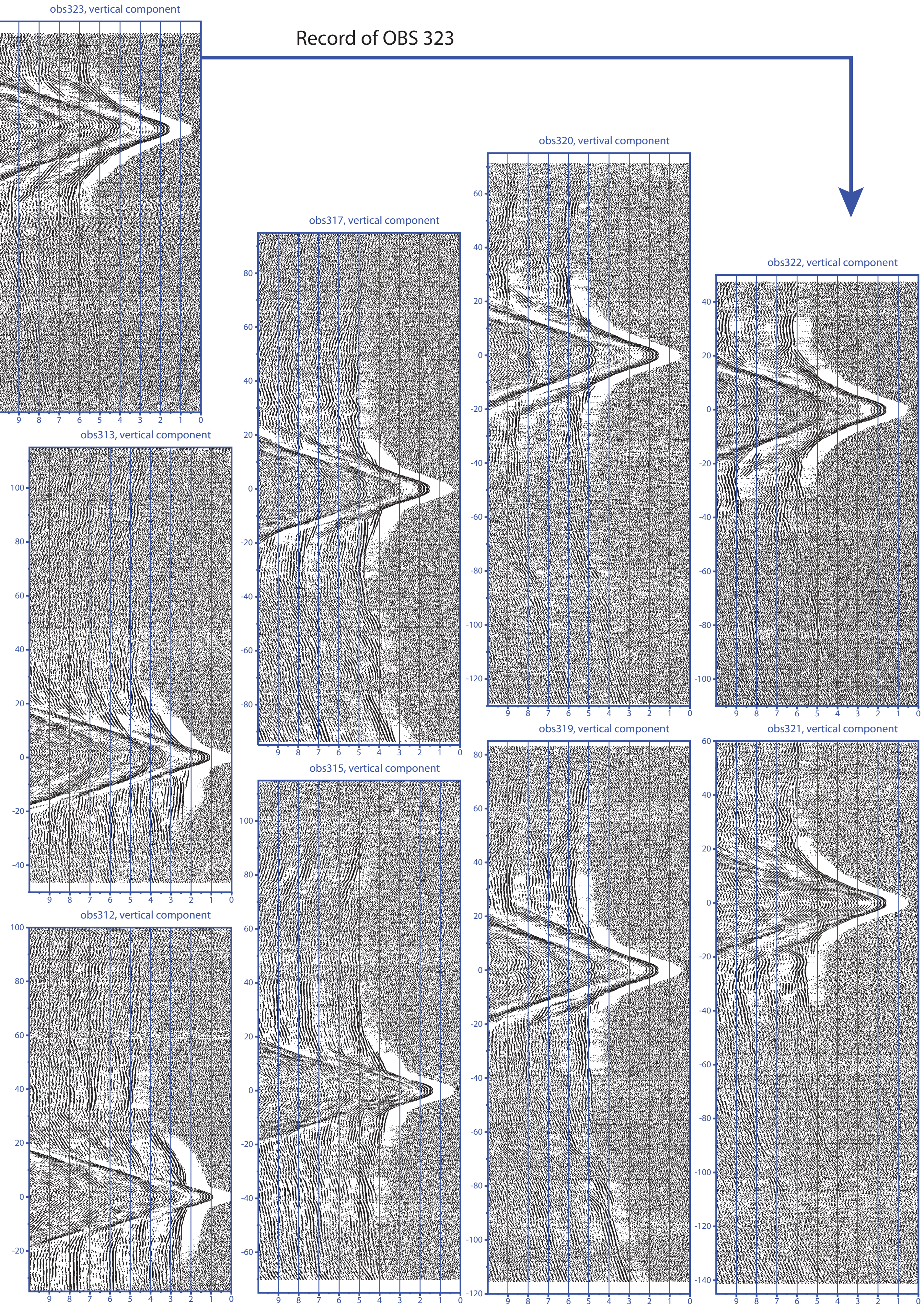
Data plots, GUMBO Line 3. OBS 301 to OBS 314



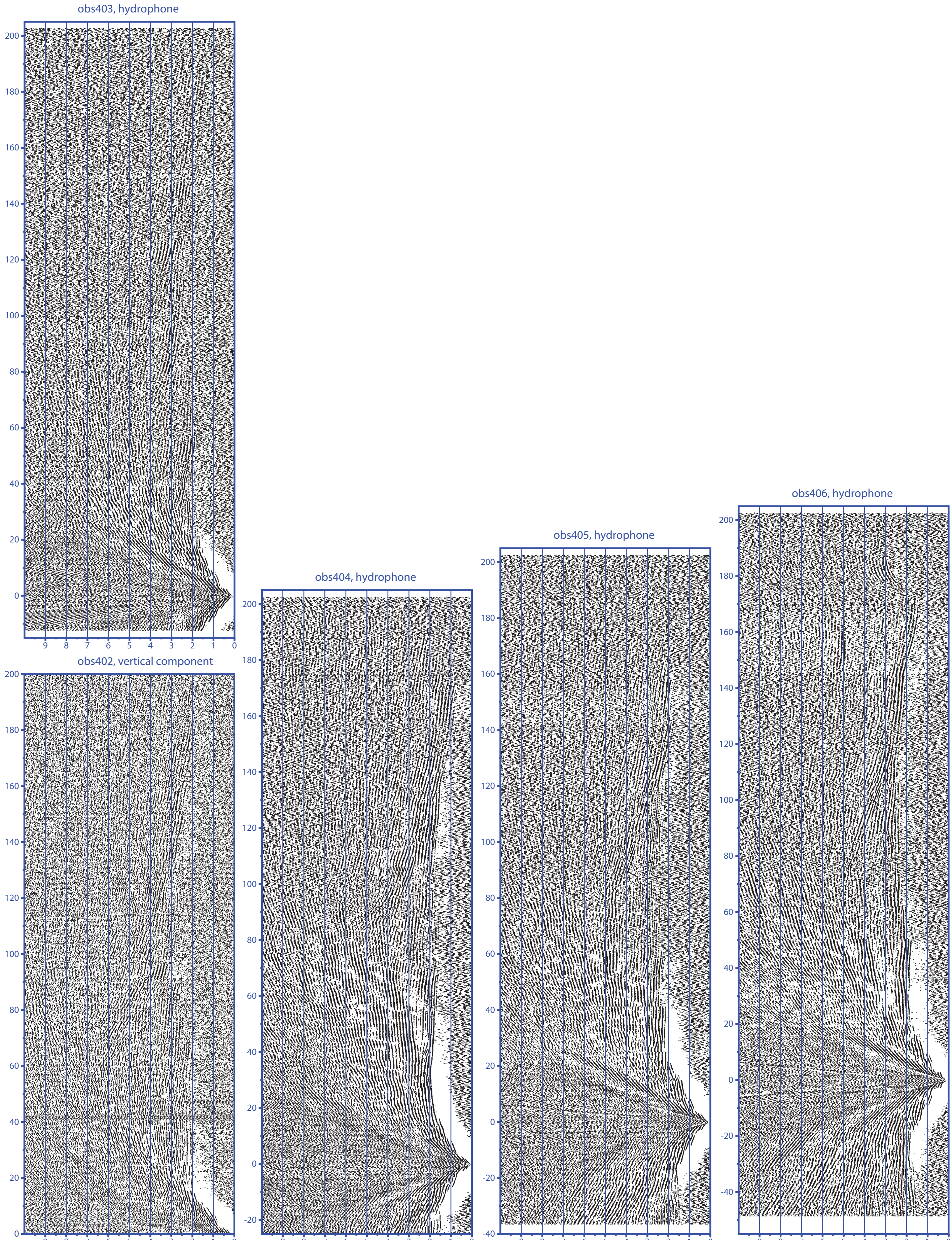
Data plots, GUMBO Line 3. OBS 315 to OBS 332



Data plots, GUMBO Line 3. OBS 333 to OBS 345

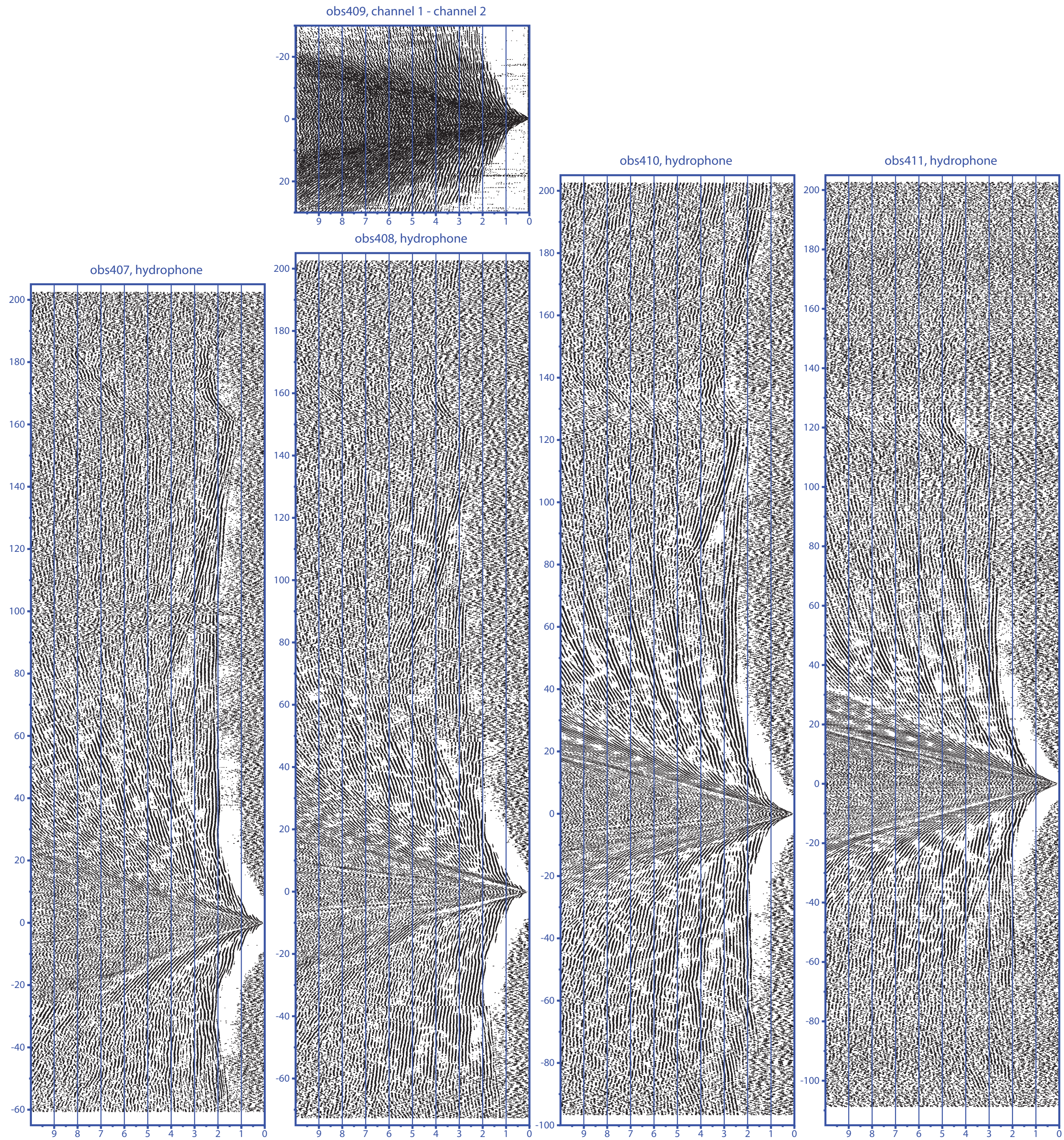


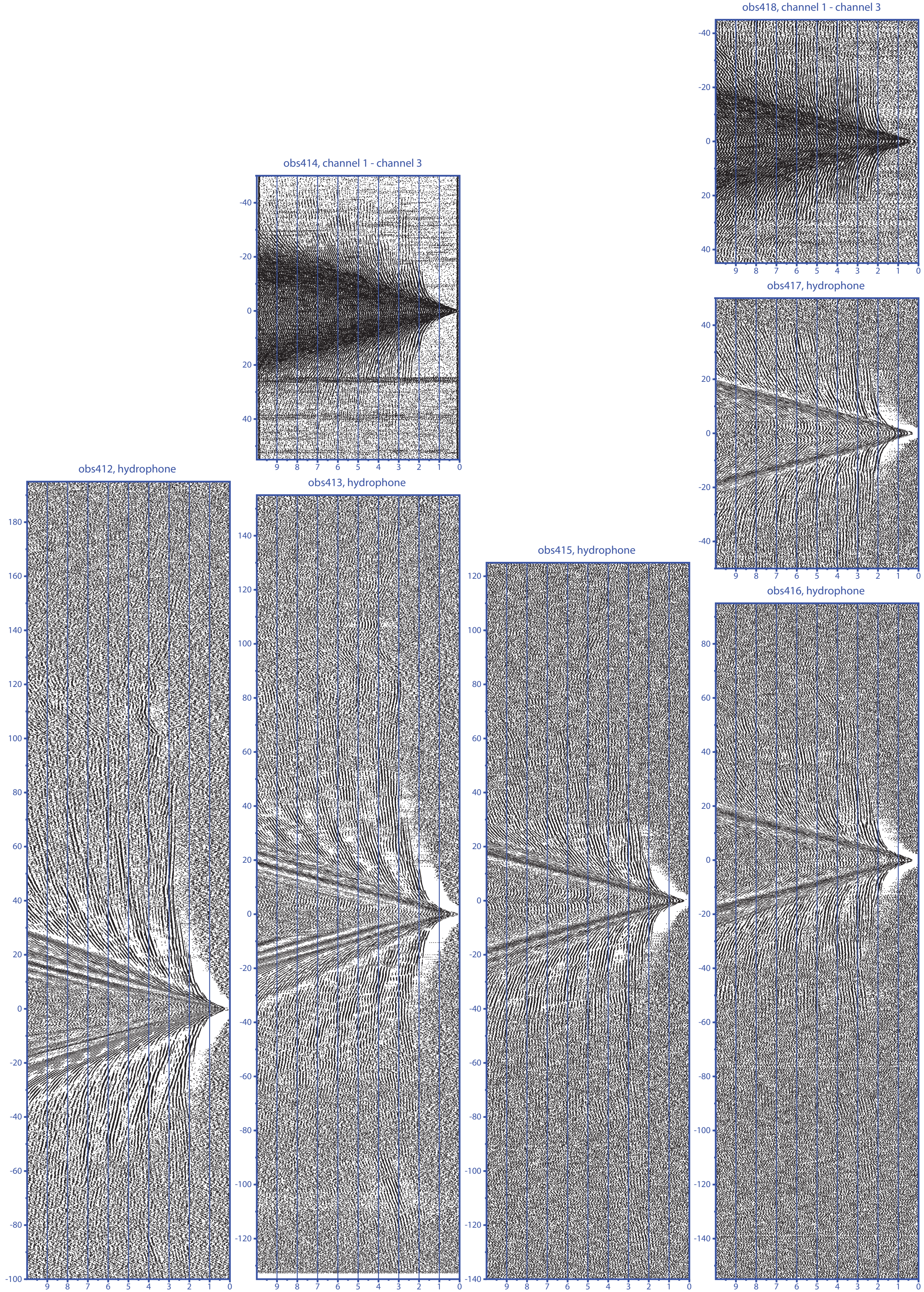
Data plots, GUMBO Line 3 infill. OBS 312 to OBS 323



Data plots, GUMBO Line 4. OBS 402 to OBS 406

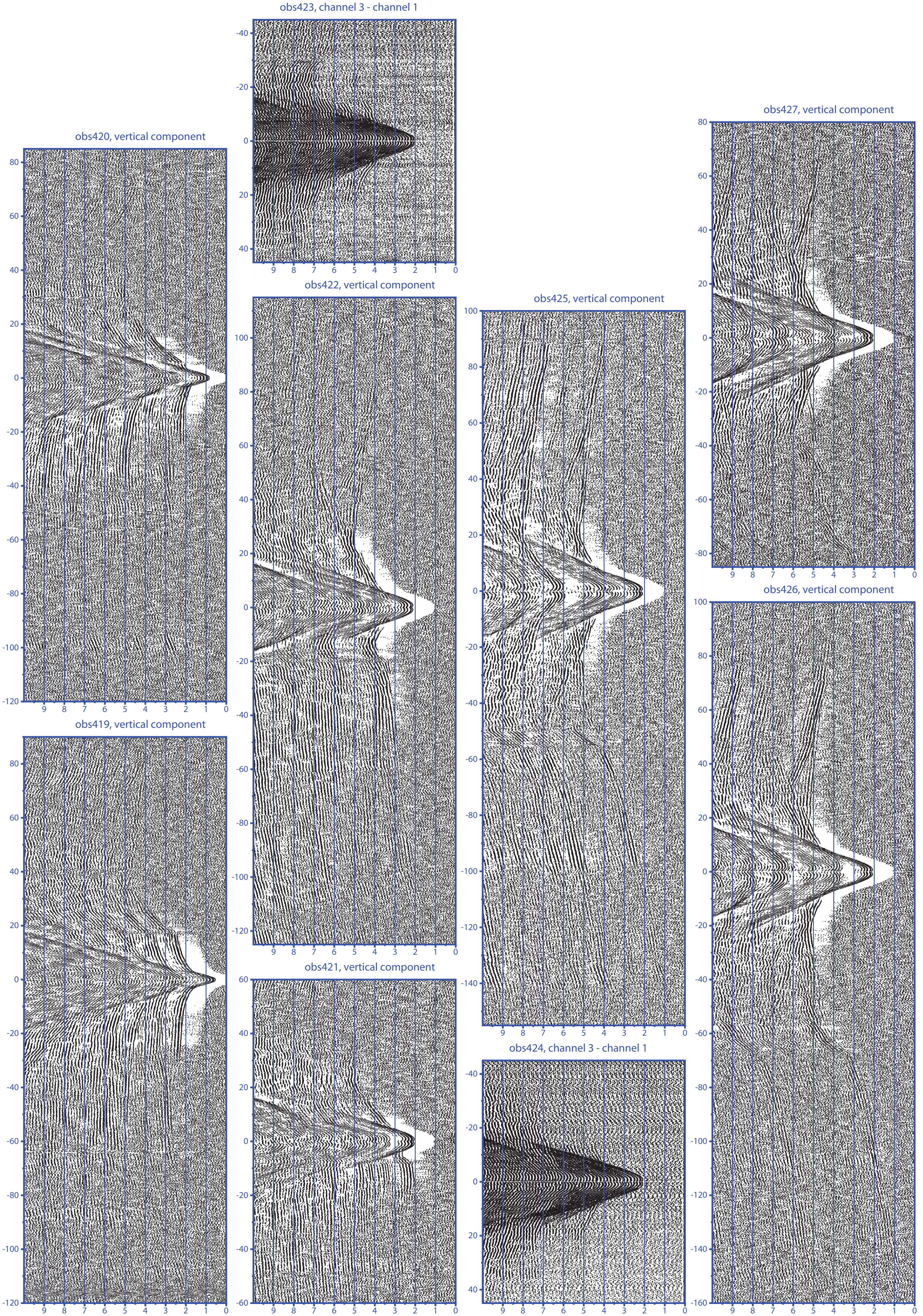
Data plots, GUMBO Line 4. OBS 407 to OBS 411

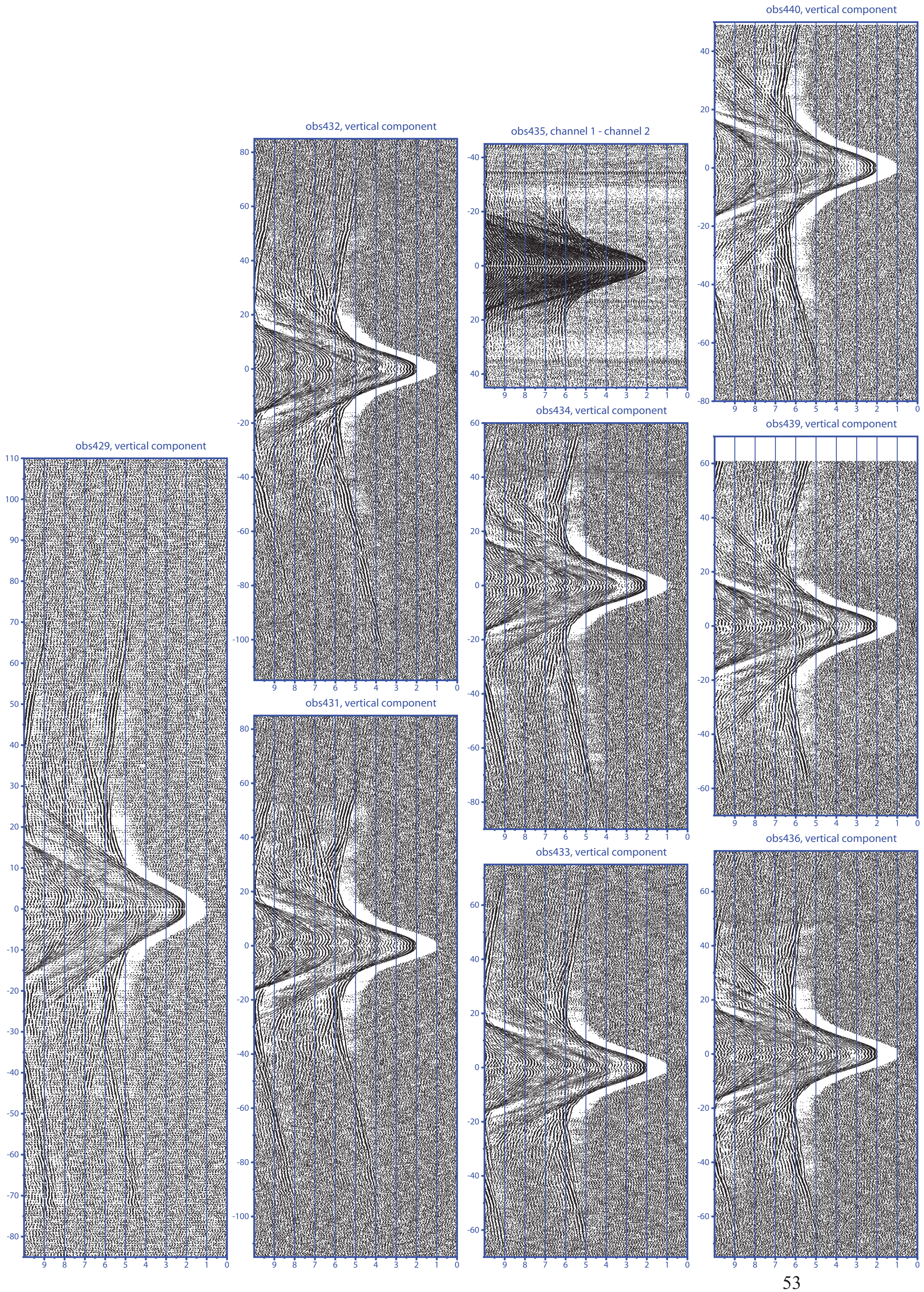




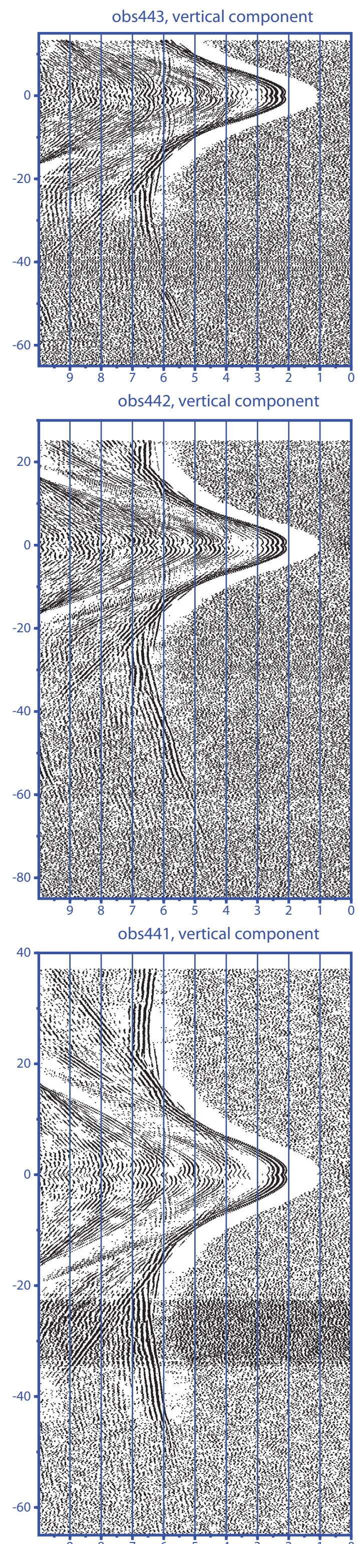
Data plots, GUMBO Line 4. OBS 412 to OBS 418

Data plots, GUMBO Line 4. OBS 419 to OBS 427





Data plots, GUMBO Line 4. OBS 429 to OBS 440



Data plots, GUMBO Line 4. OBS 441 to OBS 443