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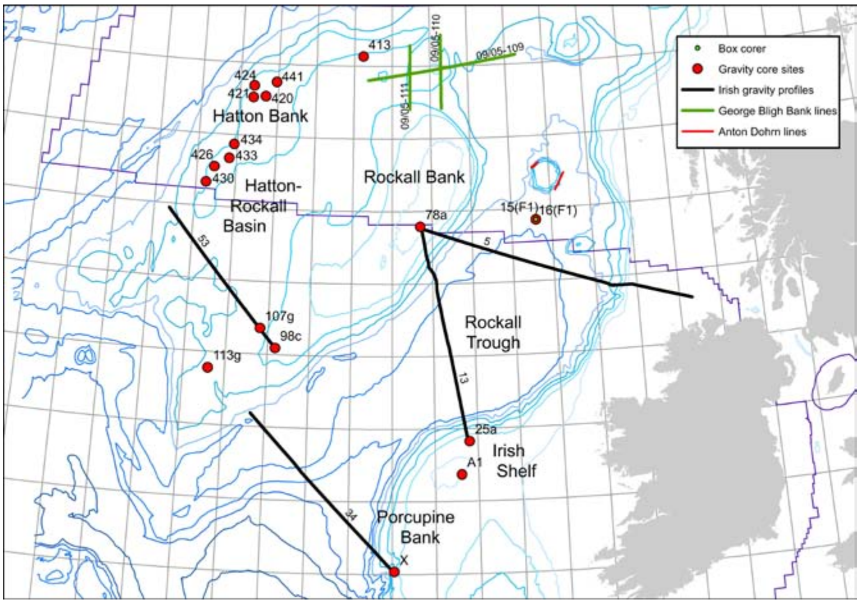
Cruise 2009/05: Site survey investigation and planning for drill sites in the Irish Shelf / Rockall / Hatton area.

Marine Geoscience Programme

Internal Report IR/09/075



BRITISH GEOLOGICAL SURVEY

MARINE GEOSCIENCE PROGRAMME

INTERNAL REPORT IR/09/075

Cruise 2009/05: Site survey investigation and planning for drill sites in the Irish Shelf / Rockall / Hatton area

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Foreword

This report documents the findings of British Geological Survey (BGS) cruise 2009/05. It provides information on 16 sites on the Irish Shelf, Rockall Bank and Hatton Bank that have been proposed as sites for rock drilling. In UK waters the 9 sites have been proposed by BGS and members of the BGS Rockall Consortium and are focused on parts of the Hatton-Rockall margin where basalt is absent - hence providing a window into the underlying geology. In Irish waters 7 site locations have been proposed by the Irish Shelf Petroleum Studies Group (ISPSG) of the Irish Petroleum Infrastructure Programme (PIP).

In addition to the site surveys, a number of secondary objectives (small geophysical grids across features of interest such as unexplained subsurface mounds, the Talisman Slide, carbonate mounds and George Bligh Bank) were identified for the cruise. As a result of bad weather, most of these additional objectives were abandoned or only partially achieved. Information on these secondary objectives was provided by Dave Long, Heather Stewart and Sev Kender at BGS and Fiona Hibbert (St Andrews BUFI student).

The cruise was coordinated by Ken Hitchen at BGS with assistance from Noel Murphy at PAD and Dave McInroy at BGS.

Acknowledgements

In addition to the BGS staff acknowledged in the Foreword, Eileen Gillespie contributed to the production of this report. BGS staff Dave Baxter, Lee Baines, Dayton Dove, Simon Ritson and Nick Smart took part in data collection during the cruise. Fiona Hibbert from St. Andrew’s University and Nick Owen from Trinity College Dublin carried out core logging and description. We would also like to thank Dr Stephen Jones at Trinity College Dublin for help with seismic oceanography.

Particular thanks to the captain and crew of RRS Discovery and staff at NOCS who provided excellent support before, during and after the cruise.

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Summary

BGS cruise 2009/05 on RRS Discovery took place between 18th August 2009 and 18th September 2009, sailing to the Irish Shelf and Rockall / Hatton area. The objectives were to carry out 16 site surveys in Irish and UK waters, investigating ground conditions for sites of proposed shallow drilling. In addition to the site surveys, a number of other tasks were identified that would address geological issues in the region.

The Irish sites were situated on Porcupine Bank, Rockall Bank and the south western edge of Rockall Bank on the margin of the Hatton Rockall Basin. All of the UK sites are on the north east – south west trending Hatton Bank.

Each site survey comprises a grid of 6 seismic lines, each 5 km long forming a grid of 3 (e.g. north – south) lines and 3 perpendicular (e.g. east – west) lines. In the centre of the grid, at the intersection of the 2 middle lines, a core is taken. In almost all cases both airgun and sparker seismic data were collected for each line. The coring equipment was a gravity core, using a 3 m or 6 m barrel as appropriate for each site.

In addition to the 16 site surveys, the following work was undertaken.

- 2 airgun / sparker lines off Rathlin Island, intended to test the equipment and provide data to support the recent JIBS multibeam survey in the area
- 3 gravity / magnetic transects across the Rockall Trough, carried out in transit between site surveys.
- 1 gravity / magnetic transect across Hatton Rockall Basin.
- 3 airgun / sparker regional seismic lines across George Bligh Bank.
- 3 sparker / airgun lines across Anton Dohrn Seamount.
- 1 gravity core and 1 box core taken in the Rockall Trough at the site of a previous piston core. This work was to support a current BUFI PhD project at St Andrews.
- 102 XBT profiles of water temperature / salinity carried out during site survey and regional seismic work.

Other planned work was not carried out as a result of bad weather reducing the time available for collection of data. Weather also decreased the quality of the seismic data collected, in particular sparker data.

This report includes a summary of data recovered and preliminary seismic interpretation. All times given in this report refer to GMT.

1 Introduction

BGS Cruise 2009/05 on RRS Discovery took place between 18th August 2009 and 18th September 2009, sailing to the Porcupine Bank area of the Irish Shelf, Rockall Bank, the Hatton Rockall Basin, Hatton Bank, George Bligh Bank and the Rockall Trough. The main objectives were to carry out 16 site surveys, 7 in Irish and 9 in UK waters, investigating ground conditions for sites of proposed shallow drilling (Figure 1).

The Irish sites were situated on Porcupine Bank, Rockall Bank and the south western edge of Rockall Bank on the margin of the Hatton Rockall Basin. All of the UK sites are on the north east – south west trending Hatton Bank.

Each site survey comprises a grid of 6 seismic lines, each 5 km long forming a grid of 3 (e.g. north – south) lines and 3 perpendicular (e.g. east – west) lines. In the centre of the grid, at the intersection of the 2 middle lines, a core is taken. Both airgun and sparker seismic data were collected for each line, except where marine mammals were identified during survey, in which case airguns were switched off. During most seismic lines physical properties of the water column were recorded using expendable bathythermograph tools (XBTs). The coring equipment used was a gravity core, using a 3 m barrel in most cases. The 6 m barrel was tested at site 113g and recovered 2 m of sediment while the barrel itself was bent. As a result, the 6 m barrel was not used again until sampling in the middle of the Rockall Trough.

After an abortive attempt to calibrate and test the seismic equipment off Rathlin Island, abandoned due to bad weather and strong (>7 kts) tides, testing was completed on the Irish Shelf on the way to the first site survey on Rockall Bank. The ship then moved south to Porcupine Bank on the Irish Shelf, north west to Rockall Bank and northwest again into UK waters to Hatton Bank.

Between 18th and 28th August, constant bad weather made data collection difficult and seismic data collected at sites 78a on Rockall Bank and 25a, A1 and X on Porcupine Bank were compromised by the poor conditions. After 28th August there were several delays to site survey work due to poor weather, including the 3rd, 7th to 9th and 11th September.

In addition to the site surveys, a number of other tasks were identified that would address geological issues in the region. Most of these tasks were not carried out after delays to site survey work. Tasks that were carried out include several transects of the Rockall Trough and Hatton Rockall Basin during which gravity and magnetic data were collected, 3 regional seismic lines over George Bligh Bank, seismic lines over Anton Dohrn Seamount and coring in the central Rockall Trough to aid in ongoing research in the area. Figure 1 summarises the main elements of the cruise.

A proposed survey on the continental margin to collect data on a major submarine landslide was not undertaken due to the poor weather and shortage of time.

1.1 SITE SURVEYS

The 16 site surveys (7 in Irish waters) investigated the near sea bed geology in the immediate vicinity of the proposed borehole locations. These sites are interpreted to be windows into Mesozoic or older sedimentary rocks (i.e. where basalt cover is absent). The aim is to build on 1999 drilling success which followed on from 1998 site surveys (RRS Challenger).

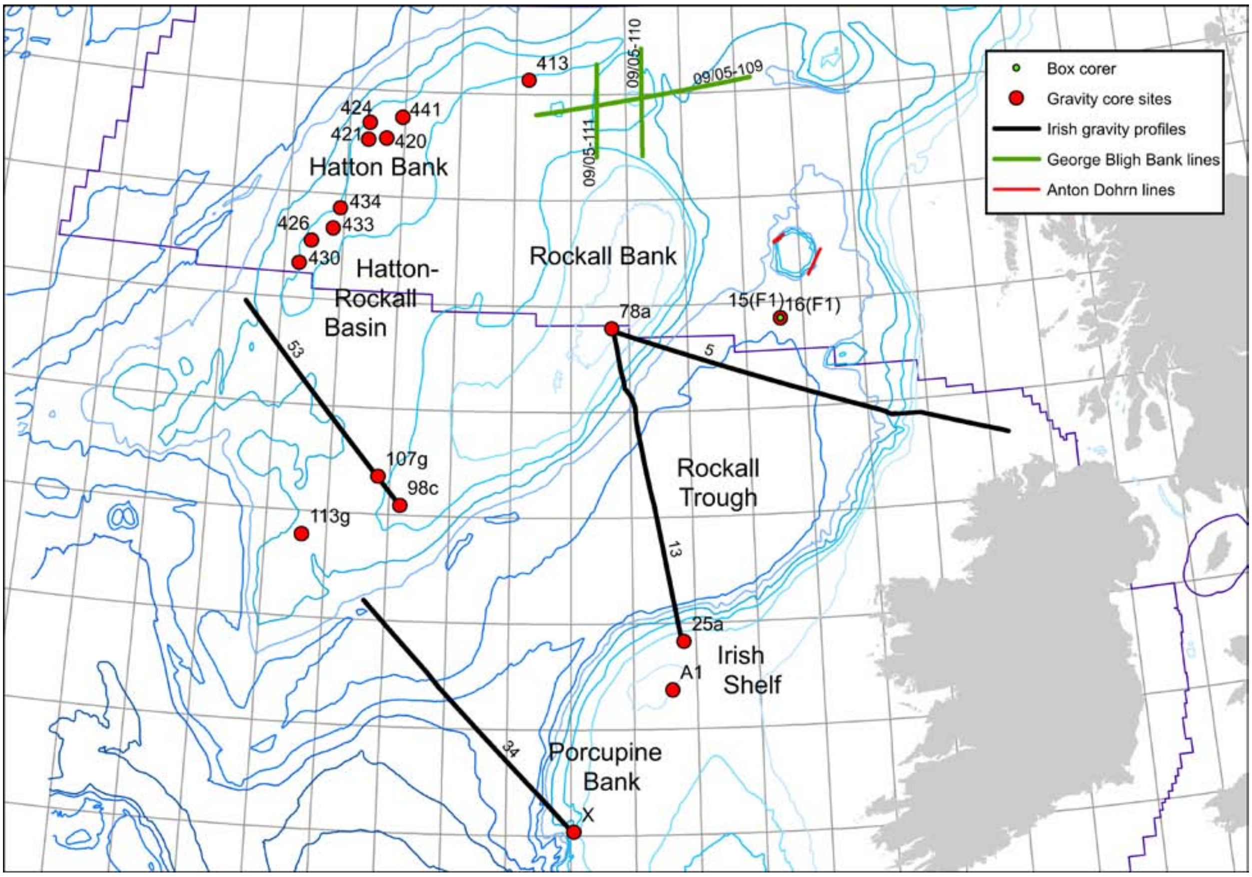


Figure 1. Cruise outline with main features. Plans of the site investigation lines are shown in Figures 21-30 and 32-37. At sites 78a, 25a, A1, 420, 421, 424, 434 and 441 gravity cores were attempted but there was no recovery.

At each site a grid of 6 seismic (sparker optimised if possible) lines was collected. Each line is ~5 km long. A gravity core was attempted at the centre of each seismic grid but only 8 were successful.

1.1.1 Site Surveys in Irish Waters

Detailed information on each of the 7 sites in Irish waters is held by the PIP Secretariat on behalf of the ISPSG, contact details below:

Contact: Martin Davies
PIP Secretariat, 7 Dundrum Business Park
Windy Arbour, Dublin 14, Ireland
Tel: +353-1-296-4667   Direct Line: +353 1 4894321
Fax: +353-1-296-4676
Email: mdavies@slrconsulting.com   Website: www.pip.ie

Regional seismic lines through the sites surveyed are included in Figures 2 to 18. Locations of the sites are given in Figure 1.

Seismic panel removed at the request of the Petroleum Affairs Division, Dublin.

Data confidential to PAD and members of the PIP ISPSG consortium.

Figure 2. Seismic line through Irish site 78a (East Rockall Bank).

Seismic panel removed at the request of the Petroleum Affairs Division, Dublin.

Data confidential to PAD and members of the PIP ISPSG consortium.

Figure 3. Seismic line through Irish site 25a (Porcupine Bank).

Seismic panel removed at the request of the Petroleum Affairs Division, Dublin.

Data confidential to PAD and members of the PIP ISPSG consortium.

Figure 4. Seismic line through Irish site A1 (Porcupine Bank).

Seismic panel removed at the request of the Petroleum Affairs Division, Dublin.

Data confidential to PAD and members of the PIP ISPSG consortium.

Figure 5. Seismic line through Irish site X (Porcupine Bank).

Seismic panel removed at the request of the Petroleum Affairs Division, Dublin.

Data confidential to PAD and members of the PIP ISPSG consortium.

Figure 6. Seismic line through Irish site 113g (South Rockall Bank).

Seismic panel removed at the request of the Petroleum Affairs Division, Dublin.

Data confidential to PAD and members of the PIP ISPSG consortium.

Figure 7. Seismic line through Irish site 98c (South Rockall Bank).

Seismic panel removed at the request of the Petroleum Affairs Division, Dublin.

Data confidential to PAD and members of the PIP ISPSG consortium.

Figure 8. Seismic line through Irish site 107g (South Rockall Bank).

1.1.2 Site Surveys in UK Waters

1.1.2.1 SITE 413

The Eocene stratigraphic record in the Hatton Rockall area includes three unconformities and a variable pattern of basin infill. The Eocene culminated in a phase of differential subsidence and compression resulting in the C30 unconformity (?Top Eocene). This unconformity defines many fold structures in the area and also acts as the onlap surface for younger sediments in the Hatton Rockall Basin.

The proposed borehole will penetrate the ?Eocene succession, identify lithologies and help to constrain the ages of the unconformities (Figure 9).

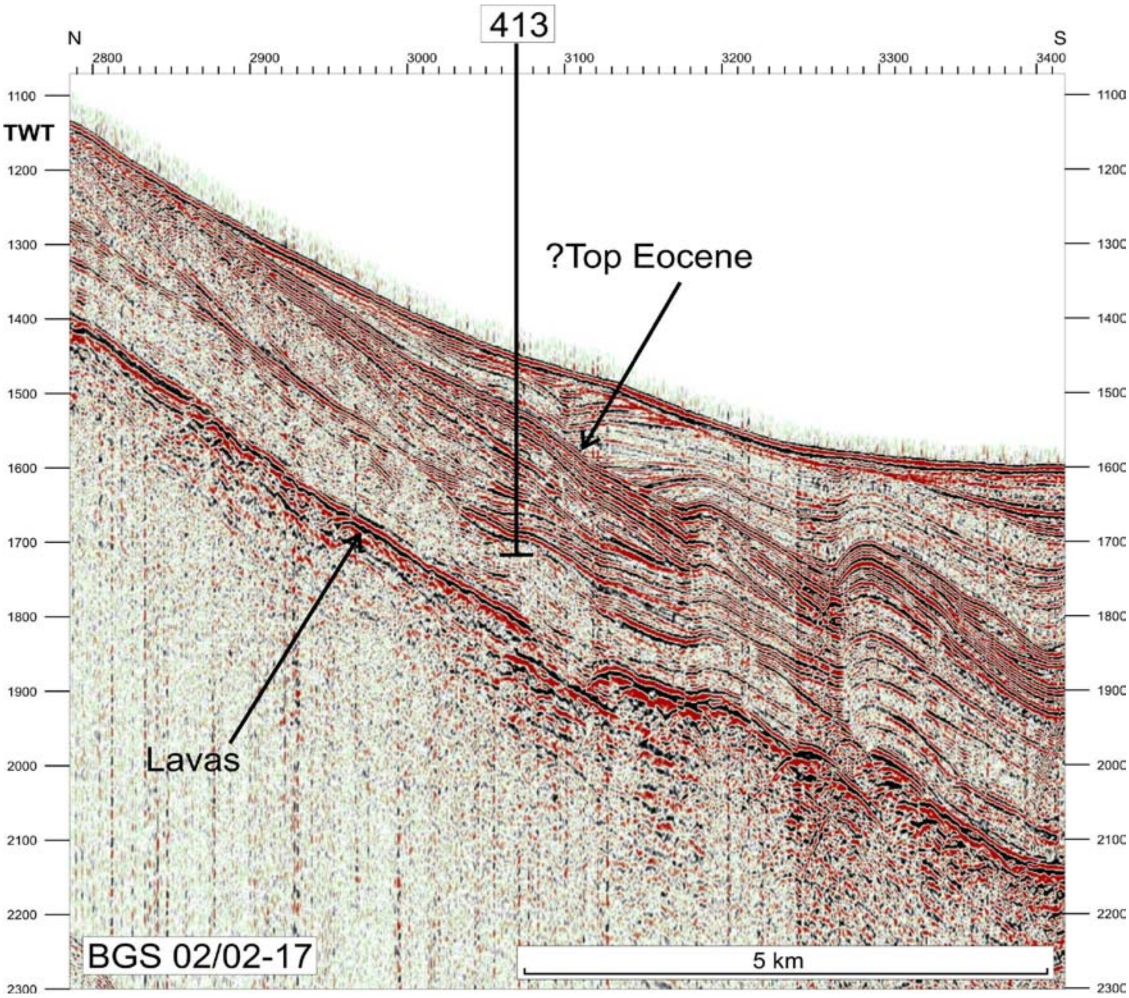


Figure 9. Seismic line through site 413. For location see Figure 1.

1.1.2.2 SITE 420

This proposed borehole is aimed at the oldest ?Mesozoic sediments in basalt window 3 (see Figure 1). Locally in this area there are patches of lavas and associated intrusions. The borehole site is designed to miss these but penetrate the dipping ?Mesozoic sediments truncated by the base Cenozoic unconformity (Figure 10).

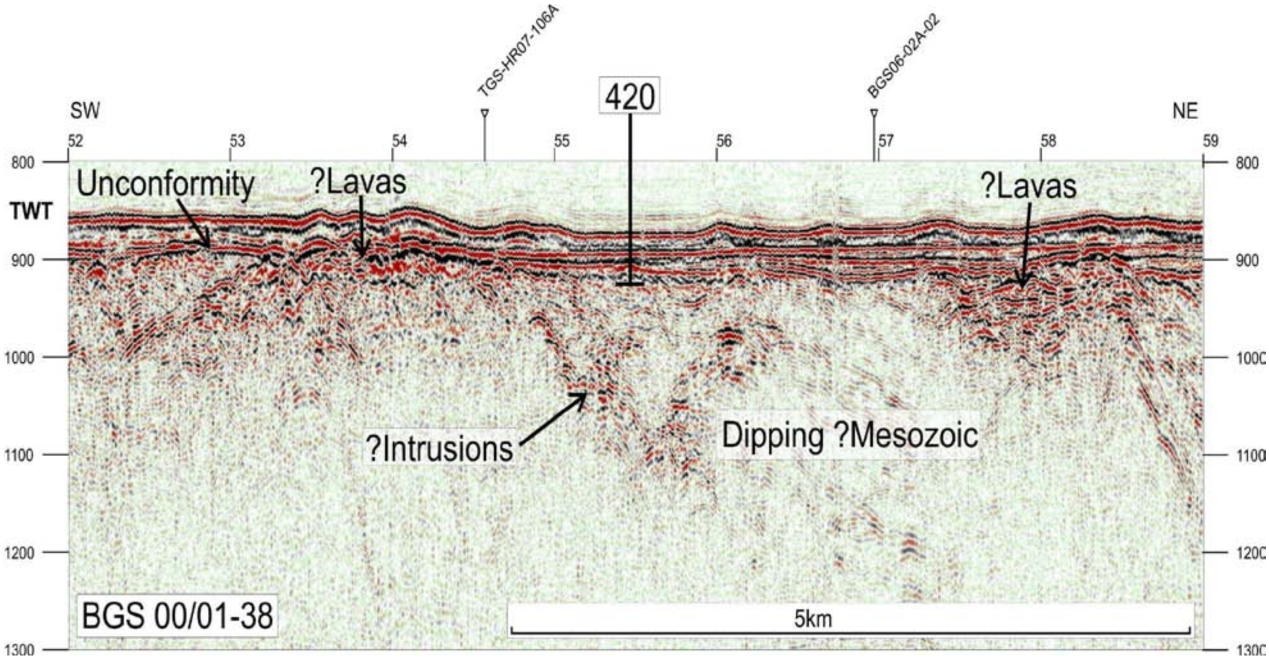


Figure 10. Seismic line through site 420. For location see Figure 1.

1.1.2.3 SITE 421

This borehole is aimed at the oldest ?Mesozoic sediments imaged in basalt window 2. Beneath the base Cenozoic unconformity the borehole is designed to penetrate the highly-reflective sequence before terminating in the underlying transparent sequence (Figure 11).

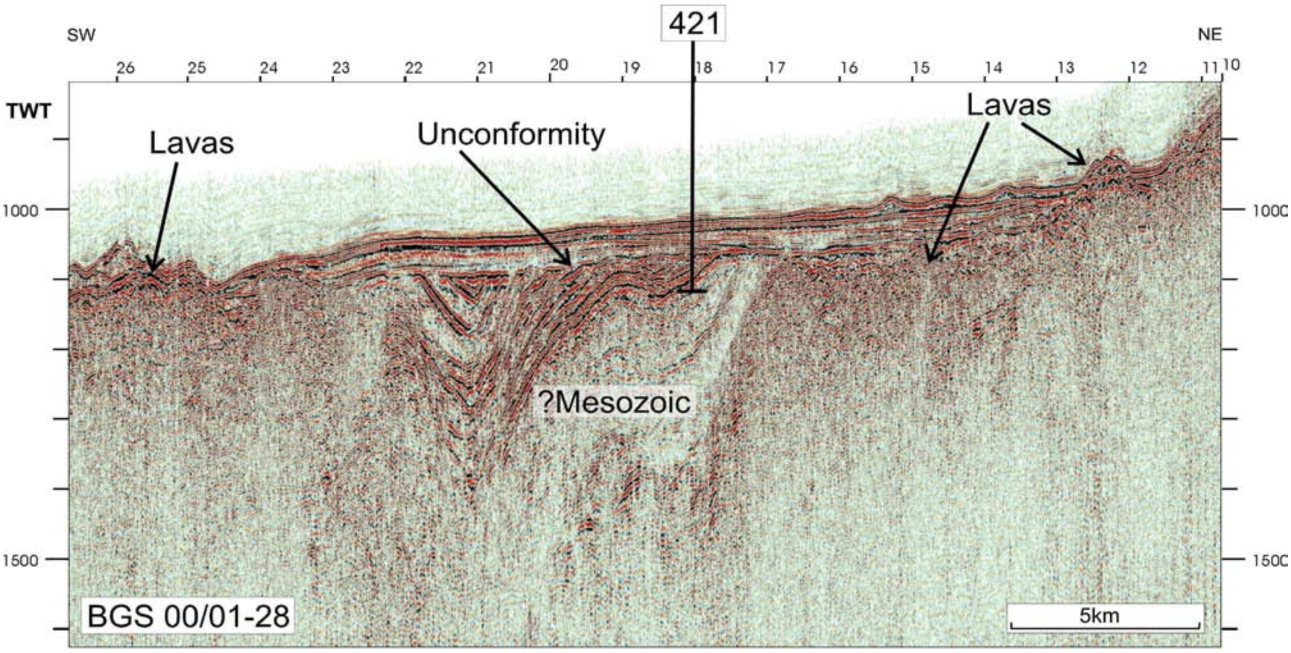


Figure 11. Seismic line through site 421. For location see Figure 1.

1.1.2.4 SITE 424

This borehole is aimed at the oldest ?Mesozoic sediments in basalt window 1. The borehole will penetrate sediments in a ‘pop-up’ structure (note reverse fault on seismic panel) possibly caused by the compression associated with the C30 event (Figure 12).

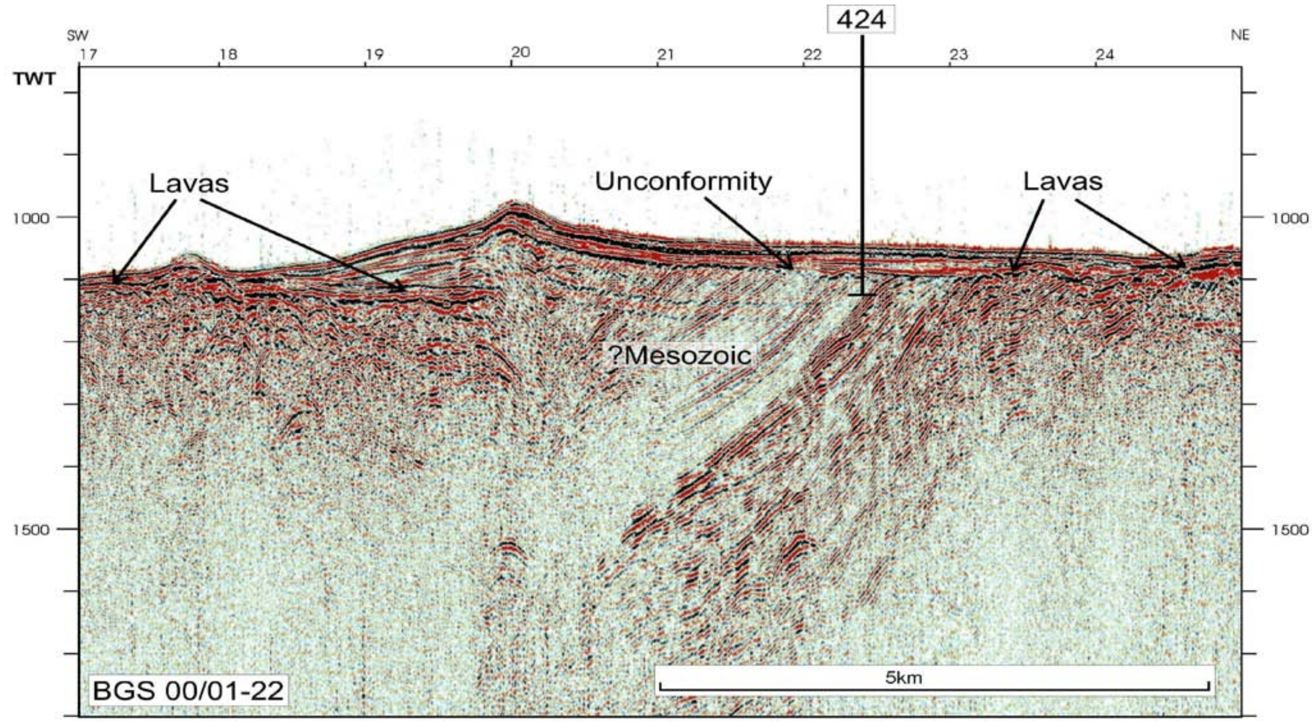


Figure 12. Seismic line through site 424. For location see Figure 1.

1.1.2.5 SITE 426

?Mesozoic (and ?older) sediments are contained in a half graben structure below the base Cenozoic unconformity (Figure 13). The borehole is designed to penetrate the oldest sediments between the subcrop of the lavas and the intrusion or basement feature. See also BGS high-resolution line 00/01-6 (Figure 14).

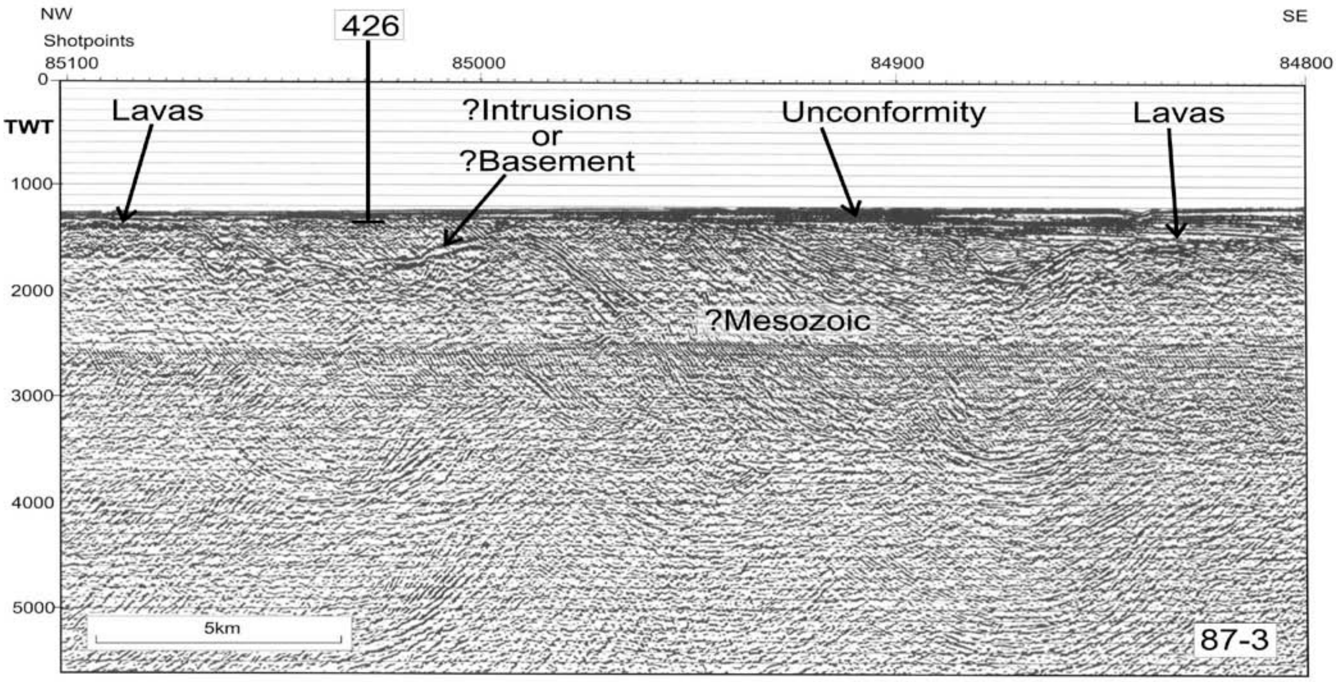


Figure 13. Seismic line through site 426. For location see Figure 1.

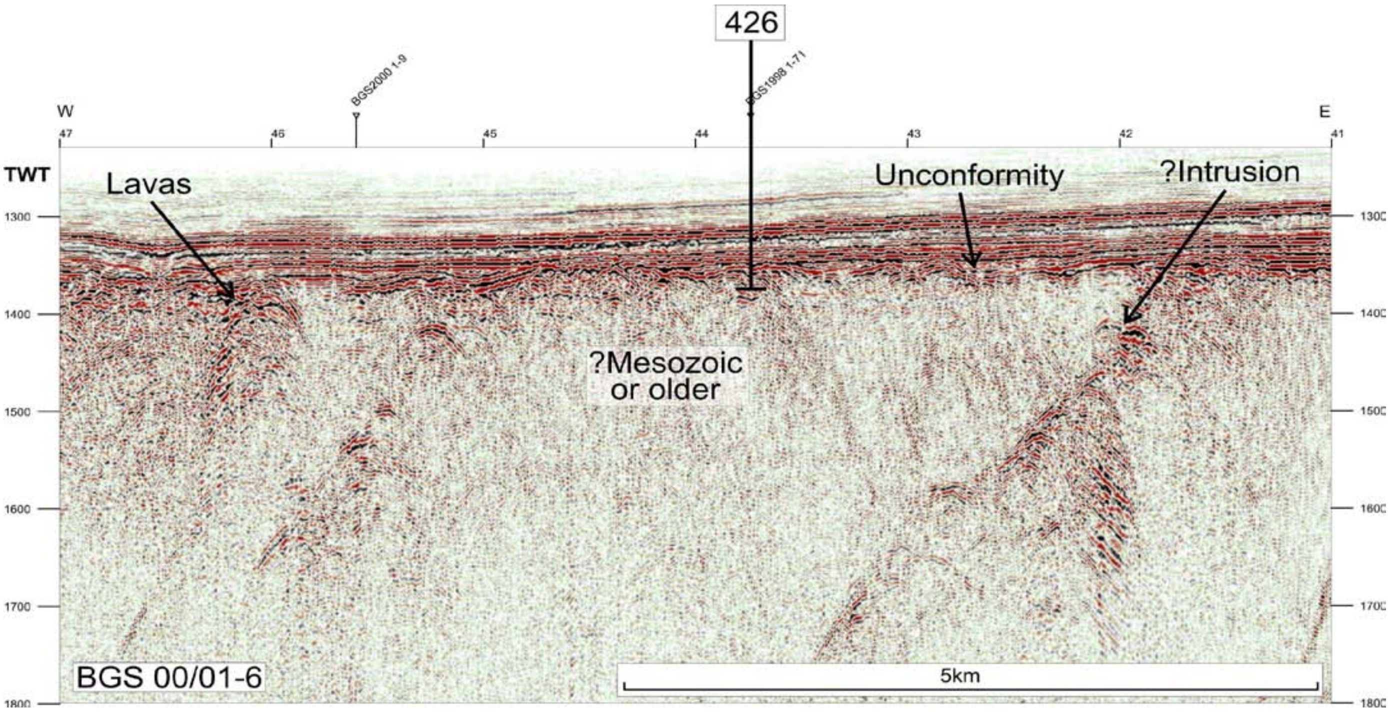


Figure 14. High-resolution seismic line across site 426. The borehole will penetrate ?Mesozoic (or older?) sediments below the base Cenozoic unconformity in the large basalt window. See also line 87-3 (Figure 13) for more regional profile.

1.1.2.6 SITE 430

This borehole is aimed at the most southerly accessible ?Mesozoic in the large basalt window, just north of the UK/Ireland median line. It will also help to constrain the age of the reflector labelled as ?Top Eocene on Figure 15).

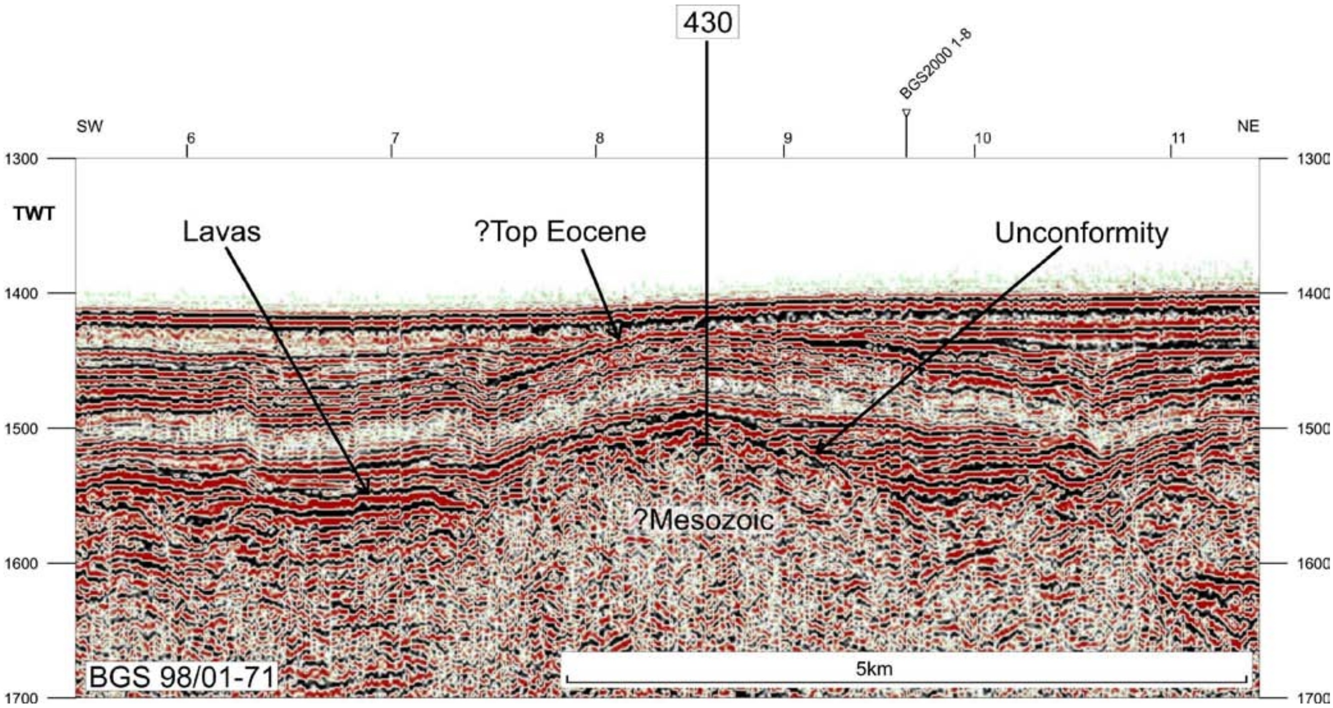


Figure 15. Seismic line through site 430. For location see Figure 1.

1.1.2.7 SITE 433

This borehole will penetrate the dipping and folded ?Mesozoic sediments below the base Cenozoic angular unconformity in the large basalt window. The lavas on the right in Figure 16 are derived from the Sandarro igneous centre. The unconformity onlap surface within the Cenozoic is probably C30.

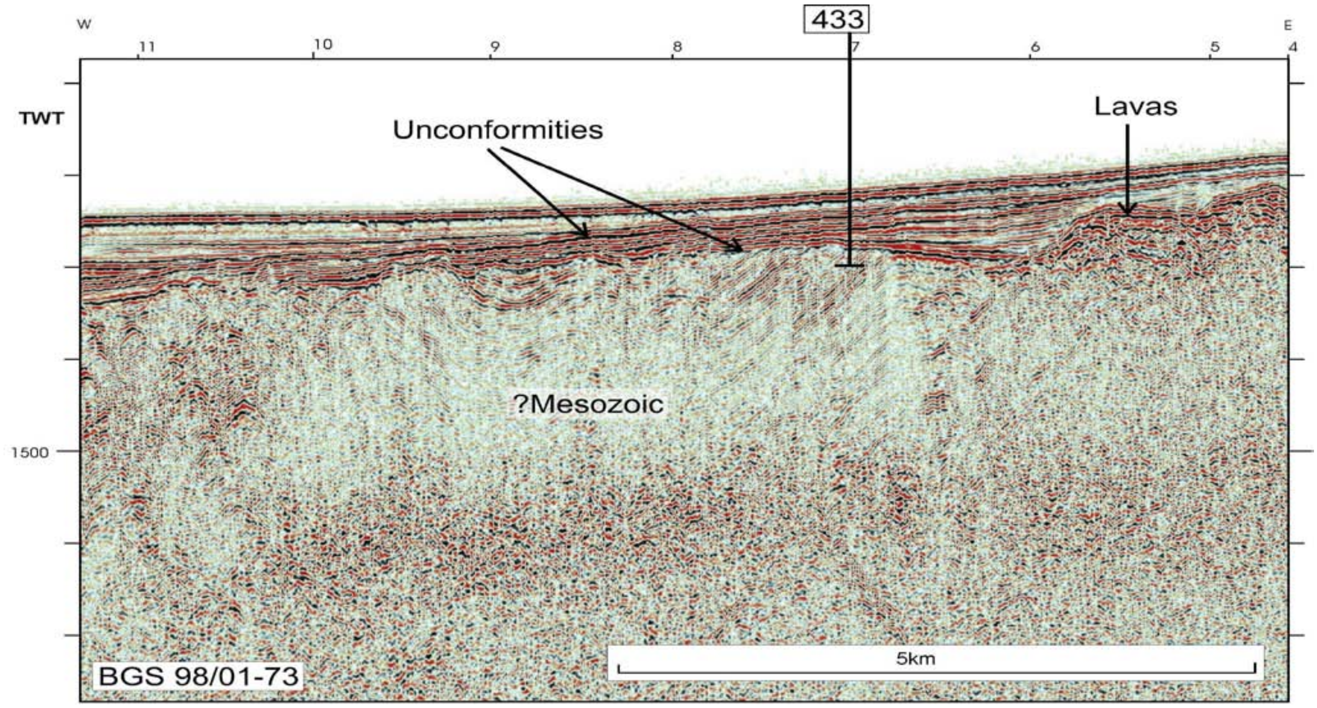


Figure 16. Seismic line through site 433. For location see Figure 1.

1.1.2.8 SITE 434

The proposed site of this borehole is aimed at the most northerly ?Mesozoic in the large basalt window (Figure 1). The base Cenozoic unconformity is only a few metres below the sea bed. There are patchy lavas and intrusions in the area which the borehole is intended to avoid (Figure 17).

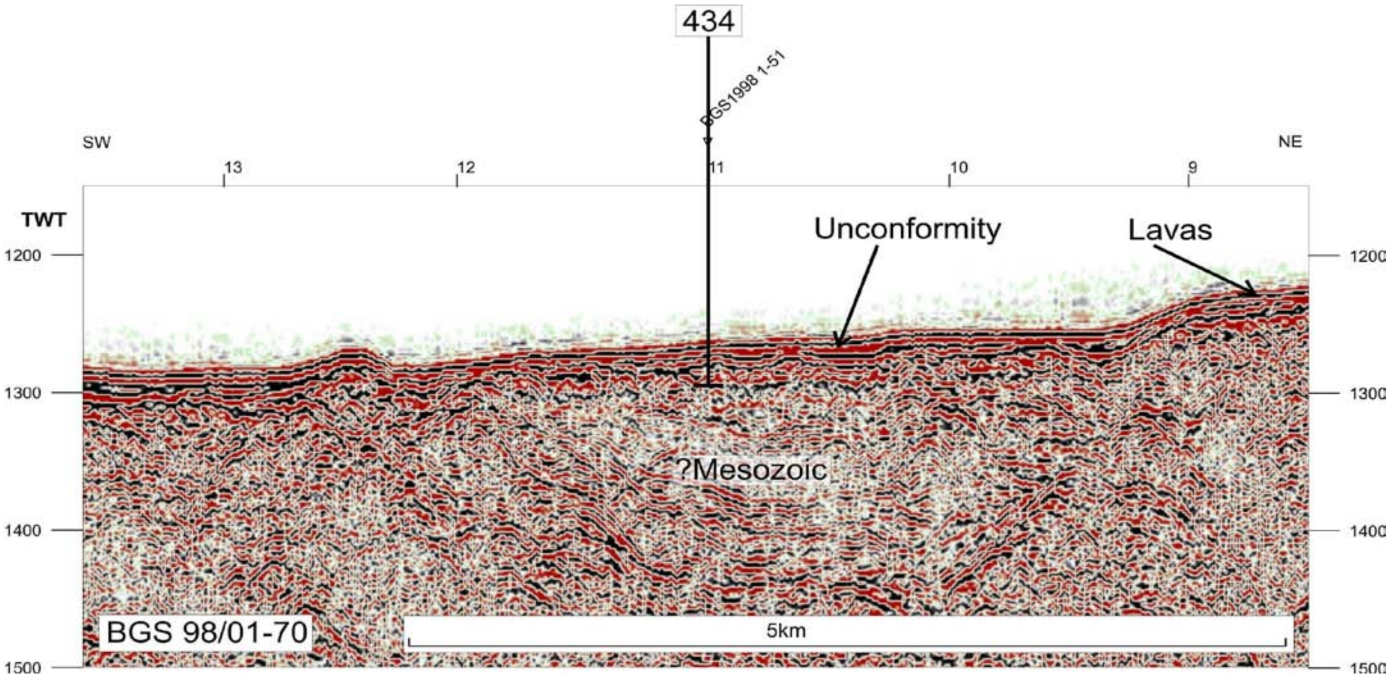


Figure 17. Seismic line through site 434. For location see Figure 1.

1.1.2.9 SITE 441B

The proposed site for this borehole is aimed at testing the nature and age of the succession represented by the truncated dipping reflectors below the base Cenozoic unconformity (figure 18). Do the reflectors represent lava flows or Mesozoic sediments? Site 441B is the preferred location.

Site 441A: Target reflectors not well imaged and might be lavas?

Site 441B: Involves drilling through a prominent reflector at the unconformity level before achieving target depth.

Site 441C: Deepest water and thickest overburden but target reflectors are well imaged (though, if sediments, would not be the oldest).

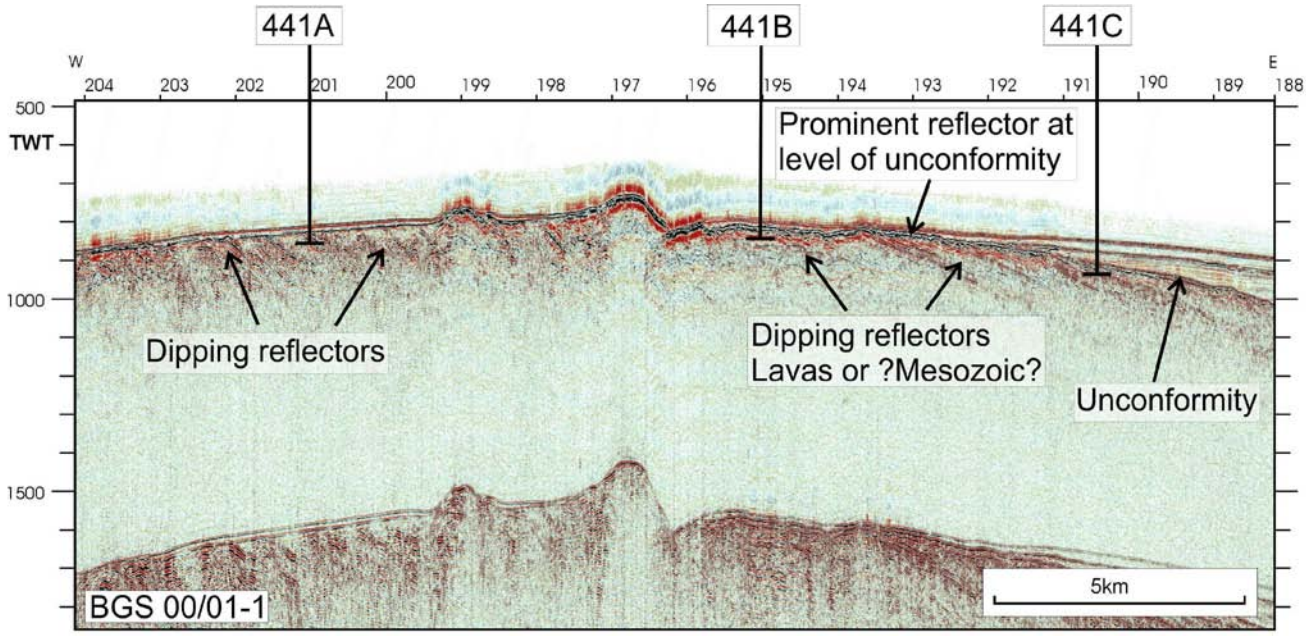


Figure 18. Seismic line through site 441. For location see Figure 1.

1.2 OTHER WORK

1.2.1 Rathlin Island (partially completed)

Eight seismic lines (high resolution sparker and airgun) were identified in 2 areas to the north and west of Rathlin Island. The high resolution seismic survey was planned to provide data on the sediment waves at sea bed and the post glacial environment of deposition.

The survey was carried out to allow testing of the seismic kit when the ship was close to port. A grid of seismic lines, comprising 8 lines 20 km in length was planned. One line was run twice in poor weather and very high currents. Poor survey conditions led to abandonment of the Rathlin Island work. The Joint Irish Bathymetric Survey (JIBS) data is an exciting data set and further attempts to collect seismic data across key features will be attempted in future years. Careful timing of data collection will be required because of the strong tidal currents in the area.

On the Irish Shelf a further airgun and sparker line was run to test the equipment.

1.2.2 Gravity / magnetic transects

Three transects across the Rockall Trough, and one across the Rockall Hatton Basin, were carried out collecting gravity and magnetic data to improve regional geophysical modelling in the area (Figure 1).

1.2.3 George Bligh Bank (partially completed)

George Bligh Bank has very poor coverage by BGS regional seismic lines, it is uncertain whether the topographic high is a product of compression, a basement high or volcanogenic.

A grid of 9 seismic (airgun optimised) was planned over this feature to close the gap in coverage but a smaller grid of three lines was all that was achieved because of weather and hence time constraints. Three lines were run with airgun and sparker (Figure 1). An example of the airgun data is shown in Figure 19 with a close up of the SW flank in Figure 20.

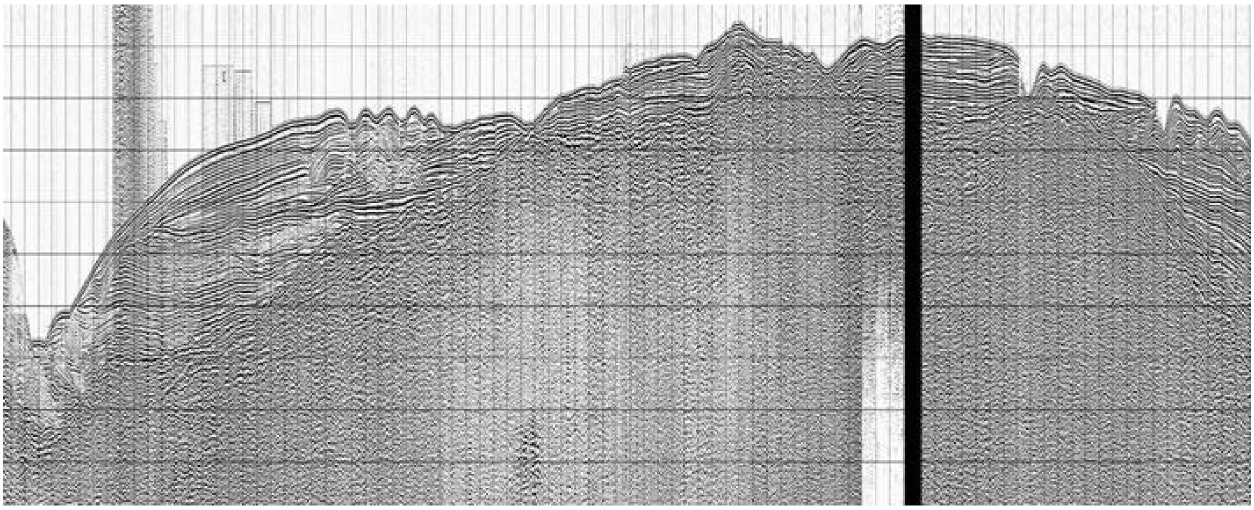


Figure 19. Regional air-gun line across the George Bligh Bank.

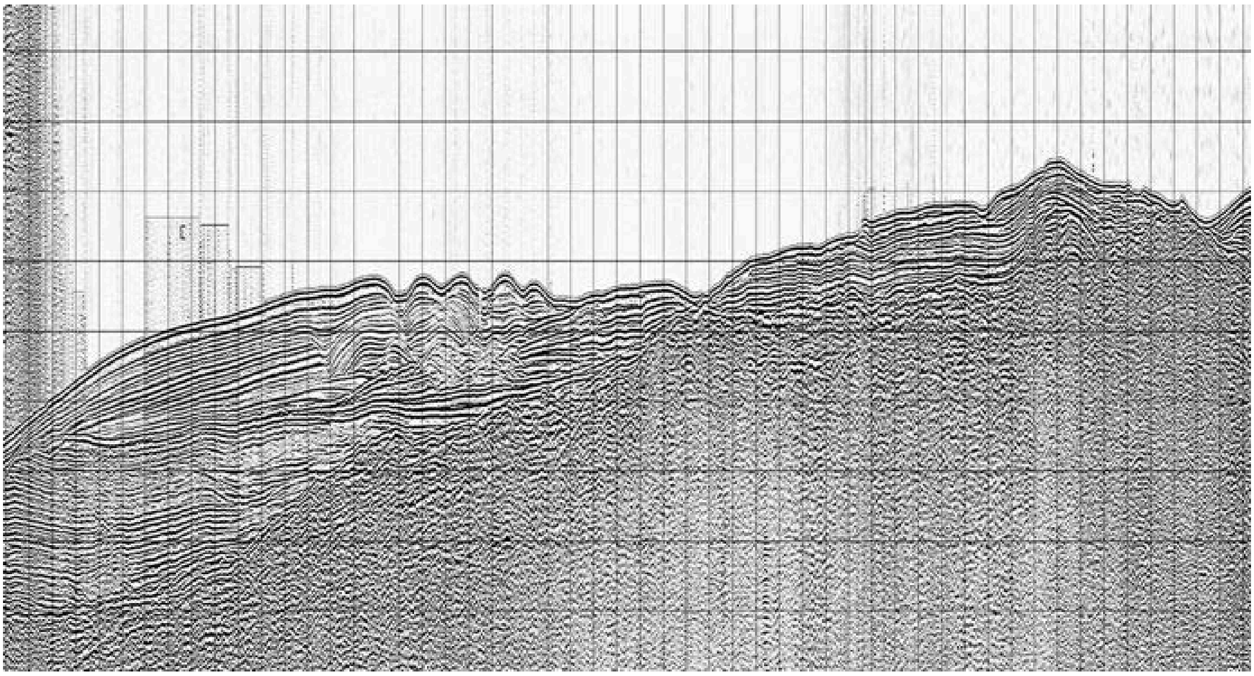


Figure 20. Close-up of Figure 19 on the south-western margin of the George Bligh Bank.

1.2.4 Rockall Trough

Ongoing work investigating the climatological records from sediment cores in the Rockall Trough was augmented by gravity and box cores which sampled the undisturbed water / sediment interface in order to allow analysis of the uppermost part of the sediment column.

One box core and one gravity core complemented a 37 m piston core which is the subject of Fiona Hibbert's work at St. Andrew's University (Figure 1).

1.2.5 Anton Dohrn (partially completed)

Three lines were run with airgun and sparker in this area (Figure 1). The track position was planned to complement the recent JNCC cruise in the area that collected multibeam and photography to assess the distribution and state of deep water habitats on and around the Anton Dohrn seamount.

1.2.6 Seismic oceanography

About 20 Sippican expendable conductivity-temperature depth (XCTD) probes and about 110 expendable bathythermograph (XBT) probes (see section 3.8) were available for this project. One hundred and two probes were deployed in total in the Rockall Trough. This work was undertaken for Trinity College, Dublin.

1.3 OBJECTIVES NOT CARRIED OUT

1.3.1 Hatton Basin Diapirs

A number of previously unknown diapir-like features have been identified in Hatton Basin. As they are only known from single lines, a grid of seismic (airgun optimised) was planned over two examples of these features to better define their geometry. These will be studied in future expeditions.

1.3.2 Talisman Slide

The Talisman Slide on the west flank of Hatton Bank is known only from a few seismic lines with incomplete coverage. A grid of 4 or 6 seismic lines (airgun optimised) over the entire slide (headwall, scarp and deposit, parallel to and perpendicular to the slope) was planned along with 2-3 gravity cores. Core positions were to be chosen to recover slide debris and underlying sediment if possible. It was extremely disappointing that time was not found for this work which was supporting joint research with the Spanish Institute of Oceanography and the Marine Geohazards Team in BGS. This is a key area for future work and may be included in the proposed 2011 James Cook coring cruise.

1.3.3 Hatton Mounds

Sea bed mounds on Hatton Bank have been interpreted as being constructional carbonate, based on video and photographic evidence). A number of seismic lines (sparker optimised) were planned between site surveys 434 and 421 and to the east of sites 433 and 441B.

1.3.4 Climate Change

Gravity cores in N Rockall (6 cores across the Feni Drift) and Hatton Basin (1 core on the Hatton Drift) were planned to examine changes from the last glacial maximum. This research was proposed as part of the Climate Change Team in BGS, and was led by Sev Kender at BGS Keyworth. Further opportunities on future cruises will be explored to take this research forward.

1.3.5 North Hatton

Two lines were planned to link existing regional seismic work to the west of George Bligh Bank.

2 Cruise Summary

2.1 MOBILISATION

RRS Discovery docked at King George V Dock, Govan, Glasgow on 12th August 2009. Mobilisation began at 08.30 on Friday 14th August and containers were loaded on board. BGS returned on Sunday 16th August to continue mobilisation. Mobilisation was completed at 18.15 on Monday 17th August. This part of the cruise went very smoothly, thanks in no small part to the assistance and help from the National Marine Facilities mobilisation team.

2.2 SURVEY

2.2.1 Rathlin Island

Arrived 19.00 18th August. Some problems with sparker. 2 attempts at running line DL1 (lines 2009050003 and 2009050004).

Very poor data as a result of rough seas and strong tidal currents, sea bed difficult to locate on CODA.

Survey abandoned 09.00 19th August and ship moved to deeper water to test equipment.

2.2.2 Rockall Trough transect 1 (Irish waters) Line 5

15.30 19th August, magnetometer deployed, brought in 19.25 20th August during bad weather. Some breaks in data record as echo sounder did not find sea bed.

2.2.3 Site survey 78a (Irish waters)

Arrived 19.25 20th August, sea too rough for seismic or coring.

10.25-11.37 21st August, 3 drops gravity core, NR.

18.53 21st August – 05.03 22nd August, 6 lines of seismic (airgun and sparker) shot (Figure 21), data poor as sea rough. Sparker data especially is poor, as the swell compensator could not be operated during acquisition. Airgun data reveal relatively little about the sediment column 0- 20 ms below sea bed.

06.53 22nd August, 1 drop box corer, no recovery.

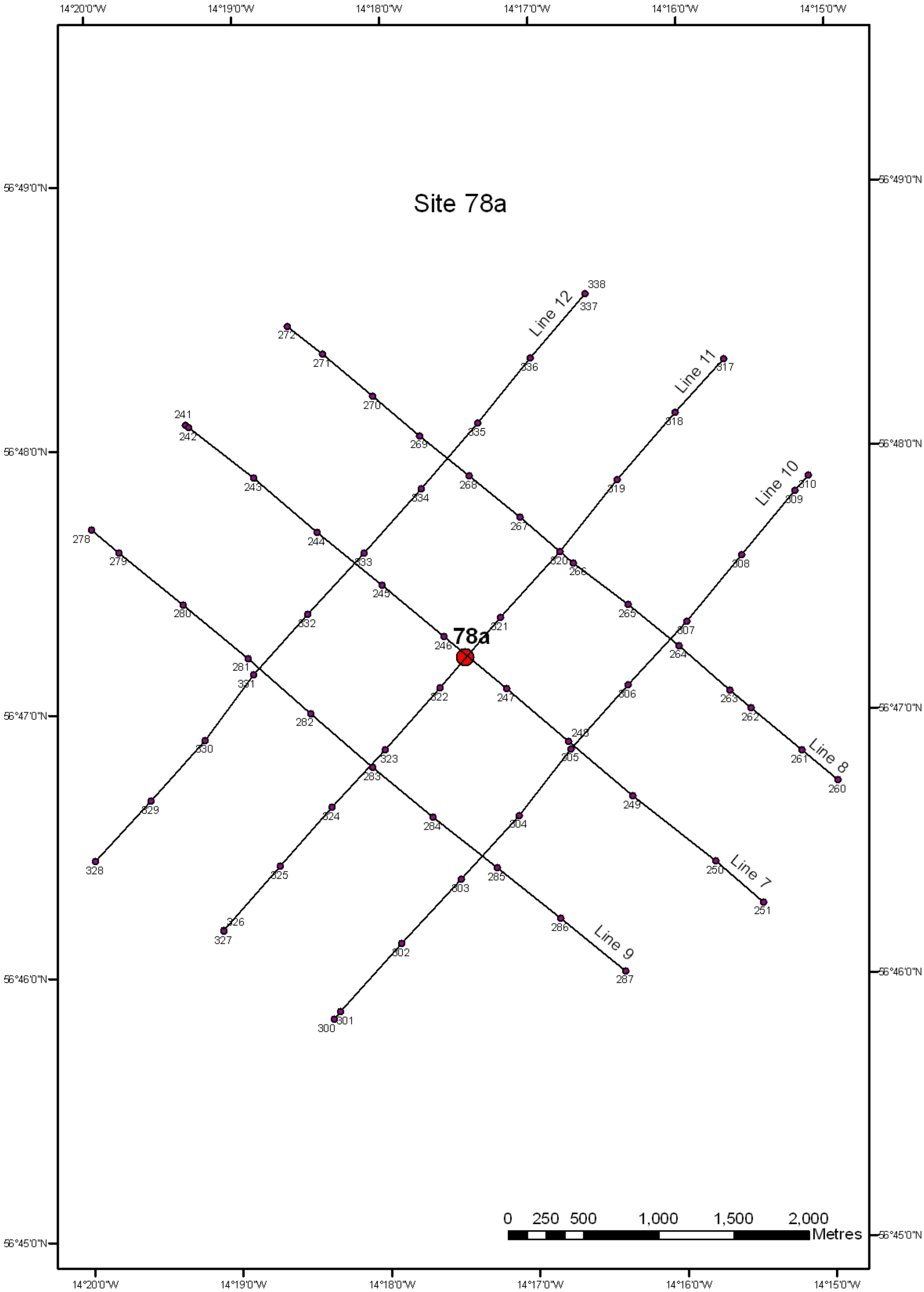


Figure 21. Survey track chart for Site 78a.

2.2.4 Rockall Trough transect 2 (Irish waters) Line 13

07.55 22nd August, magnetometer deployed, brought in 13.54 23rd August.

2.2.5 Site survey 25a (Irish waters)

15.32-23.22 23rd August, 6 lines of seismic (airgun and sparker, Figure 22) shot, data poor as sea rough, sparker especially poor.

12.43-13.00 24th August, 1 drop gravity core, no recovery.

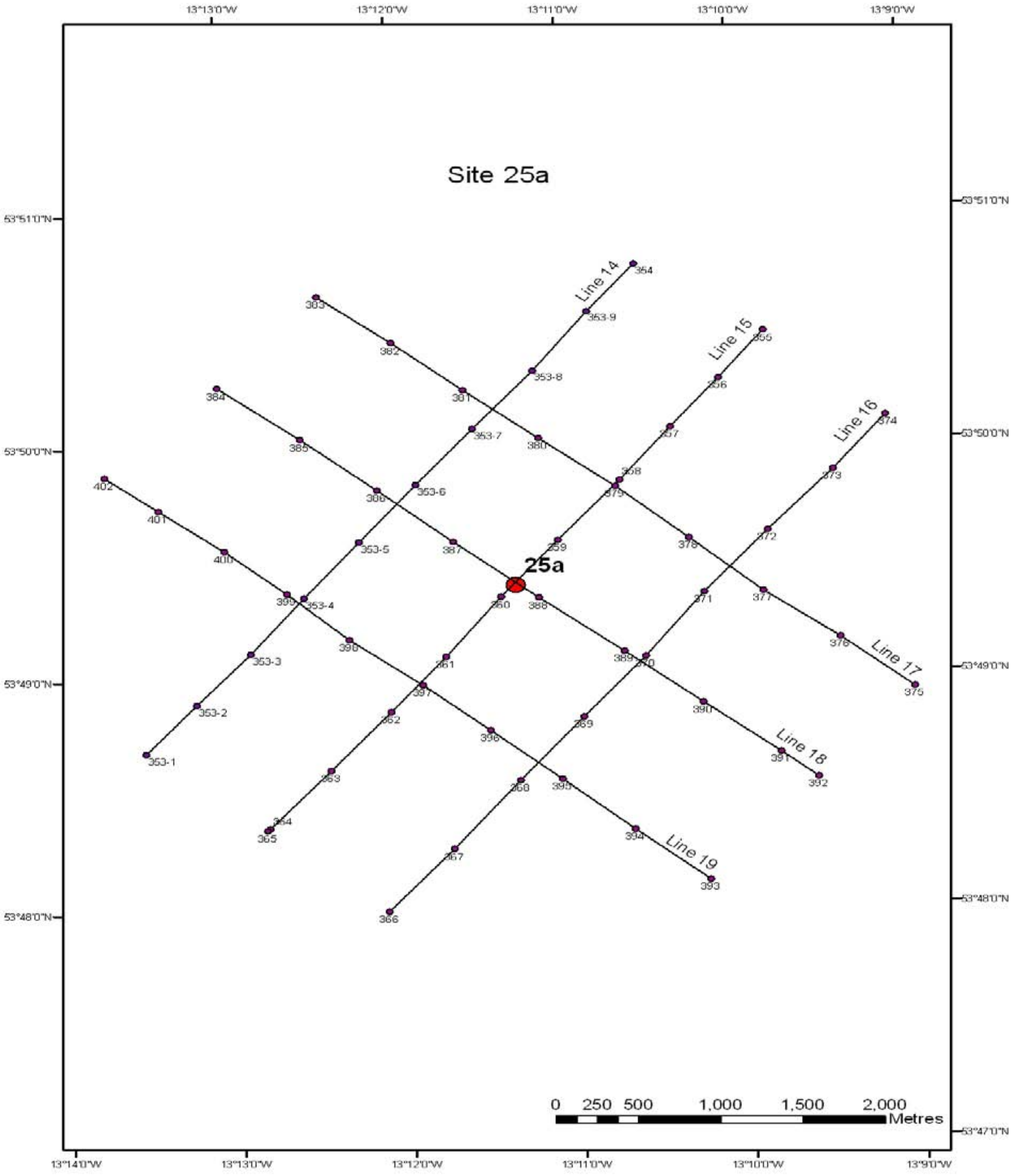


Figure 22. Survey track chart for Site 25a.

2.2.6 Site survey A1 (Irish waters)

16.34-17.10 24th August, 2 drops gravity core, NR. Bad weather stops work.

Continuing bad weather, and need to drop ship's crew member at Galway, delayed recommencement of work.

18.38 28th August – 02.23 29th August, 6 lines of seismic (airgun and sparker, Figure 23) shot, data poor.

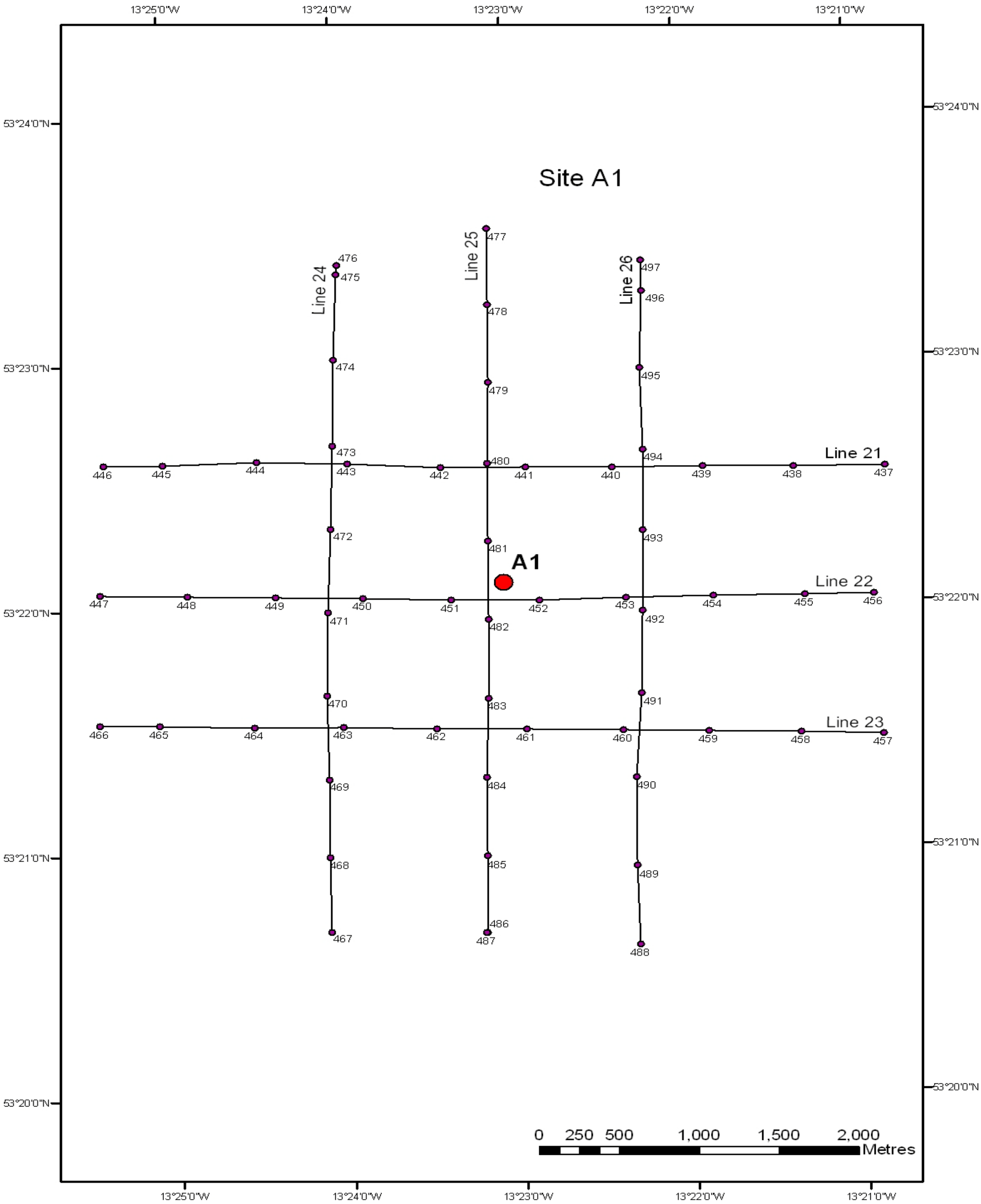


Figure 23. Survey track chart for Site A1.

2.2.7 Site survey X (Irish waters)

13.42-23.13 29th August, 6 lines of seismic (airgun and sparker; Figure 24) shot, sparker data poor as sea bed difficult to locate on CODA. Sighting of marine mammals led to airgun being switched off for 2 lines. Sparker data good as sea conditions improved.

00.44 30th August, 1 drop gravity core, 0.95 m recovered.

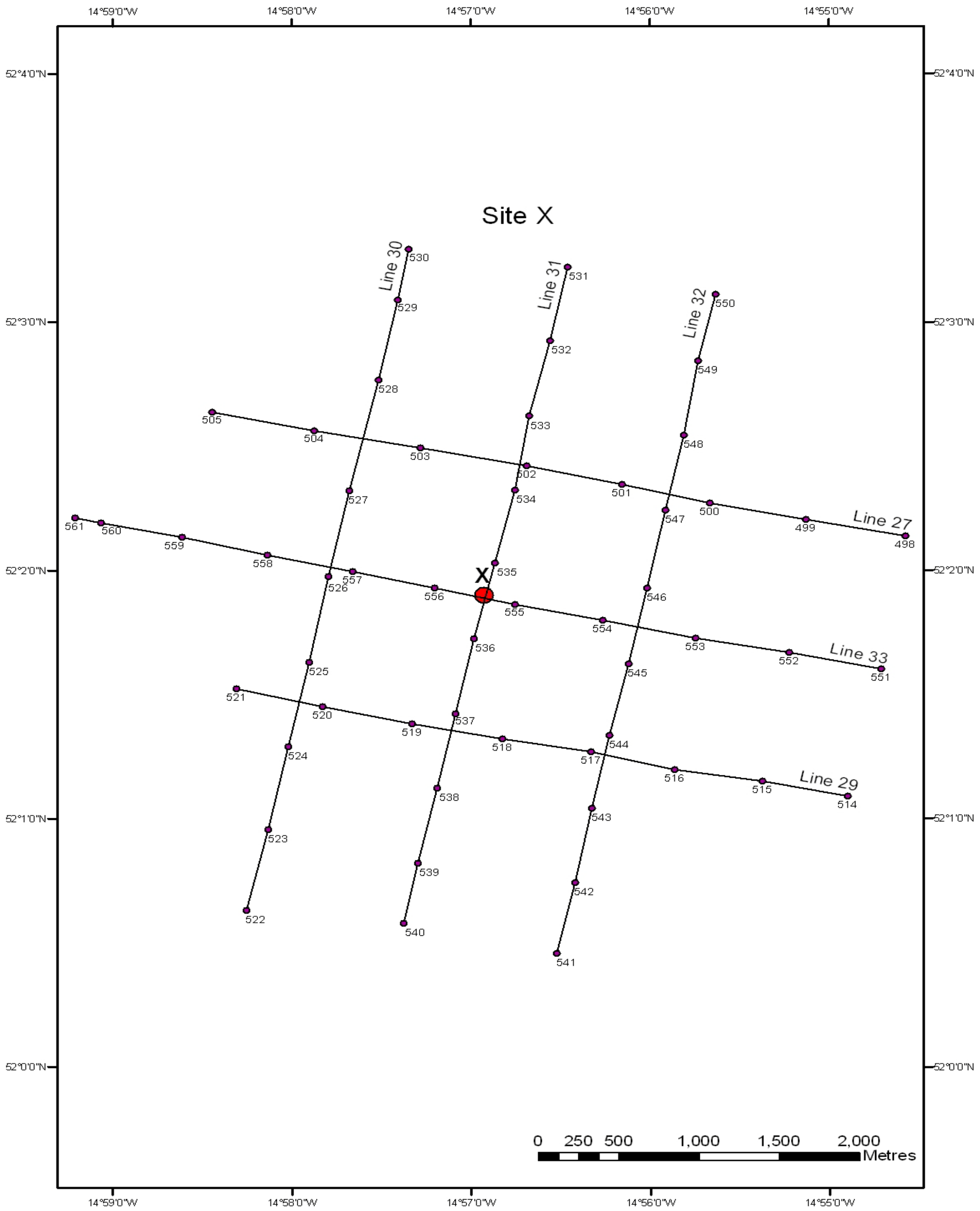


Figure 24. Survey track chart for Site X.

2.2.8 Rockall Trough transect 3 (Irish waters) Line 34

01.05 30th August, magnetometer deployed, brought in 01.09 31st August.

2.2.9 Site survey 113g (Irish waters)

03.45-10.35 31st August, 6 lines of seismic (airgun and sparker; Figure 25) shot, good quality airgun and sparker.

12.39 31st August, 1 drop gravity core, 1.89 m recovered. 6 m barrel on gravity core bent.

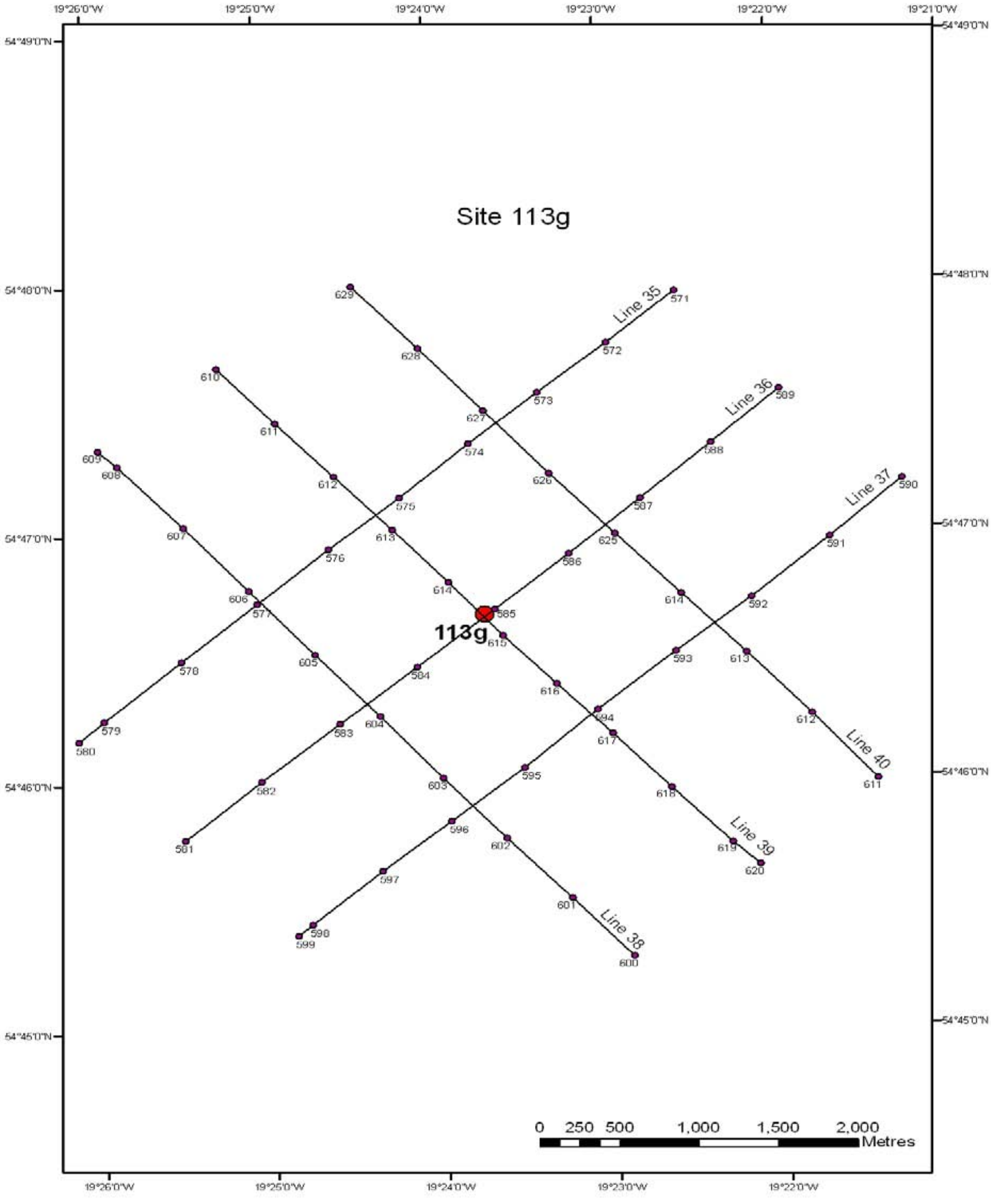


Figure 25. Survey track chart for Site 113g.

2.2.10 Site survey 107g (Irish waters)

19.50 31st August-03.12 1st September, 6 lines of seismic (airgun and sparker; Figure 26) shot, good quality airgun and sparker.

05.55 1st September, 1 drop gravity core, 1.65 m recovered.

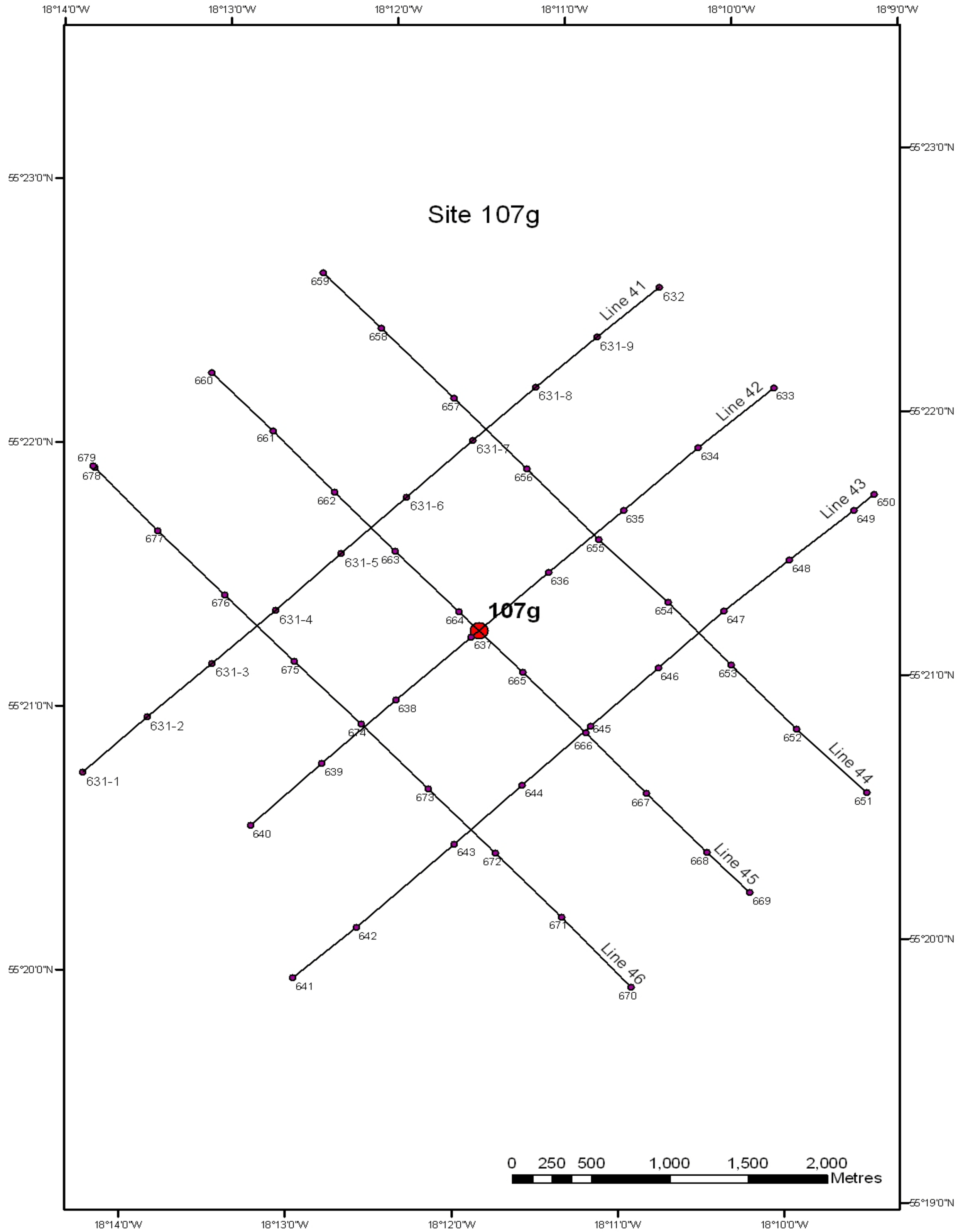


Figure 26. Survey track chart for Site 107g.

2.2.11 Site survey 98c (Irish waters)

09.39-16.50 1st September, 6 lines of seismic (airgun and sparker; Figure 27) shot, good quality airgun and sparker. Airguns off on 1 line as dolphins sighted.

20.30 1st September, 3 drops gravity core, 0.60 m recovered.

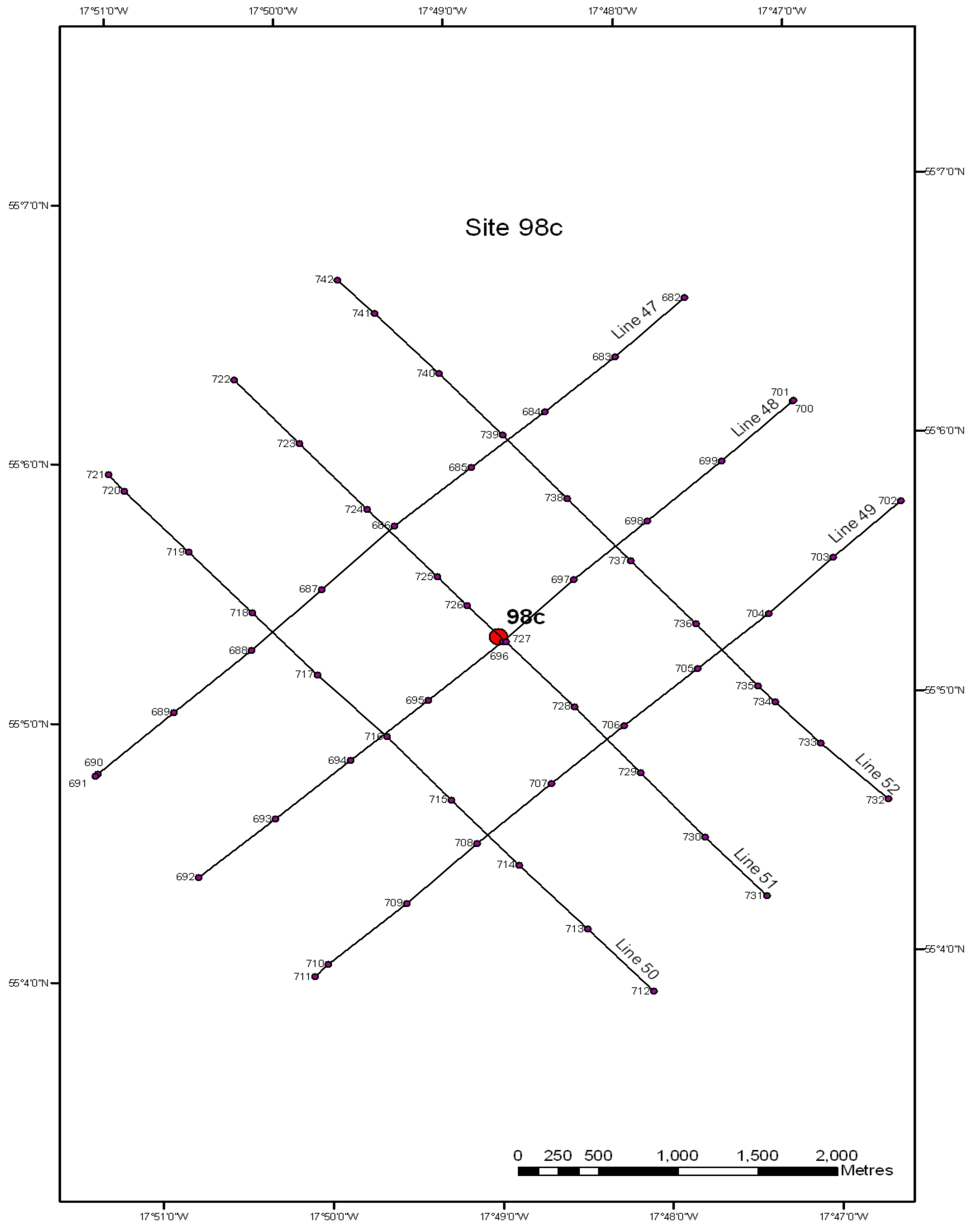


Figure 27. Survey track chart for Site 98c.

2.2.12 Rockall Hatton Basin transect. Line 53

21.15 1st September, magnetometer deployed, brought in 13.16 2nd September.

2.2.13 Site survey 430

19.02 2nd September, seismic begun.

03.40 3rd September, seismic completed (Figure 28). Airguns off for 1½ lines as Pilot Whales spotted.

04.50 3rd September, 1 gravity core drop, 2.09 m recovered.

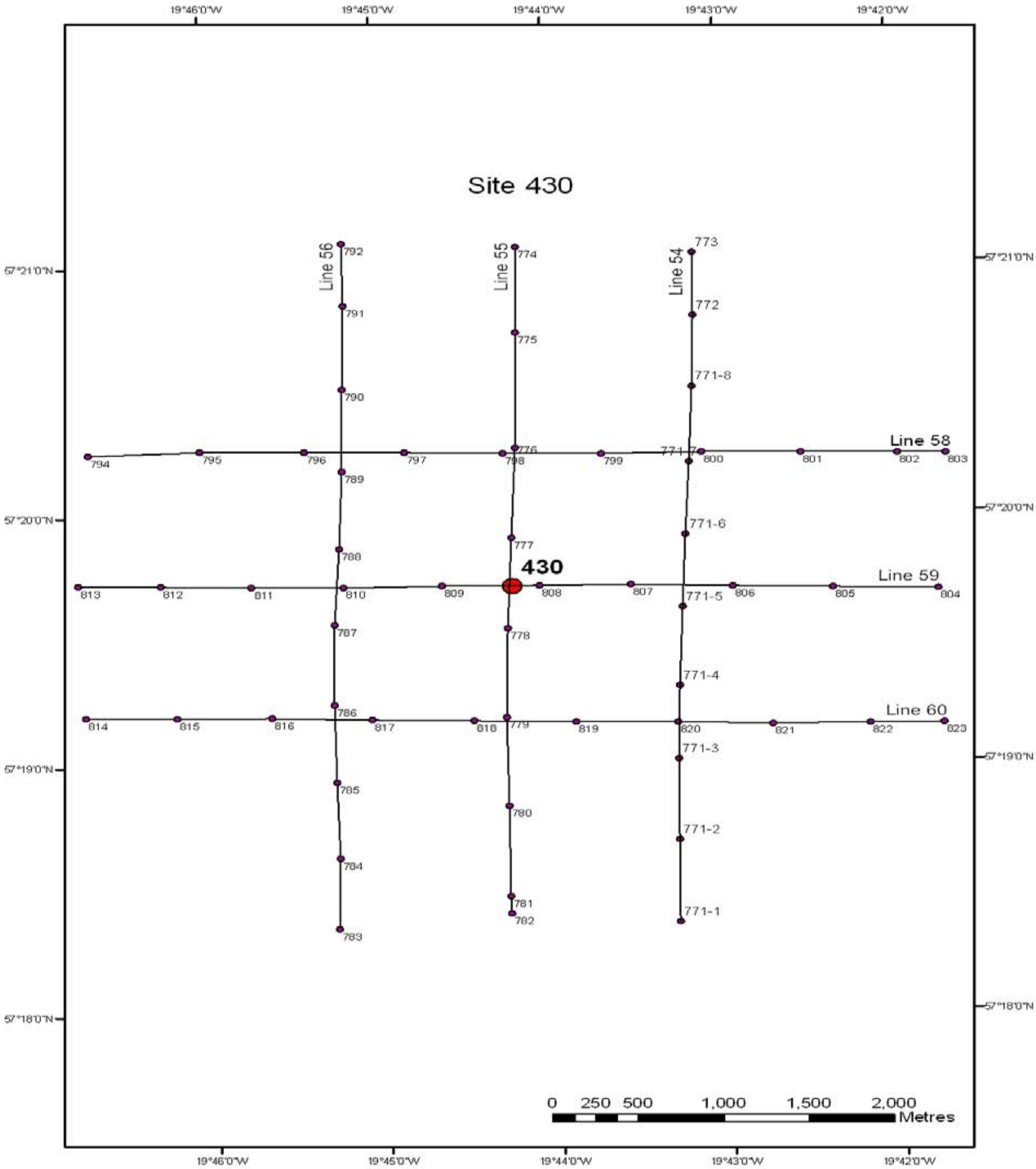


Figure 28. Survey track chart for Site 430.

2.2.14 Site survey 426

08.09-15.45 3rd September, 6 lines of seismic (airgun and sparker; Figure 29) shot.

17.14 3rd September, 1 drop gravity core, 1.91 m recovered.

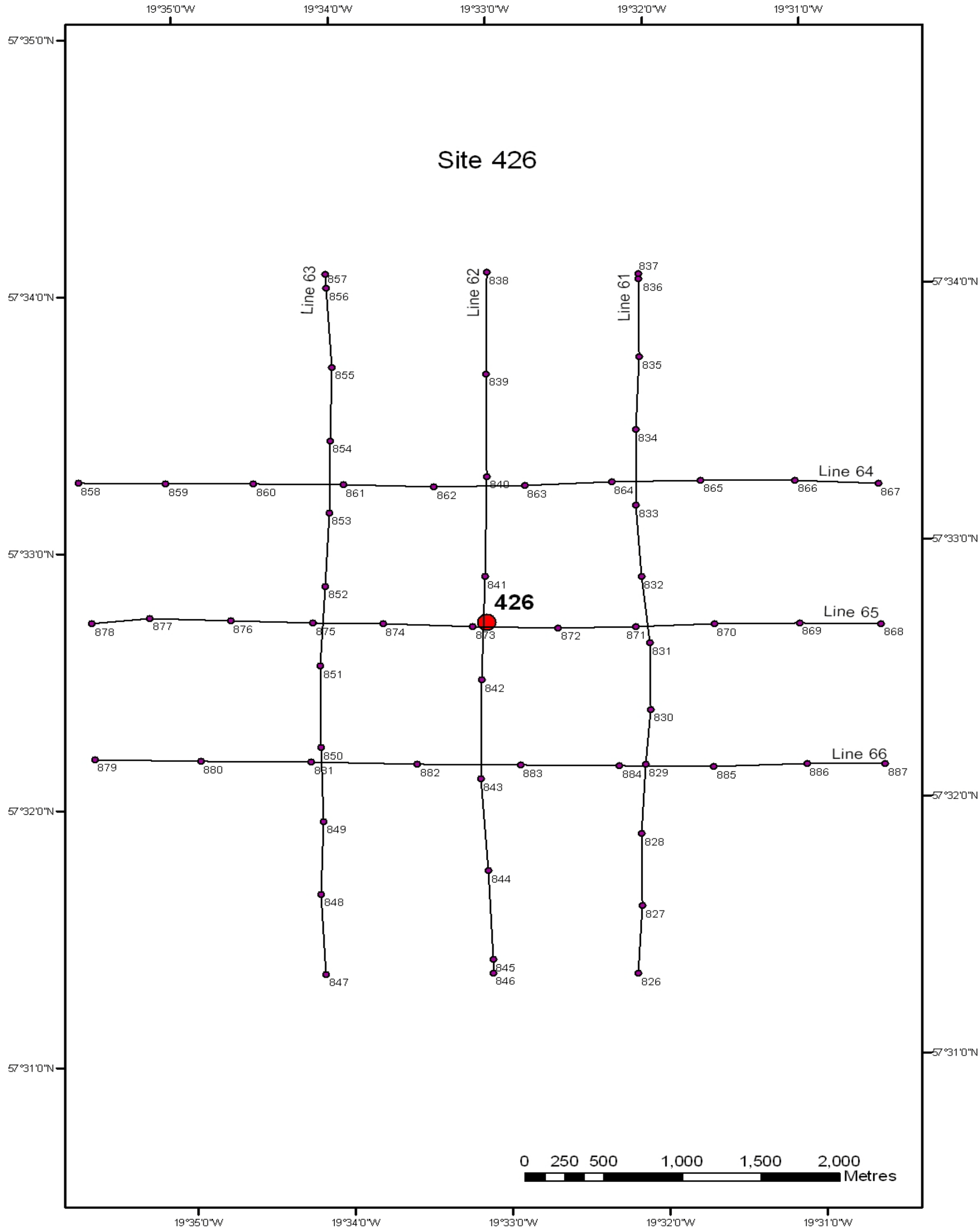


Figure 29. Survey track chart for Site 426.

2.2.15 Site survey 433

06.49-14.08 4th September, 6 lines of seismic (airgun and sparker; Figure 30) shot, good quality airgun and sparker.

16.00 4th September, 1 drop gravity core, 1.45 m recovered.

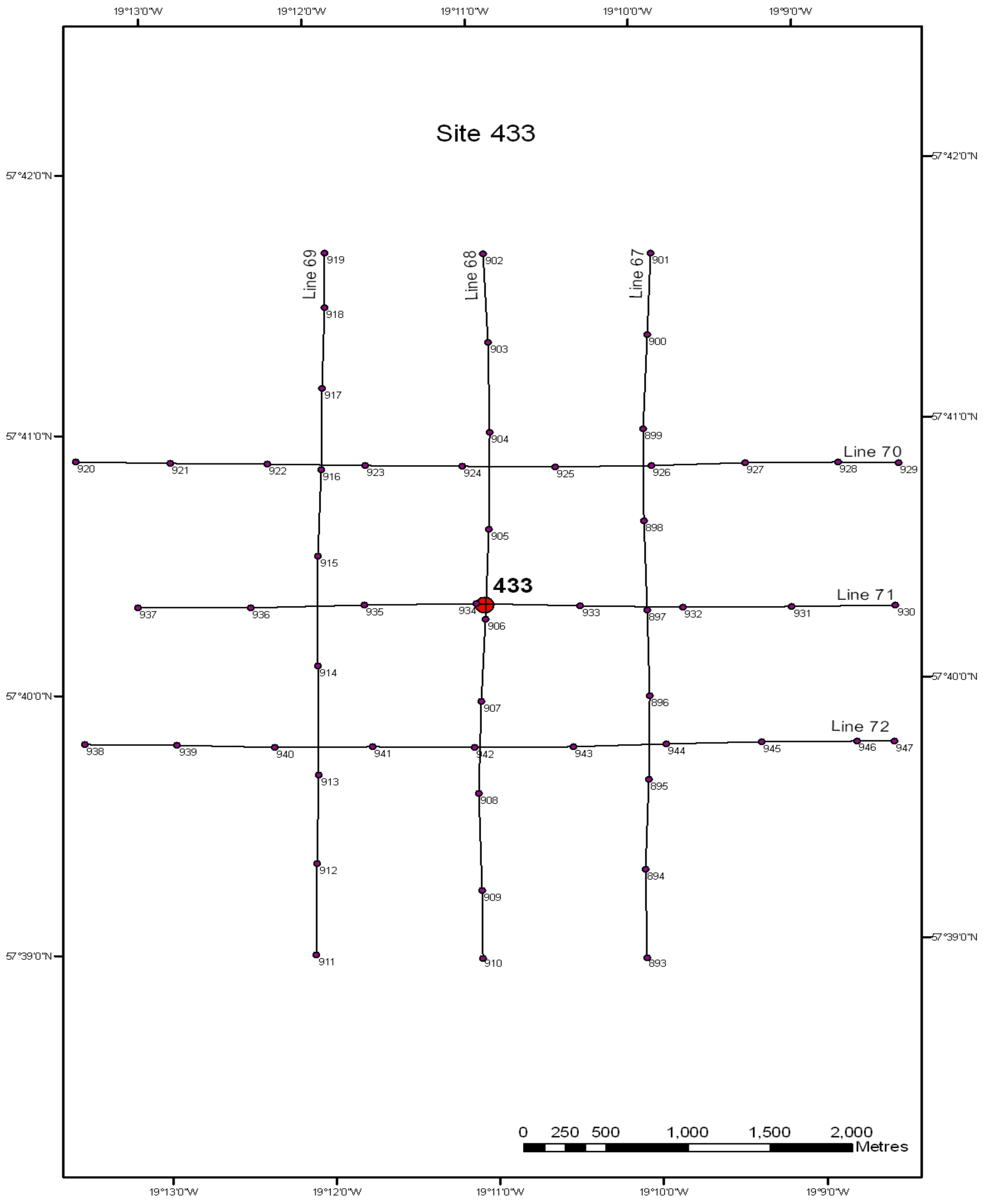


Figure 30. Survey track chart for Site 433.

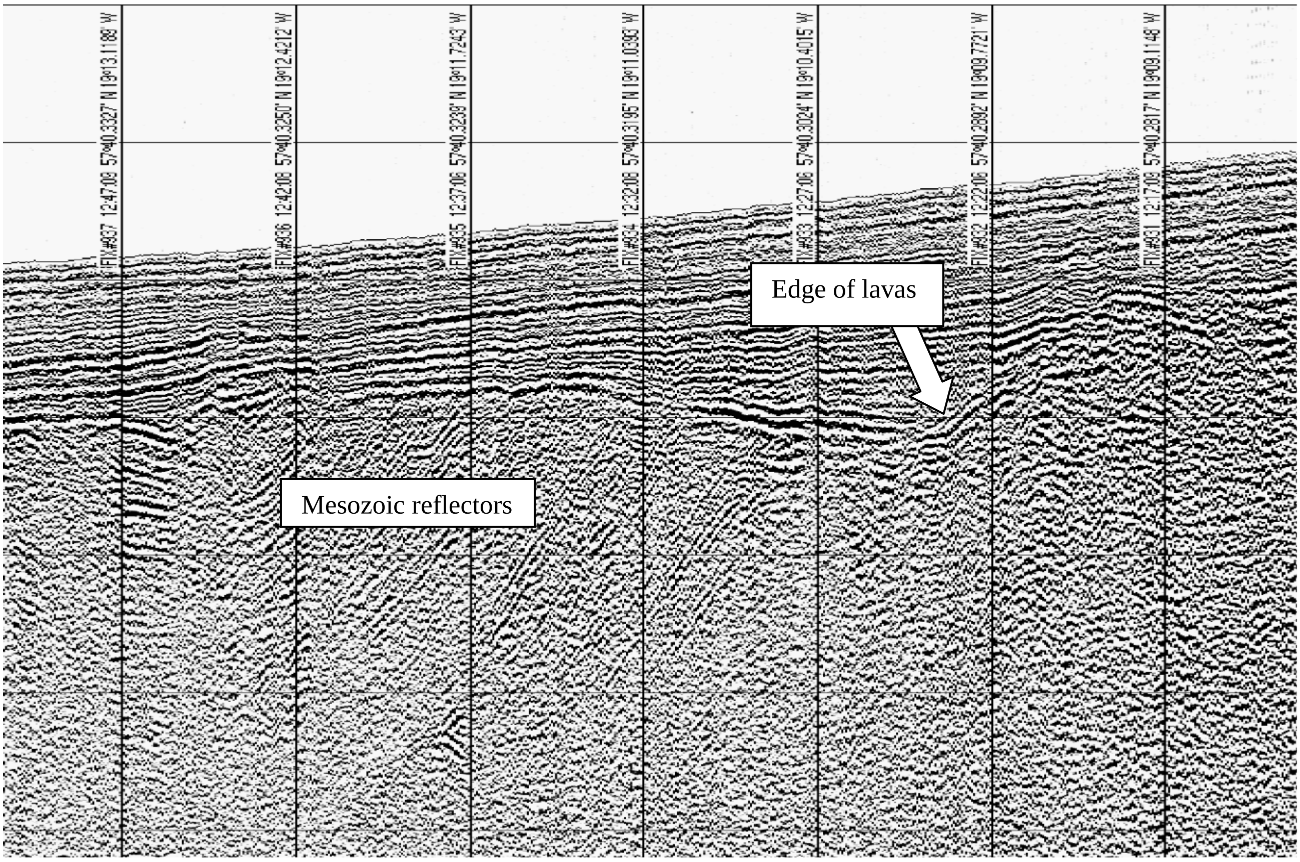


Figure 31. Example of site survey line collected using sparker equipment.

This west-east seismic line 2009/05-71 was acquired across site 433 (west to left, core location in centre of image). In the centre of the image, below the well-layered Tertiary sediment cover, probable Mesozoic reflectors can be seen dipping to the west. To the east of these reflectors a high beneath the Tertiary cover represents the edge of the lavas.

2.2.16 Site survey 434

18.05 4th September, seismic begun.

01.30 5th September, 6 lines of seismic (airgun and sparker; Figure 31) shot.

04.15 5th September, 2 drops gravity core, NR.

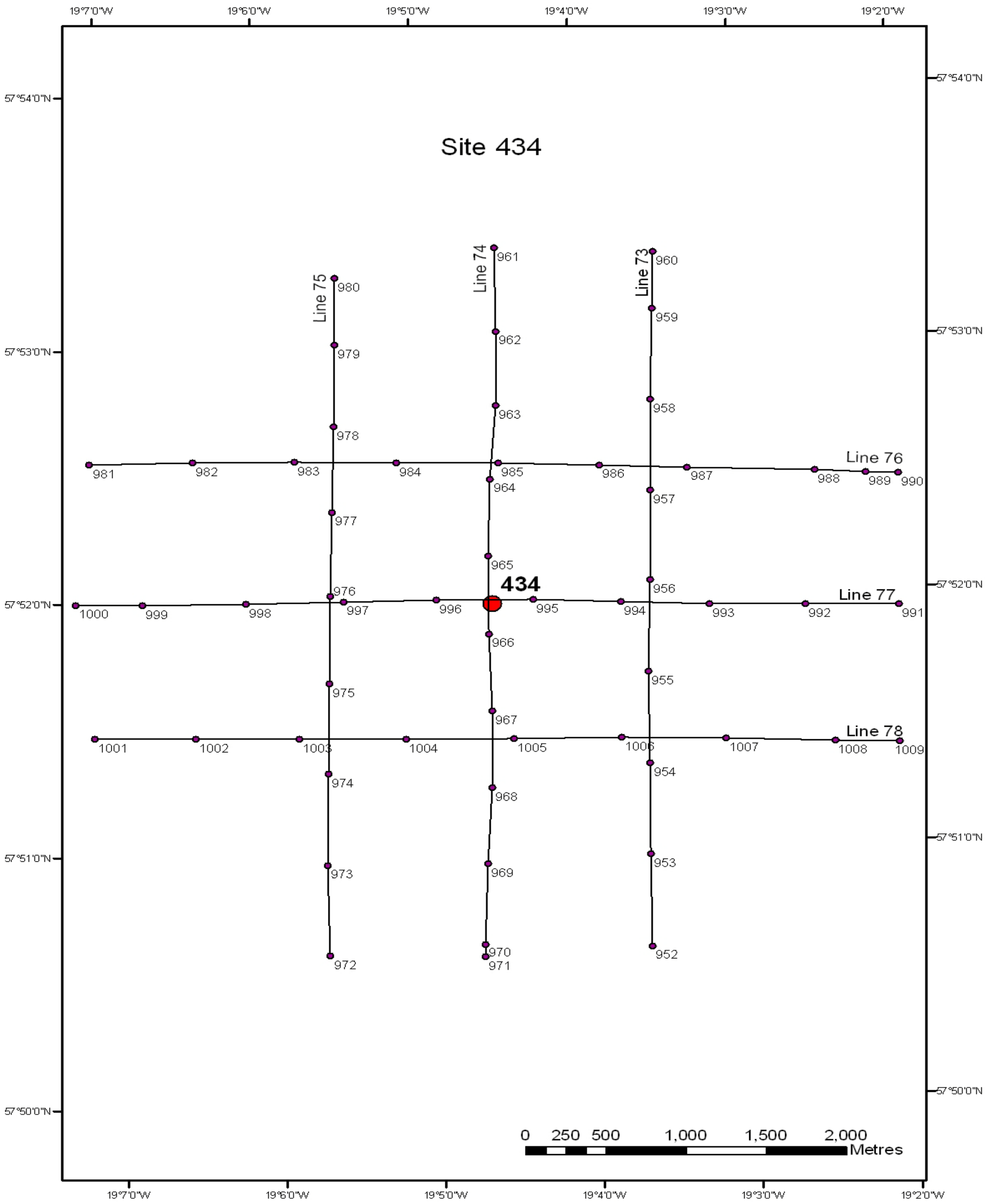


Figure 32. Survey track chart for Site 434.

2.2.17 Site survey 421

09.50-17.17 5th September, 6 lines of seismic (airgun and sparker; Figure 32) shot.

19.20 5th September, 2 drops gravity core at 421, no recovery.

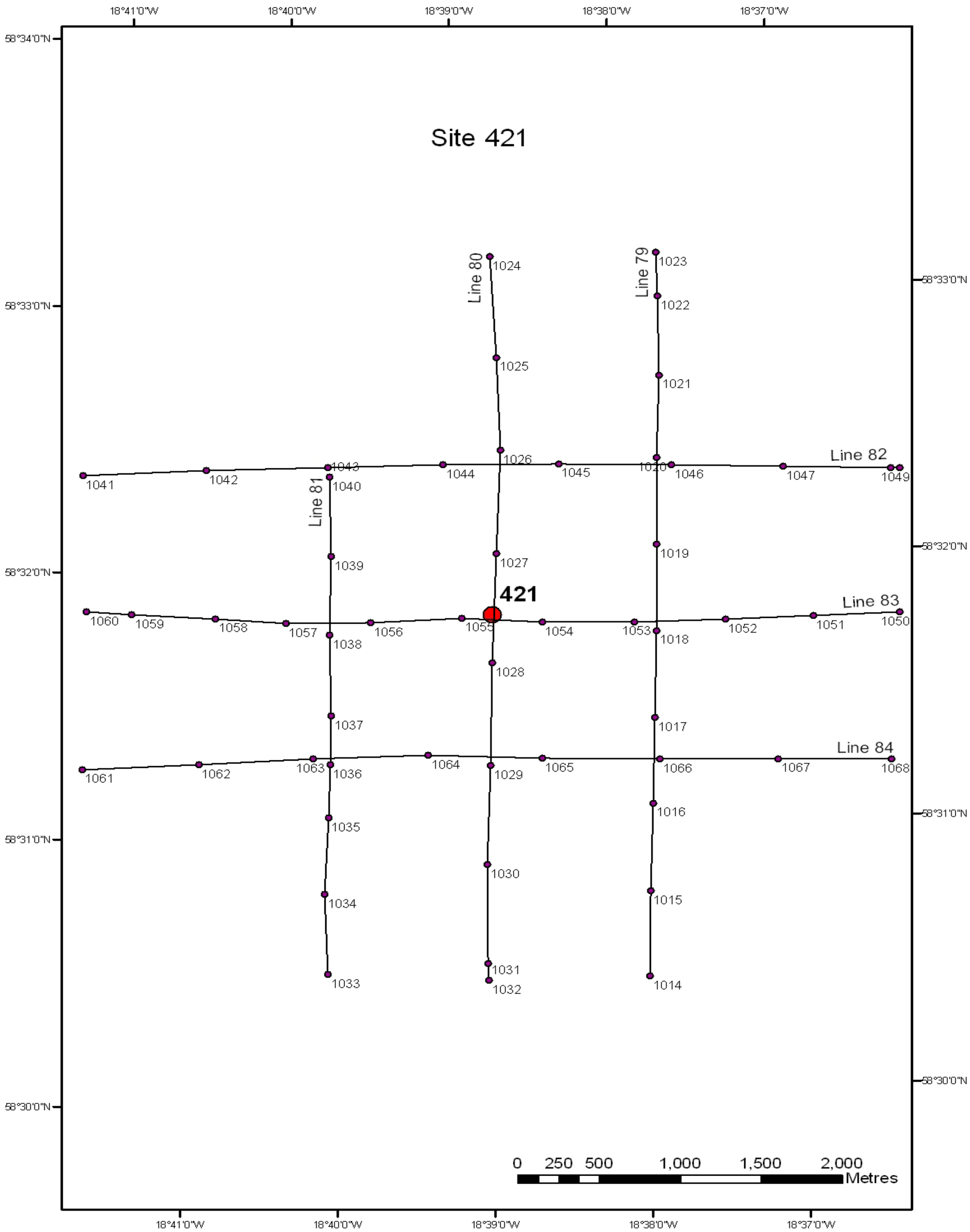


Figure 33. Survey track chart for Site 421.

2.2.18 Site survey 424

21.25 5th September, seismic begun

04.47 6th September, lines of seismic (airgun and sparker; Figure 33) shot.

07.00 6th September, 2 drops gravity core, no recovery.

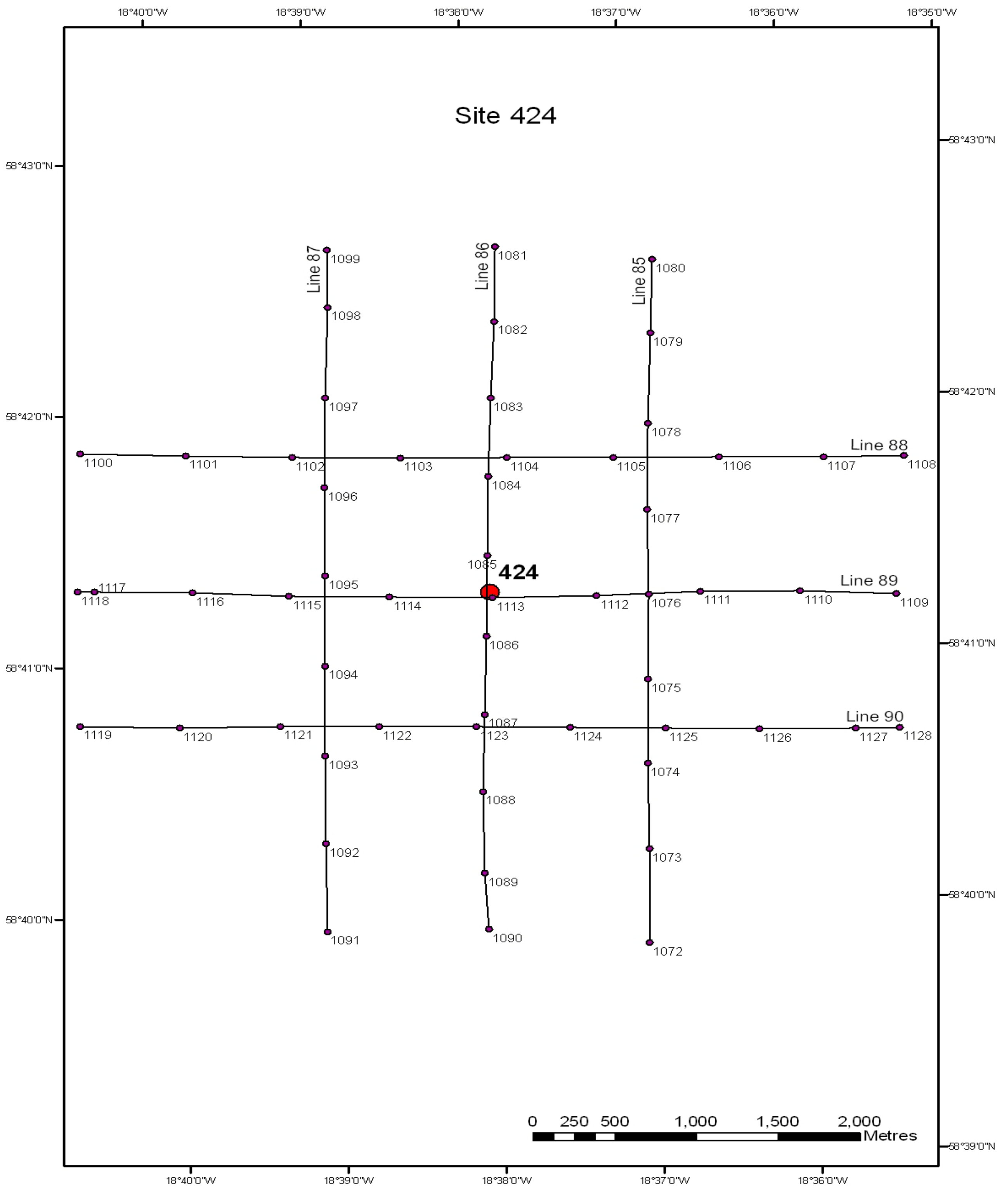


Figure 34. Survey track chart for Site 424.

2.2.19 Site survey 420

10.26-19.12 6th September, lines of seismic (airgun and sparker; Figure 34) shot.

19.45 6th September, bad weather delays further work.

14.00 10th September, 1 drop gravity core, no recovery.

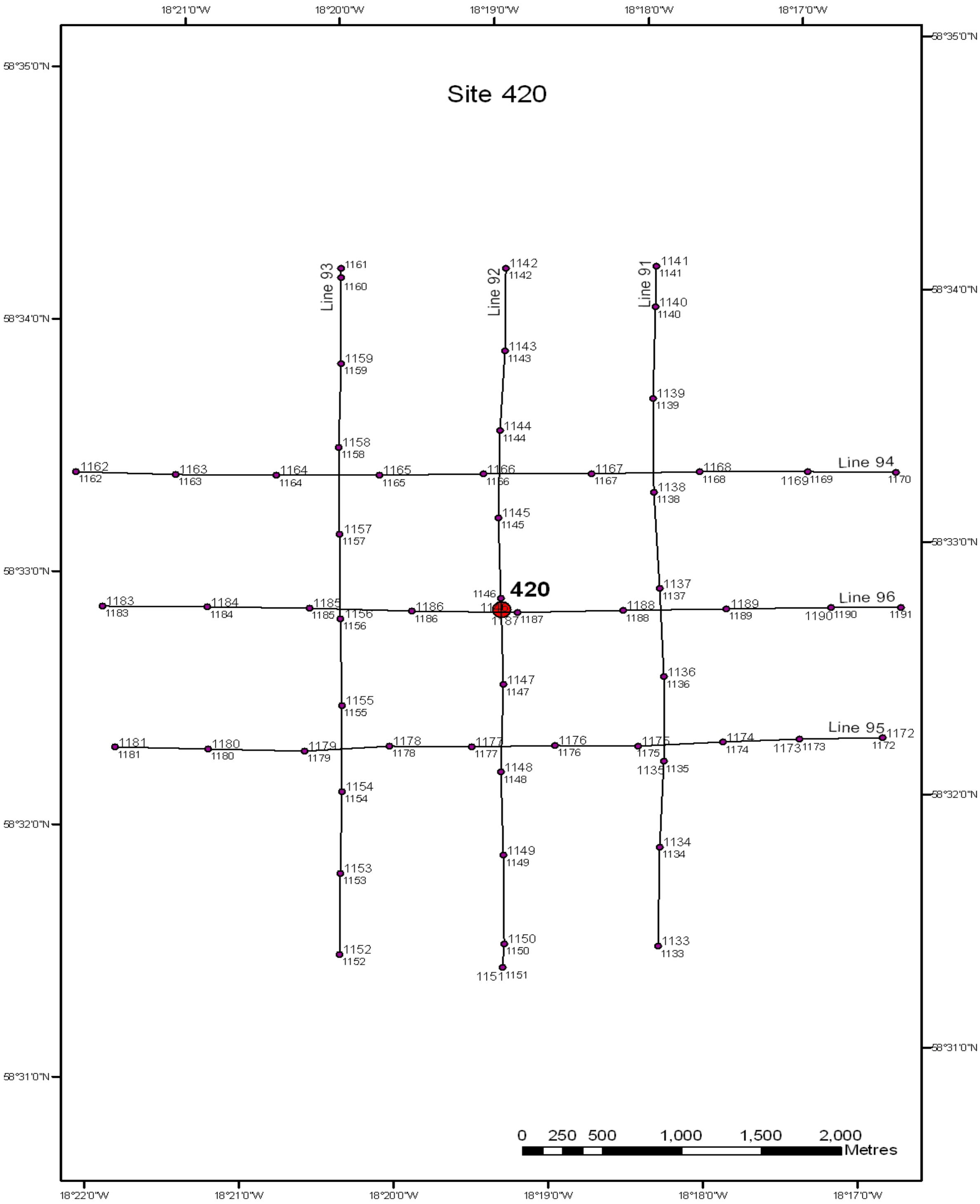


Figure 35. Survey track chart for Site 420.

2.2.20 Site survey 441B

16.39 10th September, seismic begun.

00.21 11th September, lines of seismic (airgun and sparker; Figure 35) shot.

01.56 11th September, 1 drop gravity core, no recovery.

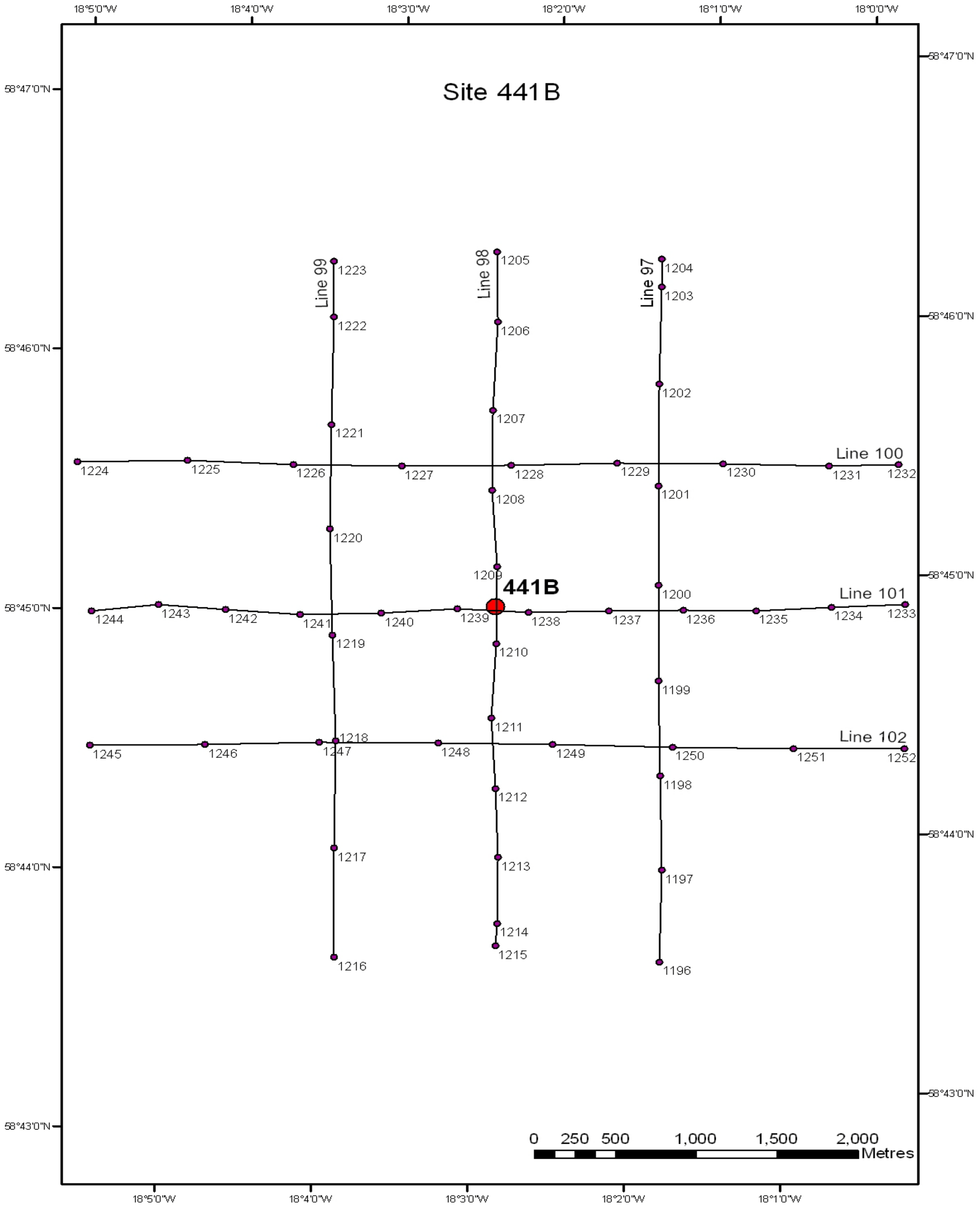


Figure 36. Survey track chart for Site 441B.

2.2.21 Site survey 413.

10.40-19.35 11th September, lines of seismic (airgun and sparker; Figure 36) shot.

21.30 11th September, 1 drop gravity core, 0.93 m recovered.

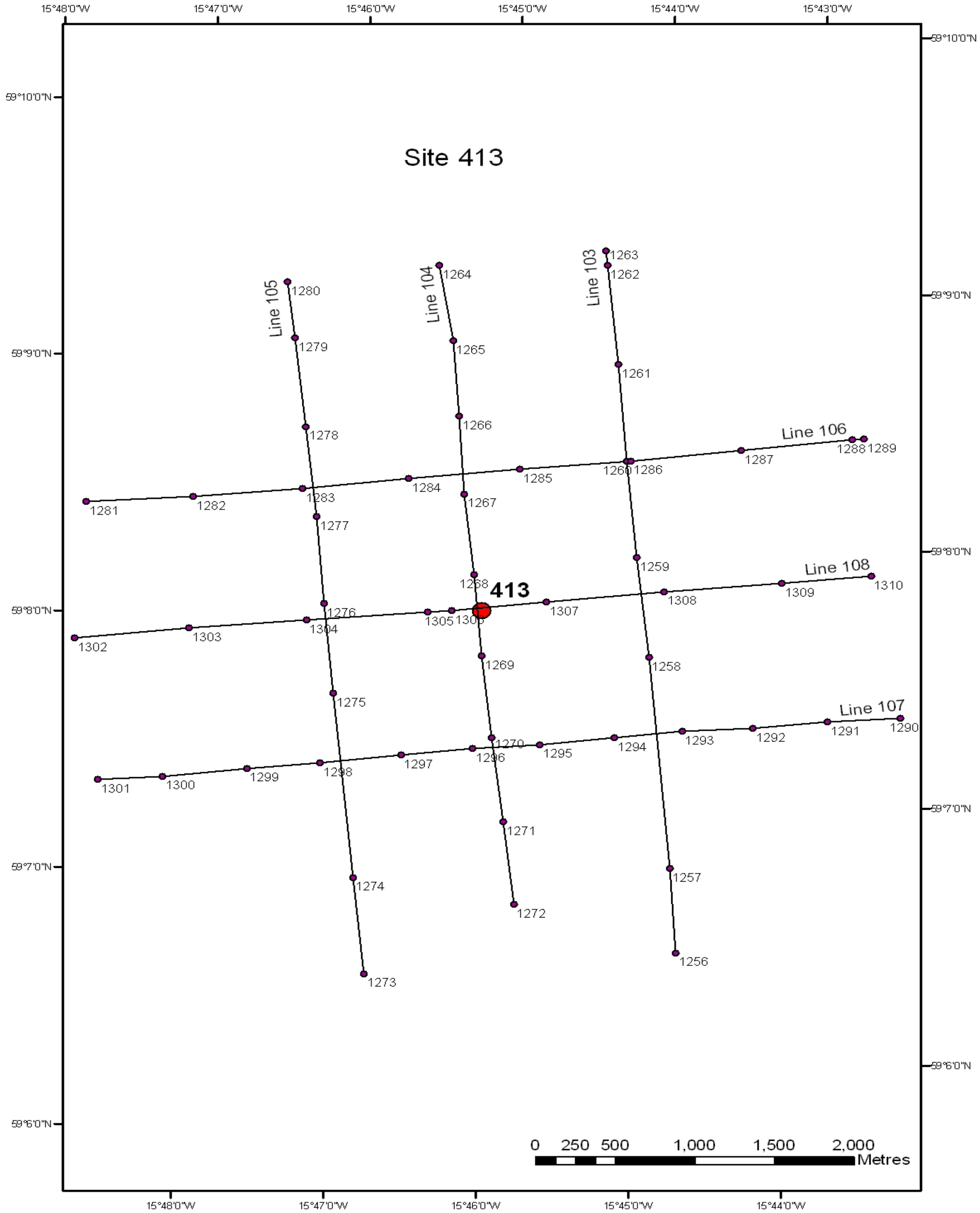


Figure 37. Survey track chart for Site 413.

2.2.22 Line GBB2

03.37 12th September, seismic begun.

11.05 13th September, seismic completed.

2.2.23 Line GBB7

20.29 13th September, seismic begun.

09.53 14th September, seismic completed.

2.2.24 Line GBB4

16.42 14th September, seismic begun.

05.12 15th September, seismic completed.

2.2.25 Site F1

21.30 15th September, 1 gravity core, 3.95 m recovery.

23.55 15th September, 1 box core, 0.80 m recovery.

2.2.26 Anton Dohrn

07.34 16th September, begin line AD2 in poor weather.

09.06 16th September, complete line AD2.

10.15 16th September, begin line AD3.

10.34 16th September, complete line AD3.

14.01 16th September, begin line AD1.

17.40 16th September, complete line AD1.

2.3 DE-MOBILISATION

RRS Discovery docked at King George V Dock, Govan, Glasgow at 08.30 Friday 18th September. Demobilisation began at 09.00 and was completed at 14.00.

Navigation

The vessel navigation, positioning and line running were undertaken by the vessel crew using their own ship supplied software and systems. This was felt to be more practical than to attempt to impose an unfamiliar (QINSy) helmsman display with all the concomitant problems and training required.

The position data were obtained from a Trimble 4000DS GPS system with an antenna on the mainmast with differential corrections being obtained from Fugro Seastar.

A digital telegram from the shipside computing system (TechSAS) including the GPS data, the ship's gyro heading and echo sounder depth was input to a PC running QINSy navigation and data logging software. This telegram allowed synchronisation of the QINSy clock to UTC derived from the NMEA GPGGA data string. The software subsequently displayed the position onto a digital chart and created a further data telegram for the Coda DA2000 seismic data logger.

The gravity meter and magnetometer data telegrams were input to the QINSy package and were logged internally and then relayed to the shipboard data logger along with the survey line number and fix number.

3 Geophysical Survey Equipment

3.1 MARINE GRAVITY METER

Lacoste and Romberg S-75, fitted with ZLS gyro pack and control box and using ZLS Ultrasys software. This generated an output stream which was recorded by both the QINSy navigation system and by the shipboard data logger. The meter sensor is installed in a purpose designed room below the water line amidships in the most stable portion of the vessel. It communicated with the laboratory recording and control PC through the ships internal wiring. The gravity meter data are contained in the Text files generated by the QINSy navigation system and stored in the Processed Data section of the Data Management Folder.

3.2 AIRGUN

Bolt 400B airgun fitted with wave modification kit. Five 40 cubic inch guns were towed on a proprietary frame with the norm being to operate 4 guns at one time with one as spare. This array was supplied with air at ~150 Bar (2000 psi) from two compressors in a purpose designed container on the back deck.

3.3 SPARKER

EG&G stainless steel Delta frame supporting 9 multitip candles (15 tips each) in 3 banks of 3, driven by up to 2400 J from a purpose built HV power supply. This was towed on its power umbilical some 20 m astern of the vessel.

3.4 HIGH VOLTAGE POWER SUPPLY

This was an Applied Acoustic Engineering CSP2400D thyristor switching high voltage power supply, capable of providing up to 2400 J in a range of 12 settings. The norm was to use 1750 J or 2000 J. This power supply was situated in a small container on the rear deck.

3.5 HYDROPHONES

The airgun signal was obtained from a SIG 30 metre 4 channel hydrophone, with all 4 channels being summed to provide a single channel seismic signal. This unit is fitted with an air filled umbilical which allows control of tow depth and this tow depth is displayed in the recording laboratory.

The sparker signal was obtained from a SIG 10 metre 7 channel hydrophone, with up to 7 channels being summed to provide a single channel seismic signal. This unit is fitted with an air filled umbilical which allows control of tow depth and this tow depth is displayed in the recording laboratory.

3.6 SEISMIC RECORDING SYSTEM

CodaOctopus Systems DA2000 provided the means to record the seismic data. This is capable of recording two independent channels of data onto internal hard drive while providing a processed printed record onto thermal recording film.

3.7 MARINE MAGNETOMETER

This was a Marine Magnetics Seaspy sensor fish towed some 150 m astern of the vessel and generating a digital output stream which was recorded by both the QINSy navigation system and the shipboard data logger. Magnetometer data are contained in the Text files generated by the QINSy navigation system and stored in the Processed Data section of the Data Management Folder.

3.8 SIPPICAN EXPENDABLE BATHYTHERMOGRAPH (+/- CONDUCTIVITY) PROBES

It has been widely recognized since 2003 that conventional marine seismic reflection data can be used to image the interior of the ocean. The technique works because small variations in the sound speed of seawater on the scale of the seismic wavelength are often sufficient to reflect seismic energy. These changes in sound speed are caused by small changes in temperature and salinity known as thermohaline fine-structure. The new technique of seismic oceanography is potentially important because it is beginning to provide a remote sensing method that can image large volumes of the ocean interior down to scales of a few metres.

This cruise offered the opportunity to compare the performance of further types of seismic reflection/backscatter image in the Rockall study area. The first type has a sparker source of around 900 Hz peak frequency and a single channel hydrophone streamer. To our knowledge, no studies of water column reflectivity from thermohaline fine structure studies using this acquisition system has been presented or published. Although some studies using a source similar to the BGS airgun system have been reported, no such data has been reported from the Rockall area, and the reported datasets were acquired using multichannel rather than single channel streamers. No work has been undertaken previously to compare such conventional seismic images with the backscattering observed by ADCP in Rockall Trough.

This work was completed for Trinity College, Dublin.

4 Sampling Equipment

4.1 GRAVITY CORER

This is a tube some 150 mm in diameter which is lowered to the sea bed on a ship's warp, where it is driven into the seabed by its weight (variable between 250 and 1000 kg, in this cruise 500 kg), thus acquiring a sample. The sample within the tube is retained by a non-return shoe and the metal external tube has a removable plastic liner within which the sample is kept. The plastic liner tube containing the sample is then cut into ~1 m lengths, sealed and then the lengths are split in half lengthways, allowing examination, sampling and description of the core.

On this cruise a 3 m barrel was deployed at the majority of sites. A 6 m barrel was carried, but on first use on Rockall Bank in 1000 m water depth (site 113g) it recovered ~2 m of core and the barrel itself was bent. After this the 3 m barrel was used at all sites until the last coring site in the Rockall Trough (F1).

4.2 BOX CORER

This corer weighs 410 kg in air. It is built from stainless steel and comprises the following structure: Steel box, approximately 50 cm along a side, with a lead weight mounted above; two jaws, pivoted about the centre of the box, such that they meet with a tight fit below the box to contain any sample within; a trigger mechanism at the top where the deployment cable is attached, whereby any tension on the cable prevents the jaws from becoming unlocked but a relaxation of tension allows two clips to let go resulting in abrupt closure of the two jaws as the tension is returned when the corer is recovered. Whilst on deck, the corer rests in a purpose built cradle above the core collection tray.

This corer was used in the Rockall Trough at the first site 78a, where there was no recovery, and at site F1.

5 Core Curation and Sampling

Cores collected were labelled and described according to the BGS procedures given in Crummy (2008). Cores were cleaned, described and photographed (archive half) and geotechnical measurements made (working half). In cores X and 107g collected in Irish waters, sub samples were taken for micropalaeontological analysis from the working half by Nick Owen of Trinity College Dublin. The four box core samples from site F1 were taken to St. Andrew’s University by Fiona Hibbert.

Cores were stored in the RRS Discovery cold store, then transferred to the BGS store at Loanhead, Edinburgh.

In total, 10 cores were collected at the following sites:

Site survey number	Core number	Lat	Long	Recovery	Number of 1m boxes
X	+52-15/02 CS	52.03165	-14.94877	0.91 m	1
113g	+54-20/01 CS	54.77781	-19.39528	1.95 m	2
107g	+55-19/01 CS	55.35378	-18.19462	1.65 m	2
98c	+55-18/01 CS	55.08782	-17.81433	0.61 m	1
430	+57-20/09 CS	57.32850	-19.73720	2.09 m	2
426	+57-20/10 CS	57.54510	-19.55130	1.95 m	2
433	+57-20/11 CS	57.67190	-19.18310	1.50 m	2
413	+59-16/04 CS	59.13150	-15.76030	0.93 m	1
F1	+56-er12/15 CS	56.8423	-11.3827	3.95 m	4
F1	+56-12/16 BC	56.8423	-11.3827	0.80 m	(4 short lengths of core)

Site survey number	Core number	Sub-sample depths
X	+52-15/02 CS	0.04 m, 0.21 m, 0.26 m, 0.41 m, 0.46 m, 0.61 m, 0.79 m.
107g	+55-19/01 CS	0.42-0.46 m.

The sub-samples were taken by Nick Owen to Trinity College, Dublin, for micropalaeontological analysis.

6 Preliminary Interpretation of Seismic Data

6.1 SITE SURVEYS

6.1.1 Site survey 78a (Irish waters)

The grid of 6 lines was shot in poor weather, locating sea bed was an ongoing problem.

The seismic lines indicate a moderately strong reflector at ~20-40 milliseconds below sea bed (ms bsb), below which is 200 ms of acoustically featureless material containing some faint, sub-horizontal undulating reflectors. The sediment above the reflector shows faint horizontal acoustic lamination and there is an indication of onlap against the underlying surface.

It is assumed that the upper unit is Neogene, overlying an older Neogene and Palaeogene unit. Both units were identified as Tertiary in Murphy and Morgan, 2008.

6.1.2 Site survey 25a (Irish waters)

Shot in poor weather, locating sea bed was an ongoing problem in particular with the sparker.

The lines indicate a strong reflector in the centre of the survey at ~50 ms bsb. This reflector is irregular and deepens to the east to 150 ms bsb. The reflector also deepens to 100 ms bsb in the west, and the surface forms a high centred on the survey area. The surface topography is particularly steep on the south east. Below this surface there is little information other than some faint, sub horizontal reflectors.

Above the reflective surface, a number of parallel reflectors show a slight dip towards the north, roughly parallel to sea bed topography. These onlap against the strong reflector, and there is some indication that uppermost reflectors are truncated at the sea bed.

The upper unit is assumed to be the thin Tertiary succession shown in Murphy and Morgan, 2008, overlying Mesozoic rocks.

6.1.3 Site survey A1 (Irish waters)

Shot in poor weather, locating sea bed was an ongoing problem in particular with the sparker. Both airgun and sparker data are poor.

In the airgun dataset there are faint reflectors parallel to sea bed in the upper most 200 ms bsb, the most prominent of which is at 110 ms bsb. There are no recognisable reflectors below sea bed on the sparker data.

This lack of data and the lack of recovery from gravity core drops, indicates bedrock near to sea bed as suggested in Murphy and Morgan, 2008.

6.1.4 Site survey X (Irish waters)

Shot in poor weather, seismic acquisition was also made difficult by proximity to the continental slope with >1000 m of relief.

The sparker record on the platform above the slope shows acoustic lamination roughly parallel to sea bed in the upper 50 ms bsb, with some indication of prograding geometry of reflectors from north to south. A small (5 ms) high at the shelf edge might be related to a constructional carbonate build up.

On the airgun data the site from which a core sample was taken appears to be small shelf with a sediment infill between bedrock highs. Bedrock reflectors also dip towards the south.

Recovery of 1 m of bioclastic sediment suggests that there is some younger cover overlying the Upper Palaeozoic target of Murphy and Morgan, 2008. This is presumably the feather edge of the sediment package shown on seismic line ISROCK-96-90.

6.1.5 Site survey 113g (Irish waters)

Seismic data indicate an acoustically parallel laminated layer to 250 ms bsb, overlying a distinct reflector below which there are little data. This distinct reflector appears to have a stepped geometry, with steps 15-20 ms in height, possibly reflecting erosion of horizons in the bedrock. Between 25 and 60 ms bsb there is a horizon with a chaotic character, possibly related to down slope transport of sediment. 1 km to the south west of the central point is an asymmetric hollow 75 ms deep.

The upper unit is assumed to be the thin Tertiary succession shown in Murphy and Morgan, 2008, overlying possible Mesozoic rocks. The recovered core is interpreted to be a Neogene part of this Tertiary succession.

6.1.6 Site survey 107g (Irish waters)

The central part of the site is a point where a distinct reflector approaches the sea bed. To the south west of this central point the reflector is exposed at sea bed. At the centre point the reflector is <10 ms from the sea bed. Below the reflector are some faint reflectors that dip towards the north or north east. In other directions the reflector is buried under up to 150 ms of parallel laminated sediment which onlaps onto the older rock.

The distinct reflector is likely to be the top ?Jurassic as shown in Murphy and Morgan, 2008. The recovered core is very similar in character to that at site 113g, and presumably represents a similar oceanographic environment. The Tertiary at this site is unlikely to exceed 15 ms in thickness.

6.1.7 Site survey 98c (Irish waters)

The centre point of the survey is a high with little acoustic character below sea bed. This high is assumed to be a bedrock feature (the ?Palaeozoic of Murphy and Morgan, 2008). Two kilometres to the south east of the centre a bank of sediment with parallel reflectors is developed, with a moat at the contact with the high.

There are a number of pinnacles or mounds on the high, these might be related to erosion of bedrock, or might, as suggested by the bioclastic sediment recovered, be carbonate mounds.

6.1.8 Site survey 430

At the centre point a succession of relatively parallel, horizontal reflectors overlie a folded succession of strong parallel reflectors. The upper unit is 20 ms in thickness and is interpreted by Hitchen (2009) to represent the post-Eocene succession. The folded unit is ~40 ms in thickness and is considered to be of Eocene and / or Paleocene age, overlying an irregular surface that is interpreted to be Mesozoic basement, below which there is no information.

The post-Eocene succession onlaps the underlying folded unit from north and south, infilling topography on the top Eocene. There is also an east and west onlap of the Eocene succession onto the Mesozoic unconformity, indicating several phases of deformation and sedimentation.

6.1.9 Site survey 426

At this site a strong reflector at 45 ms bsb forms a relatively horizontal surface, with relief of 10 ms. Below this reflector a number of features dipping to the north can be seen, presumably similar to the feature described as an intrusion in Hitchen, 2009. The overlying unit contains a number of parallel, horizontal reflectors, the lowest of which onlap onto the reflector.

The upper unit is presumably Cenozoic, overlying a package described as ?Mesozoic or older in Hitchen, 2009.

6.1.10 Site survey 433

A strong reflector at between 40 and 65 ms bsb forms a surface with some local topography, which in the south east of the survey area has been related to an escarpment representing the edge of the basalt (Hitchen, 2009). To the west of this escarpment, the underlying strata can be seen dipping steeply to the west, with an antiformal closure at the western margin of the survey line.

The overlying Cenozoic sediments contain parallel reflectors that onlap the strong reflector and in places are draped over the local topography. Upper Cenozoic reflectors are parallel to the sea bed. The onlap surface described as C30 in Hitchen, 2009 can be observed only on east-west lines and is difficult to identify.

6.1.11 Site survey 434

A strong reflector at between 20 and 65 ms bsb forms a surface with some local topography, below which are a number of steeply north dipping reflectors, with dip appearing to reduce in angle at the north end of the survey.

Overlying the strong reflector is an acoustically laminated unit. This unit contains some discontinuous reflectors below an irregular sea bed, including some thin <10 ms lenticular bodies.

6.1.12 Site survey 421

A strong reflector at 40-55 ms bsb forms a surface with relatively little topography, parallel to the sea bed which dips towards the south west. Below this reflector a synform with an axis running east-west is developed. This is presumably the smaller of the two synforms imaged on BGS line 00/01-28 (Hitchen, 2009).

Above the strong reflector is a unit containing continuous, sub-parallel reflectors which appear to merge as the unit thins towards the west.

6.1.13 Site survey 424

A strong reflector at 50 ms bsb forms a surface with relatively little topography, parallel to the sea bed which dips towards the north west. Below 50 ms bsb, reflectors dip towards the south forming the feature termed a ‘pop-up’ structure in Hitchen (2009). These reflectors also form a shallow synform with a north-south axis.

Above the strong reflector are several units containing continuous, sub-parallel reflectors. In the lower (≤20 ms in thickness) unit these reflectors parallel the strong reflector, and are onlapping in places where topography is developed This unit thins towards the south and east where the strong reflector nears the sea bed. The upper unit (≥30 ms) rests on a surface which is locally erosional and shows both onlapping and downlapping relationships including some lenticular bodies that might represent sediment transport events.

6.1.14 Site survey 420

A strong reflector at 40-50 ms bsb forms a surface with relatively little topography dipping towards the north. Below this reflector very little detail can be seen although there are faint indications of north dipping features, possible the intrusions identified in Hitchen (2009).

Above the strong reflector is a unit containing horizontal, continuous, sub-parallel reflectors which thins northwards and onlaps onto the strong reflector. Above this is an acoustically relatively featureless unit which, although having a roughly planar base, forms a sea bed with an undulating topography.

6.1.15 Site survey 441B

A strong reflector at 20-25 ms bsb forms a surface that is generally planar but dips slightly towards the east. Below this reflector little detail can be seen but faint reflectors appear to be dipping towards the east, as reported in Hitchen (2009).

Above this reflector a unit of parallel, gently undulating reflectors parallel sea bed. One kilometre to the north of the site centre a small rise on the sea bed appears to be related to the margin of a basin containing 100 ms of continuous, parallel reflectors, presumably Cenozoic sediment overlying Mesozoic rocks.

6.1.16 Site survey 413

The grid of 6 lines was shot in very poor weather, locating sea bed was an ongoing problem, the unprocessed sparker data show no usable information.

This site is situated on the northern end of Hatton Bank on the south facing slope of the bank. On the airgun lines a strong reflector at 300-350 ms bsb is assumed to represent the top basalt (Hitchen, 2009).

Above this is a complex, presumed Cenozoic succession recording several phases of erosion and onlap. The quality of the data at this site is poor and the lines do not show the level of detail of this succession that is recorded in BGS seismic line 02/09-17.

6.2 OTHER WORK

6.2.1 Rathlin Island

Two lines (both on DL1) were run using airgun and sparker. The sparker especially had problems and needed adjusting, the site itself was subject to a strong tide in excess of 7 knots and so further lines were not shot in the area.

A third line was run using airgun and sparker 100 km to the west on the Irish Shelf to test the equipment.

6.2.2 Rockall Trough transects (Irish waters)

During 3 transits across the Rockall Trough (Figure 1), gravity and magnetic data were collected. During passage over steep topography the echo sounder data were lost at times, and in rough weather during the first transit line the magnetometer was brought in.

6.2.3 Hatton Rockall Basin transect

During transit across the Hatton Rockall Basin (Figure 1), gravity and magnetic data were collected along the trace of an existing regional seismic line (HA04-9004).

6.2.4 George Bligh Bank

6.2.4.1 LINE 2009/05-109 (FORMERLY GBB 2)

This line covers a west-east transect from the Hatton Rockall Basin over George Bligh Bank into the Rockall Trough. This description is mostly taken from the sparker data beginning at the western end.

SOL Fix 1315-1349 >400 ms bsb continuous, parallel undulating reflectors below similarly undulating sea bed. No evidence of migration of features.

1350-1362 Thinning of upper 100 ms of succession onto unconformity surface, the majority of the succession is continuous, parallel reflectors.

1363-1400 From F1402 the sea bed begins to rise to the east. Upper succession of continuous parallel reflector overlies a number of strong reflectors which rise from west to east. The overlying package onlaps onto the reflectors and at F1400 is <150 ms in thickness. Below these reflectors is a package ~200 ms in thickness containing scattered parallel reflectors. The base of this package is a strong reflector that is tentatively identified as top basalt, below this surface no reflectors can be identified.

1401-1415 The sea bed rises from west to east, the upper succession thins rapidly and at F1410 is too thin to be identified. Before the termination this succession forms a mound at sea bed with 10 ms topography. There is up-slope migration of this mound crest, which can be seen throughout the upper succession (in particular on the airgun data), and also periods of vertical aggradation. The lower succession thickens to 300 ms at F1408 then thins rapidly to the east where at F1415 basalt is at or near to sea bed.

1416-1483 Sea bed rises gradually from east to west. Between F1416-1422, the basalt is near to sea bed. Beyond this, a thin veneer of continuous, parallel reflectors covers this reflector. The veneer is between 509 and 10 ms in thickness and generally forms a planar sea bed, although east of F1476 the veneer thins to <10 ms and sea bed is irregular.

1484-1494 Planar top of George Bligh bank, with a thin or absent veneer of sediment on a rough sea bed with topography of <15 ms.

1495-1520 Sea bed drops from west to east, and the reflector is covered by a eastward thickening package of continuous, parallel reflectors that does not exceed 20 ms in thickness until F1516, where the package thickens rapidly to 50 ms. Much of the thickening is caused by a unit containing poorly defined reflectors. At F1518.5 and 1520 the overlying package is truncated against sharp slopes, east of which basalt is at sea bed.

1521-1539 Sea bed drops rapidly to the east, and there is little evidence for any sediment overlying the basalt reflector.

1540-1548 At F1539 the steep slope is covered by what appears to be a tabular block of material between 150 and 250 ms in thickness. This ‘block’ dips parallel to the steep slope of the basalt reflector and contains few coherent reflectors within it, although some slightly ambiguous features suggest some internal structure. The western (highest) part of the block is roughly horizontal and the nature of the surface suggests that some erosion has taken place. At 600 ms bsb the upper surface of the block continues to dip towards the east.

1549-1570 Sea bed rises from west to east, and the block is overlain and onlapped by a rapidly thickening package of generally continuous parallel reflectors. This package is >350 ms in thickness, and contains several onlap surfaces and some cases where wave forms are suggested by the reflector geometries, to the east the package becomes more uniform and onlap surfaces are less apparent.

1571-1606 The upper package displays continuous parallel reflectors is >450 ms in thickness, one horizon at 150-180 ms bsb is undulating, in overlying units this topography is progressively lost and the sea bed is planar, dipping slightly to the east.

1607-1690 EOL The sea bed dips to the east and the package of continuous reflectors appears to be of relatively constant thickness, including the horizon of undulating reflectors.

6.2.4.2 LINE 2009/05-110 (FORMERLY GBB 7)

This line forms a south-north transect over the eastern part of George Bligh Bank, beginning in the low between George Bligh and Rockall banks. This description is taken from the sparker and airgun data beginning at the southern end.

SOL Fix 1592-1740 An unconformity 70 ms bsb at the SOL is sub parallel to sea bed, except at the SOL where it shows some topography, but rises gradually to the north to F1740 where it reaches sea bed. Above this surface is a package of continuous, parallel reflectors. These reflectors onlap onto the unconformity topography in the south and higher reflectors onlap progressively from south to north.

Below this unconformity is a complex package 250-350 ms in thickness comprising parallel, undulating reflectors draping underlying topography. Between F1701-1713 there are many small units 100 ms in thickness whose reflectors have a convex-upwards geometry. Each small unit appears to contain parallel reflectors and appear to be aggradational, but there is no coherent sense of migration of waveforms. North of F1733 reflectors in this package dip towards the north.

Below this package is a reflector with a complex topography, below which little can be seen. At F1722 and 1731 the reflector rises through the package and its upper limit is close to the upper unconformity. These highs might represent igneous intrusions, structural features or sedimentary diapirs. North of F1735 the reflector rises steeply and at 1740 it is not far beneath sea bed.

1741-1745 In this interval data are poor, but it appears that the sedimentary packages thin to almost nothing and the lowest reflector is at or close to sea bed. The sea bed rises steeply to the north.

1745-1784 The sea bed rises to the north to F1762, where the slope decreases. The lowest reflector is overlain by two packages containing poorly imaged reflectors. These packages thicken north until at F1772 they are ~300 ms in thickness, then thin towards F1784 where they cannot be distinguished at sea bed. The upper unit appears to have a well defined prograding geometry, with internal topsets and foresets visible on the airgun data. The lower unit has poorly defined internal structure.

1784-1794 The sea bed is undulating but roughly horizontal, with the lowest reflector overlain by 20-30 ms of parallel reflectors.

1795-1811 The sea bed dips gently towards the north, with 20-35 ms of parallel reflectors over a strong reflector. There is a faint indication of a lower reflector ~20 ms bsb.

1811-1821 Sea bed dips steeply towards the north, the strong reflector is overlain by a discontinuous unit containing continuous reflectors.

1821-1837 Sea bed dips gently towards the north. A package with relatively little internal structure is overlain by a discontinuous cover of parallel reflectors. Between 1821 and 1824 these reflectors show an up-slope prograding geometry. 150-200 ms bsb a strong reflector parallels sea bed. Below this another reflector is faint but visible at 270 ms bsb.

1837-1856 EOL In this area sea bed is roughly horizontal. In general, acoustic lamination is sub parallel to sea bed but undulations gain amplitude with depth.

The upper package of continuous, parallel reflectors thickens to 170 ms and contained some small wave forms and onlap surfaces. Below this is a package approximately 50 ms in thickness with no acoustic structure, underlain by 70 ms of continuous, parallel reflectors. This package thins to the south and becomes a single reflector east of F1825.

Below this package of reflectors, there is little data but at 450 ms bsb a faint area of stronger reflections might represent the acoustic basement at or near to sea bed over the top of George Bligh Bank.

6.2.4.3 Line 2009/05-111 (formerly GBB 4)

This line forms a north-south transect over the western margin of George Bligh Bank, beginning in the low between George Bligh and Hatton banks. This description is taken mostly from the airgun data beginning at the northern end.

The line typically displays a strong reflector at between 10 and 500 ms bsb, below which almost no data are visible. The test discussed the package of sediments above this reflector.

SOL Fix 1859-1895 The sea bed is undulatory, reflecting the complex wave forms in the upper part of the package. These wave forms are complex and have a topography of up to 80 ms. The majority are aggradational or south prograding, but some north prograding reflectors are present. It appears that the upper 20 ms of the package is an aggradational drape,

Between F1989 and 1997 the lower 250 ms of the package comprises a unit of continuous, sub horizontal reflectors that thickens to the north into a sub vertical feature that might be related to fault displacement and also has some expression at the sea bed.

1985-1940 The sea bed is commonly gently undulating. The upper package is between 20 and 170 ms in thickness and comprises three banks of sediment, between which are narrow channels? where the package thins to ~20 ms. In each bank reflectors are commonly continuous and parallel, although the lower part of the package contains reflectors that display foreset geometries with progradation to the south.

1940-1972 The sea bed is planar, then drops gently to the south from F1954. The upper unit of the package is up to 200 ms in thickness and comprises a bank of continuous, parallel reflectors, other than between F1948-1954 where the reflectors form a series of undulating wave forms. The base of the upper unit shows both downlap and onlap onto the lower unit and has infilled much of the erosional topography.

The lower unit is up to 350 ms in thickness, and thickens gradually from F1946 to a maximum at F1967 before terminating in a series of steep erosional scarps at F1971.5. The unit onlaps the strong reflector in the north.

1972-1984 Sea bed has a topography of >150 ms, reflecting the partial infill of topography by a series of depositional events. It appears that the lower unit in the package is absent, and the strong reflector is overlain by up to 350 ms of sediments from the upper unit, representing at least 3 phases on infill separated by erosion of possibly channel like features. Reflectors are commonly continuous and sub-horizontal, but several units 20 ms in thickness are acoustically transparent.

1984-2002 EOL The sea bed rises gently towards the south. The upper unit is complex, containing a series of lenticular bodies of sub parallel reflectors that show a range of migration directions. The topmost 20-50 ms appears to represent a period of infill and draping of the complex topography.

The lower unit comprises 200-250 ms of parallel, continuous reflectors that are parallel to sea bed and also to the underlying strong reflector. Between F1984 and 1986 the lower unit thickens from 0 to 200 ms, forming a scarp that might be related to those seen at F1971.5.

6.2.5 Anton Dohrn

Three lines were taken over presumed carbonate mounds on the north west and south east flanks of Anton Dohrn Seamount. The steep topography coupled with high swell meant that data were poor, but some information on shallow geology and mound geometry can be made out.

6.2.6 Seismic oceanography

In total, 102 of the probes were deployed at the mid-points of each seismic line. For each site survey, this usually consisted of five T11 or T5 (temperature only, maximum recordable depth 450 m and 1830 m respectively) probes and one XCTD (temperature and salinity, recordable depth 1000 m) probe. Probes were launched from the port stern area of the deck. Poor weather prevented deployment for ten of the lines surveyed during the cruise. Appropriate information regarding weather conditions during deployment, start and end time / positions were recorded on an Excel spreadsheet.

The ADCP (150 kHz) was switched on at the beginning of the cruise and continuously recorded data for the duration of the sites surveys and during transits to and from each site to compliment the probe and seismic measurements of the water column. The images will be processed. Any reflectivity will be described. Observed reflectivity will be ground-truthed by comparison with synthetic seismograms calculated from the direct oceanographic measurements. Spatial and temporal changes in reflectivity seen in groups of profiles at each coring site will be measured where possible. The new data will be compared with the existing Rockall Trough datasets. The usefulness of the previously undescribed imaging systems (sparker and 150 kHz ADCP) will be assessed. New research avenues will be identified.

Seismic oceanography provides new research opportunities by providing new images of large volumes of the ocean interior down to scales of around 10 m. At the small scale, internal waves of wavelength several hundred metres to a few kilometres can be observed and their amplitudes, frequencies and propagation speeds measured directly. Maps of internal wave properties over large spatial areas are beginning to allow wave generation sites to be identified, so that important generation mechanisms can be inferred. Interesting features seen on larger scales (tens of kilometres) include packages of highly reflective water with sharp, very steep boundaries and lenticular structures that resemble meso-scale eddies. Such features vary on time periods of hours to days, and the time scales of variation in reflectivity at different spatial scales can be quantified by looking at overlapping profile segments, intersecting lines within grids of 2D profiles, and 3D surveys. In future this information might help to estimate oceanic mixing and continental slope stability.

Seismic oceanography is also of interest to the hydrocarbon industry. Variation in sound speed within ocean water can cause serious problems in sub-seabed seismic reflection imaging. In 2D and 3D seismic surveying, water layer sound speed variations cause travel time offsets and amplitude variations between adjacent and intersecting sail lines. Water layer variability complicates the suppression of multiples from water layer reverberations. 4D seismic surveying compounds these problems. Other risks related to oceanic variability affect prospect evaluation and production. Riser design must account for shear from the water currents that generate the sound speed variability. Water temperature variability over time affects oil viscosity within the riser. All of these risks are expected to increase as hydrocarbon exploration steps out into deeper water. A thicker water layer accentuates mistakes in assigning water layer sound speeds during processing. The ability to quantify these problems using the seismic datasets themselves would be welcome.

7 Geology

All cores are gravity cores using a half ton bomb (weight) and a 3 m barrel unless otherwise stated.

7.1 SITE SURVEYS

7.1.1 Site survey 78a (Irish waters)

No recovery from gravity and box core drops suggests a hard sea bed, possibly covered by bioclastic gravel. A single gravel sized clast of fine grained basic igneous rock was recovered from the box core, however this might have been lodged in the mechanism and might not be related to sea bed geology at site 78a.

7.1.2 Site survey 25a (Irish waters)

No recovery from gravity core drop. A small quantity of gravel was recovered from the barrel of the gravity core, comprising fine grained lithic gravel (granite, gabbro and fine grained basic igneous) alongside gravel sized bioclastic debris. One bivalve fragment was 50 mm in length. These clasts suggest a hard sea bed covered by bioclastic gravel.

7.1.3 Site survey A1 (Irish waters)

No recovery from gravity core drops, suggesting a hard sea bed.

7.1.4 Site survey X (Irish waters)

Recovery of 0.93 m of sediment. 0.20 m of gravelly sand overlies a succession of muddy and gravelly sands.

7.1.5 Site survey 113g (Irish waters)

A gravity core with a 6 m barrel was used. Recovery of 1.93 m of sediment. Interbedded brown and pale grey muddy sands, dominated by forams. Five cycles with foram-rich pale sand overlain by progressively browner muddy sand. Colour differences are related to relative proportions of forams and lithic (mostly igneous) clasts. Bases are transitional in the upper 1 m, but sharp and bioturbated in the lower section.

7.1.6 Site survey 107g (Irish waters)

Recovery of 1.65 m of muddy sand. Interbedded brown and pale grey muddy sands, dominated by forams showing cycles with foram-rich pale sand overlain by progressively browner muddy sand, similar to section recovered at 113g.

7.1.7 Site survey 98c (Irish waters)

Recovery of 0.61 m of bioclastic sand and gravel. Grain size changes are marked, but composition is generally ~90% of bioclasts (both microfauna and molluscs, echinoderms, etc.) with a low proportion of lithic clasts (mostly igneous, some sedimentary rock).

7.1.8 Site survey 430

Recovery of 2.09 m of interbedded brown muddy sands and pale sands, dominated by forams. Two units of interbedded muddy sands are split by a medium grey muddy sand. Changes are common and complex, with variability in colour, grain size, contact relationships and bioturbation. Some brown horizons are sandy mud and have a soapy texture.

7.1.9 Site survey 426

Recovery of 1.91 m of sands and interbedded grey and brown muddy sands and pale sands. The upper 0.20 m of core is a foram rich sand, below which is 0.44 m of interbedded grey muddy sand and pale foram rich sand. Colour boundaries are more commonly transitional than sharp. Between 0.64 and 1.91 m the sediments are brown muddy sand and pale grey foram rich sand. Brown muddy sand / sandy mud is not abundant and forms thin bands <0.10 m in thickness, commonly disrupted by bioturbation.

7.1.10 Site survey 433

Recovery of 1.45 m of interbedded brown muddy sands and pale sands, 5 cycles of pale foram sand and brown muddy sand. Colour variations exist within units and contacts are diffuse and bioturbated.

7.1.11 Site survey 434

No recovery other than small fragments of basalt, sandstone and 1 ~5 mm bivalve, suggesting a hard sea bed.

7.1.12 Site survey 421

No recovery other than small fragments of basalt, ?felsite, sandstone and bioclasts, suggesting a hard sea bed.

7.1.13 Site survey 424

No recovery, suggesting a hard sea bed.

7.1.14 Site survey 420

No recovery other than small fragments of gneiss, basalt and a bioclast, suggesting a hard sea bed.

7.1.15 Site survey 441B

No recovery, suggesting a hard sea bed.

7.1.16 Site survey 413

Recovery of 0.93 m of interbedded grey and brown muddy sands and pale grey sands. The upper 0.21 m of core is a foram rich sand, below which is 0.13 m of interbedded grey muddy sand and pale grey foram rich sand. Between 0.34 and 0.93 m the sediments are brown muddy sand and pale grey foram rich sand. Colour variations exist within units and contacts are diffuse and bioturbated.

7.2 OTHER WORK

7.2.1 F1

A gravity core with a 6 m barrel was used. Recovery was 3.95 m of sediment. The core was cut into ~1 m lengths but these were not split on board.

A box core was also used. Recovery was 0.80 m of sediment. Four sub-samples were taken from this core.

8 Health and Safety

All scientific staff were given an introduction to RRS Discovery and safety briefing by the purser at 14.00 on Monday 17th August.

As of 17th August all scientific staff had read and signed the BGS H&S document.

During the 17th and 18th August Simon Ritson was trained as an operator of the Sparker HV equipment.

Boat drills were held at the following times:

- Tuesday 18th August, 15.15.
- Monday 31st August, 10.30.
- Friday 11th September, 10.30.

Fire alarms were tested on Saturdays at 10.30.

A Health and Safety meeting was held on board at 10.30 on 16th September.

Appendix 1 Daily Log

Please note that the times given in this log represent the time that site surveys were undertaken, and do not correspond to the time that individual seismic lines began or finished.

Date	Time GMT	Commentary
18 August 2009	12.00	Ship underway to Rathlin site.
	15.15	Boat drill.
	19.00	Commence to deploy gear; sparker failure repaired, airgun test OK. Airguns retrieved.
	21.30	Coming onto line 2009050003 (DL1).
	22.00	Sparker failure.
	23.00	Sparker failure, several attempts to repair.
19 August	03.00	Coming onto line 2009050004 (DL1).
	03.28	Data poor – very fast tide (7 kts), poor bottom tracking.
	03.54	End 2009050004.
	04.14	Sparker failure.
	07.10	Sparker running on lv setting.
	07.54	Rerun 2009050004 (DL1) Data poor as above, no fixes, sparker failed at end of line.
	09.00	Retrieve sparker, steam (290°) towards site survey 78a.
20 August	12.00	Ship underway towards 78a.
	14.00	Test airgun and sparker on Irish Shelf. Success.
	15.30	Recover kit, deploy magnetometer for line 2009050005 and
	19.30	Underway to 78a.
	20.35	Arrive on site and end magnetometer line.
		Cannot run seismic – sea too rough (F6-7, very white) to collect data. Captain advises cannot deploy gravity core as ship could not be held steady.
21 August	00.00	Weather deteriorated through night but improved after 05.00.
	09.30	Consulted Captain.
	10.25	First of three gravity cores attempted.
	11.38	Last of three gravity cores attempted. No recovery (NR).
	12.00	Cannot run seismic, waiting for sea conditions to improve.
	18.15	Deploy airgun and sparker.
	18.53	Survey 78a-4. Six lines run, airgun reasonable, sparker very poor at first, improving as sea conditions improve.
22 August	05.03	End of survey 78a-3. End of site survey at this location.
	06.30	Deploy gravity core. NR.
	07.25	Deploy box core. NR.
	07.55	Deploy magnetometer, steaming to 25a across Rockall Trough
	12.00	Transit to 25a across Rockall Trough, magnetometer raised between 12.35 and 21.00 as bad weather slowed ship.

23 August	13.55	Arrive at 25a.
	15.32	Commence site survey - sparker very poor, weather deteriorating.
	23.22	Complete site survey at 25a.
24 August	00.00	Wind F6, gusting F8, cannot hold station, gravity core not taken.
	09.50	Advised by Captain that (ex) Hurricane Bill is approaching, ship to steam to move out of path of storm.
	12.00	Ship moving NW towards UK waters, will discuss options with Captain once weather conditions are known.
	16.00	Advised by Captain that Storm Bill moving north, so ship stopped at 54 15N, 13 07W facing the weather, sailing against sea is now dangerous.
25 August	09.00	Window between storm and Storm Bill, move south to 25a to take gravity core.
	12.43	Gravity core at site 25a,. NR (small amount of gravel in barrel).
	16.30	Two gravity cores attempted at A1. No recovery. First of two gravity cores attempted at A1. NR.
	17.10	Second attempt also NR. Ship moves N to avoid storm Bill, standing to at 54N 13W.
26 August	12.00	Storm passes to S.
27 August	09.00	Standing to, swell still too rough for seismic.
	09.30	Illness in crew family means we have to steam east towards Galway, where crew member will be picked up by outer estuary pilot.
28 August	05.00	Crew member taken off.
	06.00	Slow transit to site A1, constant F7-F8 winds.
	18.38	Start of site survey at A1. Poor weather at start of shooting.
29 August	02.23	End of site survey at A1.
	14.20	Start of site survey at site X.
	23.13	End of survey at X. Some issues with sparker.
30 August	00.44	Gravity core taken, 0.93 m recovery.
	01.15	Transit across Rockall Trough to site 113g, magnetometer deployed.
	12.00	Steaming to site 113g, magnetometer deployed.
31 August	03.45	Seismic started at site 113g.
	10.35	Site survey completed at 10.35.
	11.35	Airgun and sparker onboard.
	13.30	Gravity core taken at site 113g, 1.93 m recovery.
	14.00	Begin transit to site 107g.
	19.50	Start of site survey site 107g.
1 September	03.25	Survey at 107g completed.
	05.55	Gravity core taken at 107g, 1.65 m recovery.
	06.00	Transit to site 98c.

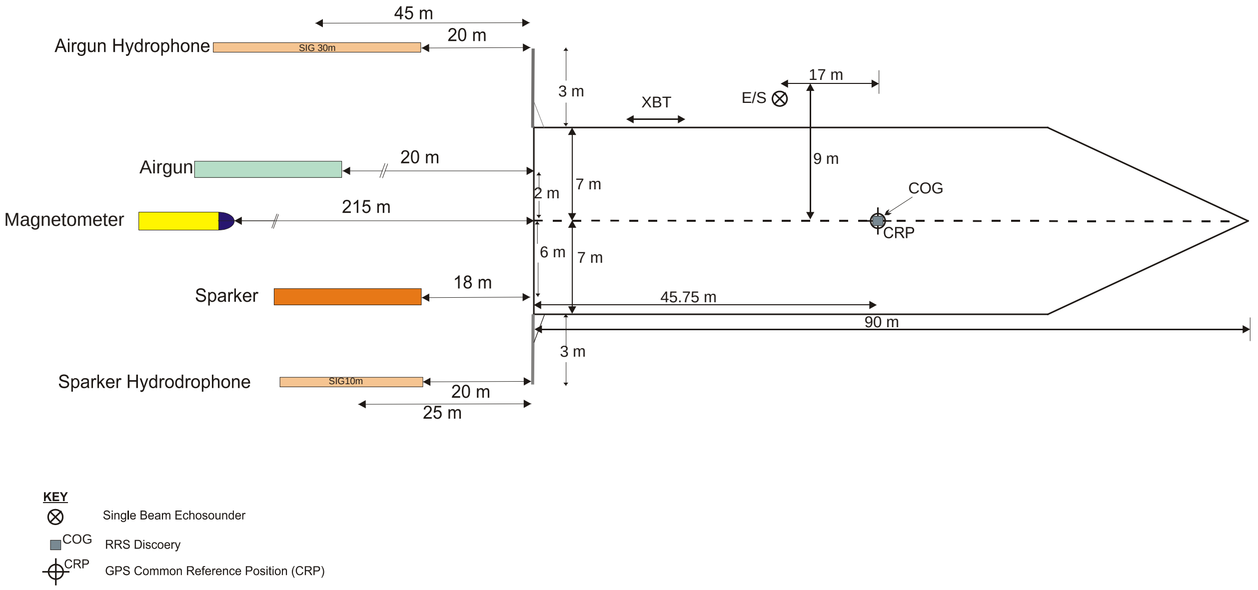
	09.39	Begin site survey at site 98c.
	16.50	Seismic completed at 98c.
	20.30	Three attempts at gravity core drops at 98c, recovery 0.61 m.
	21.00	Deploy magnetometer and transit across Hatton Rockall Basin (coincident with existing seismic line HA04-9004).
2 September	13.16	EOL across Hatton Rockall Basin.
	19.02	Start site survey at site 430.
3 September	03.40	Survey completed at site 430.
	04.50	One gravity core drop at 430, recovery 2.09 m.
	08.09	Survey begun at site 426.
	10.00	Poor weather.
	15.45	Survey completed at 426.
	17.14	One gravity core drop at 426, recovery 1.91 m.
	18.15	Transit to site 433. Weather poor, standing to.
4 September	06.49	Survey begun at site 433.
	14.08	Survey completed at 433.
	15.50	One drop gravity core at 433, 1.5 m recovered. Transit to 434.
	18.05	Survey begun at 434.
5 September	01.30	Survey completed at 434.
	04.15	Two attempts at gravity core at 434. No recovery. Transit to 421.
	09.50	Site survey begun at 421.
	17.17	Survey completed at 421.
	19.20	Two attempts at gravity core at 421. No recovery. Transit to 424.
	21.25	Site survey begun at 424.
6 September	04.47	Survey completed at 424.
	07.00	Two attempts at gravity core at 424. No recovery. Transit to 420.
	10.26	Site survey begun at 420.
	19.12	Survey completed at site 420.
	19.40	On Captain's advice move south east to avoid incoming storm.
7 September		Standing by in north Rockall Trough.
8 September		Standing by in north Rockall Trough.
9 September	12.00	Returning to site 420.
10 September	12.00	Returning to site 420.
	13.50	One attempt at gravity core at 420. No recovery.
	16.39	Site survey begun at 441B.
11 September	00.21	Survey completed at 441B.
	01.56	One attempt at gravity core at 441B. No recovery.
	02.00	Transit to site 413.
	10.40	Site survey begun at 413.
	19.35	Survey at 413 completed.
	21.30	One attempt at gravity core at 413, 0.93 m recovered. On

		Captain's advice coring was halted in deteriorating weather conditions.
	21.40	Transit to line GBB2 (2009050109).
12 September	03.57	Start line GBB2.
	10.56	Line GBB2 completed.
	11.10	Transit to line GBB7 (2009050110).
13 September	20.29	Start line GBB7.
14 September	09.53	Complete line GBB7. Transit to line GBB4.
	12.00	Transit to line GBB4 (2009050111). 2½ hour delay for repair to ship.
	16.42	Start line GBB4.
15 September	05.12	Complete line GBB4.
	05.30	Transit to site F1.
	21.30	One gravity core at F1, 3.95 m recovery.
	23.55	Box core at F1, 0.80 m recovery. Begin transit to line AD2.
16 September	07.34	Begin line AD2 in poor weather.
	09.06	End line AD2.
	09.42	Start line AD3.
	10.34	End line AD3.
	10.45	Transit to line AD1.
	14.01	Start line AD1.
	17.40	End line AD1.
	17.50	Transit to Glasgow.
17 September		Transit to Glasgow.
18 September		Transit to Glasgow

Appendix 2 Scientific Personnel

	Name	Organisation	Role
1	Alick Leslie	BGS	Principal geologist
2	Dayton Dove	BGS	Geologist
3	Dave Wallis	BGS	Electronic engineer and party chief
4	Davie Baxter	BGS	Mechanical engineer
5	Simon Ritson	BGS	Electronic engineer
6	Lee Baines	BGS	Mechanical engineer
7	Nick Smart	BGS	Surveyor
8	Fiona Hibbert	St. Andrew's University	Geologist
9	Nick Owen	Trinity College, Dublin	Irish observer / geologist.

Appendix 3 Equipment Layback Diagram



RRS Discovery - Survey BGS2009/05

Appendix 4 Line Summary Sheet

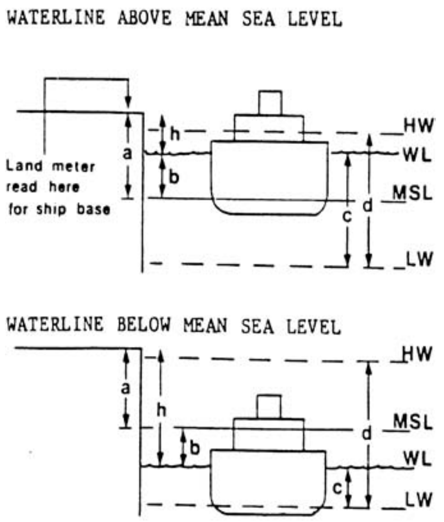
Line Number	Project (UTM Zone)	Planning Line Number	Dir	Date (dd-mm-yy)	Time (hh:mm :ss)	Date (dd-mm-yy)	Time (hh:mm :ss)	Length (km)
2009050001	29	DL1	293	18-08-09	21.30.00	18-08-09	22.00.00	2.60
2009050002	29	DL1	293	18-08-09	23.00.00			No data
2009050003	29	DL1	293	19-08-09	03:28:00	19-08-09	03:54:00	2.60
2009050004	29	DL1	282	19-08-09	07:54:00	19-08-09	08:27:00	2.60
2009050005	28	Gravmag1	290	19-08-09	15:40:00	20-08-09	19:25:00	436.00
2009050006	28	78-4	130	21-08-09	19:08:42	21-08-09	19:48:13	5.00
2009050007	28	78-5	130	21-08-09	20:41.00	21-08-09	21:56:00	5.00
2009050008	28	78-6	310	21-08-09	22:18:12	21-08-09	23:12:00	5.00
2009050009	28	78-4	130	21-08-09	23:50:00	22-08-09	00:35:00	5.00
2009050010	28	78-3	40	22-08-09	01:41:00	22-08-09	02:23:00	5.00
2009050011	28	78-2	220	22-08-09	02:56:00	22-08-09	03:40:00	5.00
2009050012	28	78-1	40	22-08-09	04:18:00	22-08-09	05:03:00	5.00
2009050013	28	Gravmag2	174	22-08-09	08:43:00	23-08-09	13:54:00	333.59
2009050014	28	25a-1	40	23-08-09	15:32:00	23-08-09	16:16:00	5.00
2009050015	28	25a-2	220	23-08-09	16:56:35	23-08-09	17.41.00	5.00
2009050016	28	25a-3	40	23-08-09	18.15.35	23-08-09	18.55.00	5.00
2009050017	28	25a-6	310	23-08-09	19.49.00	23-08-09	20:29:45	5.00
2009050018	28	25a-5	130	23-08-09	21:13:24	23-08-09	21:51:00	5.00
2009050019	28	25a-4	310	23-08-09	22:38:24	23-08-09	23:23:00	5.00
2009050020	28	25a-6	310	23-08-09				No data
2009050021	28	A1-1	271	28-08-09	18:38:51	23-08-09	19:22:12	5.00
2009050022	28	A1-2	91	28-08-09	20:01:40	23-08-09	20:45:10	5.00
2009050023	28	A1-3	271	28-08-09	21:21:09	23-08-09	22:04:19	5.00
2009050024	28	A1-4	1	28-08-09	22:54:00	23-08-09	23:35:28	5.00
2009050025	28	A1-5	181	29-08-09	00:15:00	29-08-09	01:00:00	5.00
2009050026	28	A1-6	1	29-08-09	01:40:00	29-08-09	02:23:00	5.00
2009050027	28	X-1	274	29-08-09	13:42:09	29-08-09	14:17:00	5.00
2009050028	28	X-2	101	29-08-09	14:58:00	29-08-09	15:41:50	5.00
2009050029	28	X-3	281	29-08-09	16:17:43	29-08-09	16:53:00	5.00
2009050030	28	X-4	12	29-08-09	17:46:00	29-08-09	18.26.31	5.00
2009050031	28	X-5	191	29-08-09	19:05:48	29-08-09	19:49:24	5.00
2009050032	28	X-6	12	29-08-09	20:33:00	29-08-09	21:17:01	5.00
2009050033	28	X-2	281	29-08-09	22:28:09	29-08-09	23:13:13	5.00
2009050034	27	Gravmag3	321	30/08/09	01:51	31/08/09	01:09:00	418.00
2009050035	27	113g-1	232	31/08/09	03:45	31/08/09	04:27:00	5.00
2009050036	27	113g-2	46	31/08/09	05:00	31/08/09	05:40:00	5.00
2009050037	27	113g-3	228	31/08/09	06:19	31/08/09	07:00:00	5.00
2009050038	27	113g-4	319	31/08/09	07:53	31/08/09	08:34:00	5.00
2009050039	27	113g-5	139	31/08/09	09:09	31/08/09	09:57:00	5.00
2009050040	27	113g-6	317	31/08/09	10:35	31/08/09	11:15:00	5.00
2009050041	27	107g-1	49	31/08/09	19:50	31/08/09	20:35:00	5.00

2009050042	27	107g-2	233	31/08/09	21:10	31/08/09	21:45:00	5.00
2009050043	27	107g-3	49	31/08/09	22:23	31/08/09	23:07:00	5.00
2009050044	27	107g-6	319	31/08/09	23.54	31/08/09	00:33:00	5.00
2009050045	27	107g-5	136	01/09/09	01:10	01/09/08	01:54:00	5.00
2009050046	27	107g-4	320	01/09/09	02:32	01/09/08	03:12:00	5.00
2009050047	27	98c-1	232	01/09/09	09:39	01/09/09	10:19:00	5.00
2009050048	27	98c-2	49.9	01/09/09	10:51	01/09/09	11:31:00	5.00
2009050049	27	98c-3	234	01/09/09	12.06	01/09/09	12:48:00	5.00
2009050050	27	98c-4	319	01/09/09	13.35	01/09/09	14:16:51	5.00
2009050051	27	98c-5	140	01/09/09	14.51	01/09/09	15:31:32	5.00
2009050052	27	98c-6	320	01/09/09	16.07	01/09/09	16:50:00	5.00
2009050053	27	HatBa-1	320	01/09/09	21.15	02/09/09	13:15:51	270.00
2009050054	27	430-1	1	02/09/09	19.02	02/09/09	19:46:42	5.00
2009050055	27	430-2	181	02/09/09	20.25	02/09/09	21:03:32	5.00
2009050056	27	430-3	1	02/09/09	21.42	02/09/09	22:26:20	5.00
2009050057	27	430-4	91	02/09/09	23.15	Re-run as line 58		
2009050058	27	430-4	91	03/09/09	00:03	03/09/09	00:45:00	5.00
2009050059	27	430-5	277	03/09/09	01:22	03/09/09	02:07:00	5.00
2009050060	27	430-6	82.9	03/09/09	02:46	03/09/09	03:30:00	5.00
2009050061	27	426-1	351	03/09/09	08:09	03/09/09	08:59:00	5.00
2009050062	27	426-2	191	03/09/09	09:33	03/09/09	10:08:00	5.00
2009050063	27	426-3	345	03/09/09	10:44	03/09/09	11:30:00	5.00
2009050064	27	426-4	91	03/09/09	12:17	03/09/09	13:02:00	5.00
2009050065	27	426-5	271	03/09/09	13:40	03/09/09	14:30:00	5.00
2009050066	27	426-6	91	03/09/09	15.06	03/09/09	15:45:00	5.00
2009050067	27	433-1	350	04/09/09	06:49	04/09/09	07:29:00	5.00
2009050068	27	433-2	188	04/09/09	08:11	04/09/09	08:49:00	5.00
2009050069	27	433-3	357	04/09/09	09:24	04/09/09	10:02:00	5.00
2009050070	27	433-4	86	04/09/09	10:52	04/09/09	11:35:00	5.00
2009050071	27	433-5	272	04/09/09	12:11:00	04/09/09	12:50:00	5.00
2009050072	27	433-6	92	04/09/09	13.25	04/09/09	14:08:02	5.00
2009050073	27	434-1	2	04/09/09	18:06	04/09/09	18:44:00	5.00
2009050074	27	434-2	181	04/09/09	19:23	04/09/09	20:08:00	5.00
2009050075	27	434-3	1	04/09/09	20:43	04/09/09	21:22:12	5.00
2009050076	27	434-4	92	04/09/09	22.12	04/09/09	22:53:20	5.00
2009050077	27	434-5	272	04/09/09	23.32	05/09/09	00:16:10	5.00
2009050078	27	434-6	94	05/09/09	00:52	05/09/09	01:30:00	5.00
2009050079	27	421-1	354	05/09/09	09:51	05/09/09	10:33:00	5.00
2009050080	27	421-2	195	05/09/09	11:06	05/09/09	11:42:00	5.00
2009050081	27	421-3	2	05/09/09	12.17	05/09/09	13:07:00	5.00
2009050082	27	421-4	92	05/09/09	13.58	05/09/09	14:32:00	5.00
2009050083	27	421-5	272	05/09/09	15.09	05/09/09	15:57:00	5.00
2009050084	27	421-6	92	05/09/09	16.41	05/09/09	17:17:00	5.00
2009050085	27	424-1	182	05/09/09	21:25	05/09/09	22:06:19	5.00
2009050086	27	424-2	2	05/09/09	22.46	05/09/09	23:30:00	5.00
2009050087	27	424-3	182	06/09/09	00:03:21	06/09/09	00:41:00	5.00
2009050088	27	424-4	97	06/09/09	01:36	06/09/09	02:15:00	5.00
2009050089	27	424-5	269	06/09/09	02:50	06/09/09	03:32:00	5.00

2009050090	27	424-6	94	06/09/09	04:05	06/09/09	04:47:00	5.00
2009050091	27	420-1	354	06/09/09	10:26	06/09/09	11:03:00	5.00
2009050092	27	420-2	182	06/09/09	11:40	06/09/09	12:22:00	5.00
2009050093	27	420-3	2	06/09/09	12:55	06/09/09	13:37:00	5.00
2009050094	27	420-4	92	06/09/09	14:31	06/09/09	15:12:00	5.00
2009050095	27	420-6	272	06/09/09	17.07	06/09/09	17:54:00	5.00
2009050096	27	420-5	92	06/09/09	18:34	06/09/09	19:12:00	5.00
2009050097	27	441B-1	3	10/09/09	16:39	10/09/09	17:15:00	5.00
2009050098	27	441B-2	183	10/09/09	17:59	10/09/09	18:45:00	5.00
2009050099	27	441B-3	3	10/09/09	19:24	10/09/09	19:56:00	5.00
2009050100	27	441B-4	93	10/09/09	20:49	10/09/09	21:27:00	5.00
2009050101	27	441B-5	273	10/09/09	22:12	10/09/09	23:06:00	5.00
2009050102	27	441B-6	93	10/09/09	23:45	11/09/09	00:20:00	5.00
2009050103	27	413-1	354	11/09/09	10:40	11/09/09	11:16:00	5.00
2009050104	27	413-2	183	11/09/09	11:54	11/09/09	12:36:00	5.00
2009050105	27	413-3	359	11/09/09	13:13	11/09/09	13:51:00	5.00
2009050106	27	413-4	89	11/09/09	14:55	11/09/09	15:31:00	5.00
2009050107	27	413-6	269	11/09/09	16:27	11/09/09	17:20:00	5.00
2009050108	27	413-5	89	11/09/09	19:01	11/09/09	19:35:00	5.00
2009050109	28	GBB2	81	12/09/09	03:58	13/09/09	10:56:00	227.00
2009050110	28	GBB7	0	13/09/09	20:29	14/09/09	09:53:00	113.00
2009050111	28	GBB4	180	14/09/09	16:42	15/09/09	05:12:00	98.00
2009050112	28	AD2	242	16/09/09	07:34	16/09/09	09:06:00	12.70
2009050113	28	AD3	50	16/09/09	09:42	16/09/09	10:34:00	7.50
2009050114	28	AD1	209	16/09/09	14:01	16/09/09	17:40:00	29.00

Appendix 5 Gravity Base Ties

Name of Ship: RRS Discovery **King George V Dock, Berth 8**	**Date:** 17 August 2009 **Julian Day: 229**



Gravity Meter Observation
Harbour Base Connection

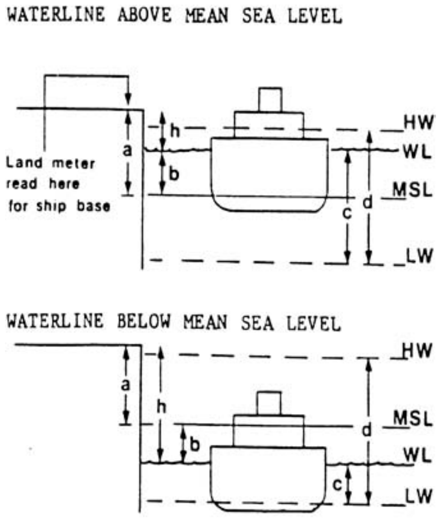
Time(GMT)	Place	Reading
1351	Ship	5101.68
1403	Bollard 92	5101.83
1414	Ship	5101.75
1425	Bollard 92	5101.77
1435	Ship	5101.70
1444	Bollard 92	5101.77
1452	Ship	5101.72
Land Meter	**L&R G356**	

Calculation of Height of Tide	
Use Admiralty tide tables. Times GMT.	
Time of Observation	1815
Interval from High Water	3hr 17
All heights in metres	
Height of preceding HW or LW	0.7
Height of Succeeding HW or LW	3.0
Predicted Tide Range **(d)**	2.3
Factor for time interval (from curve for standard port).	0.5
Height of Tide above LW **(c)**	1.15
Half Tide Range **d/2**	1.15
Height of Tide above MSL = **c – d/2 = b**	0
Height of ship base above Waterline **(h)**	3.70
Height of ship base above MSL=**h + b = a**	3.70

Portable Meter calibration Factor (p)	1.04
Meter diff. to ship corrected for drift(q)	0.08
Harbour Station Value	981588.1
Diff. to ship (p X q)	0.08
Uncorrected ship base value	981588.0
Free air correction = 0.31 X a (Add)	1.15
Ship base corrected for FA	981589.15
Bouguer correction for water slab. Pier=0.04b, Wall=0.02b. (Subtract)	0
Corrected ship base value	**981589.2**
Ship borne Meter Harbour Reading	
Marine meter L&R S-75	
Ship meter cal factor (k)	0.9911
Time (GMT)	1815
Ship borne meter reading	12293.6
FA correction= 0.13b/k (Add)	0
FA corrected value	12293.6
Bouguer correction. Pier=0.04b/k. Wall=0.02b/k (Subtract)	0
Corrected Harbour Reading	**12293.6**

Post-Survey

Name of Ship: RRS Discovery **King George V Dock, Berth 10**	**Date:** 18 September 2009 **Julian Day: 261**

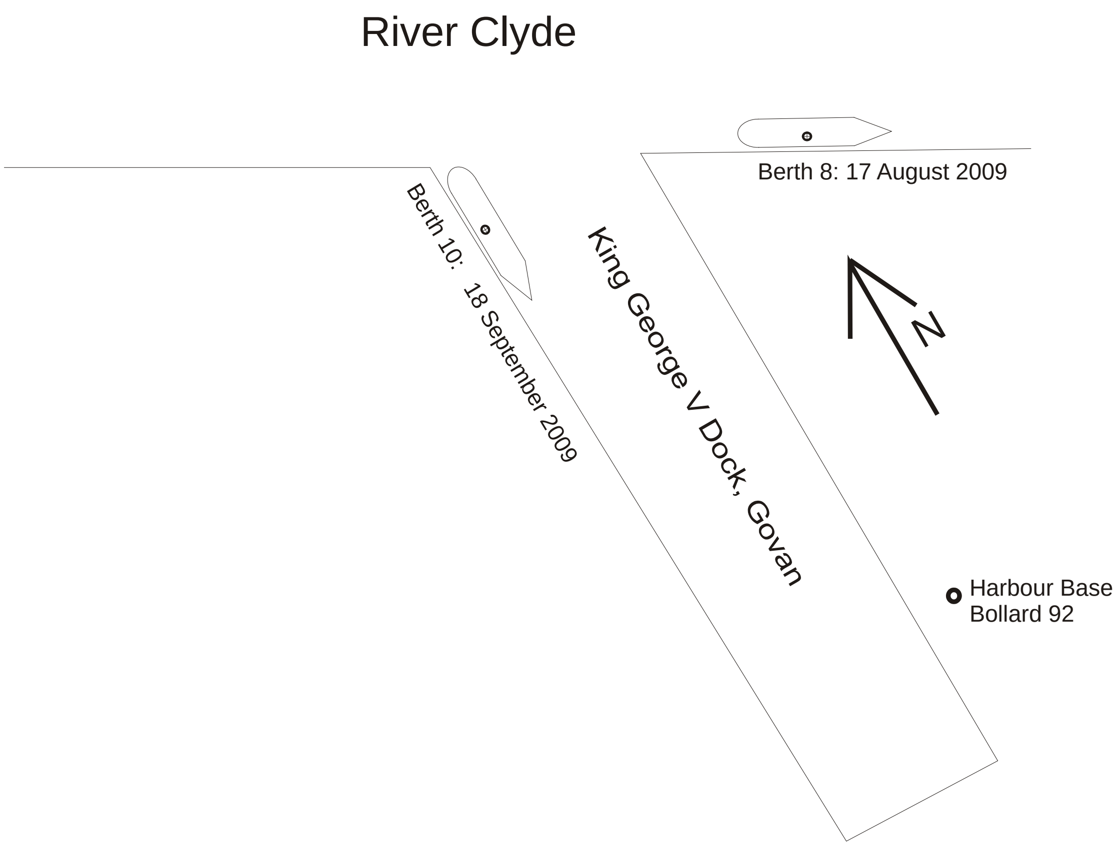


Gravity Meter Observation
Harbour Base Connection

Time(GMT)	Place	Reading
0830	Ship	5101.52
0855	Base	5101.61
0915	Ship	5101.47
0930	Base	5101.59
0942	Ship	5101.51
0955	Base	5101.64
1005	Ship	5101.53
Land Meter	**L&R G356**	

Portable Meter calibration Factor (p)	1.04
Meter diff. to ship corrected for drift(q)	0.10
Harbour Station Value	981588.1
Diff. to ship (p X q)	0.10
Uncorrected ship base value	981588.00
Free air correction = 0.31 X a (Add)	1.15
Ship base corrected for FA	981589.15
Bouguer correction for water slab. Pier=0.04b, Wall=0.02b. (Subtract)	0.03
Corrected ship base value	**981589.12**
Ship borne Meter Harbour Reading	
Marine meter L&R S-75	
Ship meter cal factor (k)	0.9911
Time (GMT)	1110
Ship borne meter reading	12293.4
FA correction= 0.13b/k (Add)	0.00
FA corrected value	12293.4
Bouguer correction. Pier=0.04b/k. Wall=0.02b/k (Subtract)	0.03
Corrected Harbour Reading	**12293.4**

Calculation of Height of Tide	
Use Admiralty tide tables. Times GMT.	
Time of Observation	1110
Interval from High Water	1h00
All heights in metres	
Height of preceding HW or LW	0.4m
Height of Succeeding HW or LW	4.8m
Predicted Tide Range **(d)**	4.4m
Factor for time interval (from curve for standard port).	0.85
Height of Tide above LW **(c)**	3.74
Half Tide Range **d/2**	2.20
Height of Tide above MSL = **c – d/2 = b**	1.54
Height of ship base above Waterline **(h)**	2.16
Height of ship base above MSL=**h + b = a**	3.70



Sketch showing Gravity Base-Tie locations, Govan 2009

Appendix 6 Cetacean Observation Summary

A search for marine mammals was begun 30 minutes before the airguns were switched on. If marine mammals were sighted within 500 m of the ship, the airguns were switched off immediately and were not switched on until 30 minutes had elapsed since a sighting.

Marine mammals were identified during seismic survey at the following times:

29th August, 16.55-17.40 and 18.17-19.45. Dolphins.

1st September, 15.08-15.35. Dolphins and Pilot Whales.

2nd September, 19.20-19.55. Dolphins and Pilot Whales.

11th September, 18.50-18.55. Pilot Whales.

12th September, 15.04-15.34. Dolphins.

14th September, 18.11-18.50. Whales and Dolphins.

16th September, 07.46-07.59. Dolphin.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

CRUMMY, J. 2008. Marine survey data management handbook. BGS Specifications. *British Geological Survey Internal Report* IR/08/024.

HITCHEN, K. 2009. BGS site survey (and regional geophysics) cruise to Hatton-Rockall area, August-September 2009. *British Geological Survey Report.* Informal planning document only.

MURPHY, N, and MORGAN, C. 2008. High Priority shallow borehole sites. *Shallow Borehole Prospect Inventory*, PIP Project IS06/11a.