CRUISE REPORT

A wide-angle seismic and subsidence study of conjugate margin systems in the Eastern Black Sea Basin

R/V ISKATEL

Trabzon-Trabzon

17th February-11th March 2005

T. A. Minshull, D. J. Shillington and C. L. Scott

Contents

Summary

The Eastern Black Sea Basin was formed by lithospheric extension in Jurassic-Paleocene times; the precise timing of extension remains disputed. It forms a convenient natural laboratory for the study of extensional processes at large degrees of extension because ongoing sedimentation has preserved a detailed record of its subsidence history, and the geometry of stratigraphic units is recorded by an extensive grid of seismic reflection profiles. The basin also has significant hydrocarbon exploration interest. However, the deep structure of the basin is very poorly known, with no crustal-scale seismic work since the 1960s. We conducted a wide-angle seismic experiment involving up to 34 ocean bottom seismometers (OBSs) and up to ten landstations deployed on four lines and recording shots from a 9-gun, 3140 cu. in. airgun array fired every 60-90 s. Line 1 was a ~470-km profile shot along-strike through the centre of the basin. Lines 3 and 4 were each ~160 km long and crossed the Mid-Black Sea High, with Line 4 extending into the edge of the Western Black Sea Basin and Line 3 crossing Sinop Trough. Line 2 was ~100 km long and crossed the most easterly part of the basin that is relatively unaffected by Neogene compressional deformation. An initial examination of the OBS data shows that Moho reflections are recorded on most instruments, at ranges of 40-100 km depending on crustal thickness. A clear set of crustal and sedimentary arrivals are also seen.

Crew List

Vasyl Godunko	Master
Boris Poltochenko	First Mate
Oleg Ivanov	Second Mate
Pavlo Yurchak	Third Mate
Petro Pavlenko	Radio Operator
Oleksandr Lebedev	Boatswain
Valeriy Tkachnko	Able seaman
Ruslan Mazur	Able seaman
Stepan Gorbenko	Chef
Vitaliy Milanchenko	Steward
Oleksiy Korobko	Hydrographer
Anatoly Zaporozchenko	Chief Engineer
Oleksandr Kybalnyk	Second Engineer
Viktor Bessonov	Second Engineer
Vasyl Godlevsky	Third Engineer
Yevgeniy Kubatov	Electrician
Oleksandr Vasylenko	Electrician
Viktor Kelin	Motorman
Mikhaylo Sukhanov	Motorman
Mikhaylo Mironchak	Motorman
Oleksandr Kravchenko	Motorman
Vitaly Logunov	Motorman
Dr Dimitri Ilinski	Geopro Party Chief
Petro Skydan	Geopro Engineer
Vitaly Proskura	Geopro Hydrographer
Leonid Voloshyn	Geopro Engineer
Yuri Zhukov	Geopro

Vasiliy Kazakov	Geopro
Alexander Kazakov	Geopro
Alexander Elnikov	Geopro
Anatoliy Alyabyev	Geopro
Andrey Martynenko	Geopro (from 28/2)
Prof. Tim Minshull	Southampton Oceanography Centre
Dr Donna Shillington	Southampton Oceanography Centre
Caroline Scott	Southampton Oceanography Centre
Dr Murat Erduran	Karadeniz Technical University (to 28/2)
Tayfun Besevli Dogan	TPAO
Tarzan	Ship's dog

The following participated in installation of seismic stations onshore:

Dr Nicky White	University of Cambridge
Max Shaw-Champion	University of Cambridge
Dr Steve Jones	Trinity College, Dublin
Dr Katy Raven	BP
Dr Ali Demirer	TPAO
Taner Demirbulut	BP interpreter
Bulent Kayaten	BP driver
Recep Avci	TPAO driver

Coordination in the UK, Germany and Turkey involved the following:

Dr Rose Edwards	Southampton Oceanography Centre
Dr Ashley Price	BP
Dr Ben Peterson	BP
Dr Tengiz Mustafaev	BP
Prof. Kenan Gelisli	Karadeniz Technical University
Dr Gundogan Coskun	TPAO
Prof. Jannis Makris	Geopro

Background to the Cruise

This cruise formed part of a research project entitled "Integrated seismic and subsidence study of conjugate margin systems in the Eastern Black Sea Basin". The project was funded by the UK Natural Environment Research Council (NERC), BP Turkey, and TPAO, through the UK Ocean Margins LINK program, and conducted by scientists from Southampton Oceanography Centre (SOC), the University of Cambridge, Trinity College Dublin, Karadeniz Technical University (Trabzon), BP and TPAO. Onshore seismometers were provided through the NERC-funded SEIS-UK pool based at the University of Leicester. A detailed description of the events leading up to the cruise is given in the first annual report of the project. Finally cruise dates of 2nd-18th February 2005 were planned and applications for diplomatic clearance made to Turkey, Georgia and Russia for 1st-28th February 2005. Clearance was received from Turkey and Georgia, but not Russia. Safety concerns led us to abandon plans to work in Georgian waters as the work area was offshore from the disputed territory of Abkhazia.

Summary of Comments on Vessel and Equipment Performance

1. It is clear than Prichernomor Geologia, which operates the *Iskatel*, is not currently set up to work in the commercial world. I would not advise working with this organisation in the future. The *Iskatel* was supposed to be in Trabzon on 1st February and in fact arrived on 17th February, a delay that resulted in considerable additional expense and inconvenience for the scientific party, and could have compromised the whole experiment.
2. The *Iskatel* proved fit for purpose. Its compressors performed well and, after some initial difficulties as the officers adapted to an unfamiliar task, it was manoeuvred with considerable skill during OBS recoveries. The main limitation was a lack of EM log, which meant that the ship's speed through the water was unknown. There was also unusually frequent downtime for engine maintenance. A lack of any system for receiving weather forecasts beyond 24 hours limited experiment planning. Accommodation is basic but of reasonable quality given the size of the ship; however showers and toilets are in need of renovation.
3. The echosounder performance was poor, and would have been inadequate in a region of rougher bathymetry. A towed echosounder fish would have been a better solution.
4. The compressors and airguns worked well throughout, with only a few hours of downtime for a leaking umbilical hose.
5. OBS performance was good. Of 80 deployments, two OBSs were not recovered, and one recorded no data. On two occasions the wrong acoustic release code was sent and a distant OBS was released; this cost some time but fortunately did not result in instrument loss. The geophone data quality was excellent; hydrophone data were poorer, though good data were obtained on the final profile. The simple recovery method used was highly effective, though would not have worked on a larger, less manoeuvrable ship with a higher afterdeck.

Diary of Events (all times are UTC)

Tuesday 25th January (JD 25)
The land party, consisting initially of Nicky White, Max Shaw-Champion, Steve Jones and Katy Raven, flew to Trabzon. Onshore activities are covered by a separate report.

Thursday 3rd February (JD 34)
Tim Minshull, Donna Shillington and Caroline Scott flew to Trabzon. Three Geopro engineers were on the same flight. Flights had been booked on the basis that *Iskatel* would leave Odessa as soon as written permission from Turkey had been received, since an initial delay associated with certification had been solved. The ship was therefore expected in Trabzon on 5th or 6th February. However, before flying out we were informed of a further delay – the ship would not leave Odessa until 4th February. TPAO confirmed that they would like to participate in the project and would contribute some funds to the project, and stated that their financial commitment would be greater if an additional OBS profile could be acquired across the Mid Black Sea High.

Friday 4th February (JD 35)
The SOC group visited Karadeniz Technical University. An initial meeting was held with Prof. Kenan Gelisli, Head of the Department of Geophysics, Dr Murat Erduran, Dr Mehmet Arslan and Dr Yusuf Bayrak. They expressed strong interest in the experiment and it was agreed that data from the experiment could be made available to them. The possibility of KTU recording our airgun shots on their permanent seismic station, a Guralp CMG40T, and also on three portable Guralp seismometers owned by the Department, was discussed briefly. They showed us some evidence for seismicity offshore, particularly at the so-called Trabzon and Ordu faults. Dr Erduran then took us to the Marine Science Institute at Sürmene, about 25 km away. Our Turkish permission letter had specified that we should make contact with this institute. We met the Associate Dean Dr Kodir Hamdi. We then returned to Trabzon and later met Dr Ertuğ Düzgüneş, the Dean of Marine Science at the University's staff club. Dr Düzgüneş offered any help he could give us, but clearly our work would not address the direct interests of the Marine Science Institute, which are in water column seabed studies.

Saturday 5th February (JD 36)
We were informed by Geopro of a further delay to the *Iskatel*, which would not now depart from Odessa until 7th February. The delay was later attributed to the slow pace of Ukranian bureaucracy. In view of *Iskatel*'s delay, the possibility was raised of the SOC group visiting TPAO in Ankara to discuss in detail the location of the additional profile and TPAO's participation in the wider project.

Sunday 6th February (JD 37)
The SOC group suggested to TPAO a location for a profile across the Mid Black Sea High. The profile would have to be shot after the first profile in order to minimise transit times, and consumables would need to be purchased in Trabzon before departure. An offer made by e-mail to Geopro of an additional payment to acquire the additional profile. Ali Demirer confirmed that TPAO should be able to organise an extension to the *Iskatel*'s permission beyond 28th February in order to shoot the additional profile.

Monday 7th February (JD 38)
We were informed that the ship was still loading supplies and would sail from Odessa during the early hours of 8th February. The captain expected to be in Trabzon on the morning of 11th February. A price for 20 OBS deployments along the additional profile was agreed with Geopro, and we agreed to underwrite the consumable costs for the additional deployments so that consumables could be purchased in time for the *Iskatel*'s arrival. Since the land party would be in Giresun the following day, about two hours from Trabzon, it was agreed that rather than visiting Ankara, the SOC group would discuss the additional line location with Ali Demirer in Giresun.

Tuesday 8th February (JD 39)
At an evening meeting in Giresun, TPAO's involvement in the project, and the location of the additional profile, was discussed further.

Wednesday 9th February (JD 40)
It was agreed that the 4th line would be optimally located along an existing reflection profile perpendicular to the Mid-Black Sea High. Coordinates of this profile were

provided by TPAO. TPAO agreed to push for an extension of our diplomatic permission by 10 days to allow the additional work to be completed. We were informed by Geopro that the *Iskatel* was further delayed by bad weather and now expected to arrive in Trabzon on 12th February. The SOC group therefore decided to stay in Giresun a second night. There was heavy snowfall and an abortive attempt was made in the afternoon to establish one of the line 2 seismometer sites.

Thursday 10th February (JD 41)
The weather was much better, with sunshine and thawing snow. The SOC group spent the morning with the land party establishing the first site on line 2, then departed with a BP driver for Trabzon. Geopro informed us that the *Iskatel* had had to anchor in the bad weather, so was not now expected until 13th February, but that it was on its way again.

Friday 11th February (JD 42)
We were informed by TPAO that an application for extension of the diplomatic permission should be submitted through the British Embassy in Ankara.

Saturday 12th February (JD 43)
We were informed of a further delay to the *Iskatel* – it would not be in Trabzon until the afternoon of 15th February. Such a delay could not be explained by weather conditions, which were by now good. We inferred that the vessel had likely not left Odessa, and that information received to date on the progress of the ship was probably false. Any further delay would endanger the whole project, because our permission to work expired on 28th February. An e-mail was sent to the British Embassy in Ankara requesting urgent transmission of a request for a 10-day extension of the project to the Turkish Ministry of Foreign Affairs.

Sunday 13th February (JD 44)
We were informed by Dimitri Ilinski of Geopro that he had spoken again to the director of Prichernomor Geologia in Odessa, and also to relatives of Geopro contractors who had joined the *Iskatel* in Odessa, and obtained a different and perhaps more accurate description of the vessel's progress. It had indeed mobilised during the night of 7th February, but had been delayed in harbour for five days awaiting customs clearance, so had only finally left Odessa on 12th February, a full two weeks later than originally planned. It was now expected in Trabzon during the morning of 15th February. Geopro were again resetting the start time of recording in their OBSs, to 1800 on 17th February. Later we were informed that the vessel had to stop at Sevastapol because of severe weather in the northern and western Black Sea.

Monday 14th February (JD 45)
The vessel was still hove to in Sevastapol awaiting better weather. Weather reports appeared to confirm bad weather in that area, though at Trabzon the sea was calm. The British Embassy in Ankara submitted the application for a 10-day extension to the Ministry of Foreign Affairs.

Tuesday 15th February (JD 46)
Around 0715, it was confirmed that the *Iskatel* was leaving Sevastapol, with an expected arrival time of approx. 2200 on 16th February.

Wednesday 16th February (JD 47)
The *Iskatel* continued across the eastern Black Sea, but slow initial progress led to a revised ETA in Trabzon of 0500 on 17th February.

Thursday 17th February (JD 48)
The *Iskatel* arrived at Trabzon port around 0530. The scientific party joined at 0730. By 1100 all equipment had been loaded. At 1205 the gangplank came up and *Iskatel* departed a few minutes later. At 1325 the ship stopped for about 30 minutes to deploy the deep-water echosounder on a pole on the starboard side. However, it was observed that the pole bent if the ship's speed exceeded 6 knts, so at 1535 the echosounder was brought inboard again. The first OBS was deployed at 1850, in relatively calm seas.

Friday 18th February (JD 49)
OBS deployment continued through the day. There was a break of about 2.5 hours when the ship's engine oil pressure dropped and the ship had to heave to in order to effect repairs. Negotiations continued with TPAO regarding their commitment to finance the additional 4th line. During the late afternoon the MFA issued permission for the additional ten days work.

Saturday 19th February (JD 50)
The final OBS (#34) was deployed at 0650. A 35th was not possible because several glass spheres were damaged. The ship steamed a little further along the line and then the echosounder was installed. This proved to be rather time-consuming – over five hours elapsed between the deployment of the last OBS and the start of good echosounder data. The delay was mainly in operation of the shipboard unit, which was unfamiliar to Geopro staff. Airgun deployment took only just over an hour, but a further 90 minutes was required to synchronise the shots from all nine airguns, and the first "production" shot was at 1510. One 310 cu. in. gun failed at 1703. This reduced the source to about 90% of its operating volume, so a repair was effected – it turned out that a cable had just come loose. Shooting with the full array restarted at 1842. Weather conditions were remarkably good, with flat calm seas and warm sunshine.

Sunday 20th February (JD51)
Airgun shooting continued. At 0904 a 500 cu. in. gun on the starboard beam failed. The beam was recovered for repairs, and the ship circled back to repeat part of the line. At 1400 shooting began again with the full 9-gun source.

Monday 21st February (JD 52)
Airgun shooting continued, still in flat calm seas. One 310 cu. in. failed and shooting was stopped at 1509. The problem was diagnosed as a damaged hose and following a repair, shooting recommenced at 2032.

Tuesday 22nd February (JD 53)
Airgun shooting continued without incident until 1949, when we stopped at the 12-mile limit of Turkey. The first OBS was released at 2123 and recovered at 2224.

Wednesday 23rd February (JD 54)
OBS recovery continued, still in good weather conditions. Some instruments took several passes to successfully catch them

.

Thursday 24th February (JD55)

OBS recoveries continued smoothly to the recovery of OBS15. However, OBS16 did not respond to acoustic ranging. A release signal was sent and the surface searched visually and with the radio receiver an hour later, but there was no sign of the OBS. A possible poor connection between the computer and the acoustic deck unit was diagnosed, and a couple of hours were spent investigating this possible fault. The deck unit was also moved to a different laboratory and the transducer deployed from a different point to reduce background noise levels. However, a there was still no response from the instrument. A search was made at the surface, with the ship traversing circles of ~700 m radius and then 1.5 km radius about the deployment point. Finally, acoustic ranging was tried from four different directions. After 8 hours on site, the instrument was abandoned to move on to OBS17. Further recoveries proceeded smoothly. The weather forecast for sea area Georgia (the eastern half of the Black Sea) was poor for the day, with force 6-7 winds predicted. However, this poor weather must have passed to the north; ~2 m of swell built up during the day but then subsided again during the evening.

Friday 25th February (JD56)

OBS recoveries continued in flat calm seas again. However, there was thick fog in the morning, which slowed recovery of some instruments. The fog cleared at midday but returned in the evening. Because of doubts about the acoustic deck unit and/or transducer, arising from the many spurious acoustic ranges generated, Geopro decided to send a second deck unit and transducer to the ship. Since the SW end of line 4 was close to Sinop, a short visit there for a transfer of equipment would only cost 6-8 hours and would give a lot more security for recoveries on the remaining three lines. This boat transfer proved quite complex to arrange at a convenient time, but eventually was fixed for the afternoon of the 28th. OBS recoveries continued through the day. Some time was lost when at the site of OBS29 the release code was transmitted for OBS28, which we had intended to leave on the seafloor. The mistake was spotted after about 1.5 hours, and then a further three hours were spent returning to the site of OBS28 to recover it in case it had already been released.

Saturday 26th February (JD57)

The final OBS, number 34, was recovered at 1415. We then steamed to the southwest end of Line 4, which took about 6 hours, and began OBS deployments afresh.

Sunday 27th February (JD58)

Deployment of 17 OBSs on Line 4 was completed at 0945, and shooting began at 1126. To save some time, the vessel speed for shooting was increased to 4.3 knts at the start of the line. Shooting continued for the rest of the day without incident. However, a southwesterly gale developed during the evening and after around 1600 the speed decreased steadily, to around 3.8 knt at the end of the day.

Monday 28th February (JD59)

The gale continued and the sea state worsened considerably in the early morning hours. At 0410 the ship was forced to change course to face the wind and hence deviate to the north of the line. The ship's speed dropped to a low of around 2 knts. At 0610 the ship was able to turn back parallel to the line, and as conditions improved the line was rejoined at 1201. The maximum deviation was about 1.3 km. The line

was completed at 1220. The airguns and echosounder were recovered and about two hours were spent fixing an engine problem; at around 1500 we departed for Sinop. We arrived at Sinop around 1845 and completed a boat transfer at 2000 – Murat Erduran left the vessel and Andrey Martynenko from Geopro joined with a spare acoustic deck unit and transducer. Given the poor weather conditions, the captain decided to spend the night at anchor in Sinop harbour.

Tuesday 1st March (JD60)
The *Iskatel* departed Sinop anchorage at 0701 and arrived at OBS1 at 1226. Unfortunately the acoustic code for OBS2 was sent by mistake, and several hours were lost before the mistake was realised. It turned out that OBS2 was release by this transmission, and we were very fortunate to pick up OBS2 about 6 km downwind from its drop site. OBS3 was recovered at 2238 in worsening weather, and the captain decided that it was no longer safe to complete further recoveries.

Wednesday 2nd March (JD61)
During the night *Iskatel* steamed slowly along the line with head to wind. In the morning there was a slight improvement in the weather, so at 0704 we turned back down the line and arrived at the site of OBS7 at 0830. There was then a one-hour break for engine maintenance. The OBS was recovered, but then there was a further four-hour break while a cylinder was changed in the ship's engine. OBS recoveries then continued, proceeding back down the line to OBS4 and then on towards OBS8.

Thursday 3rd March (JD62)
OBSs 8 and 9 were recovered successfully, but acoustic contact with OBS10 was doubtful and there was no sign of this OBS on the surface an hour after the release command was sent. After five hours on site, the OBS was abandoned. We were now concerned that we would not have time to complete our program by March 10th, so decided to reduce the number of OBSs deployed on Line 3 from 20 to 14. OBS recoveries continued during the day, though strong winds and rough seas in the evening made them more difficult.

Friday 4th March (JD63)
OBS recoveries were completed at 0013 and deployments began on Line 3 at 0328. Deployments were completed at 1635. There was then a break of about 11 hours while the ship loaded ballast water to replace spent fuel and increase stability; during this time the echosounder was reinstalled and airguns were tested on deck.

Saturday 5th March (JD64)
Shooting on Line 3 began at 0505. The weather deteriorated through the day, with strong winds and high seas in the afternoon to early evening. In these conditions the *Iskatel* struggled to maintain speed. However, the weather calmed somewhat during the night.

Sunday 6th March (JD65)
Shooting on line 3 was completed at 0641. OBS recoveries commenced at 0845 and continued through the day, with steadily improving weather.

Monday 7th March (JD66)
OBS recoveries were completed at 1252 in calm, sunny weather, and the transit commenced to the northern end of Line 2.

Tuesday 8th March (JD67)
OBS deployment on line 2 commenced at 0627 and was completed at 1502. The weather remained calm. Shooting commenced at 1829 after two hours of maintenance on the ship's steering system. The weather deteriorated slowly during the evening.

Wednesday 9th March (JD68)
The weather deteriorated more rapidly and at 0105 shooting was stopped to bring in the guns. This proved a very hazardous operation, with a lot of water washing onto the afterdeck. We learned later that water also penetrated the gun shack where the acoustic deck units were stored, and one unit suffered water damage and was rendered inoperable. The ship turned upwind to the northwest, and then later steamed downwind. At 0955, in slightly better weather, we began steaming back to the line. Shooting recommenced at 1652.

Thursday 10th March (JD69)
Line 2 was completed at 0401 and the first OBS was recovered at 0623. OBS recoveries continued throughout the day in improving sea conditions.

Friday 11th March (JD70)
The last OBS was recovered at 0835. There was a two-hour delay for engine maintenance, and then we departed for Trabzon, arriving at 1450.

Navigation

Scientific navigation used the Bridge GPS system, which was logged by a PC installed on the bridge. A second GPS aerial was installed ~35 m aft of the primary aerial, and supplied an independent system used at times for scientific watchkeeping in the main laboratory. Geopro supplied and operated a computer system displaying real-time navigation, OBS positions, way-points, etc. OBSs were typically deployed within 50 m of the intended line, and shots were generally within ~10 m of the intended line, with a standard deviation of ~5 m from the line.

Echosounder

An Atlas DESO30 dual-frequency echosounder was used for deep-water echosounding, since the ship had no deep-water system of its own. The echosounder was operated at 12 kHz and the transducer was deployed on a long pole fixed to the forward starboard quarter (Figure 1). Installation of the pole was a hazardous exercise involving a Geopro engineer descending a Jacob's ladder to about 1 m above the waterline to fix it to a bracket. The echosounder generated both paper and digital records. The paper record was fairly clean, but the digital record showed frequent drop-outs with anomalous depths. Such dropouts became particularly common in poor weather. Dropouts were removed in subsequent processing by Geopro, and there were sufficient valid depth readings for a good record to be reconstructed. A significant limitation was that the pole bent at ship speeds greater than about 6 knots,

so the echosounder could not be operated during transits, but rather only during periods of shooting. At the end of each profile the transducer cable had to be detached from the deck unit and the pole assembly dismantled, only to be put back together and rewired into the deck unit at the start of the next profile. This procedure, but it did introduce a short delay before and after each profile. Perhaps more importantly, it meant that for parts of line 4 where the shooting track deviated from the intended track, no bathymetric data are available. Fortunately the bathymetry along line 4 is extremely flat.

Figure 1: Echosounder with its pole

Seismic Source

The seismic source design was based on a design successfully used by Geopro under contract to the University of Cambridge for the Atlantic Margins Project in 2000. The source consisted of two sub-arrays and a total of nine Bolt Long Life airguns towed in strings from chains (Figure 2). Each gun was supported by its own buoy. The desired operating depth was 9 m; unfortunately the depth sensors available were incompatible with the shipboard system to read them, so there was no independent measure of depth. However, based on previous experience of towing at 4 knts, the guns were suspended 11 m below the buoys to achieve 9 m operating depth. The high quality of data acquired suggests that the guns were at the correct depth. The array had a total volume of 3140 cu. in., comprising 3 x 500 cu. in., 4 x 310 cu. in. and 2 x 200 cu. in. guns (Figure 3). Two 500 cu. in. and two 310 cu. in. guns, at the front of the

starboard and port strings, respectively, were clustered so that their bubbles coalesced. The airguns were deployed and recovered rapidly by sliding the chain holding each string together along fixed rails – one for each string.

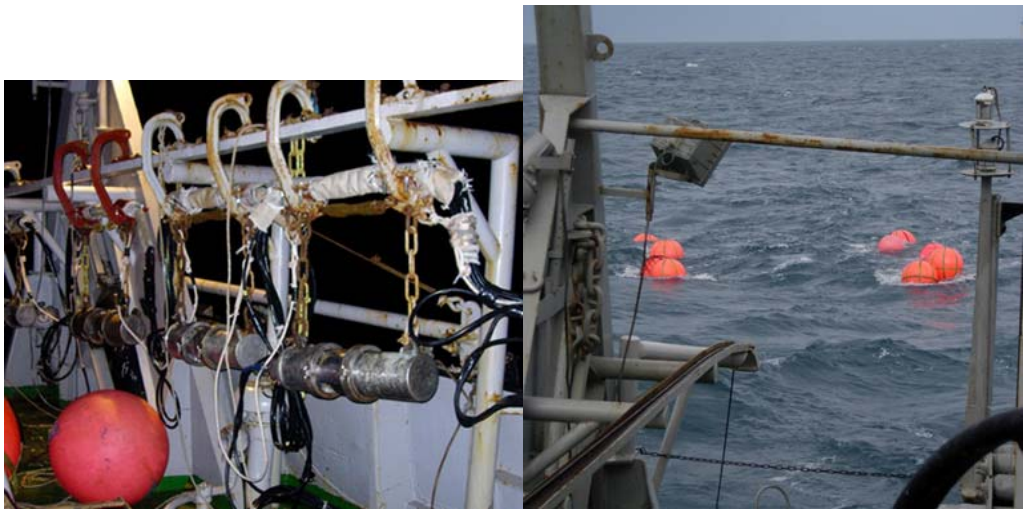


Figure 2: Port airgun string (left) and deployed airgun source (right)

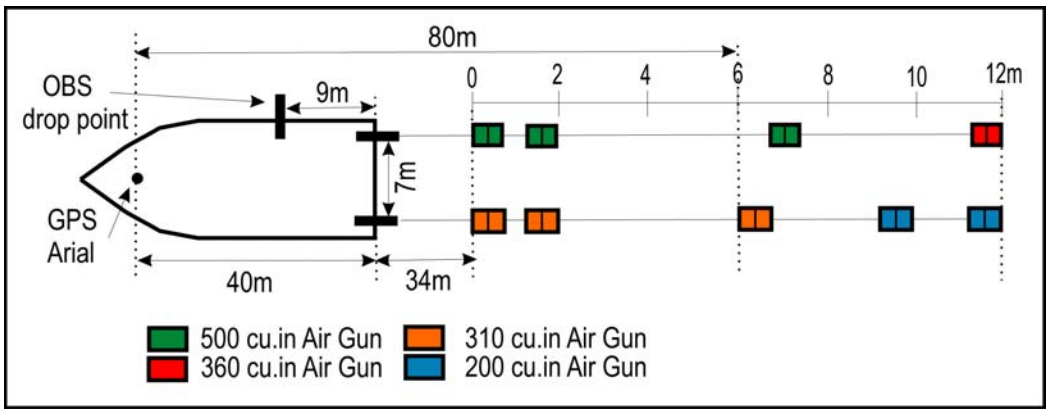


Figure 3: Geometry of airgun array. Guns were towed at ~9 m depth

Shot Timing

Airgun shots were triggered from a stable clock that was synchronised with GPS at the start of the cruise. A pulse from this clock was logged on a spare SEDIS III data logger from an OBS. The SEDIS clock was synchronised with GPS before each line and its drift measured by checking against GPS after each line. These measurements demonstrated that, while the SEDIS clock drifted a few tens of milliseconds during each line, the clock controlling the airgun shots was stable within less than 1 ms. Shots from different airguns were synchronised within 2 ms by a gun controller, so that the peak pressure was aligned 50 ms after the exact second of the nominal shot time. The final SEGY records delivered by Geopro start at the shot instant.

Ocean Bottom Seismometers

The Geopro OBSs are housed in 17" Benthos glass spheres weighing 23 kg in air. These spheres were attached to a 17 kg anchor, which is released using a burn-wire mechanism. The release systems use Benthos acoustics; surprisingly a spare transducer and deck unit were not shipped for this experiment, apparently because of clashes with other experiments going on at the same time. The data loggers are 16-bit loggers designed and built by Geopro, and were operated at a 4 ms sample rate. The loggers were powered by a set of twelve 1.5 V alkaline batteries (D-cells). The sensors were a Benthos hydrophone and a three-component Input-Output 4.5 Hz seismometer, housed in the base of the glass sphere. The top of the hard hat of the glass sphere was cut away, and a light inside the glass spheres made them easily visible at night. Each OBS also had a radio transmitter. The instruments were deployed using a lightweight release mechanism pulled by a thin rope. The instruments have no strayline; recoveries were effected generally by using a boat-hook on a long pole to catch the small loop of rope on the top of the OBSs, and man-handling aboard (two-man lift). This approach proved more effective than the net that Geopro usually use, which could not be lifted high enough out of the water by the ship's crane. Once the ship had manoeuvred alongside an instrument, recoveries were completed smoothly in quite high seas.

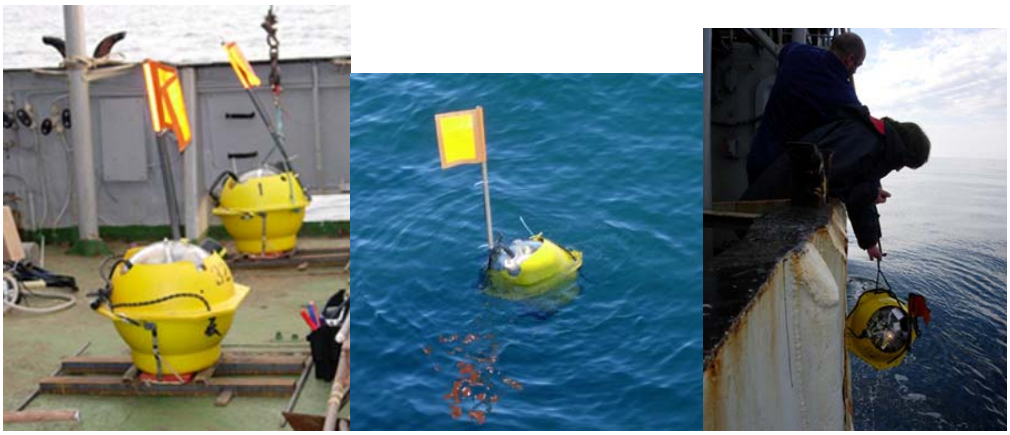


Figure 4: OBS ready for deployment (left), awaiting recovery (centre) and being hauled aboard (right)

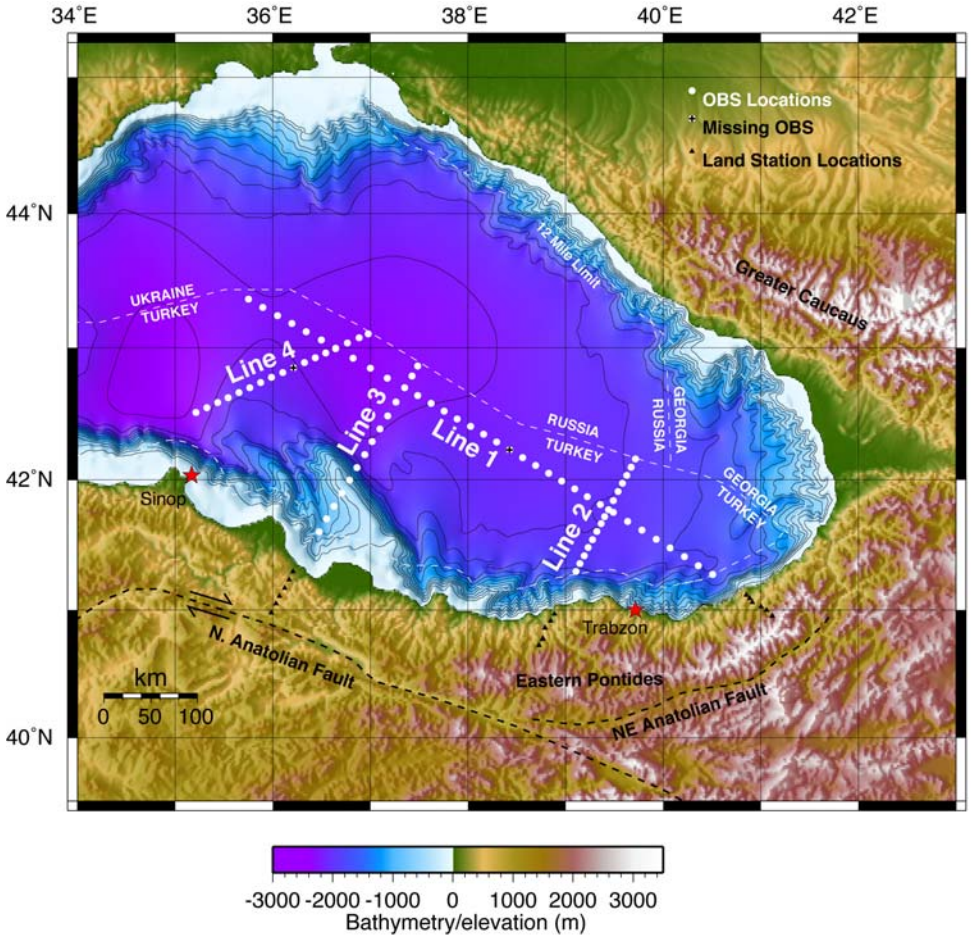
OBS performance was generally good. Glass spheres were a mixture of Benthos and Nautilus spheres. Several of the Nautilus spheres spalled glass during their first deployment, and one was so badly damaged that it could not be re-used. For Line 1 the gain on the hydrophones was set too low, so only high-amplitude, near-offset arrivals are seen well in hydrophone data. However, the vertical geophones yielded good records, and the horizontal geophone components were also generally good, though noisier as expected. Higher gains used on Line 4 did little to improve the hydrophone records. A variety of different hydrophone and preamplifier combinations were tried on Line 3; all gave better records on the first two lines, and some gave records comparable in quality to that of the vertical geophones. For Line 2 the hydrophone data quality is good, though still not as good as for the vertical geophone.

Wide-Angle Seismic Profiles

Some profiles were shot in several overlapping segments; these are given letters in Table 1.

Table 1: Wide-angle seismic profiles

Profile	Start time	Start shot	End time	End shot	Comment
1-test	1340/50	1	1509/50	88	Slow start + synchronise
1a	1510/50	89	1810/50	269	Last 68 shots with 8 guns
1b	1842/50	270	0912/51	1140	
1c	1400/51	1141	1509/52	2650	Synchronised after 15 shots
1d	2032/52	2651	1949/53	4047	Synchronised after 15 shots
4	1126/58	1	1220/59	997	Synchronised after 11 shots
3	0505/64	10	0641/65	1034	Synchronised from start
2a	1829/67	1	0105/68	395	
2b	1652/68	396	0401/69	1065	



Map of the eastern Black Sea region. Bathymetry and elevation taken from the Gebco Digital Atlas (One Minute Grid), and locations of the Northern Anatolian Fault and Northeast Anatolian Fault taken from Barka and Rellinger (1997).

Figure 5

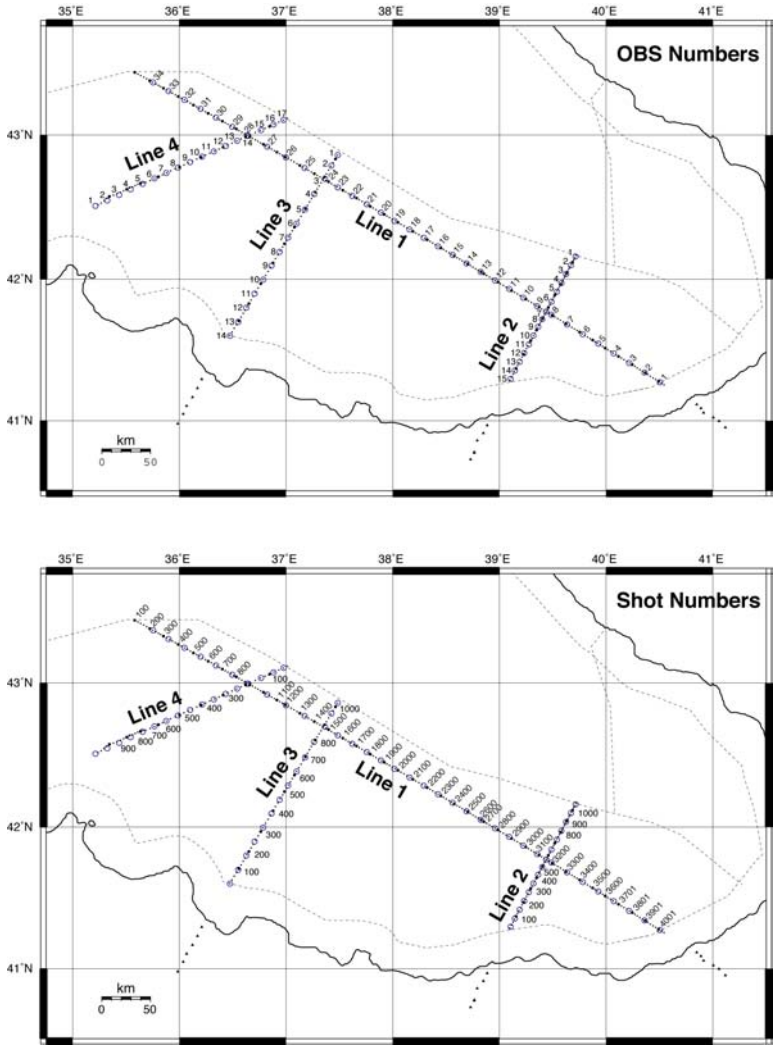
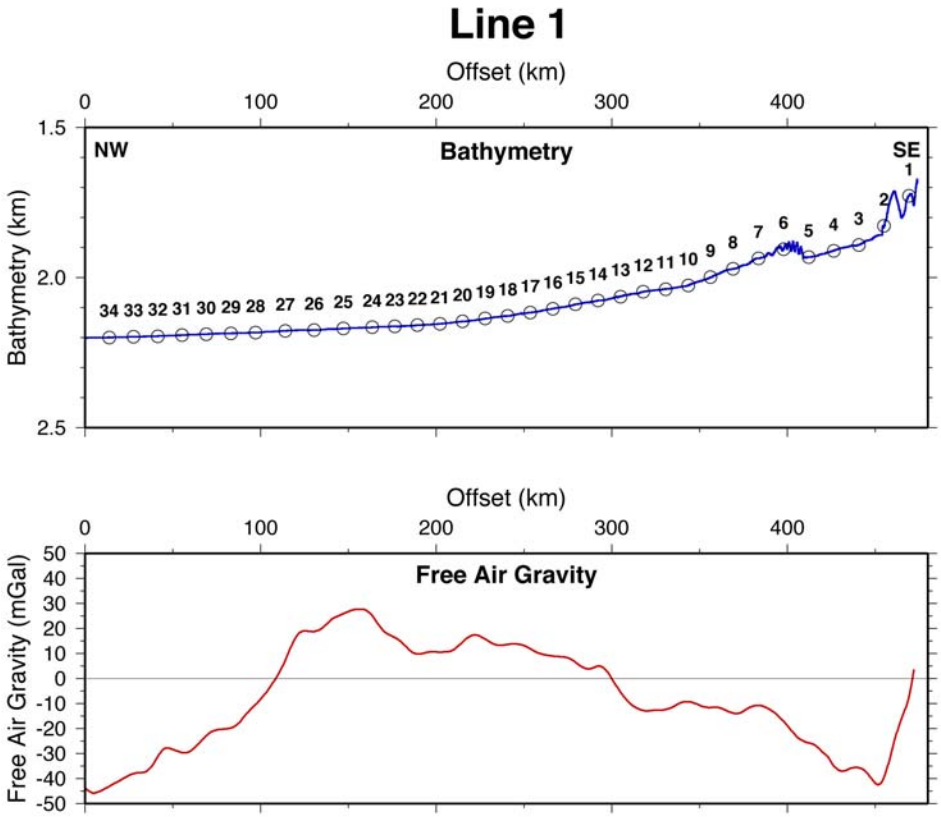


Figure 6: OBS positions on the wide-angle seismic profiles (above) and shot numbers along the profiles (below)

Profile	Start time	Start shot	Start Latitude	Start Longitude	End time	End shot	End Latitude	End Longitude	Comment
1-test	1340/50	1	??	??	1509/50	88	43.43879516	35.56397464	Slow start + synchronise
1a	1510/50	89	43.43821822	35.56537949	1810/50	269	43.3380316	35.81360895	Last 68 shots with 8 guns
1b	1842/50	270	43.33992915	35.81062049	0912/51	1140	42.86139038	36.96636189	
1c	1400/51	1141	42.88200886	36.91717579	1509/52	2650	42.02096449	38.89223726	Synchronised after 15 shots
1d	2032/52	2651	42.06723497	38.78940969	1949/53	4047	41.2526598	40.55023426	Synchronised after 15 shots
4	1126/58	1	43.1297222	37.055	1220/59	997	42.5108333	35.2125	Synchronised after 11 shots
3	0505/64	10	41.5902778	36.4633333	0641/65	1034	42.8802778	37.4988889	Synchronised from start
2a	1829/67	1	41.275	39.09	0105/68	395	41.6511111	39.3502778	
2b	1652/68	396	41.6394444	39.345	0401/69	1065	42.1702778	39.7233333	

Line 1:

Line 1 was ~470 km long and traversed the centre of the Eastern Black Sea Basin from the eastern flank of the Mid Black Sea High to offshore Rize. It was roughly coincident with a BP/TPAO seismic reflection profile BP91-109, which was recorded to 15 s. The OBS spacing was about 13 km.



The upper panel shows bathymetry derived from a shipboard echosounder with the locations and position numbers of OBSs. The lower panel shows satellite gravity with free air corrections.

Figure 7

The shot interval was 60 s, equivalent to a spatial interval of about 120 m. The sea state was good throughout the period of shooting. Data quality is high, with crustal and mantle arrivals typically detected to ~100 km range; some example record sections from various parts of the line are included. A "stepping back" of sediment arrivals indicates the presence of a thick low-velocity zone along most of the profile, which disappears as the Mid Black Sea High is approached. Apparent velocities for most of the crustal section are high (~6.8 km/s).

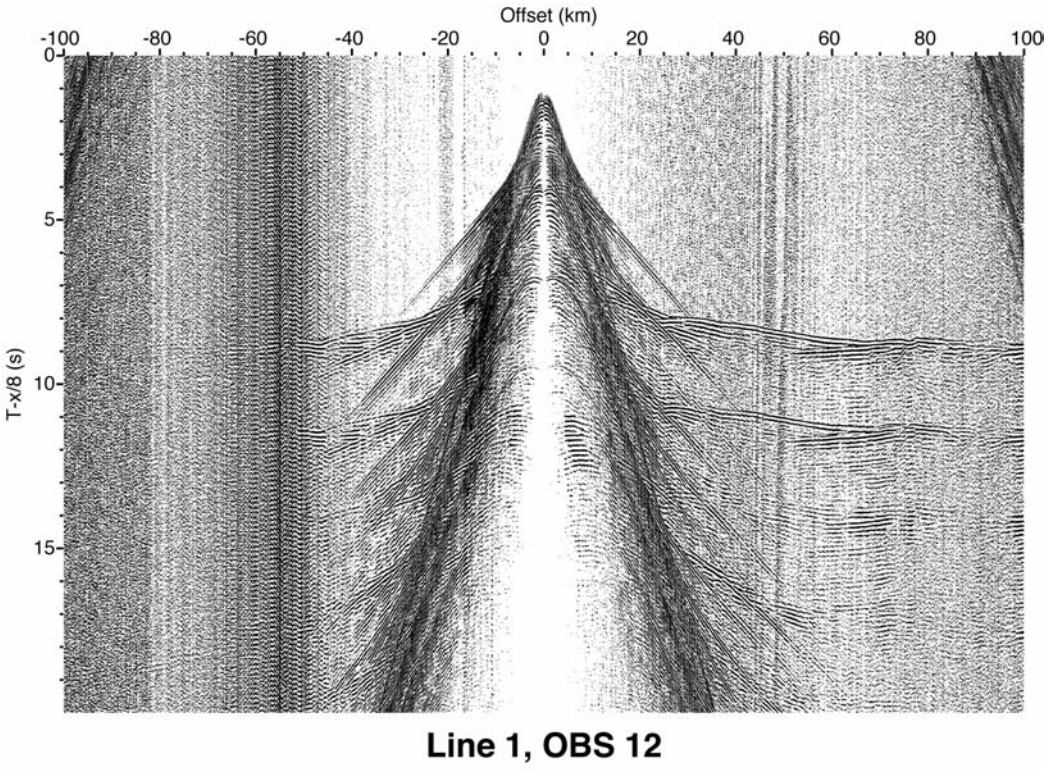


Figure 8: Representative seismic data from Line 1

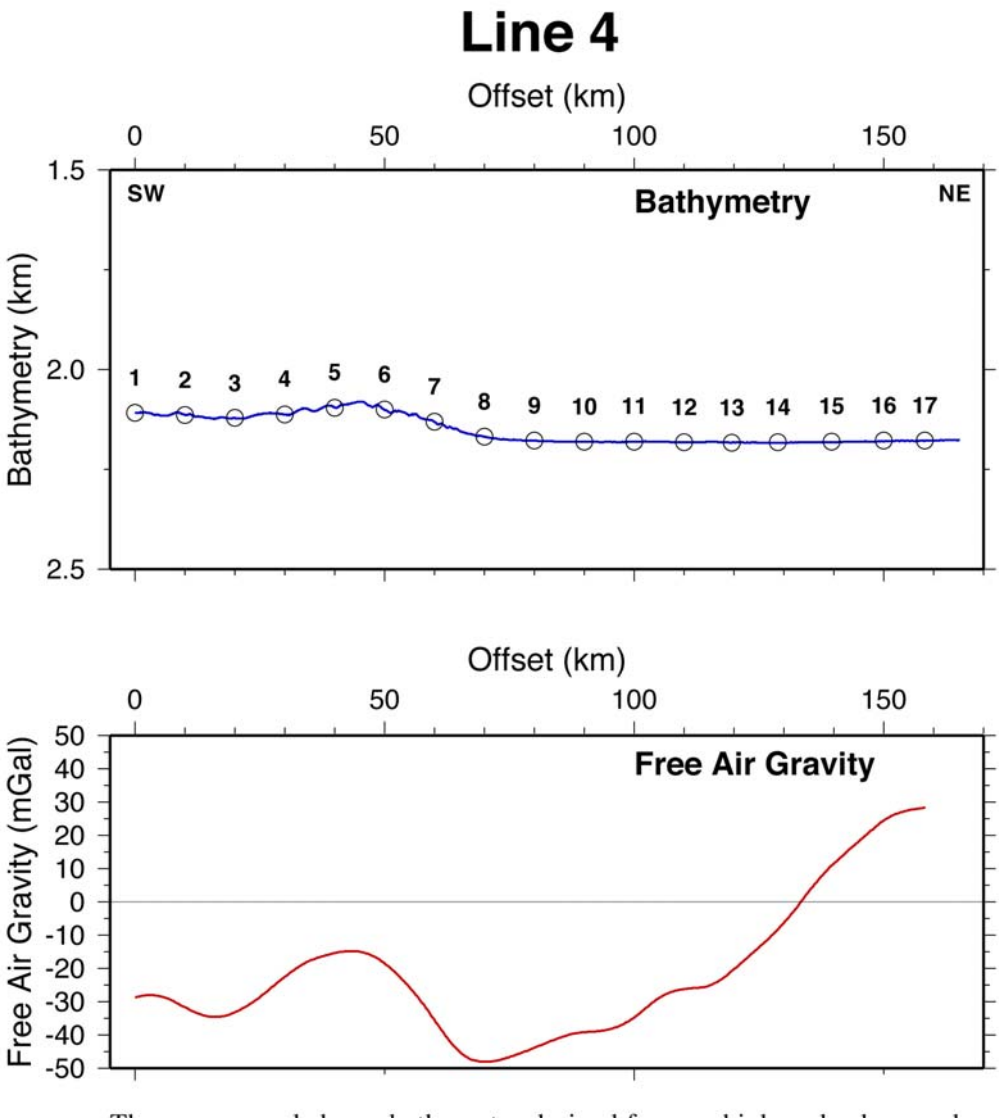
Table 2: Line 1 OBS Locations

	DEPLOYMENT								RECOVERY								
OBS	Latitude			Longitude			Jul.	Time	Latitude			Longitude			Jul.	Time	Depth
Pos. No.	Deg	Min		Deg	Min		Day	(GMT)	Deg	Min		Deg	Min		Day	(GMT)	(m)
1	41	16.42	N	40	30.36	E	48	18:50	41	16.719	N	40	30.34	E	53	22:24	1727
2	41	20.548	N	40	21.682	E	48	20:05	41	20.878	N	40	21.842	E	54	00:36	1828
3	41	24.63	N	40	13.02	E	48	21:17	41	24.928	N	40	12.387	E	54	03:26	1892
4	41	28.719	N	40	4.312	E	48	22:22	41	29.158	N	40	3.969	E	54	05:44	1911
5	41	32.788	N	39	55.607	E	48	23:29	41	33.093	N	39	55.187	E	54	08:04	1932
6	41	36.849	N	39	46.865	E	49	00:31	41	36.96	N	39	46.98	E	54	10:19	1906
7	41	40.884	N	39	38.116	E	49	02:01	41	41.1	N	39	38.2	E	54	12:41	1936
8	41	45	N	39	29.223	E	49	03:04	41	45.06	N	39	29.05	E	54	15:07	1971
9	41	48.618	N	39	21.317	E	49	03:58	41	48.65	N	39	21.22	E	54	17:24	1999
10	41	52.239	N	39	13.394	E	49	04:51	41	52.25	N	39	13.39	E	54	19:47	2026
11	41	55.843	N	39	5.482	E	49	00:05	41	55.83	N	39	5.43	E	54	22:12	2038
12	41	59.441	N	38	57.532	E	49	06:35	41	59.404	N	38	57.519	E	55	00:37	2047
13	42	3.033	N	38	49.548	E	49	07:27	42	3.083	N	38	49.586	E	55	02:53	2063
14	42	6.606	N	38	41.597	E	49	08:19	42	6.563	N	38	41.59	E	55	05:10	2077
15	42	10.156	N	38	33.634	E	49	09:16	42	10.142	N	38	33.611	E	55	07:28	2089
16	42	13.74	N	38	25.59	E	49	10:12	MISSING								2104
17	42	17.286	N	38	17.572	E	49	11:04	42	17.24	N	38	17.731	E	55	19:22	2117
18	42	20.82	N	38	9.54	E	49	11:57	42	20.82	N	38	9.6	E	55	21:36	2128
19	42	24.36	N	38	01:48	E	49	12:51	42	24.386	N	38	1.373	E	56	00:00	2137
20	42	27.887	N	37	53.416	E	49	13:43	42	27.897	N	37	53.514	E	56	02:17	2146
21	42	31.394	N	37	45.338	E	49	14:36	42	31.444	N	37	45.948	E	56	05:16	2154
22	42	34.83	N	37	37.23	E	49	15:28	42	35.035	N	37	37.074	E	56	07:34	2158
23	42	38.39	N	37	29.12	E	49	16:21	42	38.337	N	37	29.202	E	56	09:55	2163
24 (line3, 3)	42	41.85	N	37	21.94	E	49	17:17	42	41.87	N	37	21.1	E	65	14:23	2166

25	42	46.37	N	37	10.5	E	49	21:19	42	46.46	N	37	10.67	E	56	13:12	2170
26	42	50.807	N	36	59.989	E	49	22:33	42	50.84	N	37	0.13	E	56	15:39	2175
27	42	55.245	N	36	49.46	E	49	23:38	42	55.29	N	36	49.6	E	56	18:03	2178
28	42	59.746	N	36	38.11	E	50	00:47	42	59.631	N	36	39.044	E	57	01:22	2183
29	43	3.481	N	36	29.749	E	50	01:45	43	3.459	N	36	29.849	E	56	22:41	2185
30	43	7.245	N	36	20.66	E	50	02:47	43	7.21	N	36	20.66	E	57	05:04	2189
31	43	10.898	N	36	11.894	E	50	03:44	43	10.95	N	36	11.8	E	57	07:19	2192
32	43	14.543	N	36	2.904	E	50	04:44	43	14.63	N	36	3.01	E	57	09:42	2195
33	43	18.17	N	35	54.001	E	50	05:46	43	18.23	N	35	54.14	E	57	11:52	2198
34	43	21.797	N	35	45.09	E	50	06:48	43	21.83	N	35	45.18	E	57	14:15	2199

Missing OBS or OBS without data

Line 4:
Line 4 was shot across the Mid Black Sea High and was coincident with BP/TPAO reflection line BP91-106. It was centred on the Andrusov Ridge, oriented perpendicular to the strike of the Ridge, and extended ~80 km either side of the summit of the Ridge. The OBS spacing was about 10 km. The shot interval was increased to 90 s for this profile to avoid any possibility of interference between previous-shot water waves and the Moho triplication, which was expected to occur at longer ranges for some OBSs because of the thicker crust. The spatial shot interval was ~180 m at the northeastern end of the line but decreased to ~110 m at the southwestern end as the ship's speed decreased in increasingly poor weather conditions.



The upper panel shows bathymetry derived from a shipboard echosounder with the locations and position numbers of OBSs. The lower panel shows satellite gravity with free air correction.

Figure 9

The OBS data were noisier than on line 1, presumably because some ocean wave and wind noise propagated to the seafloor. However, Moho reflections can be detected on almost all OBSs. Fortuitously the Moho triplication is at shorter range for instruments in the centre of the profile where very long ranges are not available, because reflection points are beneath the thinner crust either side of the Ridge. The low-velocity zone present on Line 1 is generally absent on Line 4.

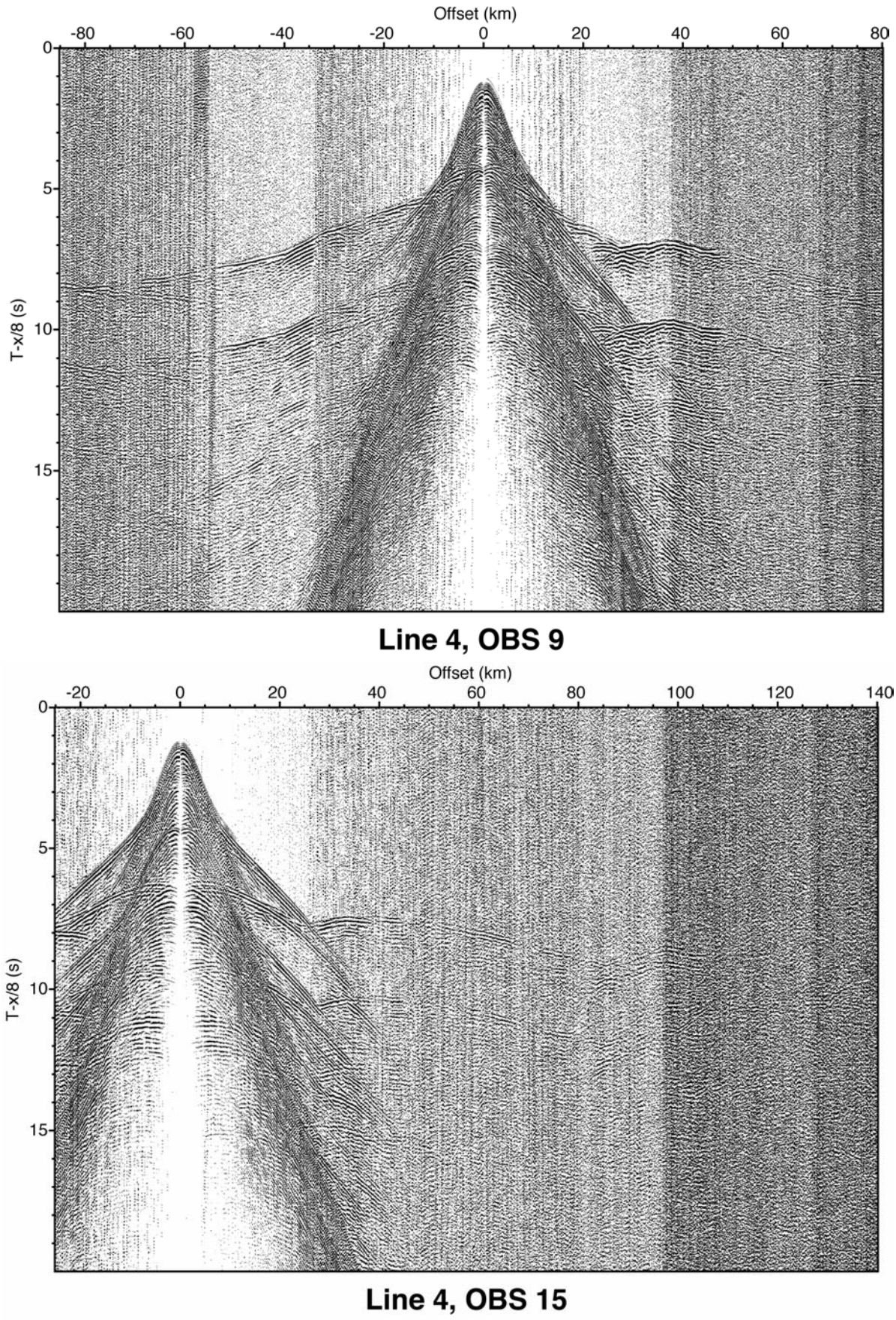


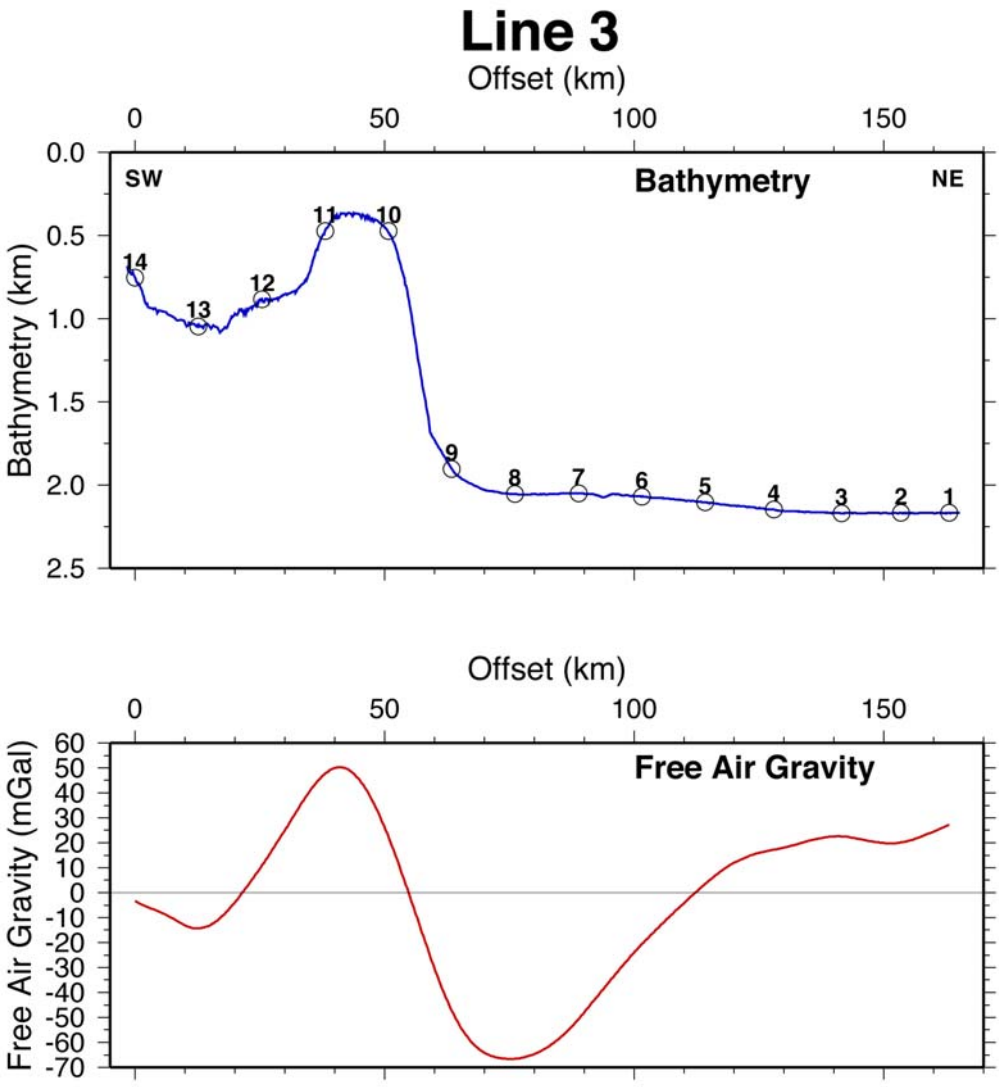
Figure 10: Representative seismic data from Line 4

Table 3: Line 4 OBS Locations

	DEPLOYMENT								RECOVERY								
OBS	**Latitude**			**Longitude**			**Jul.**	**Time**	**Latitude**			**Longitude**			**Jul.**	**Time**	**Depth**
Pos. No.	**Deg**	**Min**		**Deg**	**Min**		**Day**	**(GMT)**	**Deg**	**Min**		**Deg**	**Min**		**Day**	**(GMT)**	**(m)**
1	42	30.66	N	35	12.761	E	57	20:37	42	30.35	N	35	13.17	E	60	16:54	2108
2	42	32.952	N	35	19.398	E	57	21:25	42	29.86	N	35	20.22	E	60	20:06	2114
3	42	35.233	N	35	26.023	E	57	22:44	42	35.16	N	35	24.82	E	60	22:36	2122
4	42	37.522	N	35	32.473	E	57	23:21	42	37.5	N	35	32.65	E	61	19:43	2112
5	42	39.802	N	35	39.33	E	58	00:16	42	39.72	N	35	39.32	E	61	17:44	2095
6	42	42.074	N	35	45.984	E	58	00:58	42	42	N	35	46.02	E	61	15:43	2101
7	42	44.338	N	35	52.651	E	58	01:41	42	44.23	N	35	52.63	E	61	10:18	2131
8	42	46.596	N	35	59.323	E	58	02:25	42	46.575	N	35	59.338	E	62	00:42	2168
9	42	48.849	N	36	6.005	E	58	03:09	42	48.849	N	36	6.005	E	62	02:41	2178
10	42	51.094	N	36	12.699	E	58	03:54	MISSING								2181
11	42	53.331	N	36	19.4	E	58	04:37	42	53.21	N	36	19.41	E	62	11:19	2180
12	42	55.558	N	36	26.11	E	58	05:21	42	55.55	N	36	26.2	E	62	13:24	2182
13	42	57.68	N	36	32.488	E	58	05:59	42	57.68	N	36	32.63	E	62	15:14	2183
14	42	59.731	N	36	38.741	E	58	06:41	42	59.68	N	36	38.93	E	62	17:13	2182
15	43	2.105	N	36	45.944	E	58	07:25	43	2.05	N	36	46.17	E	62	19:00	2180
16	43	4.43	N	36	53.018	E	58	08:08	43	4.28	N	36	53.33	E	62	22:16	2178
17	43	09:47	N	36	58.784	E	58	09:47	43	6.313	N	36	58.784	E	63	00:13	2178

Missing OBS or OBS without data

Line 3:
Line 3 was shot from offshore Samsun, across Sinop Trough and Archangelsky Ridge and into the centre of the Eastern Black Sea Basin, where the free air gravity anomaly is the highest and presumably the crust is the thinnest. Line 3 is coincident with TPAO reflection profile KDZ91-43/43A, which was shot to 10 s two-way time in deep water. The OBS spacing was about 12 km and the profile length was ~160 km. The profile was shot in a fairly poor sea state throughout. The shot interval was maintained at 90 s, corresponding to a spatial interval of ~180 m, though reducing to ~150 m in parts of the line when the sea state was worse.



The upper panel shows bathymetry derived from a shipboard echosounder with the locations and position numbers of OBSs. The middle panel shows satellite gravity with free air correction.

Figure 11

Data quality was again generally good, though more variable than on the other profiles. Some instruments in the region of Archangelsky Ridge gave good arrivals only to relatively short offsets, and mantle arrivals in OBSs at the northeast end of the profile were truncated abruptly at 50-60 km range. These effects probably result from shadow zones caused by the seabed and basement relief, rather than limitations in OBS performance. The best record section, from OBS14, shows clear arrivals throughout the length of the profile.

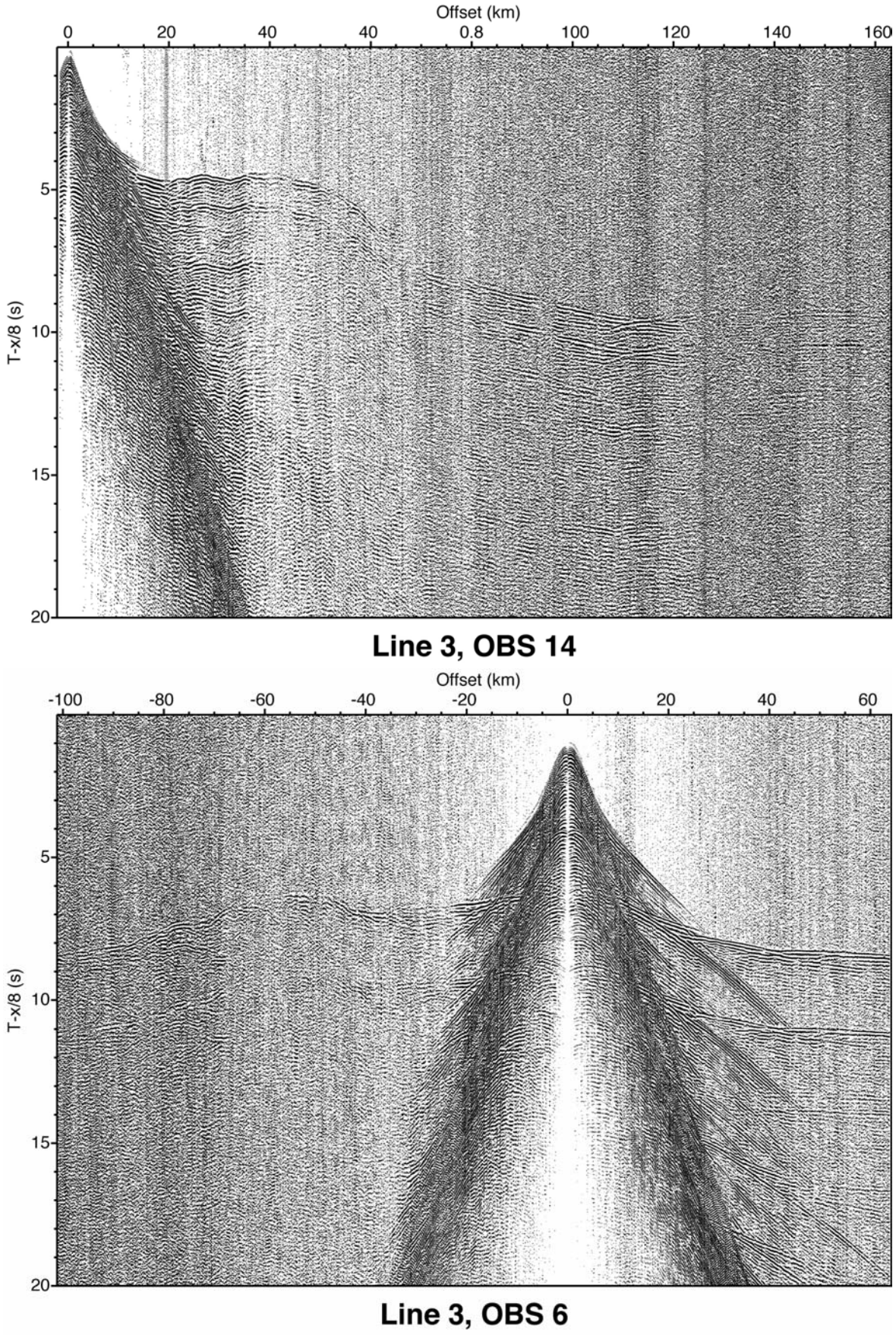
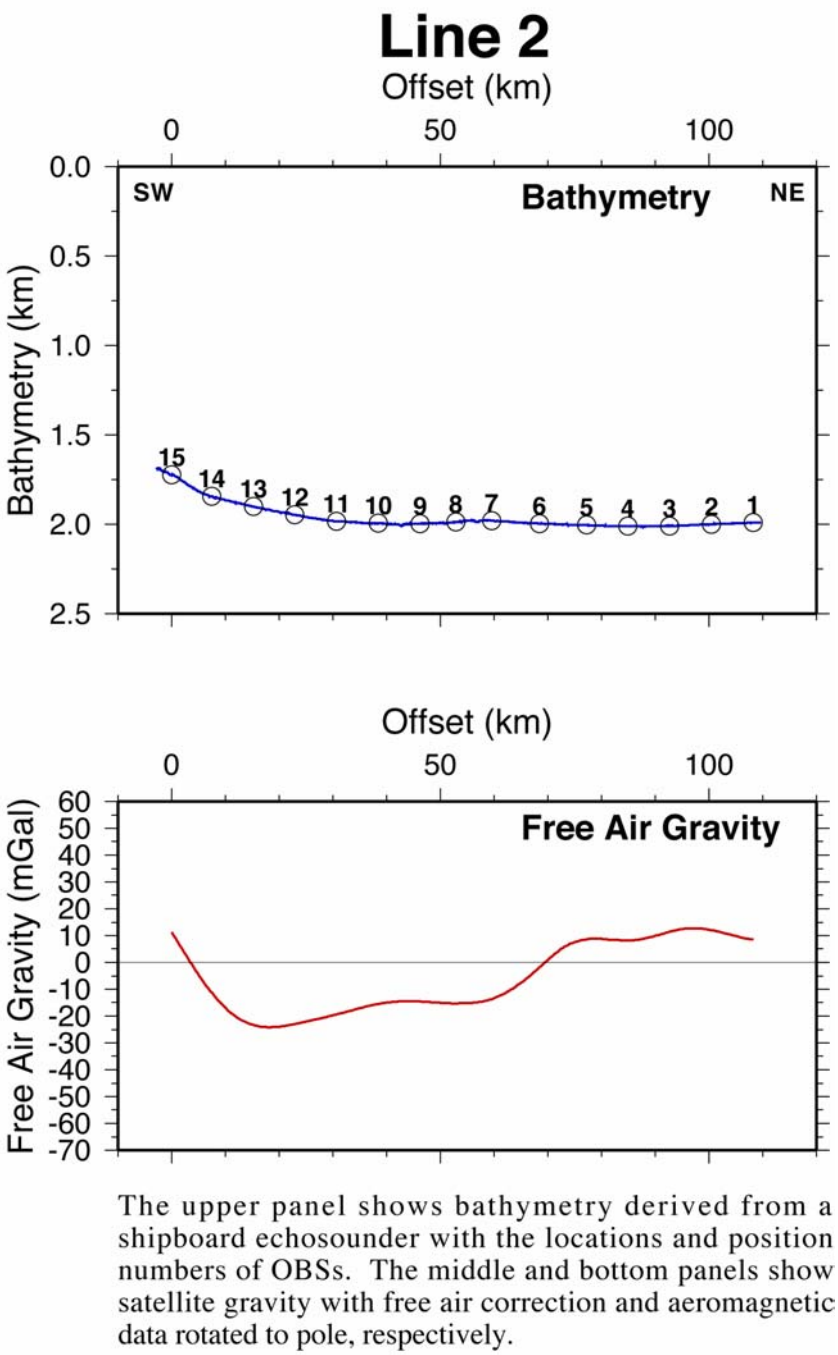


Figure 12: Representative seismic data from Line 3

Line 3 OBS Locations

	DEPLOYMENT								RECOVERY								
OBS	**Latitude**			**Longitude**			**Jul.**	**Time**	**Latitude**			**Longitude**			**Jul.**	**Time**	**Depth**
Pos. No.	**Deg**	**Min**		**Deg**	**Min**		**Day**	**(GMT)**	**Deg**	**Min**		**Deg**	**Min**		**Day**	**(GMT)**	**(m)**
1	42	51.83	N	37	29.12	E	63	03:28	42	51.975	N	37	28.84	E	65	09:58	2167
2	42	47.37	N	37	25.47	E	63	04:18	42	47.5	N	37	25.38	E	65	12:10	2168
3 (line1, 24)	42	41.85	N	37	21.94	E	49	17:17	42	41.87	N	37	21.1	E	65	14:23	2170
4	42	35.57	N	37	15.86	E	63	06:10	42	35.48	N	37	15.99	E	65	16:45	2148
5	42	29.19	N	37	10.67	E	63	07:12	42	29.15	N	37	10.73	E	65	18:49	2104
6	42	23.31	N	37	5.919	E	63	08:23	42	23.28	N	37	5.88	E	65	21:22	2069
7	42	17.42	N	37	1.19	E	63	09:56	42	17.403	N	37	1.155	E	65	23:28	2050
8	42	11.51	N	36	56.41	E	63	11:04	42	11.443	N	36	56.64	E	66	01:47	2054
9	42	5.63	N	36	51.78	E	63	12:10	42	5.449	N	36	51.26	E	66	04:16	1903
10	41	59.75	N	36	47.07	E	63	13:05	41	59.595	N	36	47.38	E	66	05:39	472
11	41	53.85	N	36	42.39	E	63	14:00	41	53.862	N	36	42.78	E	66	07:22	472
12	41	47.95	N	36	37.72	E	63	14:49	41	48.15	N	36	37.96	E	66	09:12	883
13	41	42.04	N	36	33.08	E	63	15:44	41	42.07	N	36	33.29	E	66	11:00	1045
14	41	36.13	N	36	28.44	E	63	16:35	41	35.89	N	36	28.73	E	66	12:52	755

Line 2:
Line 2 was shot from offshore Giresun to the centre of the Eastern Black Sea Basin, parallel to Line 3. Line 2 is close to BP/TPAO reflection profiles BP91-79 and BPT02-123 in Turkish waters, and approximately collinear with profile 578432 in Russian/Georgian waters. The OBS spacing was about 7 km and the profile length was ~100 km. The profile was shot in a fairly poor sea state throughout. The shot interval was reduced 60 s since the line is too short for water waves from previous shots to be a problem. Due to the slow vessel speed during shooting, the spatial shot interval was 90-100 m.



The upper panel shows bathymetry derived from a shipboard echosounder with the locations and position numbers of OBSs. The middle and bottom panels show satellite gravity with free air correction and aeromagnetic data rotated to pole, respectively.

Figure 13

Data quality was very good throughout this line, though maximum offsets are limited to ~100 km by the length of the profile.

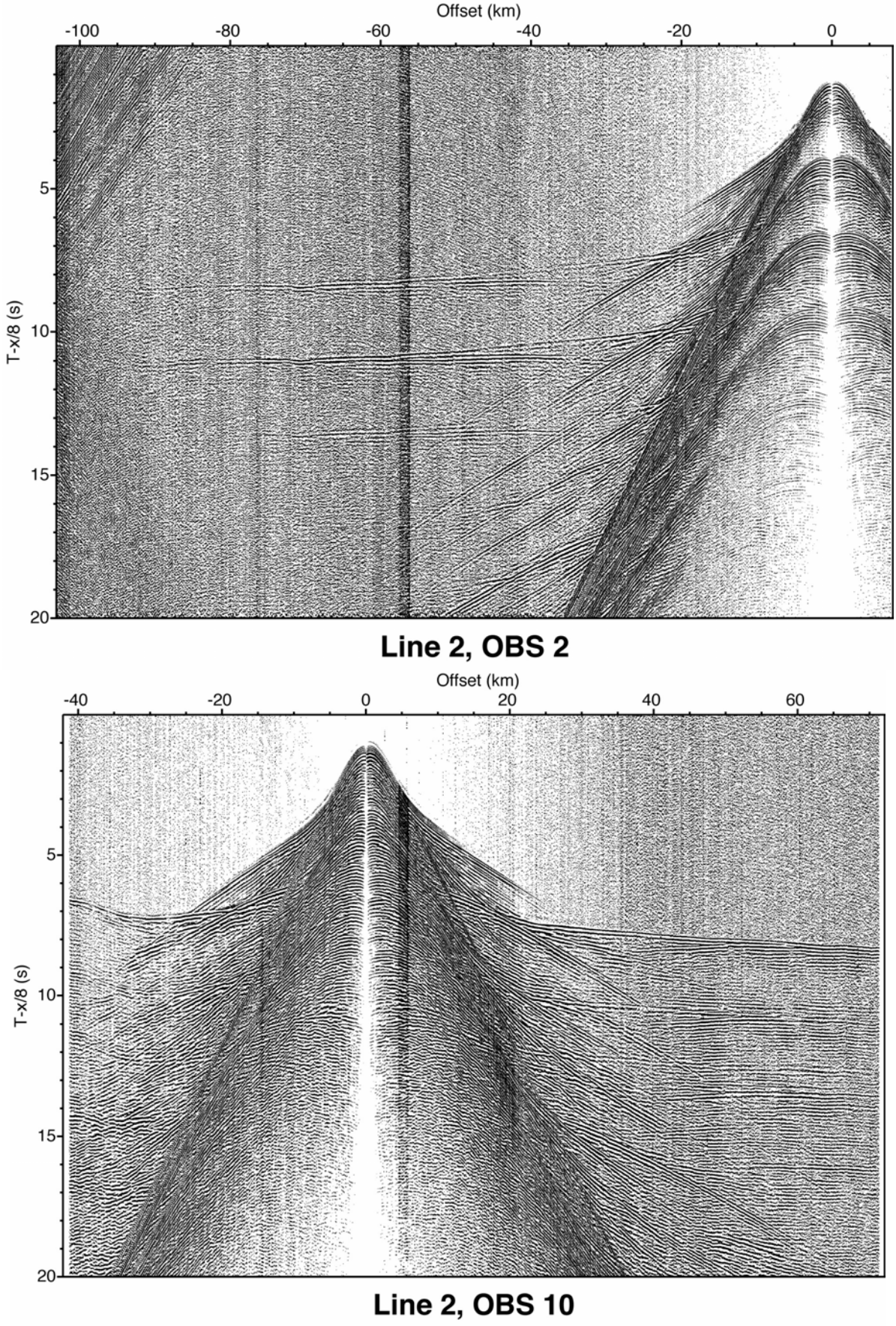


Figure 14: Representative seismic data from Line 2

Line 2 OBS Locations

	DEPLOYMENT								RECOVERY								
OBS	**Latitude**			**Longitude**			**Jul.**	**Time**	**Latitude**			**Longitude**			**Jul.**	**Time**	**Depth**
Pos. No.	**Deg**	**Min**		**Deg**	**Min**		**Day**	**(GMT)**	**Deg**	**Min**		**Deg**	**Min**		**Day**	**(GMT)**	**(m)**
1	42	9.487	N	39	42.87	E	67	06:27	42	9.514	N	39	42.72	E	69	06:23	1989
2	42	5.792	N	39	40.21	E	67	07:05	42	5.994	N	39	40.27	E	69	08:14	2000
3	42	2.103	N	39	37.58	E	67	07:45	42	2.09	N	39	37.9	E	69	10:25	2009
4	41	58.41	N	39	34.93	E	67	08:25	41	58.45	N	39	35.19	E	69	12:20	2009
5	41	54.71	N	39	32.3	E	67	08:58	41	54.69	N	39	32.54	E	69	14:11	2004
6	41	50.54	N	39	29.33	E	67	09:36	41	50.28	N	39	29.56	E	69	16:00	1997
7	41	46.33	N	39	26.32	E	67	10:17	41	46.37	N	39	26.35	E	69	17:42	1979
8	41	43.15	N	39	24.07	E	67	11:01	41	43.18	N	39	24.04	E	69	19:19	1986
9	41	39.93	N	39	21.8	E	67	11:33	41	40.02	N	39	21.79	E	69	20:56	1996
10	41	36.22	N	39	19.18	E	67	12:08	41	36.271	N	39	19.26	E	69	22:42	1993
11	41	32.53	N	39	16.57	E	67	12:43	41	32.672	N	39	16.87	E	70	00:44	1982
12	41	28.83	N	39	13.98	E	67	13:16	41	28.834	N	39	14.25	E	70	02:38	1947
13	41	25.13	N	39	11.38	E	67	13:50	41	24.968	N	39	12.48	E	70	05:00	1901
14	41	21.42	N	39	8.78	E	67	14:24	41	21.432	N	39	9.353	E	70	06:52	1844
15	41	17.88	N	39	6.31	E	67	15:02	41	17.953	N	39	6.807	E	70	08:35	1724