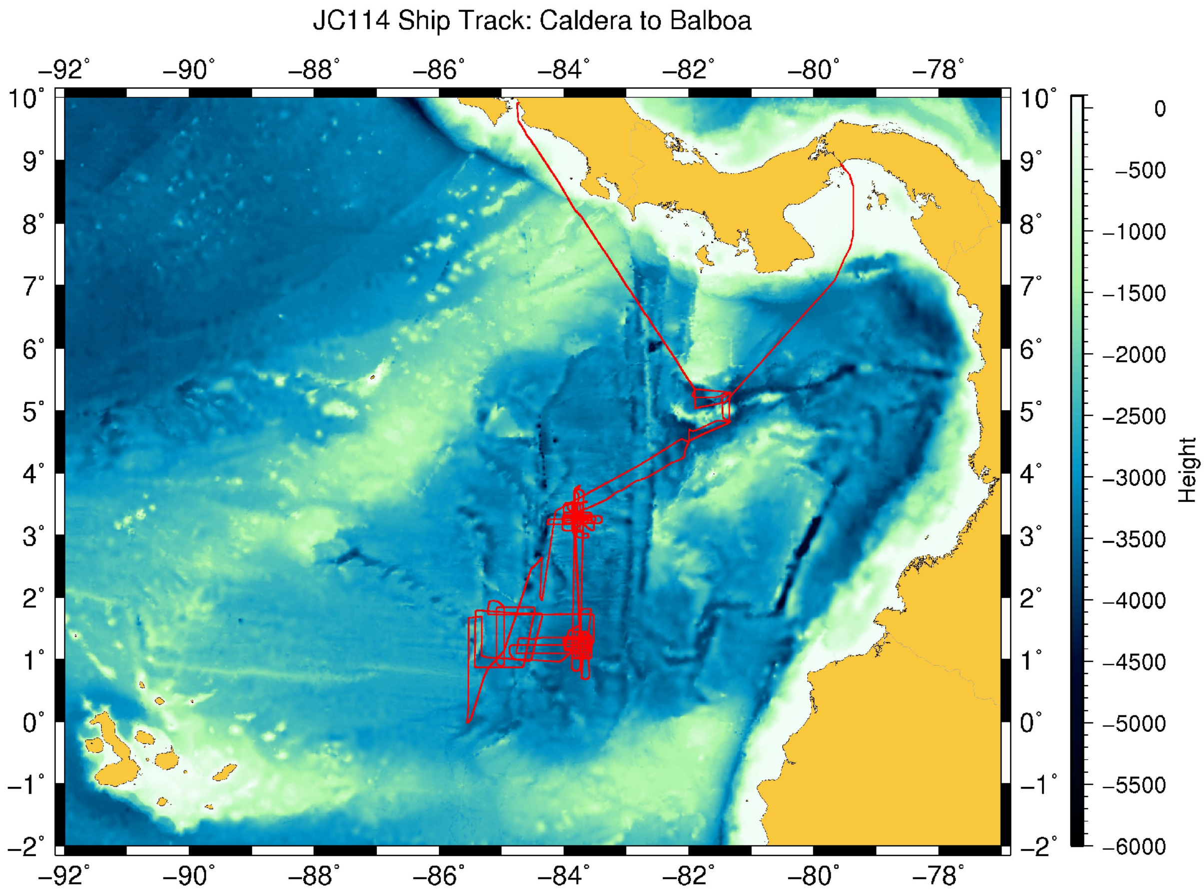
RRS James Cook JC114

Cruise Report

OSCAR – Oceanographic and Seismic Characterisation of heat dissipation and alteration by hydrothermal fluids at an Axial Ridge

22nd January - 6th March 2015
Caldera (Costa Rica) – Balboa (Panama)



Dr Richard Hobbs **and** **Professor Christine Peirce**

Department of Earth Sciences
University of Durham
South Road
Durham
DH1 3LE

r.w.hobbs@durham.ac.uk **christine.peirce@durham.ac.uk**

Table of Contents

Summary

The OSCAR research programme in the Panama Basin consisted of three cruises on the RRS JAMES COOK, namely JC112, JC113 and JC114, and a single cruise on the FS SONNE, SO238. This cruise report relates to JC114 but should be read in conjunction with the reports for the other cruises involved in the OSCAR project as a whole.

The primary objective of JC114 was to collect geophysical data around the Costa Rica Rift (North Grid, NG) and Ocean Drilling Programme borehole 504B (South Grid, SG), including both high and low resolution normal incidence multichannel seismic reflection data, wide-angle seismic refraction using both ocean-bottom seismographs and the synthetic aperture (SAP) approach, potential field data (gravity and magnetics), swath bathymetry depth and backscatter data, and shallow sub-bottom profiler data.

During the cruise 3500 line-km of multichannel seismic reflection profiles were acquired of which 1000 line-km were synthetic aperture using two ships to synthesize an 8.5 km streamer. This cruise was the first time that the NERC and its National Marine Facility has supported and undertaken such a two-ship synthetic aperture seismic acquisition. All but 400 line-km where shot with a dual source to simultaneously acquire both high and low resolution images. Most of the seismic shots were also recorded on ocean bottom seismometers (OBS). Eighty-three OBS were deployed which included two specially designed vertical hydrophone arrays to directly measure the source signature. Together the OBS recorded over 3000 line-km of wide-angle seismic refraction data. In the each of the two 3D grids over 250000 shots were recorded and on the SAP 70000 shots were recorded. Data quality is generally excellent and was first-pass processed through-out the cruise for quality control purposes. This cruise was the first to use heavier bottom weights for the OBS which has resulted in outstanding recordings of shear-waves propagated through the oceanic crust and overlaying sediment.

During the cruise, continuous swath mapping of the area and adjacent fracture zones revealed evidence for significant off-axis volcanic activity including a potentially new volcanic centre that was not mapped on the 2008 GEBCO compilation.

1. Cruise objectives

1.1 Introduction

The cooling of young oceanic crust is the principal physical process responsible for removing heat from the solid Earth to the hydrosphere. Close to a mid-ocean ridge, rapid cooling is dominated by hydrothermal circulation of seawater through the porous and fractured basalt crust. This hydrothermal fluid is then discharged into the ocean mainly along the ridge through distinct vents called 'black smokers'. The primary objective of this interdisciplinary project is to investigate the effects of this heat loss and hydrothermal circulation on both the solid Earth and the ocean. The data collected as part of the OSCAR project will be used to derive an integrated circulation model, that will be constrained by geophysical, geological and physical oceanography data, which will include fluxes through the seabed.

From a geological viewpoint, understanding of the dynamics of the heat exchange mechanism in the solid Earth requires the resolution of small-scale structural and morphological characteristics of the upper crustal interface between the heat source and ocean. The location of permeability zones and conduits that control the fluid movement is hotly debated, as is the geological nature of seismically imaged layers and their boundaries. Many contradictory models exist, and the majority of these are based on observations made at ridge axes, and do not include the variation in physical properties of the upper crust as it ages and spreads off-axis. OSCAR aims to resolve this debate by acquiring a new geophysical dataset of the upper oceanic crust from ridge axis to ridge flanks, in a location where not only has a spatial variability in heat flux been observed, but also where there is hydrological, geological and geophysical control provided by one of the deepest boreholes drilled to date, into the oceanic crust at site Ocean Drilling Programme (ODP) borehole 504B.

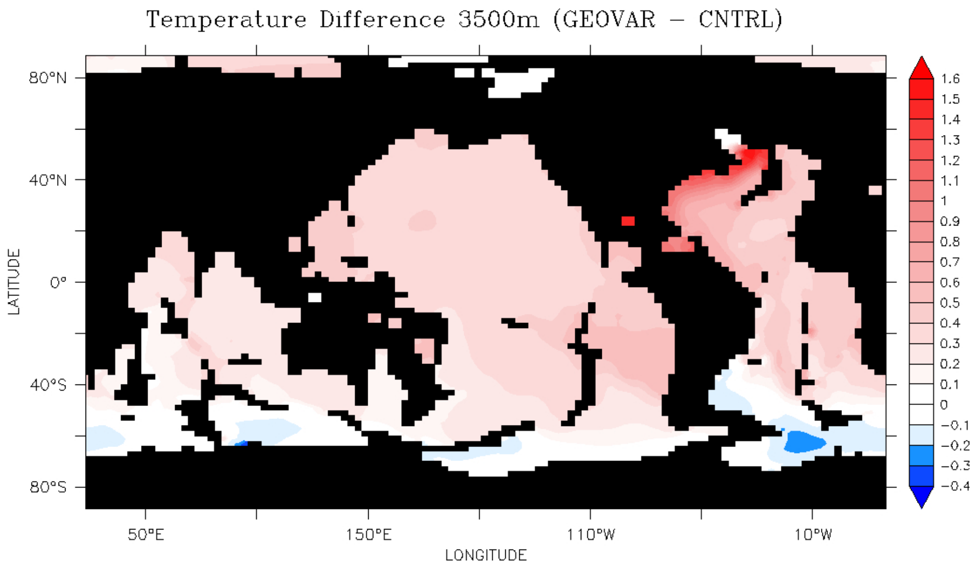


Figure 1.1. Modelled temperature difference (°C) at 3500 m depth caused by spatially distributed geothermal heating based on the age of ocean crust (Hofmann & Maqueda, 2009).

From an oceanographic viewpoint, it has been generally assumed that geothermal heating only has a small effect on global circulation, but recent modelling has demonstrated that this assumption is wrong and geothermal heating has an influence on mixing in the abyssal ocean and wider effects on the global thermohaline circulation (Fig 1.1). The modelling is parameterised on a coarse grid and results are based on passive heating above an impermeable seabed and, hence, do not include the dynamic uplift created by the hydrothermal plumes which may, through entrainment, provide a mechanism to lift the cold dense water away from the bottom boundary layer. The coarse resolution of the simulations also means that any large contrasts in the spatial distribution of geothermal and hydrothermal fluxes are not properly represented. In this project, direct measurements of ocean circulation and vertical mixing along a ridge axis and across its flanks have been made, and will be used to build the first high resolution regional ocean-crust model that accounts for both geothermal heat and mass fluxes through the seafloor.

The aims of the OSCAR project require an interdisciplinary dataset which integrates both physical oceanography and geophysical characteristics. Using these data, a new integrated model of the ocean and hydrothermal circulations at active ocean ridges and ridge flanks will be parameterised. This model will provide valuable insight and new constraints on the thermal processes involved, and will set a new benchmark for integrated Earth-system experiments, resulting in both a new representation of the geothermal fluid and heat fluxes at mid-ocean ridges and a better understanding of what geophysical and oceanographic data can actually resolve in the context of an oceanic axial ridge setting.

The coupling of the ocean and the lithosphere through hydrothermal flow, and the impacts of this flow on both the evolution of the oceanic crust and basin-scale ocean circulation, are the central themes of the OSCAR project.

1.2 Study area

A comprehensive investigation of the interaction between geothermal flow and oceanic mixing and circulation requires a combined field and modelling approach in a geothermally active region, with significant tidal and thermohaline circulation, mixing and upwelling. Also, to address the geophysical and geological effects of this hydrothermal flux requires an active spreading ridge with geological constraints provided by a borehole within a distance that can be surveyed within a single geophysical experiment.

The Panama Basin (Fig. 1.2), which contains the Costa Rica Ridge (CRR) and ODP borehole 504B, is an ideal laboratory for the investigation of these processes. There is a wealth of existing oceanographic, geophysical, geological and geochemical data acquired over many years in independent studies including: numerous heat flow measurements around 504B; detailed down-hole geological and geophysical logging; multichannel seismic (MCS) reflection and ocean-bottom seismograph (OBS) surveys over the CRR and 504B respectively; and physical oceanography (PO) data including part of a World Ocean Circulation Experiment (WOCE) profile.

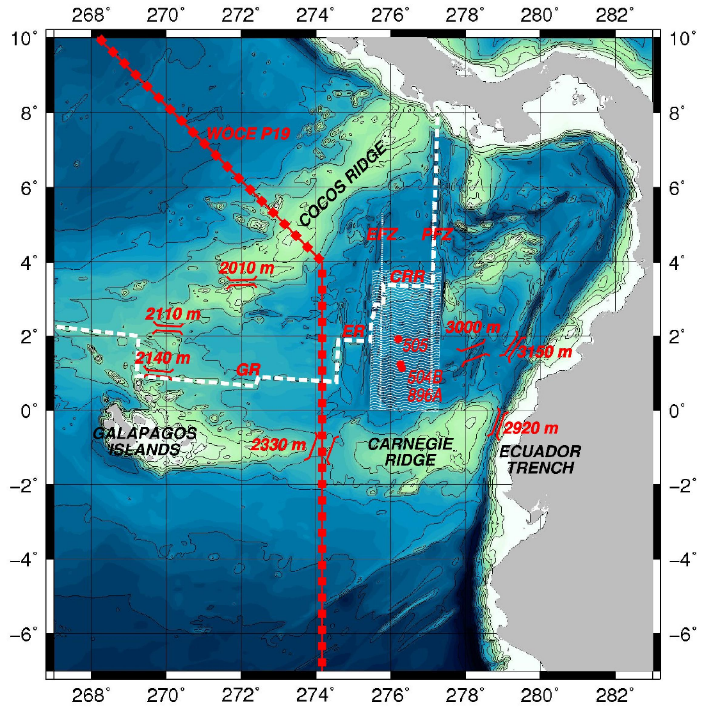


Figure 1.2. Map of the Panama Basin bounded by the Cocos and Carnegie Ridges. The spreading centre (white dashed line) and the EFZ (Ecuador Fracture Zone) and the PFZ (Panama Fracture Zone) which bound the CRR (Costa Rica Ridge) are marked. WOCE P19 is the track of the World Ocean Circulation Experiment PO profile; ODP drill sites are marked as dots, as are the location of sills and their respective depths (parallel lines). The white shaded box shows the principal research area for JC114.

The Panama Basin itself is a small ocean basin in which the direct effects of geothermal heating on ocean temperature and circulation can be measured and studied in relative isolation from large scale influences. Taking the 2300 m isobath as the basin's natural lateral boundary, then its area is a mere 7×10^5 km^2. The lateral communication between the basin and the rest of the Pacific Ocean only occurs through the 2920 m deep Ecuador Trench and the shallow (2330 m) sill of the Carnegie Ridge. It is the isolation of the basin from external influences, except inflow through the Ecuador Trench and downward mixing from above, that makes it an ideal location for the investigation of geothermal and hydrothermal oceanographic impacts.

The inflow through the Ecuador Trench was estimated by Lonsdale (1977) at 0.35 Sv. The average geothermal flux in the basin can be estimated from the digital age map of the ocean floor (Müller et al., 1997) and the Stein & Stein (1992) formula for linking the age of the bedrock to the heat flow through the crust. The basin-averaged geothermal heat flux is 273 mWm^{-2}, which is more than three times the global average. The inflow potential temperature at the Peru Basin end of the Ecuador Trench is 1.75 ºC and, on average, the potential temperature of the outflowing water at 2300 m is 2.0 ºC (Locarnini et al., 2009). Including these values the following interesting results emerge:

- the geothermal heat flux on its own is sufficient to heat up the basin by almost 0.15 ºC, and explains nearly 55% of the water temperature increase as fluid transits through the basin;

- the remaining 45% is the energy necessary to heat the water in the basin to the observed value, and must be provided by downward diffusion, with a vertical diffusivity at 2300 m of around 1×10^{-4} m^2s^{-1}, a value which is about 10 times larger that the canonical open ocean background mixing rate (e.g. Polzin et al., 1997).

These simple calculations strongly support the notion that geothermal heat flow plays a central role in the energy balance of the Panama Basin.

1.3 Project objectives

The OSCAR project is underpinned by six basic questions about the solid Earth and ocean system that were addressed during cruises JC112, JC113, JC114 and SO238. These questions revolve around a better understanding of shallow oceanic crustal structure and how fluid flows through it and conveys heat to the overlying ocean. A schematic definition of the oceanic crust is shown in Fig. 1.3, with the possible fluid flow paths marked.

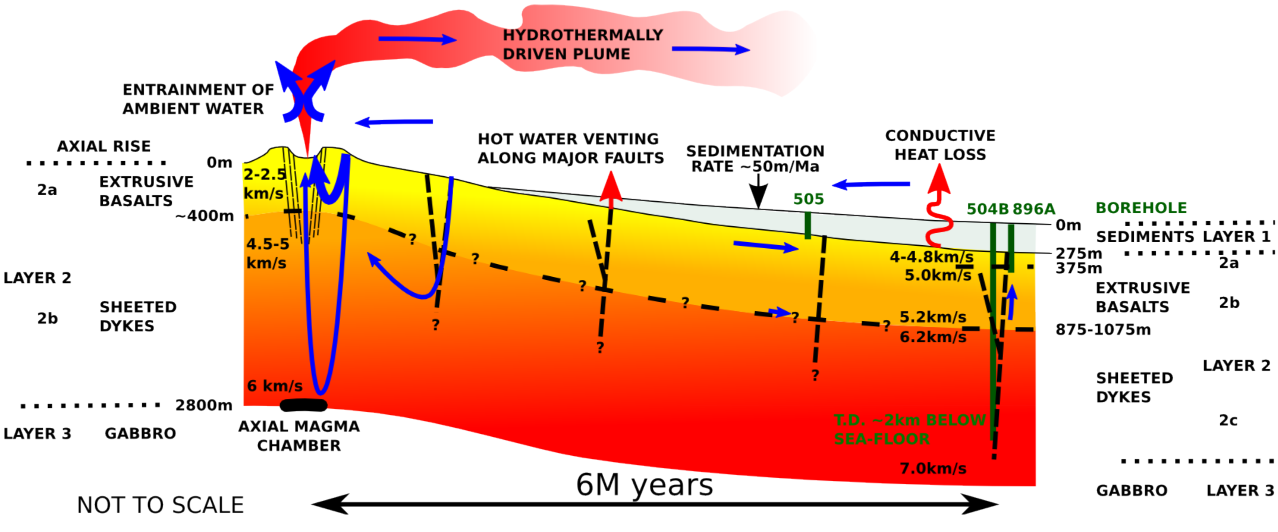


Figure 1.3. Cartoon showing the structure of the ocean crust from the Costa Rica Ridge to 504B. The blue and red arrows are indicative of the water and heat flow in the crust and ocean.

a) ***What is the layer 2A/B interface?*** At the mid-ocean ridge axis this interface is understood to represent the transition from a layer of extrusive flows to the dyke feeder system as defined by changes in the velocity gradient. As the crust ages the velocity gradient gets perturbed by chemical alteration resulting from hydrothermal circulation. The relationship between velocity and geological structure can be calibrated at 504B located some 6 Ma off-axis. The objective here is to geophysically map the transition from axis to borehole.
b) ***Do dykes play a significant role in fluid flow on- and off-axis?*** Despite their relatively low porosities, dykes have been shown by micro-earthquake and anisotropy studies to be important for ridge crest and near ridge crest hydrothermal circulation. Electromagnetic studies also show that hydrothermal fluids penetrate to the deeper parts of layer 2 and to a significant distance in the off-axis region, but their role in ridge flank fluid flow is unclear. The objective is to estimate crack density and orientation within a few kilometers of the ridge axis and how this changes on the ridge flanks.
c) ***How do faults in the upper crust influence the flow of fluids between crust and ocean?*** Tectonic features are thought to play an important role in fluid flow at upper crustal levels providing pathways through impermeable layers. For example, flow in faults beneath sediment layers on the ridge flanks, in areas without significant basement outcrop, has been proposed to explain the discrepancy between predicted and observed heat flow. The objective is to map heat flow (cruise JC113) variation relative to surface topography using swath bathymetry data, and the relationship to basement structure determined using seismic reflection and sub-bottom profiler data.
d) ***What is the role of geothermal fluxes in establishing and maintaining the heat budget of an abyssal basin?*** Theoretical observations and global ocean models indicate that geothermal heating has a strong thermodynamic signature in the abyssal ocean, of the order of 0.3 to 0.5 ºC, and is a key control on the abyssal circulation. However, observational evidence of the impact of geothermal and hydrothermal processes on the ocean circulation of any particular basin is, to the best of our knowledge, non-existent. The objective is to quantify the influence of geothermal heating on the observed temperature in the Panama Basin.
e) ***How does the basin-scale distribution of diapycnal mixing depend on the distribution and intensity of geothermal heating and hydrothermal venting?*** We anticipate that all the mixing regimes in which geothermal processes play a role can be characterised by sampling along the axial ridge valley, the ridge flanks and adjacent fracture zones. Current, temperature, salinity, turbidity and $^{3}He/^{4}He$ concentrations were measured at all depths over a spring-neap tidal cycle during JC112 and JC113. The objective is to constrain detailed basin-scale modelling of the water flow in the Panama Basin.
f) ***What is the importance of fluid exchange between the crust and the deep ocean?*** In all ocean modelling studies to date, geothermal forcing is synonymous with heat flux. None of these studies has considered the relative importance of fluid (mass) exchanges between the crust and the ocean. We know that high-temperature hydrothermal fluid is distributed over very long distances by the large-scale circulation and that significant hydrothermal flow occurs at low temperatures. The objective is to build three-dimensional coupled solid Earth ocean models to explore the influence of mass exchange and tidal forcing on geothermal heat flux.

The data from cruise JC114 directly addresses the first three (a, b & c) of these OSCAR objectives.

1.4 Cruise plan

The plan was to collect seismic data throughout the study area (Fig. 1.4) and, in particular, within two grids located at the CRR and 504B drill-hole, connected by flow-line profiles. The acquisition programme was split into three parts:

1) a dense grid of profiles at the CRR, with 25 OBSs deployed in a 5x5 grid with a node spacing of 5 km. Reflection data to be acquired along five E-W and five N-S profiles that would pass over the nodes (the North Grid, NG) and vertical array VA_01;
2) a second identical OBS grid centred on the ODP 504B borehole with a similar set of reflection profiles (the South Grid, SG) and vertical array VA_02; and
3) three 270 km-long synthetic aperture profiles joining the two grids, with OBSs deployed along the central profile (Synthetic Aperture Profiles, SAP).

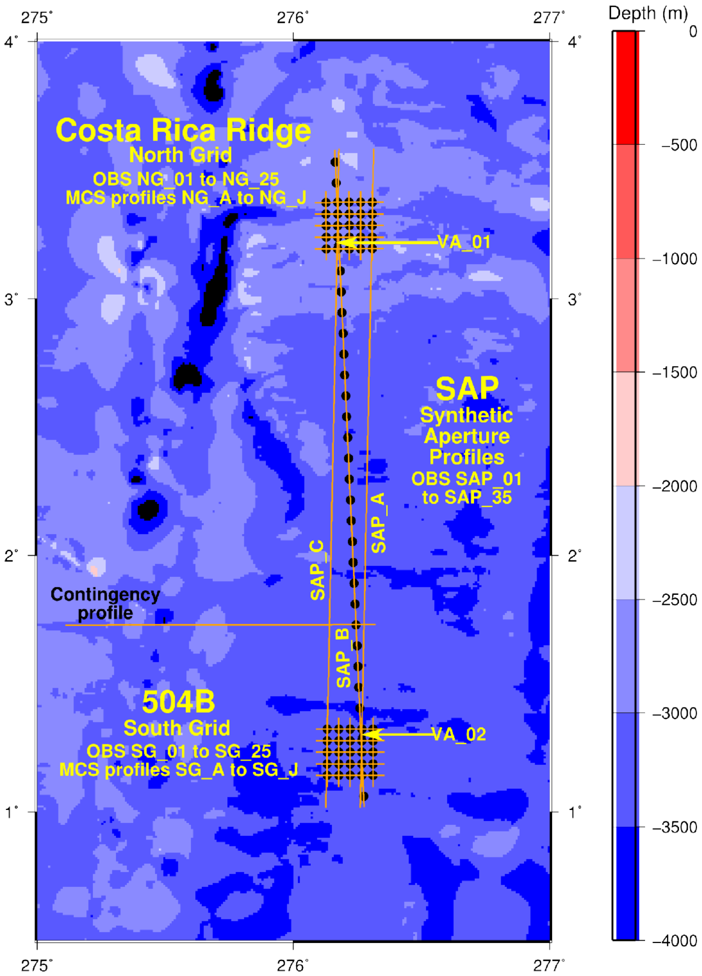


Figure 1.4. JC114 cruise plan with two grids, one centred on the Costa Rica Ridge (North Grid, NG) and one on ODP 504B (South Grid, SG), with three synthetic aperture profiles (SAP) linking the grids together. OBS and vertical array (VA) locations marked by black dots.

Pre-cruise modelling predicted that the likely critical range of offsets required to constrain layer 2 of the oceanic crust, in any resulting velocity model, would be between 3 and 8 km offset. As this exceeded the multichannel streamer length (4.5 km) available for the cruise, a synthetic aperture profiling technique was adopted which requires two vessels, one towing a seismic source and 4.5 km multichannel streamer and a second vessel with a seismic source only, that follows the first vessel at nearly twice the length of the streamer. Shots from the lead vessel provide offset ranges of 0-4.5 km and shots from the second provide offset ranges 4.5-9.0 km which, together, synthetically create the equivalent of a single 9 km multichannel streamer towed by a single vessel.

For JC114 seismic source had to perform a number of functions. Firstly, provide a high resolution image of the sedimentary cover over the oceanic basalt basement. Secondly, provide sufficient low frequency seismic energy for entire crust and uppermost mantle wide-angle acquisition. Finally, enable imaging of structure within the oceanic crust, crust itself, when the either the seabed or the sub-seabed basement surface are highly heterogeneous and scattering. Consequently, three arrays were designed: a) a GI-airgun array to provide the higher frequency sediment column and shallow basement imaging; b) a medium frequency, low volume Bolt-airgun array to provide the shallow-to-mid-crustal wide-angle imaging; and c) a low-frequency mid-to-large volume G-airgun array to provide the deep crustal-to-uppermost mantle wide-angle imaging. The GI and Bolt arrays were towed from the COOK and the G array was towed from the SONNE for the synthetic aperture acquisition only.

1.5 Trials cruise (JC110)

Prior to transiting the Panama Canal at the start of JC112/JC113, there was a short trails cruise to install and test the seismic system with the acquisition parameters required for JC114. This trials included deployment of the various COOK airgun source arrays and the multichannel streamer, and tested the Sercel SEAL data acquisition system by firing a number of test shots, with parameters set to those specified for JC114, and recording them. Also the maximum safe turning rate was established for both the 1500 and 4500 m-long streamer configurations and whether or not turns could be undertaken in both the port and starboard directions with all, or part of the towed equipment fully deployed.

The trials identified a number of problems and issues. Firstly, the allocated technical support staff were not fully aware of the acquisition parameters that the trials was supposed to test. However, this was mitigated by the presence of a senior member of the science party for JC114, who could explain the requirements to the seismic sub-contractor providing the shot firing and data recording hardware, and ensure tests were configured to meet requirements. Secondly, the time allocated to actual testing was too short to fully assess capability and ensure compliance with the specification since periods of data acquisition were limited to a few hours at best. In this context the inability to tow the Bolt array components consistently and reliably at the prescribed depth was not fully apparent, and neither was the software failure that occurred with the data-logging system at the maximum required trace length which was within the design specification as defined by Sercel. The consequences of these issues will be addressed in Sections 2.2.2 & 2.3.1.

It was observed during the trials that the front end of the streamer was very buoyant and towed too shallowly and would, at the very least, need ballasting before use during JC114, and possibly even a longer lead-in section in addition. Also it was found that whilst towing both the airguns and the multichannel streamer only starboard turns were possible to avoid the streamer tangling with the floatation buoys for the Bolt sub-arrays. The risk of entanglement is exacerbated by the propeller wash from the Cook's twin screw propulsion which draws towed equipment towards the vessel centre-line. All turns conducted whilst towing were conducted to starboard which, in some cases, would add significant amount of time to planned the acquisition, especially so for the grid surveys.

Finally, although not strictly NERC policy as yet, it is accepted that NERC-funded scientific cruises should follow the UK's Joint Nature Conservancy Committee's regulations on the mitigation of acoustic noise in the water column as best practise. As such, scientific cruises are generally required to comply with these regulations and provide an environmental impact assessment (EIA) and a marine mammal observer (MMO). This appears not to be a convention that is followed by the National Marine Facility for its seismic trials, although the same equipment is in use and the same acoustic signals are being propagated into the water column as would be the case for JC114. In the case of the JC110 trials, the scientific observer was a qualified MMO and acted on this basis as an ad hoc measure as the request of the COOK's Master.

On the basis of the JC110 trials outcome we recommend the following:

a) that a senior member of the scientific party is required to particulate in any trials cruise;
b) that a trials cruise is of sufficient duration and sufficient technically manned such that significant duration (e.g at least 24-hr operations) "soak" testing of systems can be accomplished;
c) for hired equipment, the technical support accompanying that hire for the trials cruise is specified to be the same as that to be provided for the science cruise itself; and
d) that seismic trials are subject to the same EIA and MMO requirements as scientific cruises.

2 Seismic equipment

The aims of the seismic acquisition during JC114 were as follows:

1) to image the axial magma chamber (AMC) originally surveyed during R/V Maurice Ewing cruise EW9416 to the Costa Rica Ridge;
2) to image the geometry, thickness and depositional characteristics of the sedimentary succession throughout the study area;
3) to locate the 2A/2B boundary within the upper oceanic crust and determine its variation in properties with age;
4) to provide wave-field data for full-waveform inversion of the upper crust to the base of layer 2; and
5) to map the intra-crustal layering and velocity structure and depth to Moho.

To achieve these aims the following seismic systems were utilised:

1) ocean-bottom seismic data-loggers (OBS) and GPS loggers provided by OBIF;
2) air-gun seismic source provided by NMF;
3) gun controllers, multichannel seismic streamer and data-logger provided by Exploration Electronics Ltd

The seismic source had to meet a diversity of expectations from high-frequency high-resolution imaging of the sediments to low-frequency for long-offset OBS records. To address this problem up to three sources were used for a single profile: GI-airguns provided energy at high-frequency (25-120 Hz); Bolt-airguns provided energy at mid-frequencies (10-75 Hz) and G-airguns provided energy at low-frequencies (6-32 Hz). Design of the sources is discussed in section 2.2. Timing of these sources was critical to the success of the project, this is discussed in section 2.1.

2.1 Shot firing

On the COOK two Avalon RSS-2 gun controllers were used to fire each of the GI- and Bolt-airgun arrays while for G-airgun array on the SONNE, the shot firing was controlled by a Real Time Systems Long-shot system.

The COOK shots for each set of lines were manually started on each gun controller with the GI-airgun array being fired first (at time zero) and the Bolt-airgun array fired second with a 6 s delay after the GI airguns (the combination of both shots is defined as a shot pattern). The delay was chosen to avoid the seabed-sea surface multiple of the GI shots coinciding with the primary arrivals from the Bolt shots at the OBS stations. For the NG amd SG profiles, the shot pattern was repeated on a 30 s interval. For the SAP surveys the pattern interval was increased to 60 s to include the SONNE G-airgun array which was fired at 30 s after time zero. For the EX profiles the pattern interval was 20 s and for RS_A and RS_B the interval was 15 s and 60 s respectively. The shot firing timing diagram is shown in Fig. 2.1 together with a summary in Table 1. Throughout the cruise the ship speed through the water was kept as close to 4.9 knts as possible to ensure a constant drag on the source array so the guns would maintain a constant depth to give source signature stability. Due to the effect of wind driven surface currents this results in a variable shot spacing see Appendix B. All shot times and locations were logged against GPS synchronised clocks provided by OBIF.

The SEAL seismic acquisition system (Section 2.3) was triggered by the GI-airgun controller (except for line RS_B which was triggered by the Bolt-airgun controller). The recorded trace record starts 50 ms prior to shot "aim point", the maximum amplitude of the initial acoustic pulse, with the trace length optimised for each group of profiles see Table 1 and Appendix B. For the EX, NG & SG profiles each shot record contains both the GI- and Bolt-airgun source. For the SAP profiles each shot record contains the GI-, Bolt- and the SONNE G-airgun source (note the G-airgun source controller was set with a different “aim point” delay (see Section 2.3.3); for profiles RS_A and RS_B the shot record contains the GI- or Bolt-airgun source respectively. A shot record on the multichannel streamer from an SAP profile shown in Fig. 2.2, this record is then divided into individual shot records as shown in Fig. 2.3.

Profile	**Shot pattern repetition interval (s)**	**SEAL record length (s)**
EX	20	17
NG, SG	30	27
SAP	60	47 (revised to 41 to avoid SEAL data recording issues)
RS_A	15	10
RS_B	60	17

Table 1. Summary of shot timing and multichannel seismic reflection record length, for full details see Appendix B.

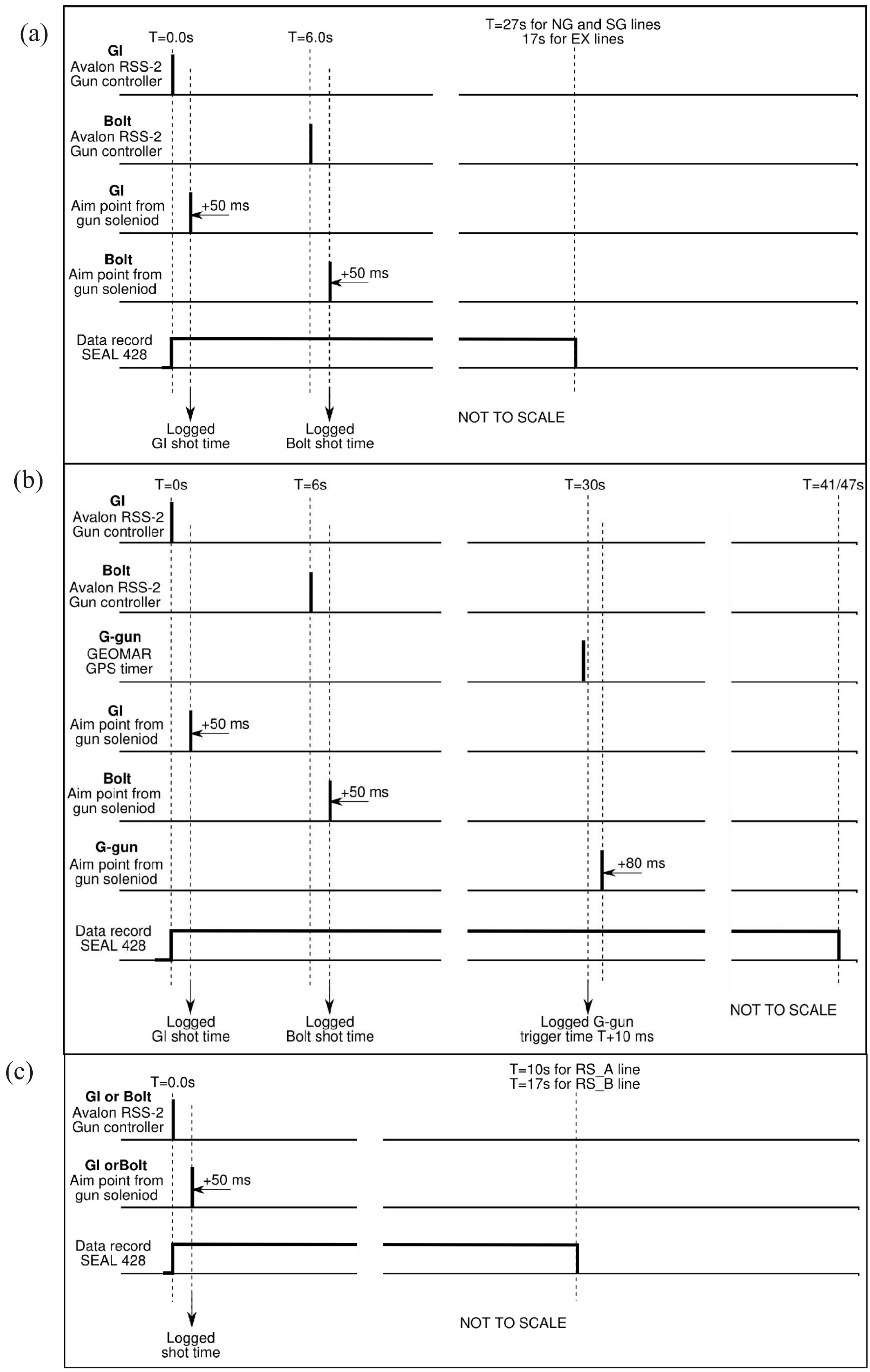


Figure 2.1. Timing diagrams showing trigger, shot fire time "aim point", logged shot time and record length for the multichannel seismic reflection data: (a) timing for the NG and SG profiles; (b) timing for the SAP profiles; (c) timing for the RS profiles.

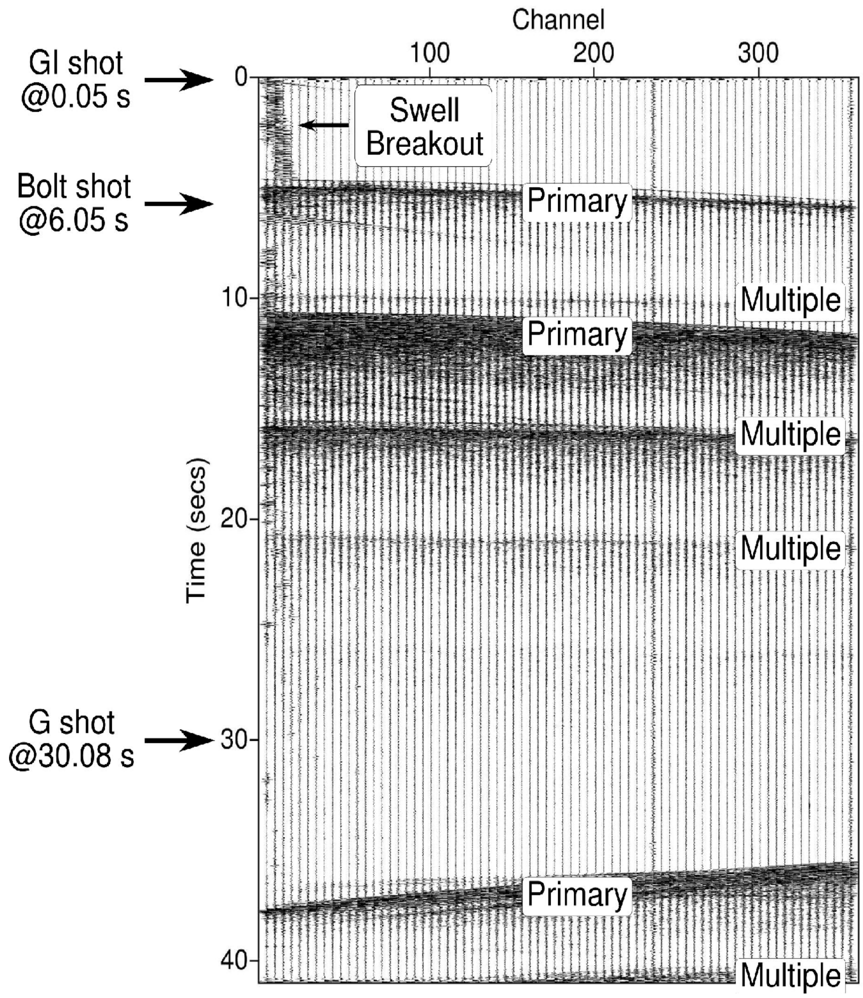


Figure 2.2. Shot record from SAP_A showing the three separate shots GI-, Bolt- and G-airgun arrays recorded on a single composite record. GI array fired at 0.05 s; Bolt array fired at 6.05 s and the G array shot fired at 30.08 s. Swell breakout noise tended to be more severe on the near-offset channels due to the front section (channels 1-12) being shallower than the specified depth of 10 m despite ballasting. For processing each shot type is extracted into its own separate record as shown in Fig. 2.3.

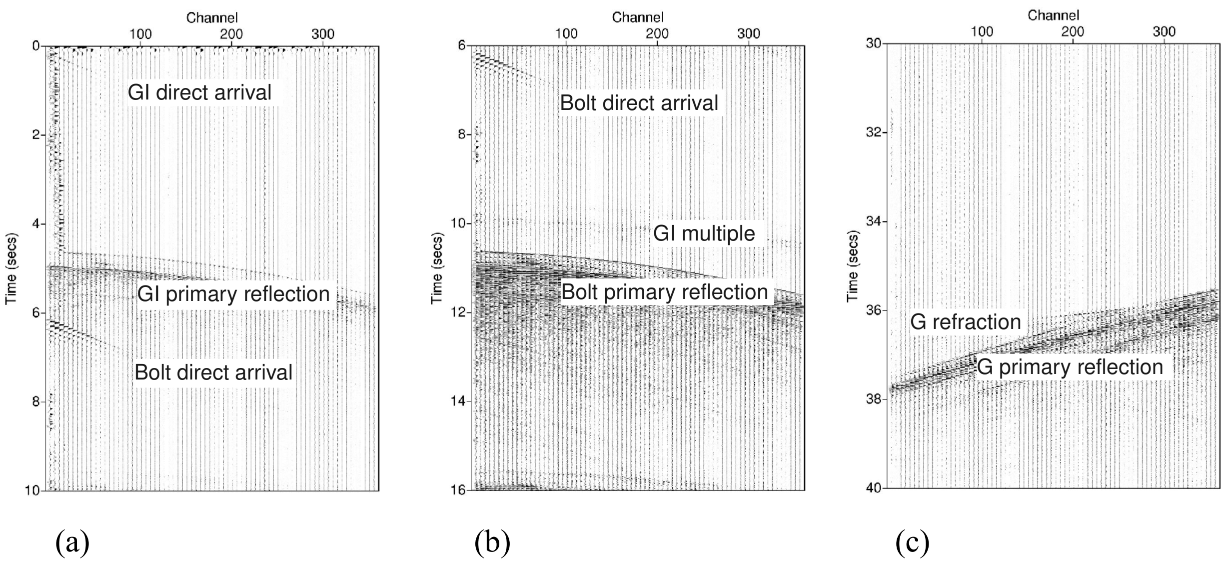


Figure 2.3. Extracted 10 s records for each of shot type: (a) GI shot; (b) Bolt shot; (c) G-gun shot.

2.2 Seismic sources

The diverse range of objectives posed a problem for optimum airgun source design. Imaging the sediment column requires a high-frequency seismic signal to resolve the fine-scale layering, whereas the wide-angle, whole crustal imaging requires a low-frequency signal to mitigate against attenuation. Additional constraints on the number and type of airgun arrays that could be towed were imposed by the limited available deck space. Consequently, the plan was to deploy six Bolt-airguns on two sub-array beams on the port side, together with a two GI-airguns on a single 3 m beam on the starboard side (Fig. 2.4).

An added complication was that GI- and Bolt-airguns prefer to operate at different pressures – 3000 psi in the case of GI-airguns and 2000 psi in the case of Bolt-airguns. However, the high pressure air manifold on the COOK can only distribute air at a single pressure. Consequently, the GI-airguns were operated at 2000 psi which degraded their output to some extent.

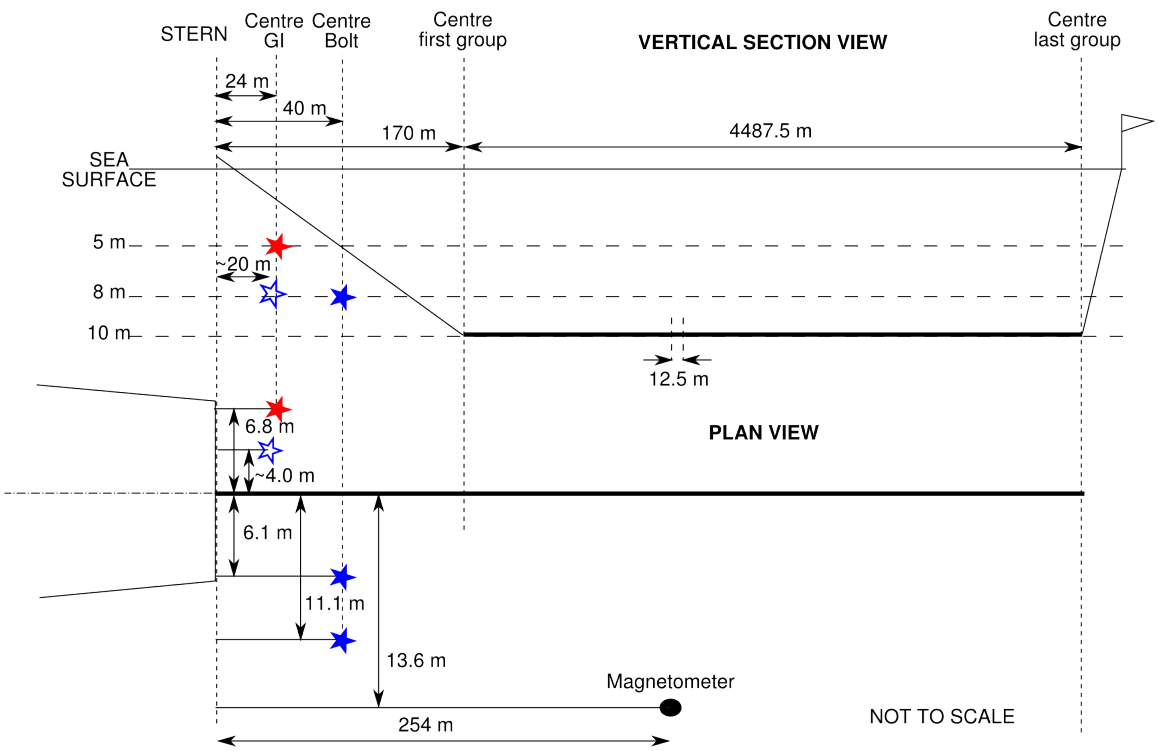


Figure 2.4. Layout of airgun sources and streamer used for the NG, SG, EX and SAP profiles; red – GI sub-array; blue – Bolt sub-array; filled stars represent centre-sub-array locations; the open star represents the additional single Bolt 500 in^3 gun towed for the EX, SG and RS_B profiles.

The source needed to provide a stable and consistent source signature to support waveform inversion. Previous experience of using airgun sub-array beams supported by a single float at the rear (e.g. RRS Discovery cruise D318) showed that, using the normal NMF approach, the beams carrying the Bolt guns do not tow horizontal and that the airgun depth of the lead (nearest stern) gun is strongly effected by tow speed through the water and distance behind ship. To meet the aims of OSCAR the beams were buoyed at both ends. For the longest-offset data data acquisition, a low frequency seismic source was provided by the SONNE during SO238, which comprised G-airguns towed using a J-rail deployment system. Details of exact seismic source configurations adopted for each profile acquired during JC114 are listed in Appendix A, and are summarised below in terms of their generic type.

2.2.1 High-resolution source

The high-resolution source consisted of a pair of GI-airguns configured to operate in harmonic mode (generator and injector chambers of the same size), towed 3 m apart one behind the other on a beam, with depth of tow controlled by a single buoy on a 5 m rope. Each gun had a total volume of 210 in^3 (105/105 in^3) and was operated at a pressure of 2000 psi for the reasons outlined above. This array was towed from a single point on the port quarter as it was small and light enough be retrieved using a deck mounted winch.

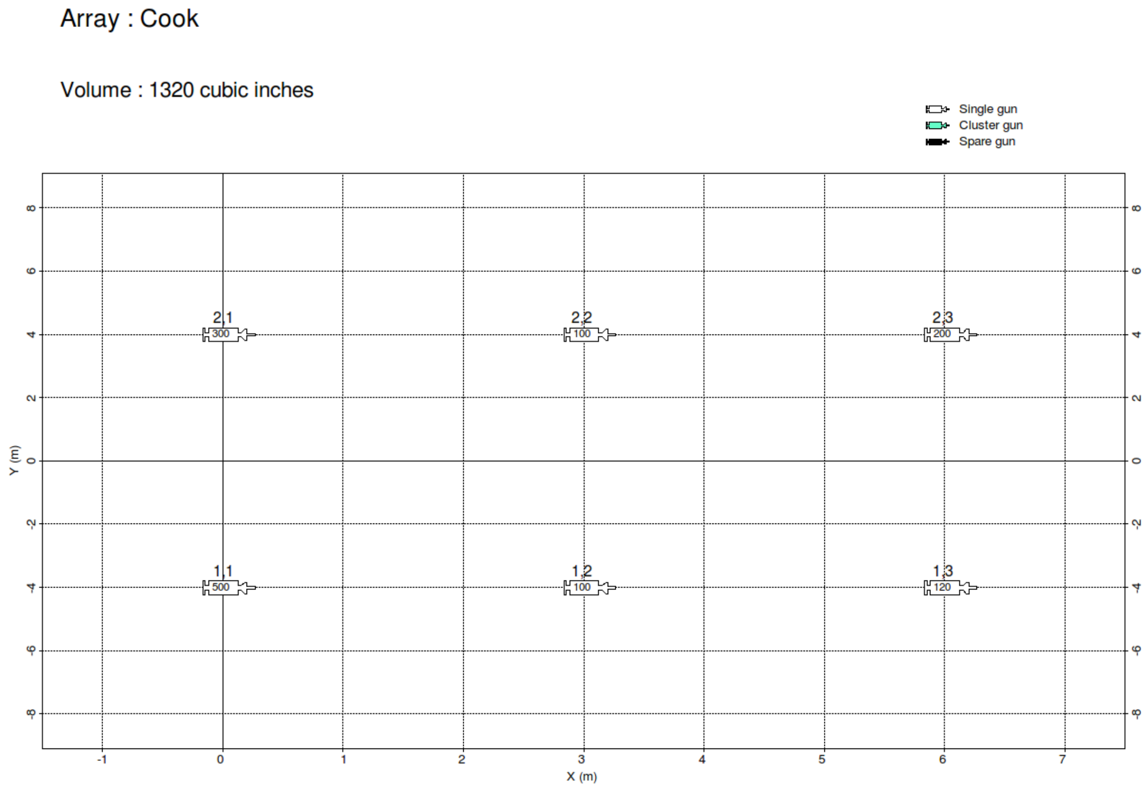
One of the synthetic aperture profiles (SAP_A) was co-located with a series of heat flow probe measurements made during JC113. This was reshot during JC114 (profile RS_A) to image the sediment column and basement surface at high resolution to best-constrain the geological setting of these heat flow measurements. The GI-airgun array was reconfigured to a tow depth of 3 m and multichannel streamer to a tow depth of 3 m (up to group 120) and 5 m (groups 121-360) to achieve the highest resolution possible with the available systems.

The GI high-resolution source was fired first all profiles was used as the reference time (T_0) for the other sources and trigger for the Sercel recording system (Fig. 2.1), except the final low-resolution line RS_B where the GI-airgun array was not used.

2.2.2 Medium-resolution source

The medium-resolution source design consisted on six Bolt 1500LL airguns towed on two beams of three-airguns each giving a total volume of 1320 in^3 fired at 2000 psi. The beams were buoyed at both ends to ensure the 8 m-defined source depth was kept constant irrespective of the speed through the water. This source was designed to provide a lower resolution reflection image of the sediment column and crust, ideally down to Moho depth, and also act as the source for the wide-angle OBS acquisition within the North and South Grids (NG and SG profiles) and SAP-B profile out to ranges of 30 km from an OBS, that should result in the recording of signals having travelled through the crust down to the Moho.

The source was initially comprised of six airguns (2x100, 120, 200, 300 and 500 in^3). Fig. 2.5 shows the predicted source signature for this array. The array was designed using the PGS Nucleus+ software provided to Durham University under an academic license. During the cruise the source was modified to overcome operational issues, which did not become apparent during the JC110 trials cruise. The original design layout was for the larger guns (300 and 500 in^3) to be at the front of each beam sub-array as per industry convention. In this position, the 500 in^3 airgun repeatedly failed with a sheared air-line connector, thought to result from recoil of the gun body and collision against the tow beam when more rigidly constrained at depth by towing floats fore and aft. As a test, the front float was removed. Though this cured the problem, the beam no longer towed horizontally at the specified depth at profiling speed and umbilical tow length. These factors play a significant part in determining the waveform shape generated by the array and consequently will impact on data quality, resolution and use for waveform inversion. The next iteration was to reverse the airgun order on the beams putting the 300 and 500 in^3 airguns in the aft positions so that there was no beam directly astern to collide with on recoil, and reverting to double floating to control the tow depth and horizontal geometry. Although this prevented any further shearing of the air-line connector, there was repeated failure of the air hose to the 500 in^3 airgun. The final iteration was to remove the 500 in^3 airgun from the sub-array entirely and replace it with a spare 300 in^3 airgun, thus reducing the total array volume but the array was now reliable.



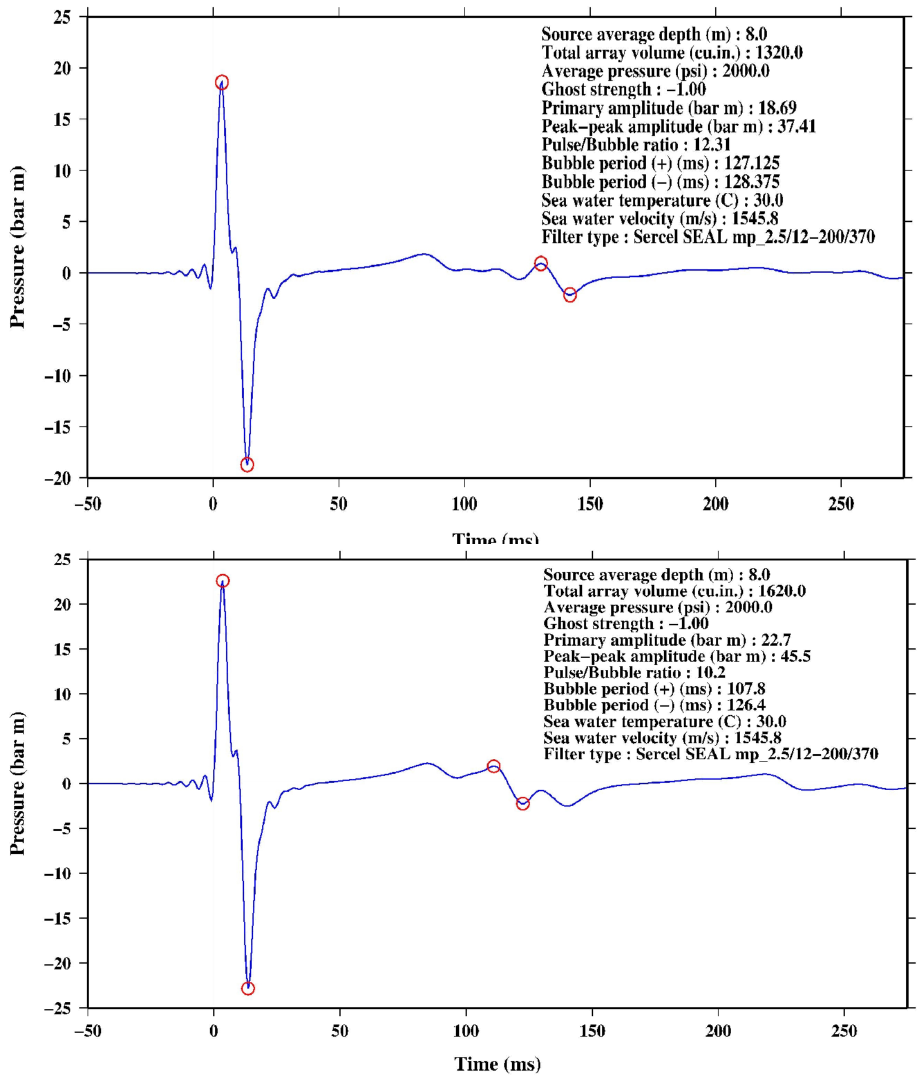


Figure 2.5. Layout and predicted source signature from the COOK Bolt airgun arrays. The upper signature is for the originally designed 1320 cu in array of six guns (illustrated). The lower signature is for the modified 7-gun 1620 cu in array where GUN 1,1 is replaced by a 300 cu in and an extra 500 cu in gun is towed directly over the stern of the vessel about 20 m in front of the main array. Source modelled using the PGS Nucleus+ software.

To ensure sufficient signal amplitude and low-frequency content for the deeper crust-uppermost mantle OBS tomography, for the the reshoot profile (RS_B) into the OBSs located on profile SAP_B and the EX and SG profiles, an additional 500 in^3 was towed as a single airgun (no float) from the stern through the A-frame. Towing without flotation meant there was no absolute control on the tow depth of this airgun although, judging from the bubble rise time, it appeared to be ~8 m. An estimated source wavelet for this modified source assuming tow depth of 8 m is shown in Fig. 2.5. The main difference is an increase in the peak-to-peak amplitude and a decrease in the peak to bubble ratio. For the two-ship, synthetic aperture acquisition with the SONNE, the 500 in^3 airgun was not used as the low-frequency, deeper imaging signals were provided by the SONNE G-airgun array.

The medium-resolution source was fired at T_0+6 s (6 s after the GI-airgun array) along all profiles except the high-resolution RS_A where it was but not used. On RS_B the GI-airgun was not used and this source was fired at T_0.

2.2.3 Low-resolution source

This source was configured as a nine G-airgun array towed by the SONNE. The resulting signals were recorded by the multichannel streamer towed by the COOK and the OBSs deployed along SAP-B. The total volume of this array was 4280 in^3 and it was fired at 3000 psi. Layout and prediced source is shown in Fig. 2.6. The objective to provide low-frequency energy for long-offset wide-angle OBSs recording along the synthetic aperture profiles was fulfilled, with usable data recorded to >80 km offset. However, as a second seismic source for the synthetic aperture profile itself, the source proved just adequate as the shape of the initial pulse was poor with evidence of poor gun synchronisation.

The low-resolution source was fired at T_0+30 s (30 s after the GI-gun array).

For analysis of the OBS and to be able to merge the G-gun shots with the Bolt shots required that both ships shoot against a common GPS time standard. To fulfil this requirement, GEOMAR, the provider of the source for the SONNE, had developed a GPS synchronised trigger box which sent a trigger pulse to their Real Time Systems gun controller. The shot timing logging systems were connected to this trigger and logged a time that was 10 ms later than the actual trigger time. The clock time break (CTB) output of the airgun controller is the actual "aim point" that the controller uses to synchronise the peak acoustic output of the individual guns. The delay between the trigger and the CTB is dictated by the default settings or the slowest firing airgun, with the fire pulses for the other airguns in the array dynamically adjusted to the CTB on a shot-by-shot basis. The shot time required to process the synthetic aperture data is the CTB not the external GPS trigger pulse. When analysing the shot log from the SONNE the error became apparent as it was not possible to match the arrival times of the shots fired by the COOK and SONNE with the recordings made by the multichannel streamer. Discussion with the science party on the SONNE, provided evidence that CTB delay was set to 80 ms after trigger (or 70 ms after the logged time). This was tested by comparing the time of arrival of the direct wave recorded on an OBS from shots fired by the COOK and SONNE. A delay between the two sources was observed which, to within picking uncertainty, confirmed this 80 ms delay and thus gave confidence that this was the default SONNE gun controller system setting. Application of the calculated shifts to the multichannel reflection data correctly aligned the recorded reflected and refracted arrivals so that the shots from the Bolt- and G-airgun sources could then be merged to synthesise a 8.5 km streamer (Fig. 2.7).

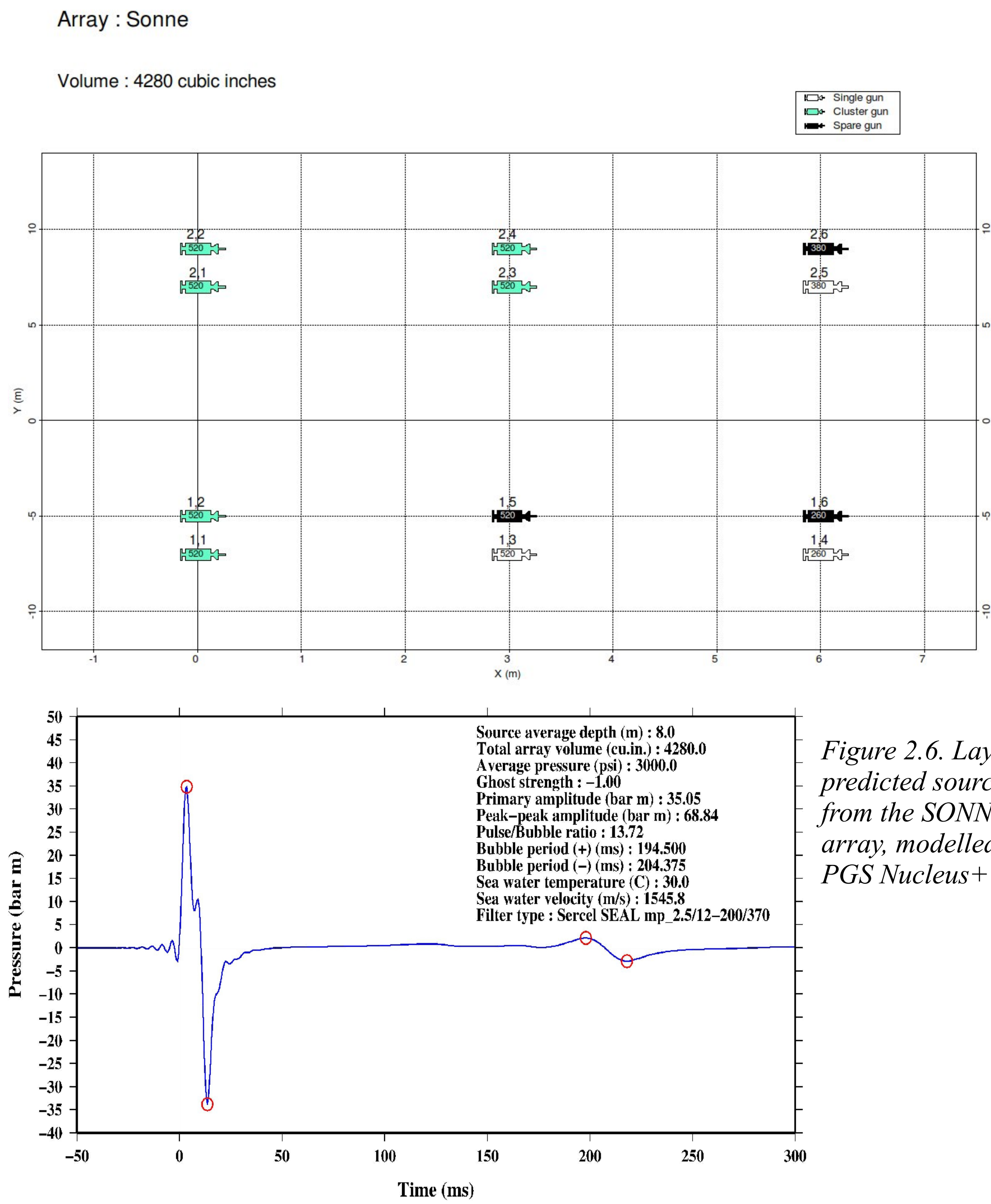


Figure 2.6. Layout and predicted source signature from the SONNE G airgun array, modelled using the PGS Nucleus+ software.

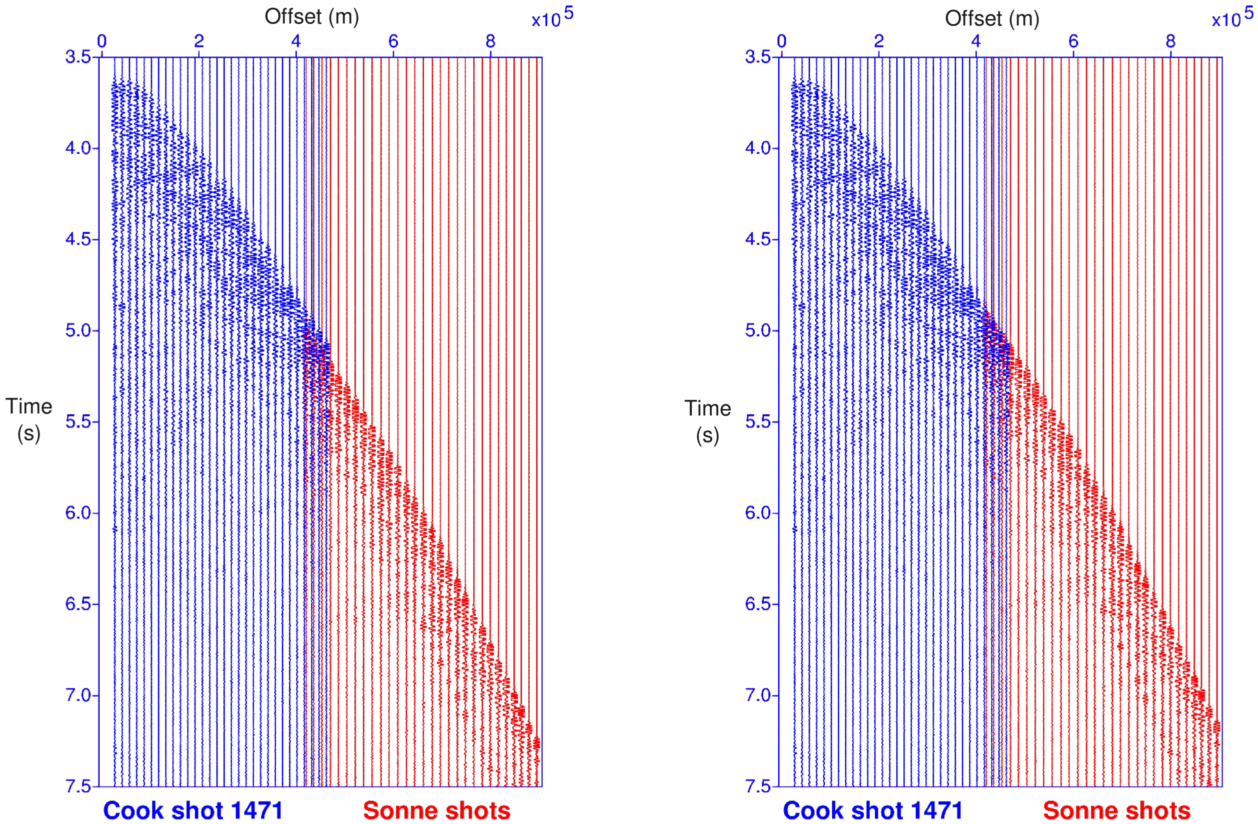


Figure 2.7. Left: merged shots from the COOK (blue) and SONNE (red) before correction. Right: merged shots after correction, note the improved match in the overlap zone between 4.2 and 4.5 km offset. A 300 m overlap between shot recordings from each vessel was purposely designed to verify geometry.

2.3 Seismic receivers

Three types of seismic receivers were used during JC114:

a) a towed Sercel multichannel streamer hired from Exploration Electronics Ltd. (EEL), together with a Sercel SEAL 428 acquisition system;
b) ocean-bottom seismographs provided by the NERC's Ocean-Bottom Instrumentation Facility (OBIF); and
c) vertical hydrophone arrays, bespoke designed and built by OBIF with moorings provided by the National Marine Facility's (NMF) Moorings Group.

2.3.1 Multichannel streamer and acquisition system

A 4500 m length of Sercel Isopar-filled multichannel streamer was used for JC114. This streamer was wound onto a winch provided by NMF and consisted of, outboard-to-inboard:

1) tail buoy with light and radar reflector;
2) tow rope ~50 m in length followed by a 50 m stretch section;
3) 30 active sections each 150 m long and with 12 active channels with a LAUM power/digitiser/relay unit located every 5 sections;
4) depth control birds with compasses every two sections (300 m apart) for 4500 m streamer; configuration and every section (150 m apart) for the 1500 m streamer configuration;
5) two 50 m spring sections;
6) armoured lead-in cable.

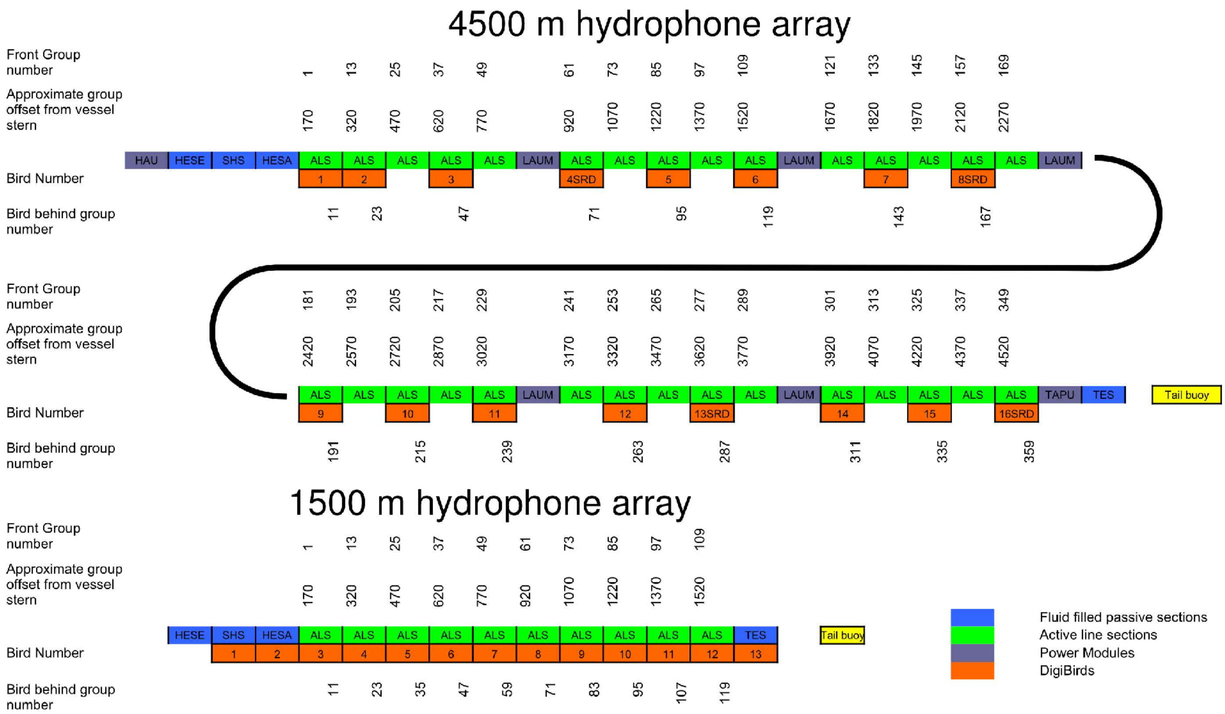


Figure 2.8. Layout of hydrophone array in both the 4500 m and 1500 m configurations. Birds with SRD have emergency buoyancy pods to prevent the streamer going to depths of more than 30 m.

On initial deployment ballasting was undertaken to adjust the neutral buoyancy depth of the streamer to the water conditions in the Panama Basin. This neutral ballasting was achieved by addition of bronze collars at pre-calculated offsets along the streamer length. However at profiling speed with the 4500 m streamer deployed it was not possible to keep the first active section at the design tow depth. A solution would have been to use a longer armoured lead-in section, but as this was not an option available the first active section (groups 1-12) was treated as part of the lead-in with the depth control starting at group 11. This means the first 12 receiver groups are noisy (Fig. 2.2) and need to be muted during processing.

The streamer was configured in two alternative arrangements (Fig. 2.8). The first configuration was only used for the North Grid survey, and consisted of a 1500 m array. This length of streamer did not require the extra power modules (LAUM). After deployment from the winch, the streamer was clamped off and separated from the remaining 3000 m on the winch, and then directly connected to the SEAL acquisition system via an adapter and deck cable. The second configuration, the full 4500 m, was used for the remainder of the cruise and was towed directly from the winch. The original rational for using a shorter streamer on the grid surveys was to save time, by negating the need for long open turns between the profiles that were only 5 km apart. In the event, rate of turn restrictions and the ability to only turn to starboard meant the time saved by only using the shorted streamer was limited. In contrast, there was a significant time saving achieved by not having to reconfigure the streamer back to 1500 m operation for the South Grid having shot the synthetic aperture profiles with the full streamer length.

Several repairs were made to the streamer during JC114. Most of these involved sealing leaks in the streamer skin. Two active sections were replaced; one at the front of the streamer that had become noisy and one at 3 km offset length that was thought to be the cause of failure of the acquisition system to record with the 47 s record length required for the synthetic aperture profiles. Prior to shooting the South Grid one of the emergency buoyancy floats was triggered at depth control bird #13. To minimise lost time the MOB-boat was launched and the offending bird and buoyancy float removed though this did mean that groups 270-290 tended to run deeper than the rest of the array.

A Sercel SEAL-428 used to record the streamer output (Fig. 2.9). This provided the necessary pre-processing and storage for the raw data in SEG-D format, a visual QC system for monitoring the streamer output during acquisition, and a shot record display post-processing and conversion to SEG-D. Data were stored locally by the SEAL system then automatically backed-up on a NAS provided by EEL and a second NAS provided by the OSCAR project.

For the North Grid and South Grid surveys the SEAL was triggered every 30 s with a 27 s record length. For the SAP surveys the SEAL was trigged every 60 s with a nominal 47 s record length but this was changed during survey to 41 s to prevent an intermittent SEAL hang-up and data loss. For the EX survey the shot interval was 20 s with a 17 s record length. For the RS surveys the record lengths where optimised for the objectives of each profile. See Section 4 for examples of data shot by each array and Appendix A & B for the details of each sub-survey configuration, shot numbers (FFID) and distribution of shot spacing associated with each profile.

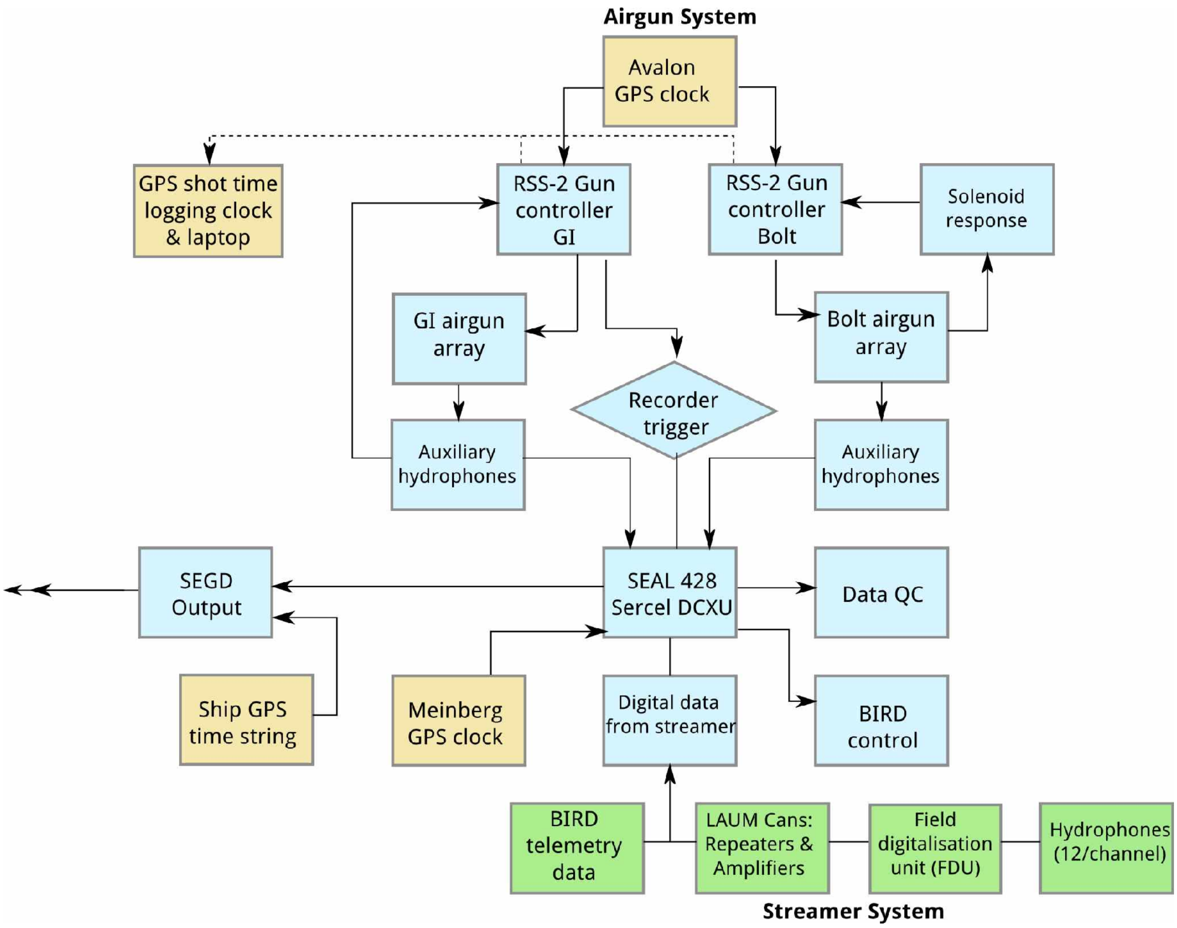


Figure 2.9. Schematic diagram of seismic acquisition system. Although there were two array seismic sources (three when working with the SONNE on the SAP survey) they were all recorded in a single SEG-D file which was then split into the separate records based on the logged shot times, see Figs. 2.2 & 2.3.

2.3.2 Ocean-bottom seismographs

During JC114 OBSs were deployed:

1) to passively record seismicity at the Sandra Ridge for the National University in Bogota;
2) to determine the velocity structure of the oceanic crust and upper-most mantle;
3) to determine seismic anisotropy within oceanic crustal layer 2 for crack/fracture analysis;
4) to measure the far-field characteristics of each seismic source array.

The OBIF provided 46 four-channel OBSs for JC114, configured to record both three-component geophone and hydrophone data. These seabed platforms comprised three models: 17 of the older "LC2000"-type; 27 of the current generation "4x4"-type; and two prototypes of the next generation. All OBSs used the same sensor configuration - Sercel L-28 4.5 Hz vertical and horizontal geophones and an High Tech HTI-90-U hydrophone. The "LC2000" records to a buffer that periodically copies to a hard disk (the disk is spun-down in the intervening periods to save power); the "4x4" records to compact flash. The new generation prototypes record to micro-SD cards and were deployed for full system test purposes only. The OBS time was calibrated prior to launch and on recovery against GPS clocks provided by OBIF.

In total there were 81 OBS deployments completed during JC114 which are detailed in Appendix C. The OBS deployment sites within each survey area were named using the convention XX_YY, where XX refers to the location:

SR	Sandra Ridge
NG	North Grid
SG	South Grid
SAP	Synthetic Aperture Profile

and YY is a site number. For example, OBS 25 in the North Grid would be called NG_25.

Four "LC2000" were deployed at the Sandra Ridge for passive monitoring of seismicity (Fig. 2.10). Twenty-five "4x4" were deployed in each of the North Grid and South Grid (Figs. 2.11 & 2.12 respectively). A further 25 instruments (15 "4x4" and 10 "LC2000") were deployed along the central synthetic aperture profile (SAP_B) (Fig. 2.13). The prototype tests were included in the South Grid by doubling-up deployments with other instruments for direct comparison of recording purposes at locations SG_08A and SG_13A (Fig. 2.12).

The OBSs in the North Grid and the five northerly SAP OBSs (SAP_01, 02, 08, 09 & 10) were deployed with three-footed concrete ballast weights as these would land on basaltic crust with little or no sedimentary cover. The remainder deployed with a flat metal ballast weight. A "drop and go" deployment strategy was adopted as accurate relocation of instrument on the seabed could be achieved using the direct water-wave

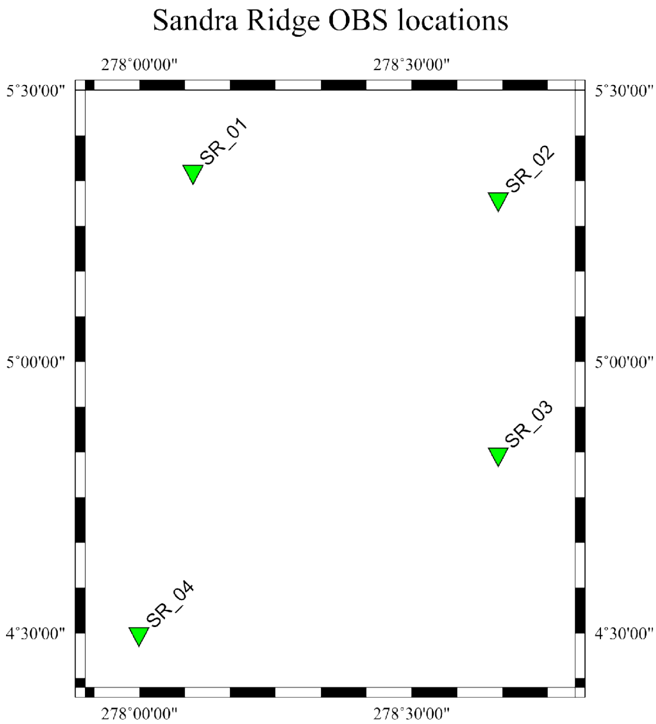


Figure 2.10. Location of passive recording OBS (green triangles) deployed at the Sandra Ridge

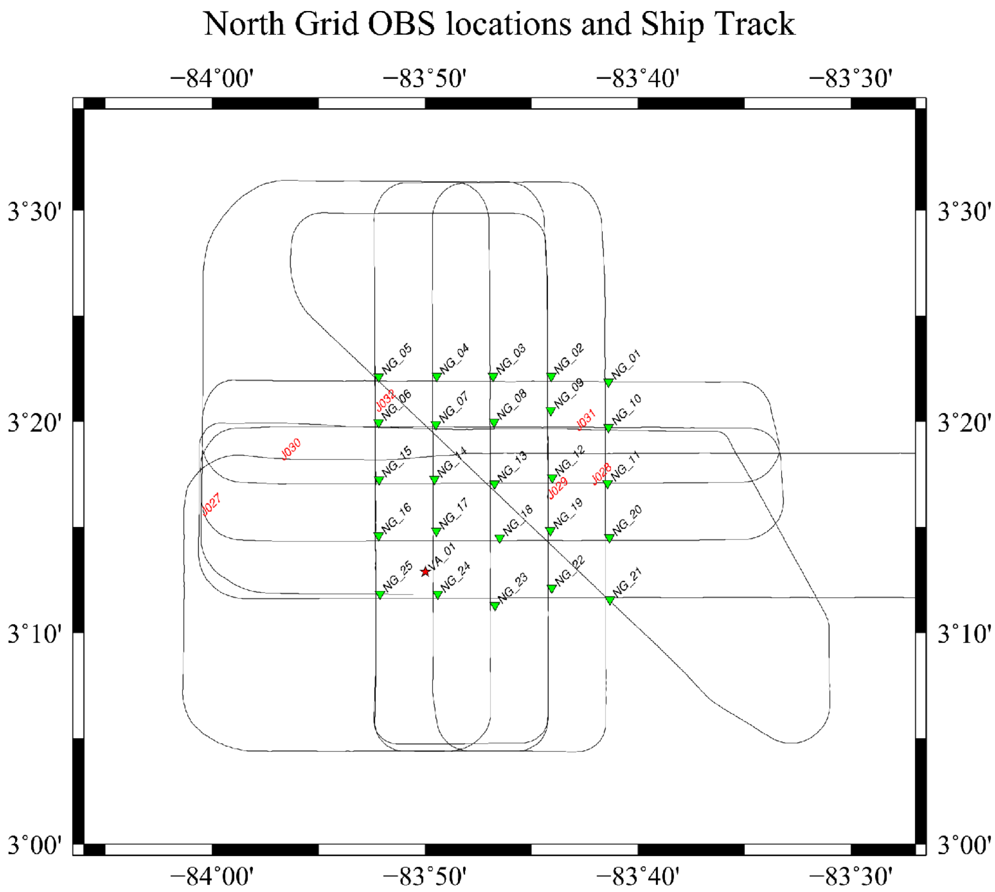


Figure 2.11. OBS (green triangles) and vertical array (VA_01) (red star) locations in the North Grid area with ship-track of the the recorded airgun sources.

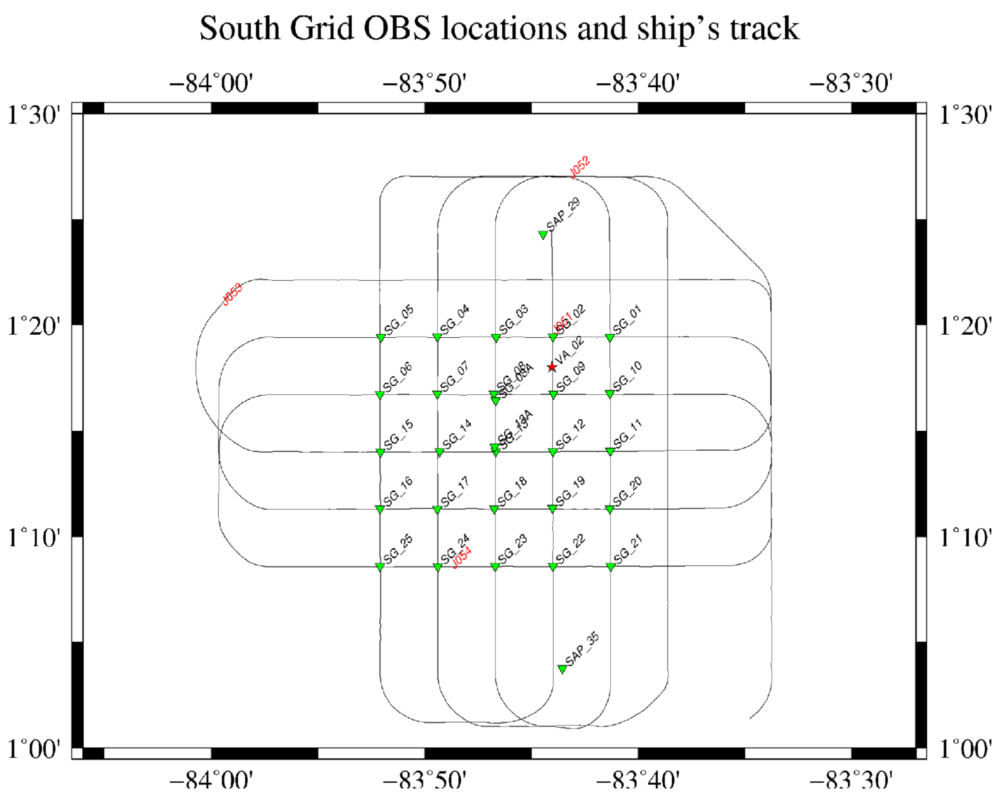


Figure 2.12. OBS (green triangles) and vertical array (VA_02) (red star) locations in the South Grid area with ship-track of the the recorded airgun sources.

arrivals from any of the seismic arrays whose firing location is accurately known. For recovery, the release enable command was generally acknowledged at ranges of 4-5 km from the OBS which activated the burn-wire releasing the bottom anchor weight. The rise of the OBS, about 1 hr, was monitored so the ship could position itself close to the expected surfacing point. This made best-use of the ship time and accrued significant contingency time which was used to shoot the EX and RS profiles (see Section 4). For the North Grid at CRR axis, recovery proceeded along east-west transects to minimise the possible effects of topography creating acoustic shadow zones and preventing long-distance activation of the release.

During JC114 the OBIF team developed and tested software to automatically monitor the slant range data output from the release deck unit and, together with anticipated rise time curves, predict when the instrument would surface. All OBSs were equipped with a flag, light and radio to assist in location and recovery. A direction-finding antenna mounted on the bridge roof provided additional surface time and bearing information to ensure quick location and recovery of each surfaced instrument.

The data quality is excellent. Only one instrument failed to record any useful data, another developed a data-logging error and two more lost one channel out of four, although in each case not a channel that would form part of the primary data analysis.

Predictably, the GI-airgun array did not produce seismic signals of sufficient amplitude or low enough frequency to be observed beyond 5-10 km from each OBS. However, the high-resolution GI-source direct water-waves will aid accurate location of each instrument on the seabed. Both the COOK Bolt-airgun and the SONNE G-airgun arrays generated usable data with offsets out to ~30 and ~80 km respectively. Figs 2.14 and 2.15 show examples of the OBS hydrophone data from the North Grid and South Grid respectively, Fig. 2.16 shows an example of one of the horizontal geophone components from the South Grid which shows strong s-wave arrivals converted at the sediment/crust interface. Fig. 2.17 shows a local seismic event recorded as part of the Sandra Ridge deployment.

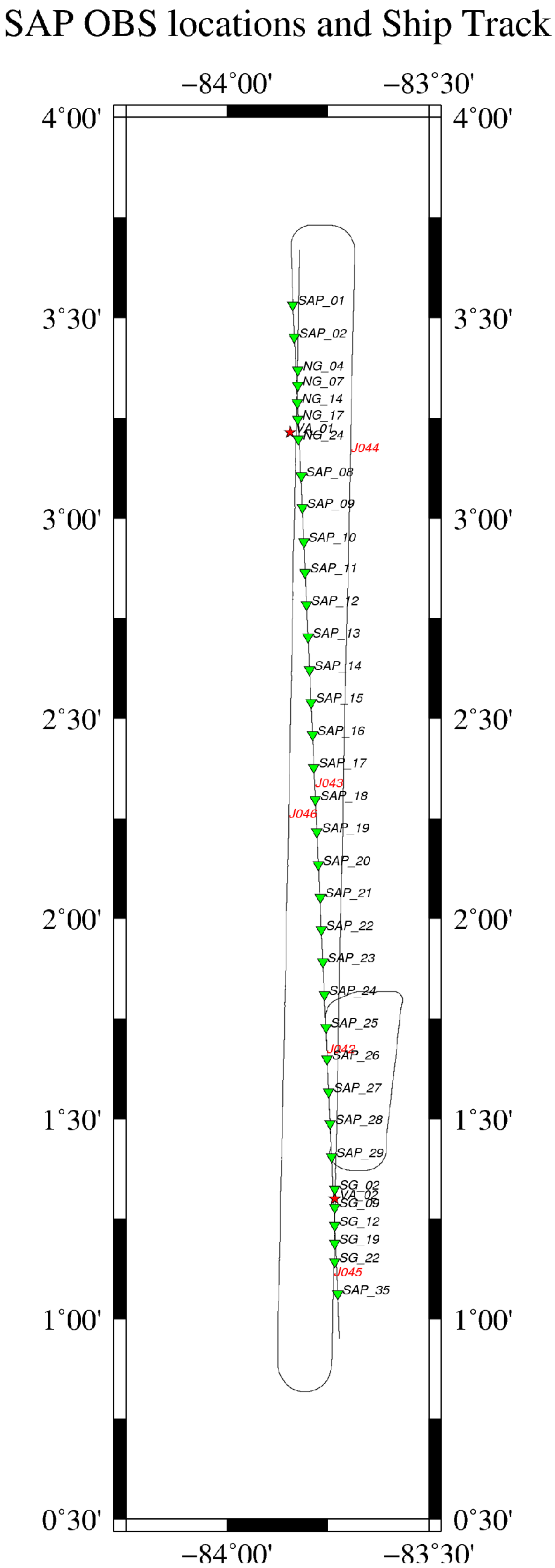


Figure 2.13. OBS (green triangles) and vertical arrays (red stars) locations for the Synthetic Aperture Profiles (SAP) area with ship-track of the the recorded airgun sources.

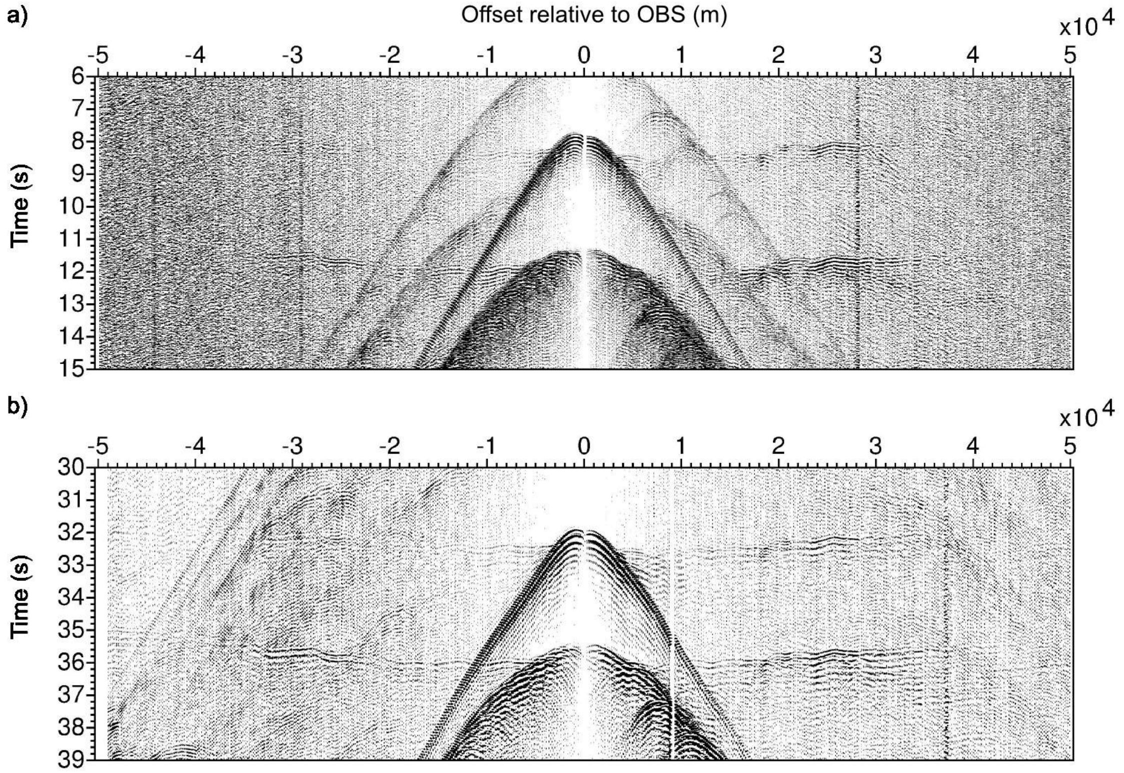


Figure 2.14. Example data from the hydrophone channel for an OBS recording the two-ship SAP_B profile from the North Grid, plotted reduced at 8 km s^{-1}. (a) Record section from the COOK Bolt source. (b) Record from the SONNE G source.

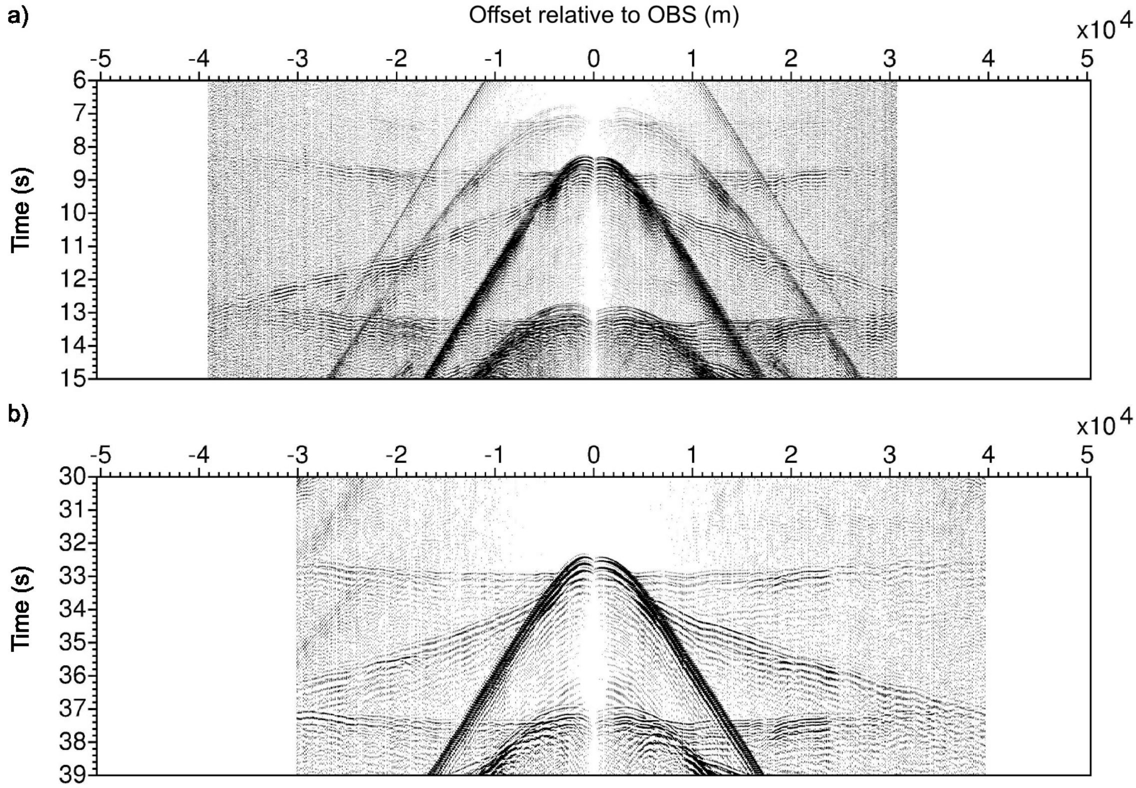


Figure 2.15. Example data from the hydrophone channel for an OBS recording the two-ship SAP_B profile from the South Grid, plotted reduced at 8 km s^{-1}. (a) Record section from the COOK Bolt source. (b) Record from the SONNE G source.

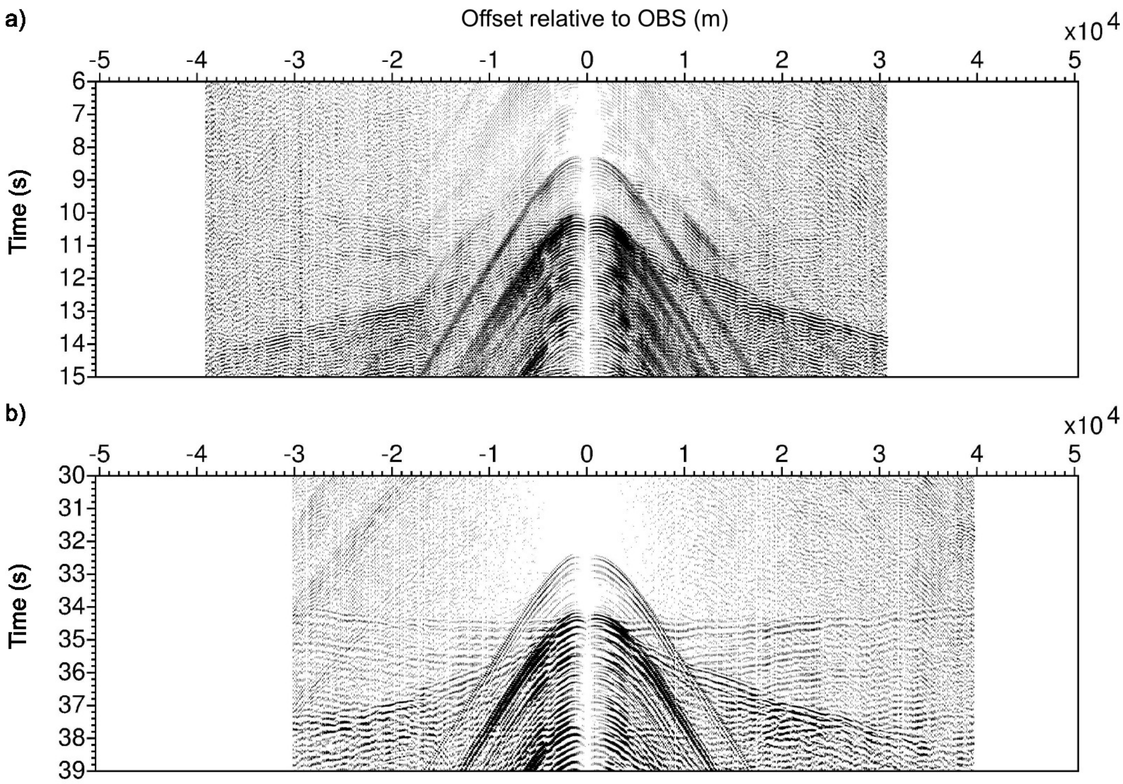


Figure 2.16. Example data from a horizontal geophone channel for an OBS recording the two-ship SAP_B profile from the South Grid, plotted reduced at 8 km s^{-1}.
(a) Record section from the COOK Bolt source. (b) Record from the SONNE G source.

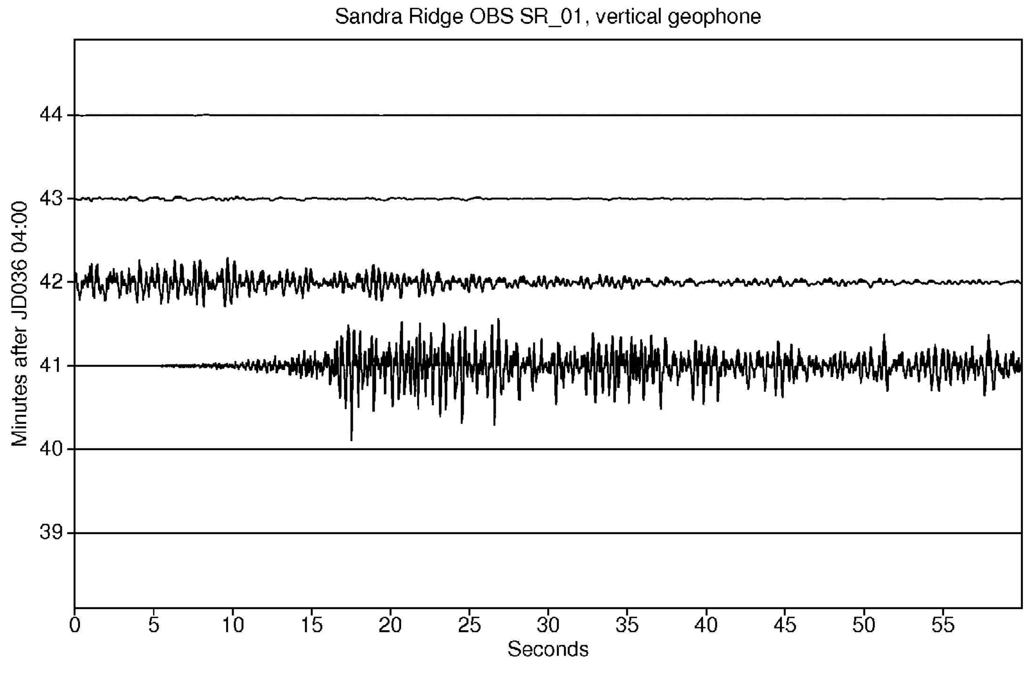


Figure 2.17. Vertical geophone record from the OBS passive monitoring array at the Sandra Ridge (SR_01) of magnitude 5.7 earthquake in the adjacent Panama Fracture Zone

2.3.3 Vertical hydrophone arrays

Two vertical hydrophone arrays (VA_01, VA_02) were deployed within the grid surveys (NG and SG), at the north and south ends of the SAP_B profile, to record the down-going source wavelet from the three different airgun source arrays. These data-loggers were based on the current generation "4x4"-type OBS data-logger with a bespoke pre-amp card required to record four hydrophone channels as opposed to the normal one hydrophone and three geophone channels specially developed for JC114 by OBIF. The backbone moorings were provided by the NMF Moorings Group, onto which were attached the three data-loggers that would each record the output from 4 High Tech HTI-90-U hydrophones attached to a single cable connected to each data-logger. The layout design of the vertical mooring is shown in Fig. 2.18. The total mooring height was 670 m from the seabed with the 12 hydrophone sensors located between 539 to 597 m, each separated by a nominal spacing of 5 m.

Each mooring was deployed was through the stern A-frame. During deployment of VA_01 excessive drag, a result of a strong surface current, caused the polyester rope of the last, top-most active section to stretch to such an extent that its water-proof connector was detached from its corresponding data-logger. This connector was reattached prior to deployment. However, on recovery one of the four data channels had not recorded any of the down-going signal so it is likely this incident broke a wire in the connector. For the second array, the distance between the hydrophones was reduced to 4.5 m to provide more slack on the cables to accommodate rope stretch, and the second array was deployed without any repeat of the problem, although the recorded data are noisier due to strumming of the slack hydrophone cable in the ambient water column current.

On recovery, VA_01 surfaced approximately 30 minutes after release, with the lower ropes tangled into the hydrophone array which made recovery difficult. A similar rise time was observed for VA_02 and again there was some tangling of ropes but, as this was anticipated, recovery was ultimately easier.

Initial data analysis shows that the array VA_01 successfully recorded data on 11 of the 12 channels and that the individual hydrophones appear to be well matched. Fig. 2.19 shows the recorded raw data as the seismic source wave travels down the array from a shot vertically above. Fig. 2.20 shows the vertical-

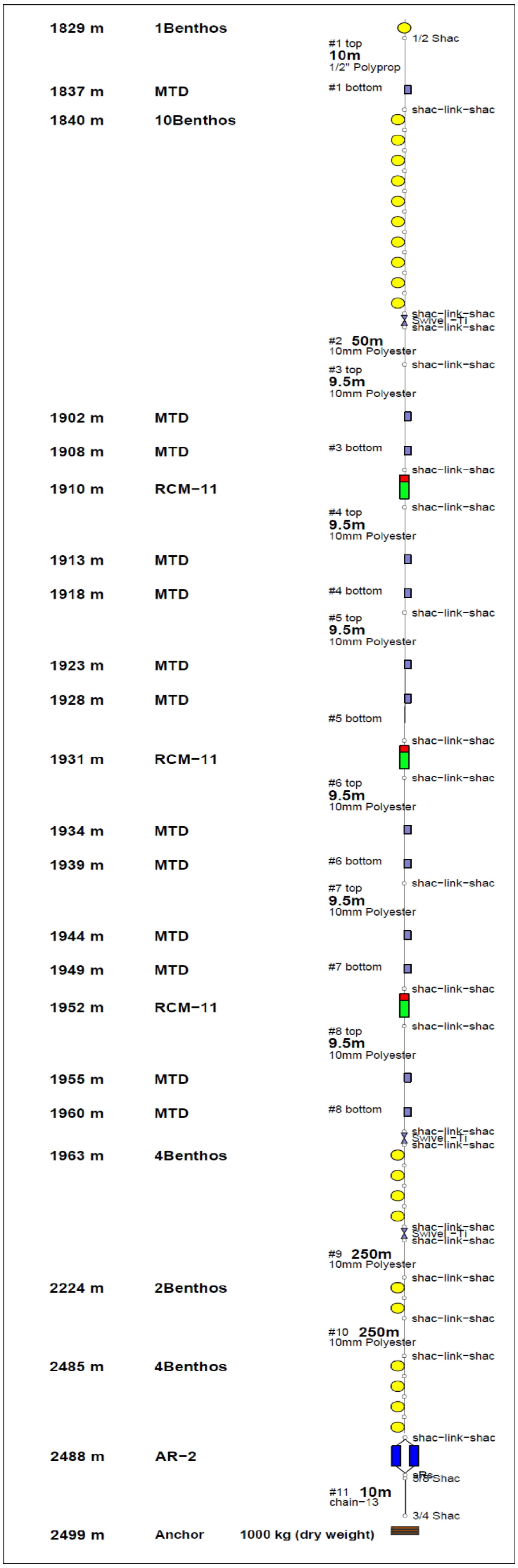


Figure 2.18. Mooring design for vertical hydrophone arrays (VA_01 & VA_02). RCM-11 units are data loggers provided by OBIF; MTD are mounting points for individual hydrophones; AR-2 are acoustic releases

array-measured summed source signature for the Bolt array (lower trace) compared with the predicted signature for that array calculated using a commercial airgun modelling package (Nucleus+ from PGS) (upper trace). Both traces are individually scaled so it is not possible to compare amplitudes and the modelled signature contains higher frequencies, so the peak-to-peak and peak-to-bubble ratios are larger as it has not yet been filtered with the impulse response of the corresponding data-loggers, as the OBIF data-logger filter, unsurprisingly, is not part of the standard set provided with the PGS modelling software. However, the overall shape is the same as is the period of the bubble pulse coda. Post-cruise, these hydrophone data will be reprocessed, using the OBIF data-logger filter characteristics to estimate the source for reflection data processing. This is believed to be the first time that such down-going wave-field recording has been undertaken in such deep water.

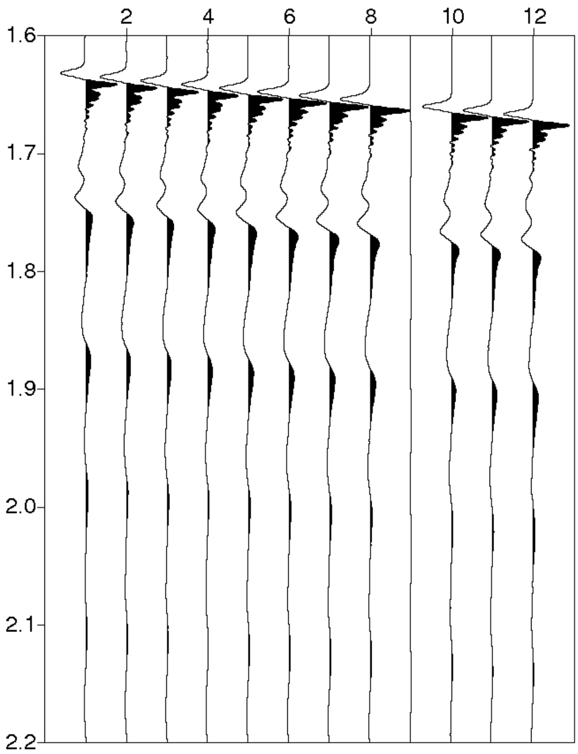


Figure 2.19. Single shot from the Bolt array recorded on the vertical hydrophone array VA_01. Channel 1 is the shallowest and channel 12 is the deepest. Channel 9 suffered a broken wire in its connection cable during deployment.

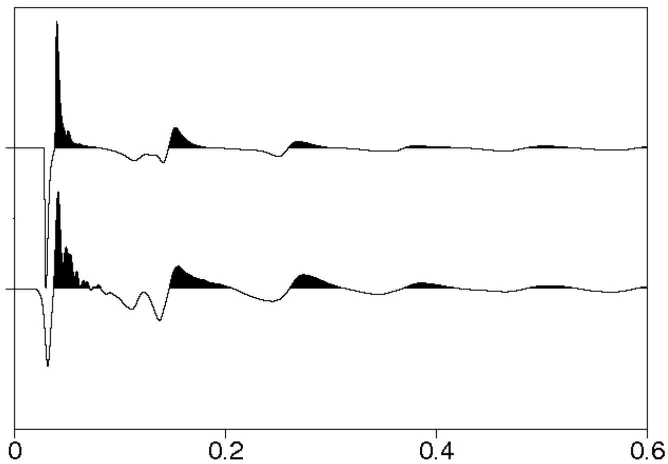


Figure 2.20. Comparison of predicted (upper) and measured (lower) wave-field for the Bolt seismic source. The shape difference is because the prediction does not include the instrument filter from the OBS logger,otherwise the shape and period of oscillation are well-matched. The predicted signature was calculated using the Nucleus+ software from PGS.

Time (s)

Time (s)

3 Marine mammal observation

As no specific guidelines were issued as part of any requested diplomatic clearance for any waters of the work area or transit routes, JC114 was operated under with best-practise approach based on the UK's Joint Nature Conservancy Council guidelines for the mitigation of the affects of acoustic noise in the water column. The approach adopted required at least an hour of visual observation prior to the start of seismic any airgun operations, and that the start of seismic shot firing would be delayed if any cetacean was sighted within a 500 m radius of the airgun array, and for at least 20 minutes after the species of concern left that zone. In all cases, a soft start approach was adopted whereby the source would ramp-up from the smallest airgun to the largest over a period of time. Given the number of airguns in use on the COOK for JC114, a three minute period between airgun addition was used. Soft start operations were only conducted during daylight hours. Shooting continued after the completion of each the multichannel seismic reflection profile only if the shots were being recorded by the OBSs and, therefore, would be used for 3D velocity structure modelling.

Sightings of Cetaceans were irregular and did not interfere with seismic operations although discretion was used on one occasion to turn off the airguns when it became clear that a pod of approaching pilot whales were going to cross the ship's path close to the seismic source. In this case operations recommenced after 10 minutes, when the pod was more than 500 m away, with a soft-start. A full record of MMO operations during JC114 can be found in Appendix D.

4 Acquired seismic profiles

4.1 Operations

The original cruise plan was to acquire seismic data at the Costa Rica Rift and at the ODP drill-site 504B. These primary cruise sub-surveys were planned as two 25 x 25 km grid acquisitions, joined by three synthetic aperture profiles linking the two grids. Time-efficient OBS deployments and recoveries accrued to the contingency time which allowed the addition of an extra survey over the Ecuador Rift ridge segment to the west of the original area in international water and extra swath profiles along the transform fault that separates the Costa Rica Rift ridge segment from the Ecuador Rift ridge segment. Further accrued time also permitted a high resolution reshoot of one of the synthetic aperture profiles. The sub-surveys that comprised JC114 are outlined below, with example seismic reflection sections included for each sub-survey to indicate data quality. For each sub-survey the shot point map is included. The corresponding OBS deployment location maps are shown in Figs 2.9-2.12.

4.2 Naming convention

The multichannel seismic (MCS) profiles within each survey area were named using the same convention as for the OBS (see section 2.3.2), XX_YY, where XX refers to the sub-survey location/type:

NG	North Grid
SG	South Grid
SAP	Synthetic Aperture Profile
EX	Extra
RS	Reshoot

and YY is a letter that refers to the MCS profile name. For example, Profile J in the North Grid would be called NG_J. Appendix A documents the airgun array and multichannel streamer configurations for all survey areas and profiles, Appendix B documents the MCS profile characteristics and shot numbers (FFID numbers) for each profile. The raw SEG-D data for each profile is archived under the profile name with an additional shooting sequence number appended.

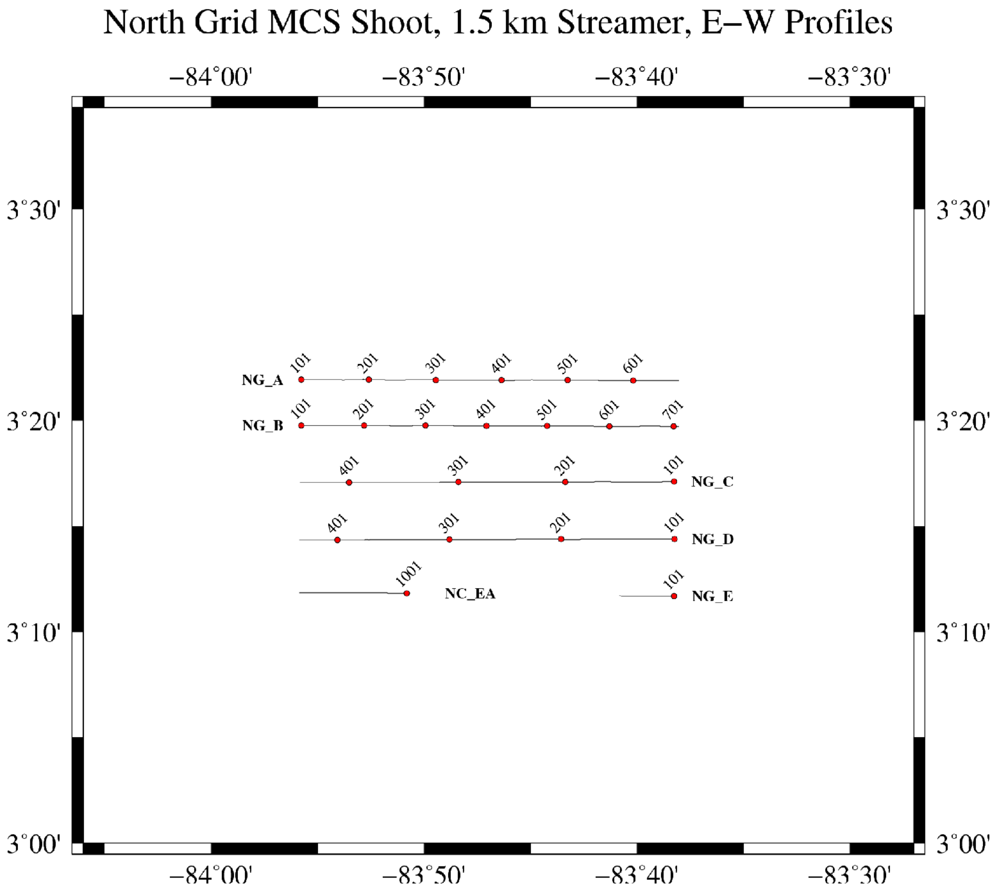
4.3 Acquisition

Five separate surveys were undertaken as part of JC114. A summary of each is outlined below, together with an example of acquired seismic reflection data from each.

4.3.1 North grid (NG)

Twenty-five OBSs (NG_01 to NG_25) where deployed in the North Grid at an approximate 5 x 5 km node spacing, together with the vertical array VA_01 (see Section 2.3.3). Deployment locations (Appendix C), revised from the original plan to avoid areas of steeply-dipping seabed (>15°) based on swath bathymetry data collected during JC112 and JC113, and are shown in Fig. 2.11. The OBSs were deployed with three-footed concrete ballast weights to maximise stability and seabed coupling, as the landing sites would not have any significant sediment cover.

Once OBS deployment was complete, the multichannel streamer in 1500 m configuration was deployed together with the GI- and Bolt-airgun arrays (Appendix A – airgun configuration #1; streamer configuration #1), and MCS data acquired with a 30 s shot interval and 27 s record length. Ten MCS profiles were acquired using this configuration comprising five east-west profiles and five north-south profiles. There were repeated problems with 500 in^3 airgun in the Bolt array during the shooting of this survey, with damage to either the air hose or air hose connector. Although most of the repairs were done during turns, a section of the NG_E profile was lost. Tracks charts of the profile locations relative to shot point numbers (FFIDs) are shown in Fig. 4.1.



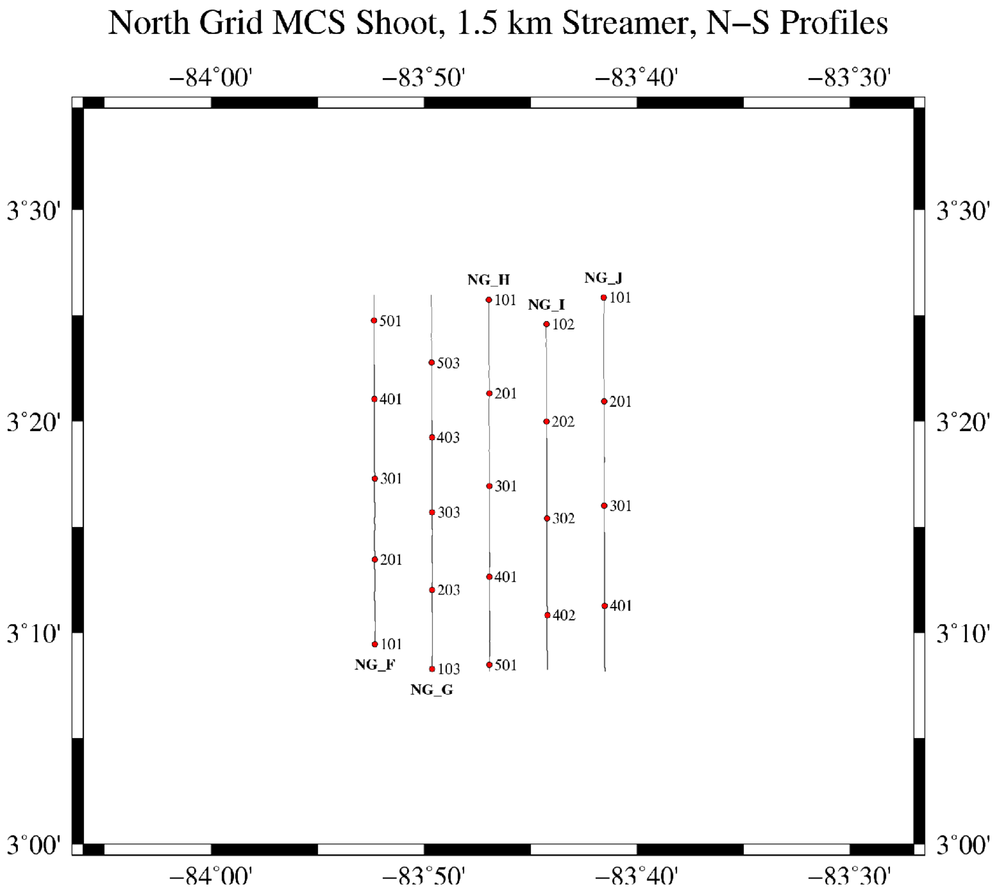


Figure 4.1. Multichannel seismic profiles shot within the North Grid. These profiles were shot with a 1500 m streamer. Shot point numbers (FFIDs) are annotated. The active Cost Rica Rift ridge segment lies along NG_B.

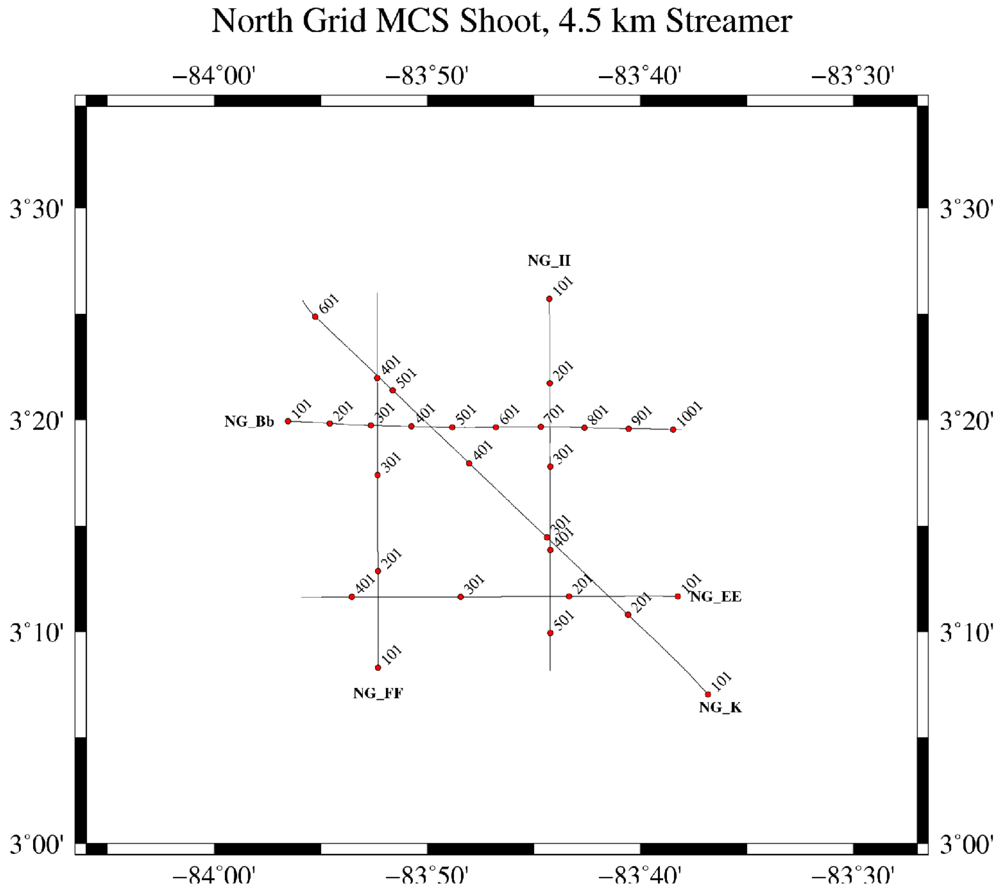


Figure 4.2. (a) Track chart for the reshoot of the NG grid with the 4500 m streamer configuration. Shot point numbers (FFIDs) are annotated.

Four of the NG profiles were then reshot using the 4500 m streamer configuration, together with an extra profile diagonally across the grid to provide shots at an oblique azimuth into the OBSs for anisotropy data analysis purposes. This additional shooting also provided an opportunity to reconfigure and balance the rest of the 4500 m length of streamer, and to practice the starboard turns in preparation for the two-ship work with the SONNE. Tracks charts of the profile locations relative to shot point numbers (FFIDs) are shown in Fig. 4.2. Track chart for all the shots recorded by the North Grid OBS is shown in Fig. 2.11.

The acquired seismic reflection data quality is good and examples from profile NG_H and the reshot NG_BB that images the axial magma chamber are shown in Figs 4.3 and 4.4 respectively. However, strong surface currents from the east, peaking at over 1 kn, resulted in a variable shot spacing on the east-west profiles (~55 m on easterly heading, ~95 m on a westerly heading) and significant streamer feather on the north-south profiles. The OBSs recorded P-wave arrivals out to 30 km - the maximum offset from each OBS at which shots were fired.

Once shooting was complete the streamer and airgun arrays were recovered, together with 20 of the NG OBSs, leaving deployed the five that lay along synthetic aperture profile SAP_B (NG_04, 07, 14, 17 & 24) and the vertical array VA_01, as these would also record the synthetic aperture shots.

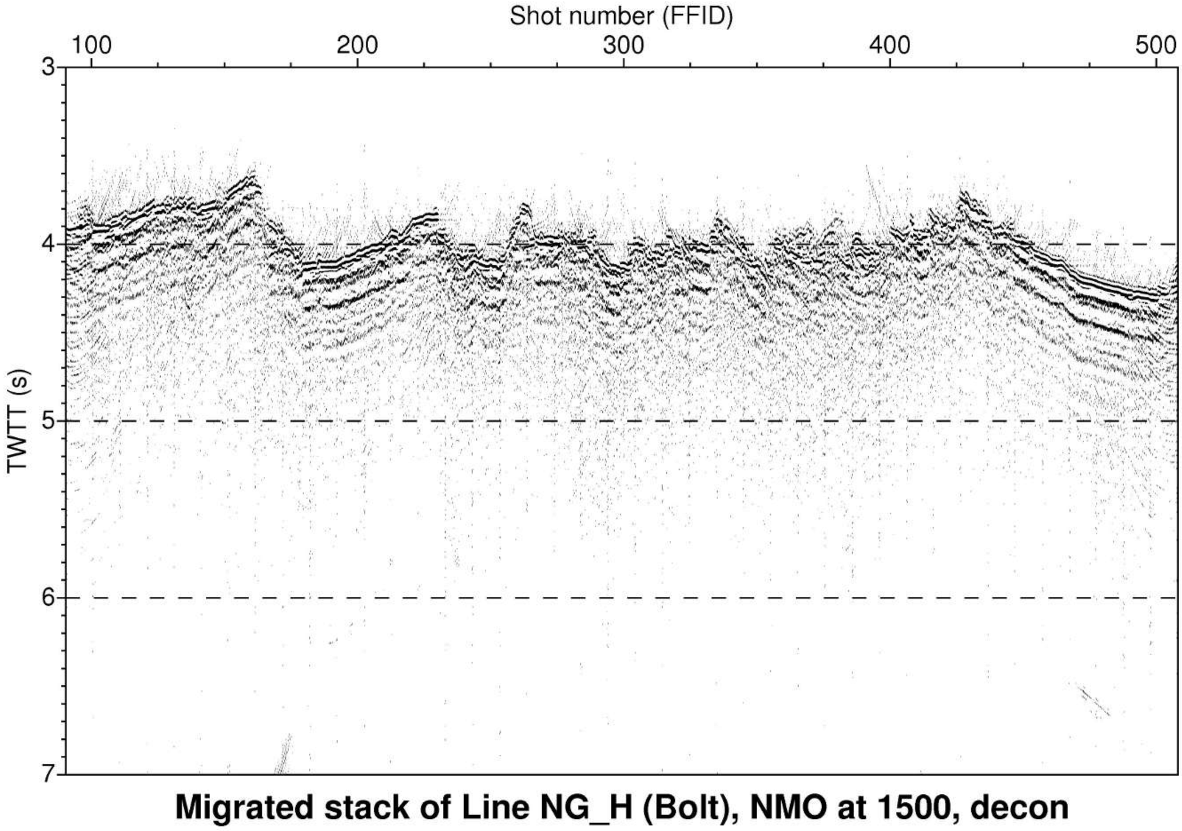


Figure 4.3. QC migration of seismic reflection profile NG_C (Bolt) processed at 1500 ms^{-1}

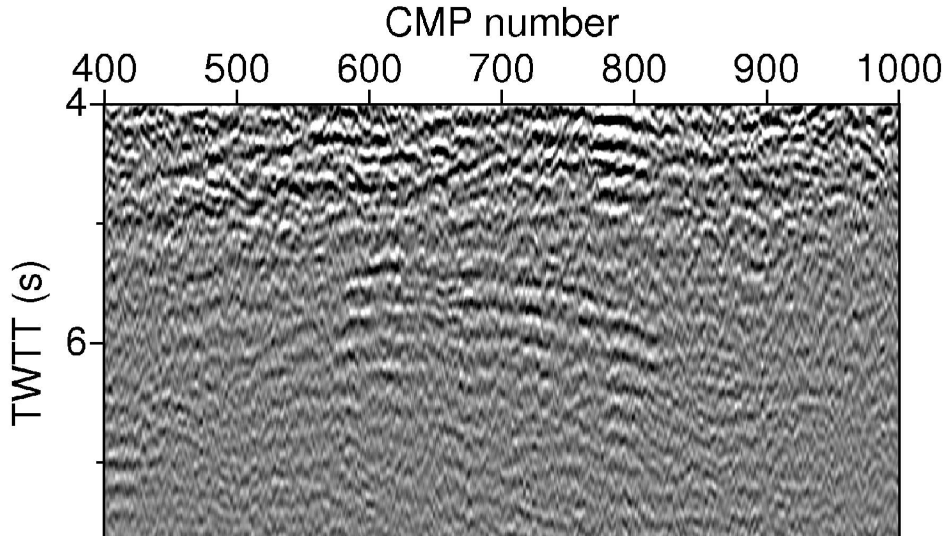


Figure 4.4. Section of brute stack MCS data from NG_BB (CMP equivalent of shot points 250 to 650) showing the reflection from the axial magma chamber between CMP 600 to 800.

4.3.2 Extra profiles (EX)

As a consequence of time-efficient deployment and recovery operations of all equipment involved in the North Grid sub-survey, several days were accrued prior to the arrival of the SONNE for the two-ship synthetic aperture acquisition. To make best use of this time, a multichannel seismic reflection survey was conducted over the Ecuador Rift and Ecuador Fracture Zone to the west, between 85°30'W-83°30'W and 0°45'N-2°00'N. This sub-survey was acquired using the combined GI- and Bolt-airgun sources but with a decreased shot interval of 20 s, a 17 s record length and the 4500 m streamer configuration (Appendix A – airgun configuration #2 then #3 after EX_A.1; streamer configuration #2). Data quality is excellent, and only light to moderate surface currents were experienced which resulted in shot point intervals of 50-60 m along all profiles. Tracks charts of the profile locations relative to shot point numbers (FFIDs) are shown in Fig. 4.5. An example of the MCS data acquired along EX_J is shown in Fig. 4.6.

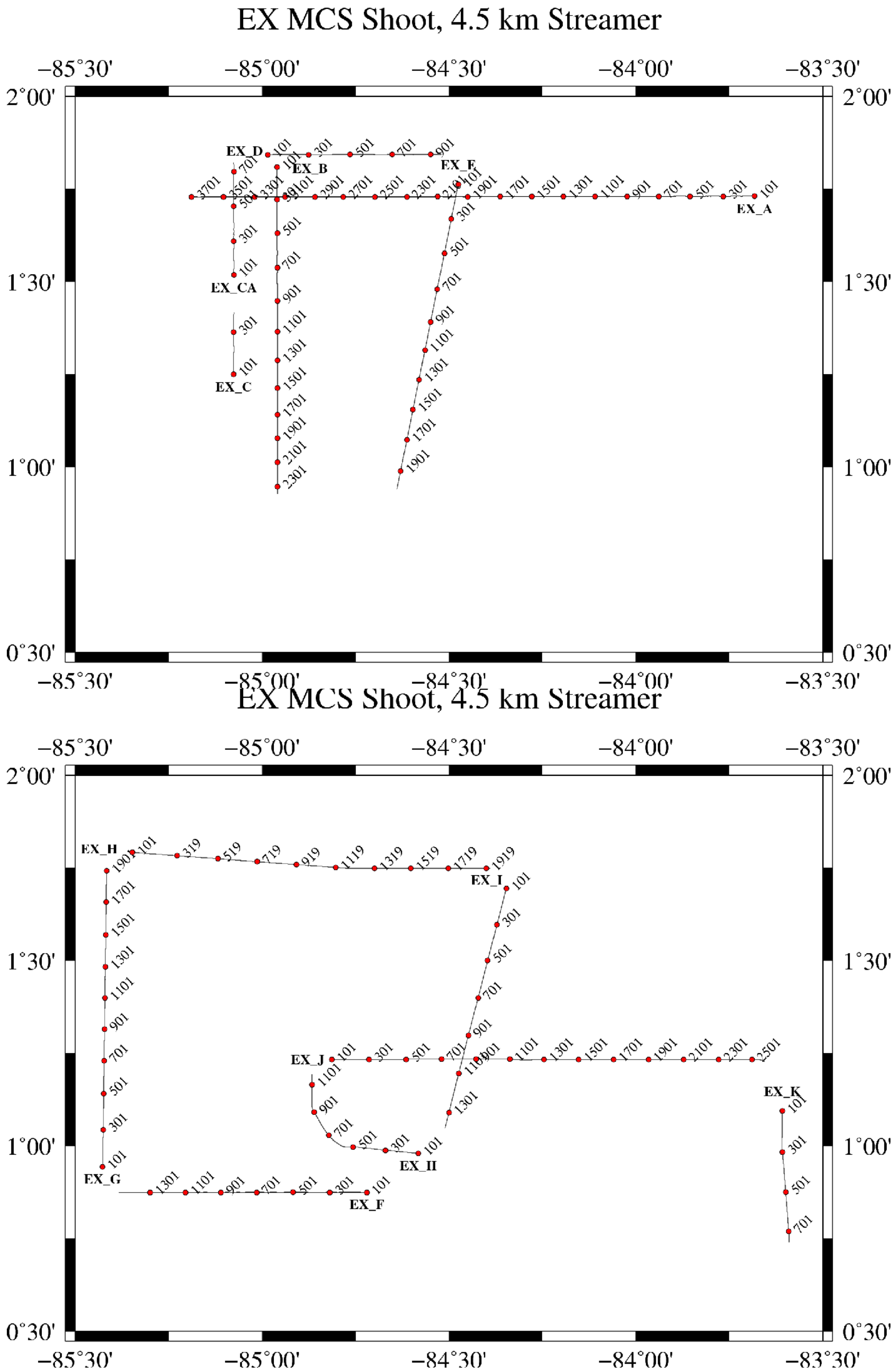


Figure 4.5. Multichannel seismic profiles shot within the Extended survey over the Ecuador ridge and Ecuador and Panama Fracture Zones. These profiles were shot with a 4500 m streamer. Shot point numbers (FFIDs) are annotated. The active ridge segment lies along EX_A.

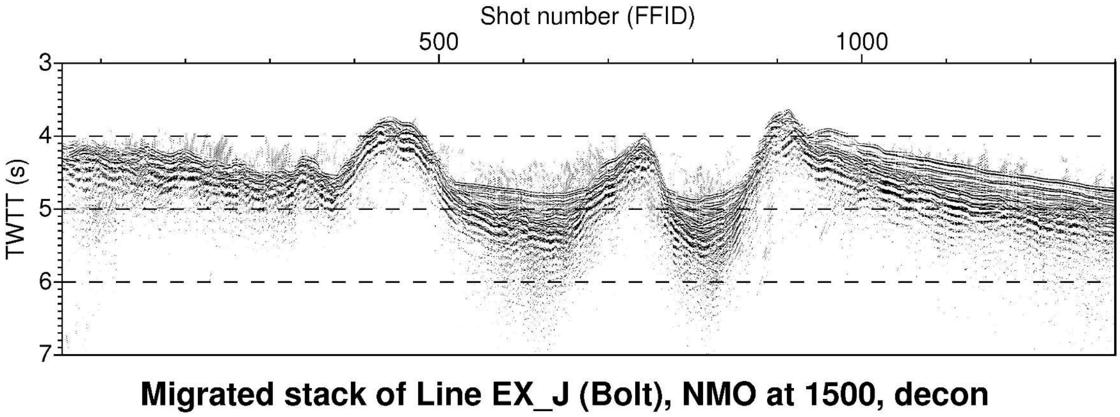


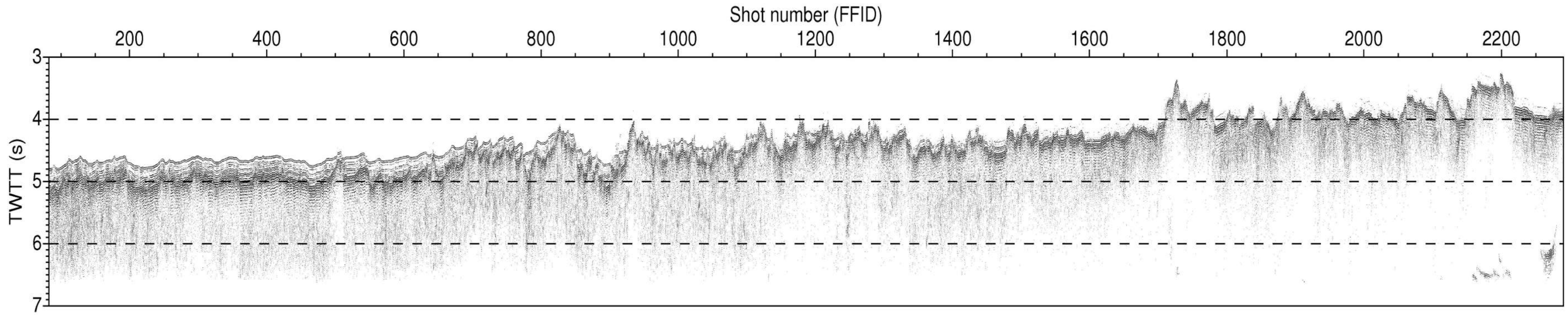
Figure 4.6. Section of QC migration of line EX_J (Bolt) that crosses the Ecuador Fracture Zone. Heatflow measurements during JC113 where made in sediments between FFID550-650.

4.3.3 Synthetic aperture profiles (SAP)

OBSs were only deployed along SAP_B, and comprised SAP_01 to SAP_35, the five South Grid OBSs that also lay along the profile (SG_02, 09, 12, 19. & 22), vertical array VA_02, and the five OBSs and vertical array remaining from the North Grid (NG_04, 07, 14, 17 & 24 and VA_01 - Appendix C). Of the SAP OBS, the five at the north end of the profile (SAP_01, 02, 08, 09 & 10) were deployed with three-footed concrete anchors. The remaining SAP OBSs were deployed with a metal grid ballast weight since these sites had sediment cover.

Once the SONNE arrived in the work area, independent turning manoeuvres were conducted by both vessels to facilitate equipment deployment and to position the SONNE at the correct distance behind the COOK whilst turning onto the start of profile SAP_B. The SONNE was positioned ~8.7 km behind the COOK to provide a 300 m overlap between the streamer recordings of the COOK shots and the streamer recordings of the SONNE shots. Three 270 km-long profiles were then acquired that link the North and South Grids. Profile SAP_B was orientated to pass over the ODP 504B drill-site and the location on the Costa Rica Rift where the axial magma chamber (AMC) had been previously observed during R/V MAURICE EWING survey EW9416. SAP_A and SAP_C provided second crossings of 504B and the AMC respectively and laterally-offset shots into the OBSs deployed along SAP_B.

The COOK towed GI- and Bolt-airgun arrays and the 4500 m streamer (Appendix A – airgun configuration #3 and streamer configuration #2). Surface currents were variable and most significant for SAP_C where they caused significant feathering of the streamer. The shot point interval for all three profiles was between 130-160 m. Data quality of the unprocessed MCS field records is good although there is some noise on the near-offset channels (groups 1-12) due to their uncontrollable shallow towing. An example of the MCS data acquired along SAP_C is shown in Fig. 4.7. Track charts of the profile locations relative to shot point numbers (FFIDs) are shown in Fig. 4.8. Track chart for all the shots recorded by the SAP OBS is shown in Fig. 2.13.



Migrated stack of Line SAP_C (Bolt), NMO at 1500, decon

sedimentary cover

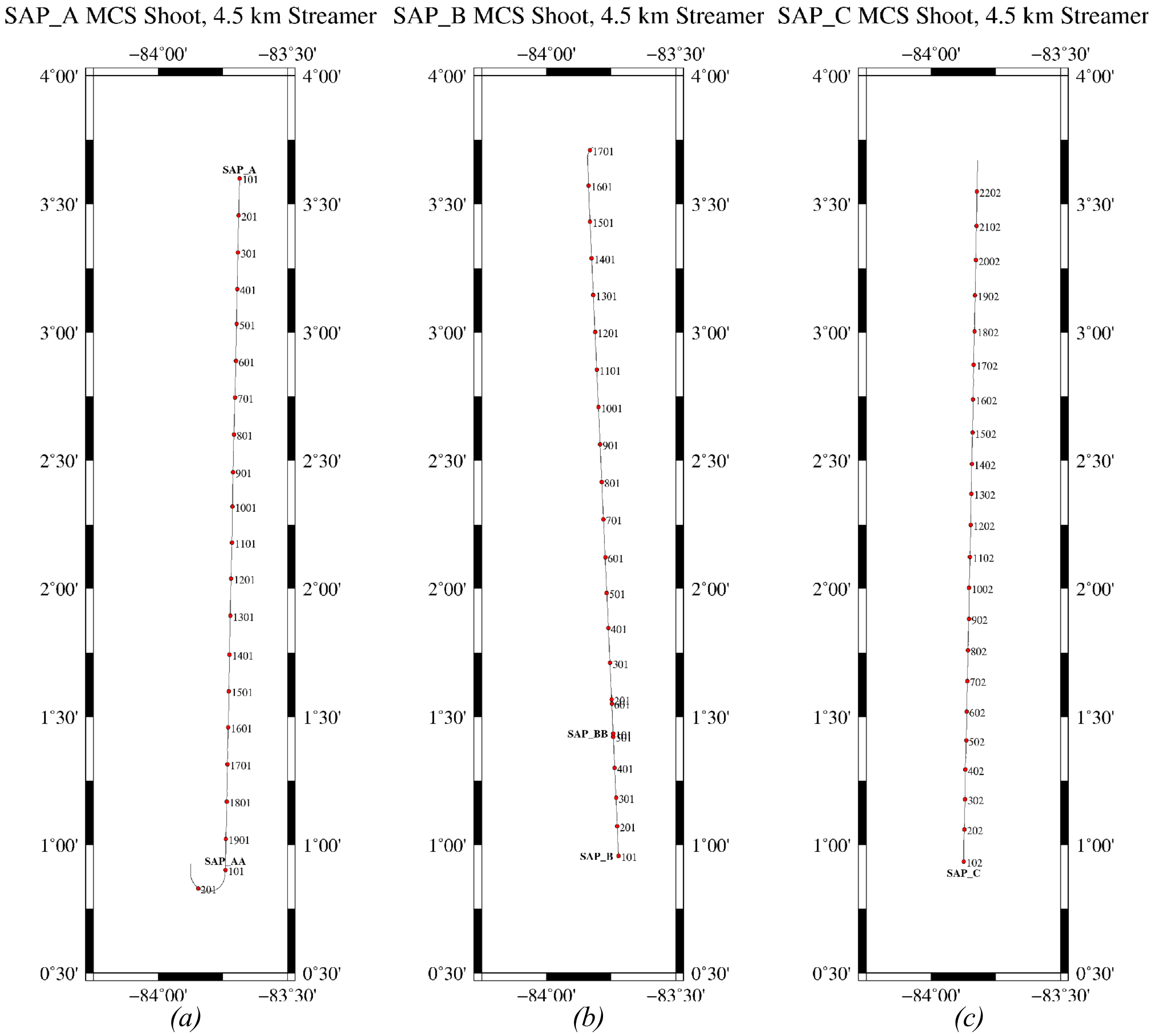


Figure 4.8. Track charts for the multichannel streamer SAP profiles. These profiles were shot with a 4500 m streamer. Shot point numbers (FFIDs) are annotated. (a) SAP_C; (b) SAP_B/BB; and (c) SAP_C.

For the SAP shooting, the GI-airgun array shot was fired at 50 ms (the aim point) after the start of record; 6.05 s later the Bolt-airgun array shot was fired. See Fig. 2.1. At 30.08 s the G-airgun array was fired by the SONNE. To "unwrap" these shots and reform them into the required synthetic aperture shot records requires accurate shot times and locations for both ships as described in Section 2.2.3.

Once shooting was complete the streamer and airgun arrays were recovered together with the OBSs, including those instruments from the North Grid (NG_04, 07, 14, 17 & 24) and vertical array VA_01. OBSs SAP_29 and SAP_35 and the OBSs who also lay along a profile within the South Grid (SG_02, 09, 12, 19. & 22) and the second vertical array (VA_02) remained deployed. The quality of the OBS records is generally excellent, particularly towards the southern end of the profile, where sediment cover improves coupling and reduces scatter of the down-going wave-field e.g. by the irregular seabed topography at the ridge axis as observed for instruments located within the North Grid and which is commonly observed in mid-ocean ridge wide-angle and MCS surveys.

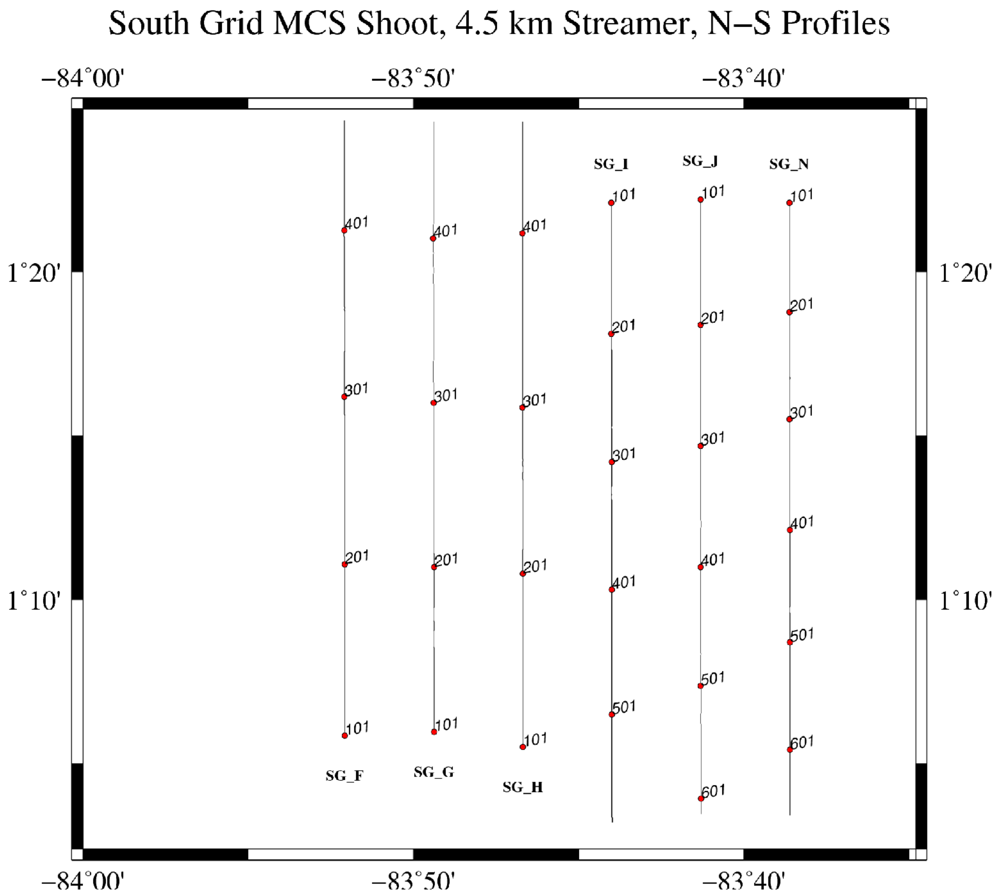
4.3.4 South Grid (SG)

For the South Grid, a further 20 OBSs were deployed to complete the 5 x 5 km node spacing deployment configuration. All OBSs were deployed with a metal ballast weight, and at the planned positions as the seabed was well-sediment covered and essentially flat-lying (Appendix C). The South Grid was then shot comprising six east-west and six north-south MCS profiles using airgun configuration #3 and the 4500 m streamer configuration #2 (Appendix A). An extra profile was added to the grid in both directions to make turning (within the starboard only constraint) with the 4500 m streamer easier. Southerly surface currents during acquisition resulted in profiles shot from south-to-north having an average 95 m shot point interval, and those shot north-to-south an average 75 m shot point interval. The quality of the reflection data is good, although there was a system failure on the east-west profile SG_A which resulted in 35 minutes of lost recording. This gap was not reshot as it was towards the end of the line. Tracks charts of the profile locations relative to shot point numbers (FFIDs) are shown in Fig. 4.9. An example of the MCS data acquired along SG_C is shown in Fig. 4.10.

After acquisition of the last SG profile, and before commencing any equipment recovery, SAP_A was reshot heading northwards at high resolution (RS_A) to image the sediment column structure and depth to, and geometry of the basement in the vicinity of the heat flow surveys conducted along this profile during JC113. During JC113, the acquired sub-bottom profiler data didn't provide adequate resolution to support heat flow analysis. For the southward leg, SAP_A was reshot again (RS_B) with medium resolution to provide longer-offset, azimuthal arrivals into the SG OBSs. A description of the reshoot survey is contained in the following section.

4.3.5 Reshoot profiles (RS)

Initial on-board processing of the GI-airgun array data along SAP_A showed that the 10 m tow depth for the streamer had limited the vertical resolution of the MCS records. Although deconvolution helped improve the image, the streamer ghost notch limited the maximum bandwidth. Consequently, given available time, was decided to reshoot SAP_A as these data could then be used to help interpret the heat flow data from JC113. RS_A was a GI-airgun array only profile, shot with airgun configuration #5 and streamer configuration #3. A shot interval of 15 s resulted in an average shot point spacing of 40 m. An example of the MCS data acquired along RS_A is shown in Fig. 4.11. Tracks charts of the profile locations relative to shot point numbers (FFIDs) are shown in Fig. 4.12. Data quality was excellent and the reshoot achieved a vertical resolution of ~5m to the base of the sedimentary cover.



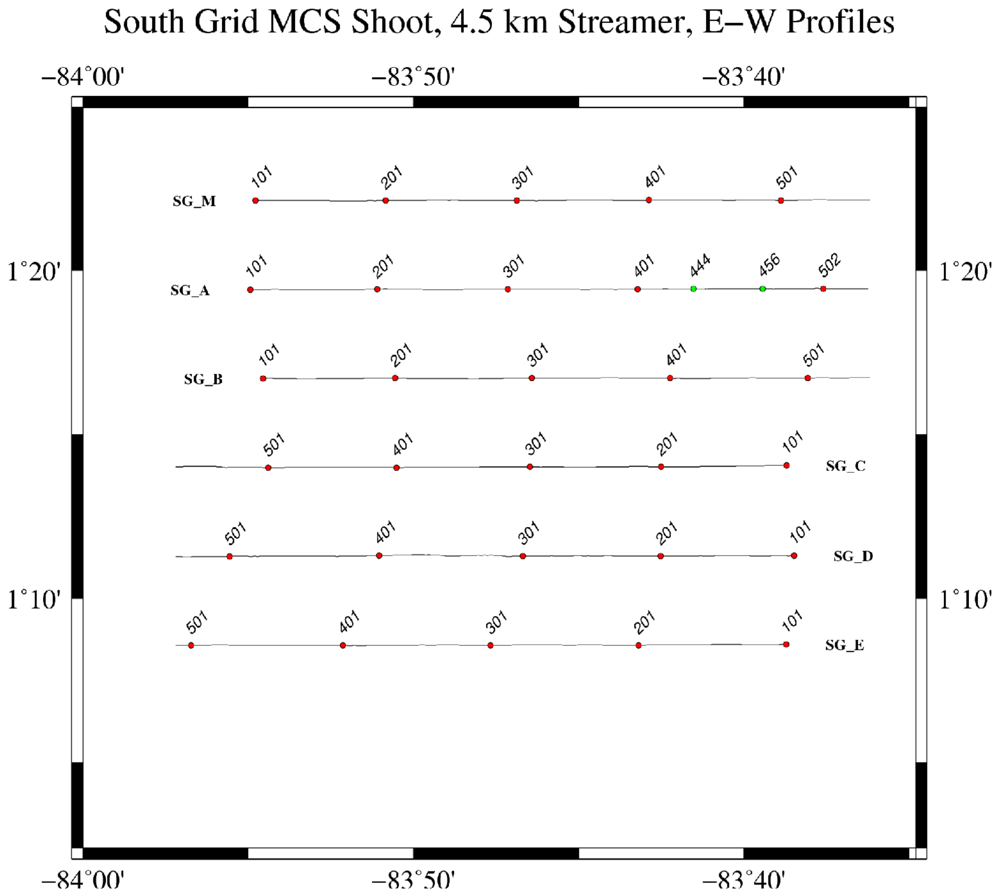


Figure 4.9. Multichannel seismic profiles shot within the South Grid. These profiles were shot with a 4500 m streamer. Shot point numbers (FFIDs) are annotated. The ODP 504B borehole lies at the intersection of lines SG_C and SG_I.

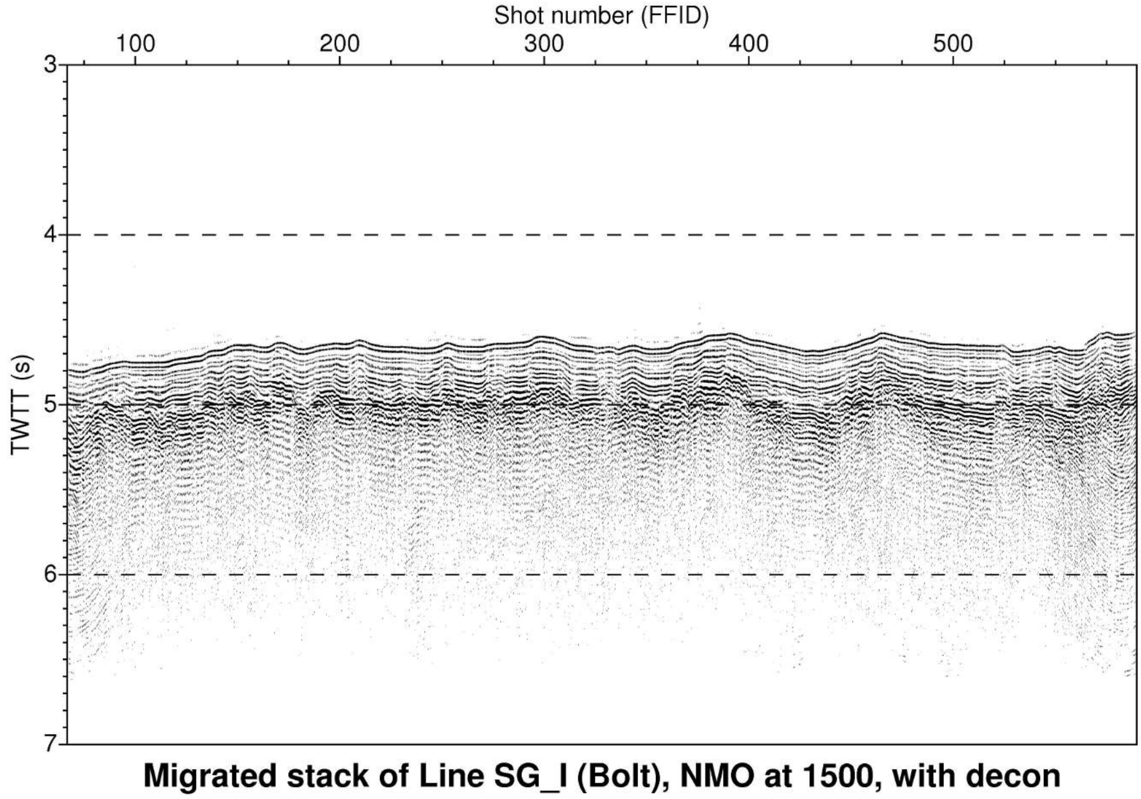


Figure 4.10. QC migration of seismic reflection profile SG_C (Bolt) processed at 1500 ms^{-1}

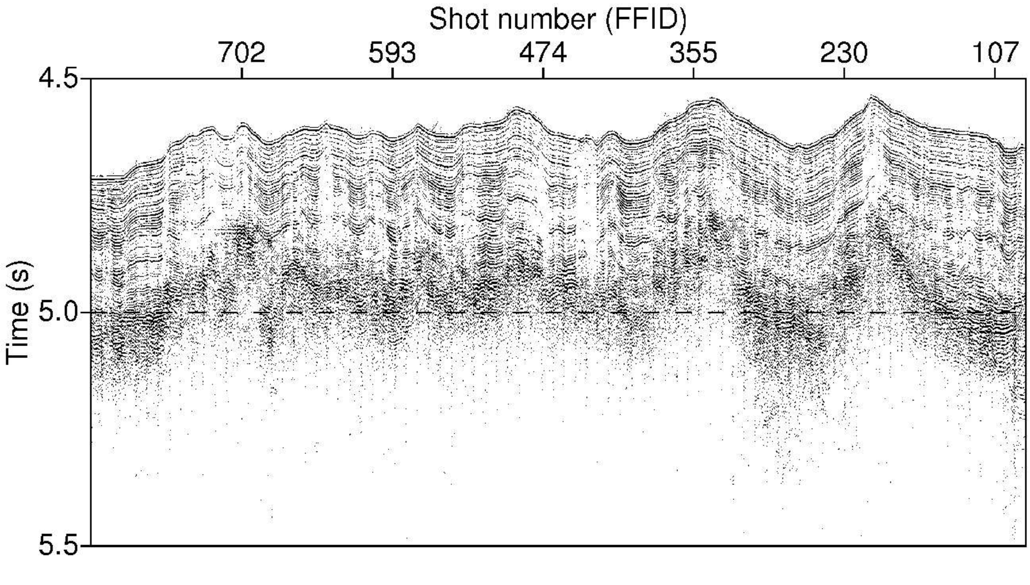


Figure 4.11. QC migration of part of seismic reflection profile RS_A (GI), over the same range as Fig. 4.10. Note the vertical scale change to highlight the high-frequency content of this profile.

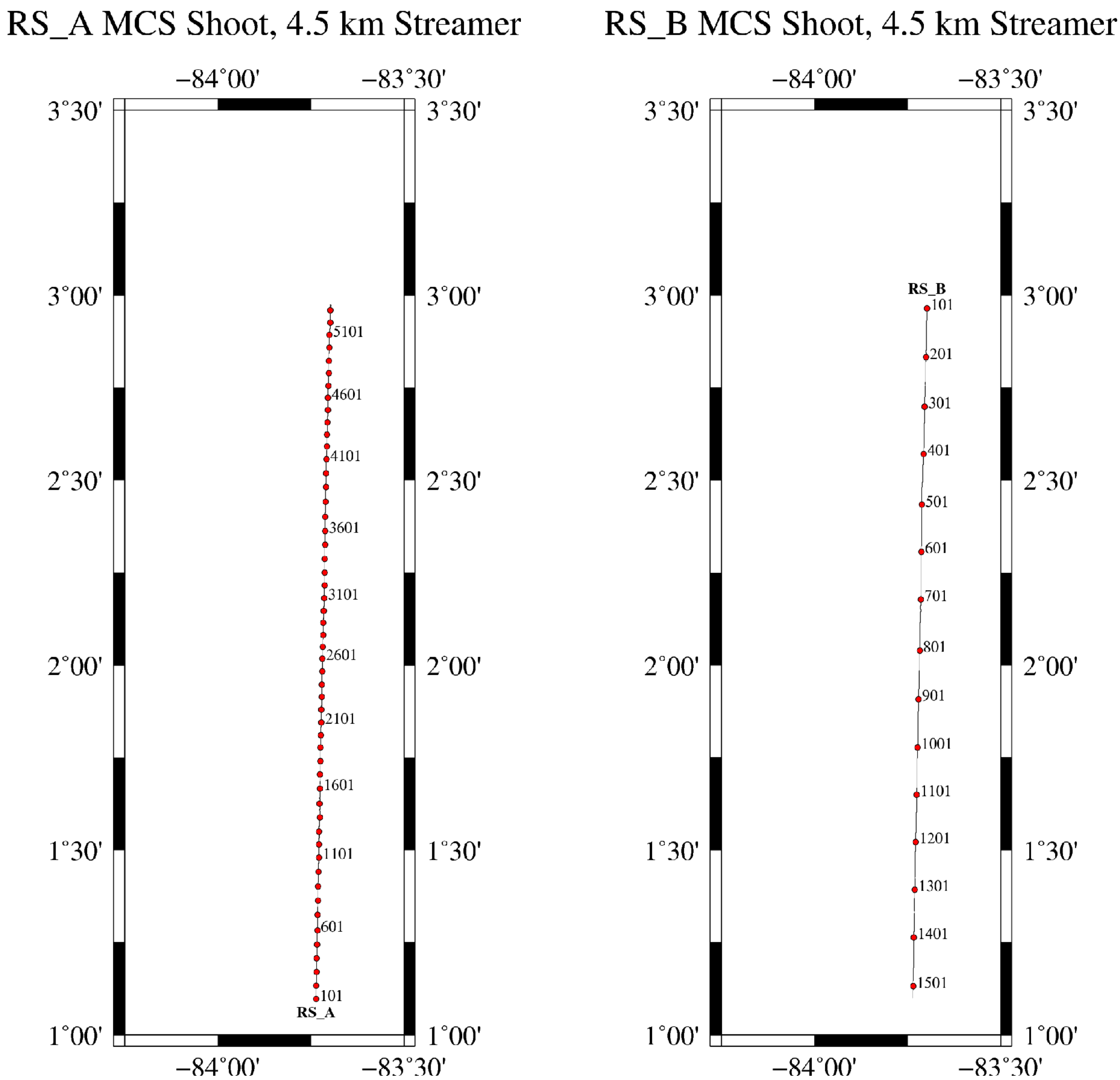


Figure 4.12. Track charts for the multichannel streamer RS profiles. These profiles were shot with a 4500 m streamer. Shot point numbers (FFIDs) are annotated. (a) RS_A was shot with only the GI source to image the sediment structure over the heatflow measurements from cruise JC113; (b) RS_B was shot with only the Bolt array as a noise test and for seismic oceanography mapping of the thermohaline structure.

For the return leg the seismic source was switched to the Bolt-airgun array (airgun configuration #6 and streamer configuration #2) and shot with a 60 s interval (Fig. 4.11), to minimise wrap-around noise on seismic oceanography images of the water column, and maximise the range of observed arrivals recorded by the OBSs by shifting the wrap-around water-wave of the previous shot out to longer-offsets than expected for the lower crust and uppermost mantle arrivals and reflections from the Moho.

5 Underway data

A track chart of the entire cruise is shown in Fig. 5.1, and a blow-up of the main work areas in Fig. 5.2. Along all tracks navigation, swath bathymetry, single-beam bathymetry, gravity, meteorology and oceanographic data were acquired as part of the underway dataset. Magnetic data were also acquired during seismic shooting and sound velocity measurements made during OBS acoustic release testing at the start of the cruise. Each of these data are described in the following sections.

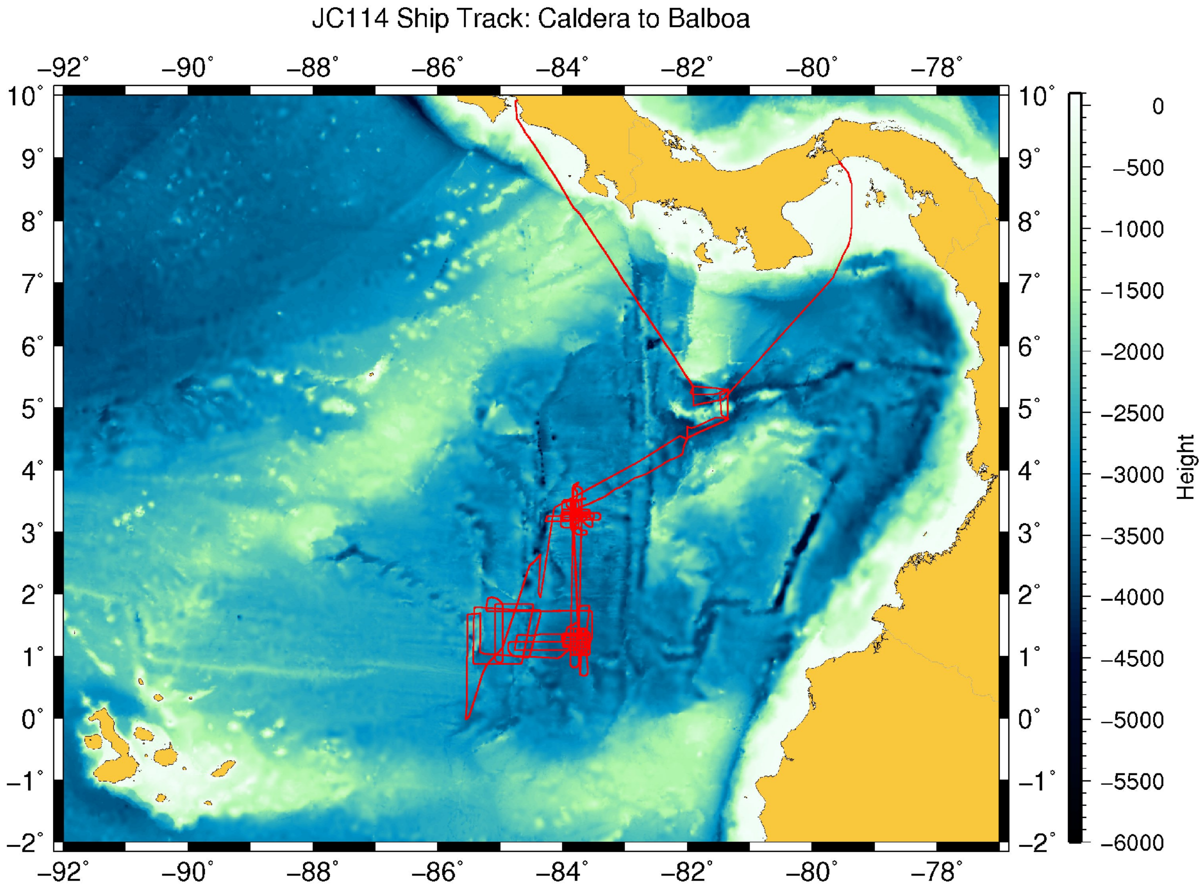


Figure 5.1. Entire track for JC114 from Caldera Costa Rica to Balboa Panama overlaid on the GEBCO bathymetry map of the area.

5.1 Navigation

All GPS and attitude measurement systems available on the COOK were run throughout the cruise. The Applanix POSMV system is the vessel's primary GPS system, outputting the position of the ship's common reference point located in the gravity meter room. The POSMV is the GPS position sent to all other scientific systems and that is repeated around the vessel. The Applanix POSMV failed and required rebooting on one occasion during which no instrumentation received positional data, except for the EM120 which receives attitude and position data from the Seapath 200 GPS system due to its superior real time heave. The POSMV failure occurred between 08:17:35 to 09:12:00 on 04/02/15 (JD035). The CNAV Techsas data-logging module also crashed on one occasion, resulting in a data gap between 06:40:20 to 06:43:11 on 23/02/15 (JD054).

5.2 Speed logs

The single-axis Bridge Skipper Log and the dual-axis Chernikeef science log were both logged. There had been no opportunity to calibrate the Cherinkeef log was not during 2014 and it is known to be very inaccurate. Data from the Chernikeef should be used with caution. The Bridge-based Skipper Log proved reliable throughout the cruise as was primarily used to monitor ship's speed through the water during seismic acquisition, to prevent damage to the streamer and maintain the source at a constant depth.

5.3 Meteorology and sea-surface monitoring

The Surfmet system was run throughout the cruise, recording both meteorology and sea-surface conditions.

5.4 Single-beam echo sounder

The EA600 single beam echo sounder was run throughout the cruise. There are breaks in the data only during OBS deployment and recovery as this system and the OBS acoustic releases operate in the same primary frequency band and cause interference with each other. The EA600 was used with a constant sound velocity of 1500 ms^{-1} throughout the water column, which allows its recorded data to be post-processed for actual water column velocity measured during the cruise.

5.5 Swath multi-beam echo sounder

The EM120 multi-beam echo sounder was run throughout the cruise. Data were logged in Kongsberg .all format. There are breaks in the data only during OBS deployment and recovery as this system and the OBS acoustic releases operate in the same primary frequency band and cause interference with each other. There are also breaks between profiles from 09:59 to 10:43 and from 15:14 to 15:30 during on 26/01/15 (JD026) due to the backup PC having to be installed when a hard drive failed on the primary system control PC.

A measured sound velocity profile, see Section 5.6 below, was input near the start of the cruise to correct readings to true depth. The quality of the swath data is excellent (Fig. 5.2), although some data is of much lower quality during the transit back to Panama when the vessel was heading into a heavier swell. In general though, with the vessel ballasted to an even keel, excellent data was acquired no matter the speed (including above 10 kn) for sea state or direction.

5.6 Sound velocity profiles

A Valeport Midas SN 22241 sound velocity profiler was attached to the OBS acoustic release test frame each time it was used, prior to both the Sandra Ridge deployments and VA_01 vertical array deployments. The locations of these sound velocity profiles are shown below and the recorded velocity-depth profiles in Fig. 5.3.

Date / Time	**Profile**	**Location**
23/01/15 21:13 (JD023)	JC114_01	5° 55.618’ N 82°16.600’ W
25/01/15 03:18 (JD025)	JC114_VA_01	3°13.020’ N 83°50.525’ W

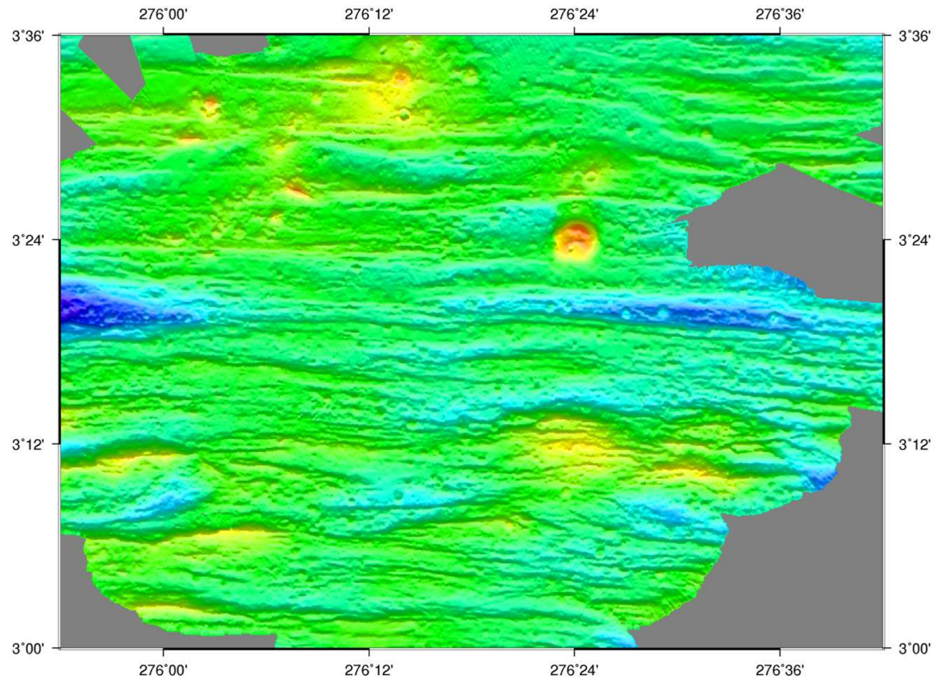


Figure 5.2. Multibeam swath bathymetry map for the North Grid area that spans the Costa Rica Ridge illuminated from the south.

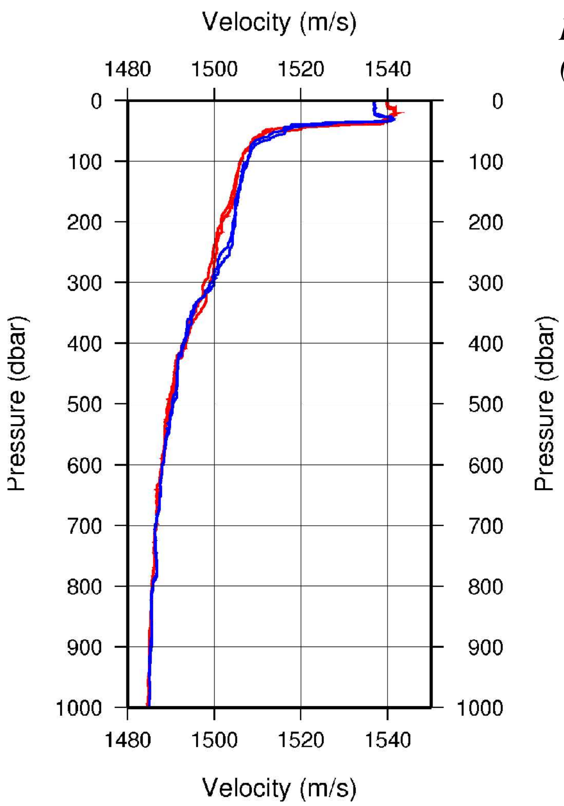


Figure 5.3. Sound velocity profiles recorded on JD023 (red) and JD025 (blue).

5.7 Acoustic doppler current profiler

Both the 75 kHz and 150 kHz acoustic doppler current profiler (ADCP) systems were run during the cruise. These systems were configured as follows. The 75 kHz system was run in broadband mode with 48 bins of 16 m with an 8 m blank. The 150 kHz system was run in narrowband mode with 96 bins of 4 m with an 4 m blank. Bottom tracking was not enabled to allow the orientation of the transducers to be calibrated due to the clearances only allowing use in deep water.

5.8 Gravimeter

The gravity meter (serial number S40) was run throughout the cruise. A tie-in was performed on 15/01/15 (JD015) at the start of the cruise (Puntarenas Costa Rica ref: 4551-1 g=978217.22 mGal) and at the end of the cruise on 7/03/15 (JD066) (Balboa Panama Rodman Pier ref: WH1056 g=978222.54 mGal). Base station ties were completed using a portable LaCoste-Romberg meter (model G-484). Control of the meter was lost at 00:19 on 26/02/2015 (JD057) when the computer programme was found to be unresponsive with an error message "Insufficient memory for operation" although there was little processor activity on-going on the control PC.

As the spring tension (ST) motor was constantly rotating increasing the count, the PC was rebooted and control of the meter was regained. The ST motor stopped at this point and the meter started to automatically decrease the ST count slowly. At 00:41 (JD057) the beam was clamped and the ST motor manually commanded to move back to the last known good reading of 6292 gu. By 00:54 (JD057) the ST motor had completed the move and the beam was unclamped. By 01:00 (JD057) the gravity reading was once more stable. The only explanation for the incident was system overheating as the ambient temperature reading on the meter was 39.7°C. On this occasion the gravity room, the outside alleyway and gym were all at a much higher temperature than normal and the sauna (in the rear of the gym) was found to have been used and still very hot. The gravity room ambient temperature ranged from 35 to 37°C for the rest of the cruise.

By the end of the cruise it was still unknown as to how the meter calibration may have been affected and what the consequences of this failure will be for the veracity of the gravity data acquired throughout the cruise. And example of the data acquired is shown in Fig. 5.4.

5.9 Magnetometer

A SeaSpy magnetometer (SN 13358) was deployed throughout all seismic surveying as summaried in the table below. The sensor lay-back from the ship's GPS reference point was 300 m, comprising 254 m of cable aft of the stern of the COOK and 46 m offset from GPS reference point to the stern of the vessel.

Survey	Start	End
JC114_NG	00:07:54 19/01/15 (JD019)	00:08:42 01/02/15 (JD032)
JC114_EX	14:33:55 04/02/15 (JD035)	13:57:22 10/02/15 (JD041)
JC114_SAP	13:57:59 10/02/15 (JD041)	18:17:29 15/02/15 (JD046)
JC114_SG_RS	21:41:29 19/02/15 (JD050)	19:01:05 25/02/15 (JD056)

There was a break in data acquisition during JC114_EX, between 19:00:40 to 19:08:06 on the 08/02/15 (JD039) when a transceiver box failed and was swapped out. An example of the acquired magnetic is shown in Fig 5.4.

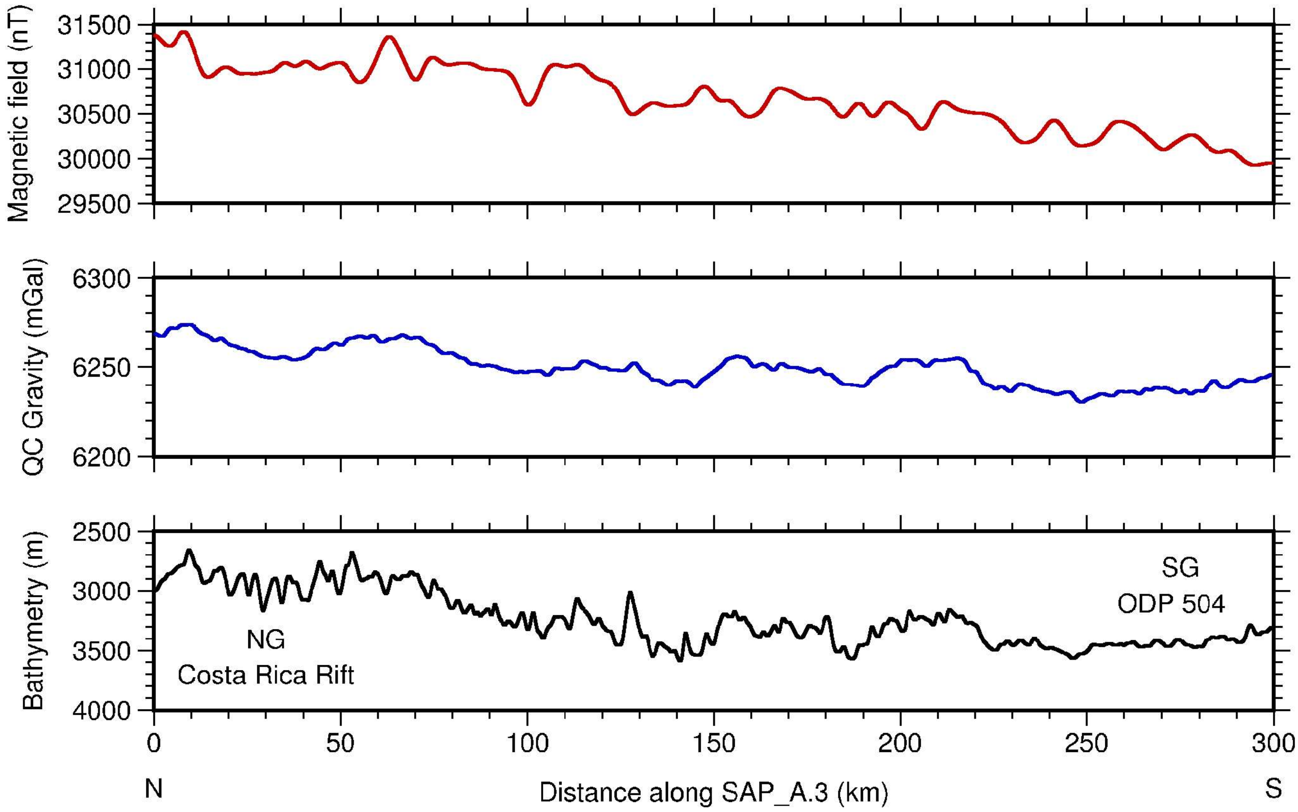


Figure 5.4. Example of potential field data (free-air gravity and magnetic field) plotted for the north-south profile SAP_A with bathymetry extracted from the EM120 multi-beam echo sounder. Both the gravity and magnetic data have had a 5 km moving average filter applied for QC display purposes.

5.10 Wave radar

The WaMos wave radar system was not requested but was run throughout the cruise as a technical test due to a failure during the previous cruise.

6. Vessel operations

In general vessel operations were excellent and there was no science time lost.

However there was a problem with the Dynamic Positioning console on the bridge over a number of days which meant it was not in regular use from JD044 to JD056, a significant part of the cruise, including the two-ship work with the SONNE. This had little impact on the cruise plan but extra care was required when changing course with the 4500 m streamer deployed.

The system to enter and revise navigation way-points is clumsy. There does not seem to be an easy way to automatically transfer way-points between the system available to the science team in the main laboratory and the bridge. Copying way-points onto paper then entering them in the bridge systems is prone to error particularly for the multichannel seismic operations like those carried out during this cruise, where each of the grids requires a minimum of 60 way-points to define all the aim-points and turns.

7. Mobilisation and demoblisation

The presence of the agent at San Jose airport on arrival in Costa Rica en-route to Caldera would have helped to more quickly resolve an issue for entry of a Chinese national. Initially they were refused entry but the issue was resolved when immigration issued an entry visa against his UK work visa.

On arrival in Balboa we needed to perform a gravity tie to the base station on Rodman pier. The taxi arranged by the agent failed to arrive. Eventually we hired our own taxi but were too late arriving at the Rodman security gate that evening to gain entry. The final gravity tie was completed the following morning. Not a major problem but it did delay the final dismantling and packing of the gravimeter ready for transport to Jamaica.

The berthing of the SONNE and COOK at the same dock in Balboa greatly facilitated the transfer of equipment and samples from the SONNE to the COOK at the end of the cruise.

8. Diplomatic clearances

Diplomatic clearance for this cruise was a serious issue and nearly resulted in having to completely revise the science plan. Unfortunately the forms requesting permission for cruise JC114 to work in Colombian water were not been correctly submitted to the Colombian authorities. This problem came to light during a telephone conference call 12 November 2014 between the Colombian officials, the British Embassy, Miguel Morales (PSO JC112) and Richard Hobbs (PSO JC114). This was despite several requests by the PSOs through NERC operations for an update on progress. Work by the Embassy in Bogotá, NERC operations and good-will on the part of the Colombian authorities enabled the cruise to go ahead as planned. The PSO is grateful for the support of all involved and their prompt action to resolve this issue. However, this episode could have been averted if there had been better communications between PSO ↔ NERC ↔ FCO ↔ Embassy ↔ government officials. A more transparent system need to be devised that ensures feedback about progress to the PSO on a regular basis so the PSO retains ownership of the process.

The other permissions were granted as requested.

9. Diary of events

Day	Date	Time (GMT)	Activity
J022	22/01/15	1600	Depart Caldera, Costa-Rica Transit
J023	23/01/15	1900	Acoustic release tests/velocity probe 5°55.616'N,83°16.600'W Transit
J024	24/01/15	0243 0612 0913 1335	Deploy SR_01 Deploy SR_02 Deploy SR_03 Deploy SR_04 Transit
J025	25/01/15	0114 0640 0849 0927 1010 1045 1119 1148 1221 1258 1328 1359 1420 1459 1524 1554 1619 1653 1726 1811 2006	Acoustic release tests/velocity probe 3 °13.387'N,83°49.757'W Deploy vertical array VA_01 Deploy NG_01 Deploy NG_02 Deploy NG_03 Deploy NG_04 Deploy NG_05 Deploy NG_06 Deploy NG_07 Deploy NG_08 Deploy NG_09 Deploy NG_10 Deploy NG_11 Deploy NG_12 Deploy NG_13 Deploy NG_14 Deploy NG_15 Deploy NG_16 Deploy NG_17 Deploy NG_18 Streamer deployment for buoyancy testing and configuration
J026	26/01/15	0426 0457 0530 0558 1143 1204 1237 1305 1335 1500 1625 1958 2023 2159 2248	Streamer recovery complete Deploy NG_19 Deploy NG_20 Swathing 3°14.784'N, 83°45.071'W 3°15.651'N, 84°10.913'W 3°10.515'N, 84°15.680'W 3°10.384'N, 83°57.073'W Deploy NG_25 Deploy NG_24 Deploy NG_23 Deploy NG_22 Deploy NG_21 Deploy 1500 m streamer Deploy airgun arrays Start profile NG_E End profile NG_E Repair Gun-1 Start profile NG_EA End profile NG_EA
J027	27/01/15	0206 0710 1000 1247 1558 2043	Start profile NG_B End profile NG_B Start profile NG_D End profile NG_D Repair Gun-1 Start profile NG_A End profile NG_A

Day	Date	Time (GMT)	Activity
		 2322	Repair Gun-1 Start profile NG_C
J028	28/01/15	0215 0919 1243 1507 1843 2232	End profile NG_C Start profile NG_H End profile NG_H Start profile NG_F End profile NG_F Start profile NG_I
J029	29/01/15	0131 0341 0746 1120 1423	End profile NG_I Start profile NG_G End profile NG_G Start profile NG_J End profile NG_J Recover 1500 m streamer Deploy and balance 4500 m streamer
J030	30/01/15	0639 1348 1641 2012	Deployment complete Start profile NG_EE End profile NG_EE Start profile NG_BB
J031	31/01/15	0118 0632 1052 1526 1911 2146	End profile NG_BB Start profile NG_K End profile NG_K Repair gun-1 Start profile NG_II End profile NG_II Start profile NG_FF
J032	01/02/15	0101 0130 0610 0806 0900 1100 1243 1435 1531 1657 1826 2006 2143 2255	End profile NG_FF Start gun/streamer recovery Gun/streamer recovery complete Deploy SAP_01 Deploy SAP_02 Recover NG_05 Recover NG_03 Recover NG_02 Recover NG_01 Recover NG_10 Recover NG_09 Recover NG_08 Recover NG_06 Recover NG_15
J033	02/02/15	0015 0140 0300 0430 0505 0704 0849 1009 1143 1300 1500 1537 1616 1656 1732 1813 1859 1945	Recover NG_13 Recover NG_12 Recover NG_11 Recover NG_20 Recover NG_19 Recover NG_18 Recover NG_16 Recover NG_25 Recover NG_23 Recover NG_22 Recover NG_21 Deploy SAP_08 Deploy SAP_09 Deploy SAP_10 Deploy SAP_11 Deploy SAP_12 Deploy SAP_13 Deploy SAP_14

Day	Date	Time (GMT)	Activity
		2033	Deploy SAP_15
		2116	Deploy SAP_16
		2201	Deploy SAP_17
		2242	Deploy SAP_18
		2321	Deploy SAP_19
		2359	Deploy SAP_20
J034	03/02/15	0042	Deploy SAP_21
		0123	Deploy SAP_22
		0203	Deploy SAP_23
		0250	Deploy SAP_24
		0331	Deploy SAP_25
		0413	Deploy SAP_26
		0440	Deploy SAP_27
		0528	Deploy SAP_28
		0615	Deploy SAP_29
		0704	Deploy SG_02
		0735	Deploy SG_09
		0803	Deploy SG_12
		0836	Deploy SG_19
		0900	Deploy SG_22
		0951	Deploy SAP_35
		1427	Deploy VA_02
		1500	Swathing 1°18.229'N 83°43.931'W
		2200	1°20.160'N 84°43.364'W
J035	04/02/15	0200	1°06.077'N 84°40.347'W
		0804	1°06.011'N 83°38.987'W
		1000	Start deploying 4500 m streamer
		1600	Deploy airguns
		1741	Start profile EX_A
J036	05/02/15	1342	End profile EX_A
		1953	Start profile EX_B
J037	06/02/15	0826	End profile EX_B
		1313	Start profile EX_C
		1453	End profile EX_C
			Repair gun-17
		1624	Start profile EX_CA
		2003	End profile EX_CA
		2108	Start profile EX_D
J038	07/02/15	0152	End profile EX_D
		0316	Start profile EX_E
		1356	End profile EX_E
		1523	Start profile EX_F
		2302	End profile EX_F
J039	08/02/15	0009	Start profile EX_G
		1010	End profile EX_G
		1121	Start profile EX_H
		2134	End profile EX_H
		2226	Start profile EX_I
J040	09/02/15	0534	End profile EX_I
		0649	Start profile EX_II
		1246	End profile EX_II
		1342	Start profile EX_J
J041	10/02/15	0330	End profile EX_J
		0502	Start profile EX_K
		0841	End profile EX_K
			MEET UP WITH SONNE
		1404	Start profile SAP_B

Day	Date	Time (GMT)	Activity
		2253	End profile SAP_B – SEAL data-logger error Recover streamer to change suspect section
J042	11/02/15	1305 1545	Start profile SAP_BB Change to 41 s record length
J043	12/02/15	1605 1904	End profile SAP_BB Start profile SAP_A
J044	13/02/15		Shooting profile SAP_A
J045	14/02/15	0223 0227 0524 0530	End profile SAP_A Start profile SAP_AA End profile SAP_AA Start profile SAP_C
J046	15/02/15	1801 1830 2226 2345	End profile SAP_C Start to recover airguns and streamer Recovery complete Meeting with SONNE
J047	16/02/15	0030 1131 1400 1602 1747 2127 2238	SONNE DEPARTS transit to VA_01 VA_01 released VA_01 recovered Recover NG_17 Recover NG_07 Recover SAP_01 Recover SAP_02
J048	17/02/15	0053 0238 0555 0742 0930 1214 1354 1530 1742 1919 2112 2308	Recover NG_04 Recover NG_14 Recover SAP_09 Recover SAP_08 Recover NG_24 Recover SAP_10 Recover SAP_11 Recover SAP_12 Recover SAP_13 Recover SAP_14 Recover SAP_15 Recover SAP_16
J049	18/02/15	0111 0320 0516 0718 0912 1109 1255 1434 1637 1850 2125 2351	Recover SAP_17 Recover SAP_18 Recover SAP_19 Recover SAP_20 Recover SAP_21 Recover SAP_22 Recover SAP_23 Recover SAP_24 Recover SAP_25 Recover SAP_26 Recover SAP_27 Recover SAP_28
J050	19/02/15	0114 0159 0242 0304 0335 0405 0440 0448 0533 0608	Deploy SG_01 Deploy SG_03 Deploy SG_04 Deploy SG_05 Deploy SG_06 Deploy SG_07 Deploy SG_08 Deploy SG_08A Deploy SG_10 Deploy SG_11

Day	Date	Time (GMT)	Activity
		0654 0704 0736 0802 0830 0854 0919 1003 1034 1116 1142 1208 1403 1845 2121 2330	Deploy SG_13 Deploy SG_13A Deploy SG_14 Deploy SG_15 Deploy SG_16 Deploy SG_17 Deploy SG_18 Deploy SG_20 Deploy SG_21 Deploy SG_23 Deploy SG_24 Deploy SG_25 Deploying streamer Launch MOB to remove floatation device from bird #13 deploying airguns Start profile SG_I
J051	20/02/15	0335 0559 0904 1225 1642 1929 2235	End profile SG_I Start profile SG_F End profile SG_F Start profile SG_J End profile SG_J Start profile SG_G End profile SG_G
J052	21/02/15	0151 0637 0916 1219 1825 2219	Start profile SG_N End profile SG_N Start profile SG_H End profile SG_H Repair gun-17 Start profile SG_C End profile SG_C
J053	22/02/15	0102 0455 0829 1207 1433 1725 1750 1830 2209	Start profile SG_M End profile SG_M Start profile SG_D End profile SG_D Start profile SG_A SEAL data logger falls over SEAL restarted End profile SG_A Start profile SG_E
J054	23/02/15	0134 0414 0757 1410	End profile SG_E Start profile SG_B End profile SG_B Reconfigure for high resolution profile Start profile RS_A
J055	24/02/15	1202 1915	End profile RS_A Reconfigure for medium resolution profile Start profile RS_B
J056	25/02/15	1900 1915	End profile RS_B Recover guns and streamer
J057	26/02/15	0030 0053 0330 0743 0913 1056 1236 1402 1532	Gravimeter overheat problem Gravimeter back on line Streamer recovery complete Recover SG_21 Recover SG_20 Recover SG_11 Recover SG_10 Recover SG_09 Recover SG_02

Day	Date	Time (GMT)	Activity
		1630 1708 1854 2055 2232 2359	Start recovery of VA_02 Recovery complete Recover SG_29 Recover SG_01 Recover SG_03 Recover SG_08
J058	27/02/15	0135 0306 0429 0556 0733 0904 1155 1320 1445 1615 1745 1908 2039 2212 2339	Recover SG_08A Recover SG_13A Recover SG_13 Recover SG_18 Recover SG_23 Recover SG_24 Recover SAP_35 Recover SG_22 Recover SG_19 Recover SG_12 Recover SG_17 Recover SG_14 Recover SG_07 Recover SG_04 Recover SG_05
J059	28/02/15	0107 0242 0419 0538	Recover SG_06 Recover SG_15 Recover SG_16 Recover SG_25 Swathing
J060	01/03/15		Swathing
J061	02/03/15		Swathing
J062	03/03/15		Swathing
J063	04/03/15	 0337 1147 1703 2220	Swathing Recover SR_04 Recover SR_03 Recover SR_02 Recover SR_01 Swathing
J064	05/03/15	 1800	Swathing Cease logging other than GPS/Gravity Transit
J065	06/03/15	 1200	Transit Arrive anchorage Panama

10. Personnel

The RRS James Cook carried a total of 43 people during JC114 as listed below:

1	A.L. SMITH	Master
2	P.D. GAULD	Chief Officer
3	D.D.A. MORROW	2nd Officer
4	S. HOXBY	3rd Officer
5	R.J. INGLIS	Chief Engineer
6	M. MURRAY	2nd Engineer
7	M.G. MURREN	3rd Engineer
8	L. PORRELLI	3rd Engineer
9	S.M. ULBRICHT	ETO
10	A. STEVENS	PCO
11	M.A. HARRISON	CPOS
12	P. ALLISON	CPOD
13	D.A. PRICE	POD
14	B. CONTEH	ERPO
15	M.S. MOORE	Seaman
16	J.D. WELTON	Seaman
17	D. MACKENZIE	Seaman
18	N.J. BYRNE	Seaman
19	D.A. CAINES	Head Chef
20	J. WATERHOUSE	Chef
21	K.J. MASON	Steward
22	T. DOCHERTY	Assistant Steward
23	R.W. HOBBS	PSO
24	C. PEIRCE	Co-PSO
25	A.H. ROBINSON	Scientist
26	E.P.M. GREGORY	Scientist
27	Q. TANG	Scientist
28	C.A. VARGAS JIMENEZ	Scientist
29	D.J. WILSON	Scientist
30	M.J. FUNNELL	Scientist
31	G.A. HAUGHTON	Scientist
32	B.J. PITCAIRN	OBIF
33	A.P. CLEGG	OBIF
34	A. GONZALEZ NAKAZAWA	OBIF
35	M. ERFANIAN MEHR	OBIF
36	M. CAMPOS GARCIA	Observer
37	N.A. SLOAN	TLO
38	J.E. SCOTT	Technical Support
39	W.M.C. RICHARDSON	Technical Support
40	A.J. LEADBEATER	Technical Support
41	M. MALTBY	Technical Support
42	M.J. SMITH	Exploration Electronics Ltd
43	R.C. VAN HAREN	Exploration Electronics Ltd

11. References

Locarnini, R. A., A. V. Mishonov, J. I. Antonov, T. P. Boyer, H. E. Garcia, O. K. Baranova, M. M. Zweng, and D. R. Johnson, 2010. World Ocean Atlas 2009, Volume 1: Temperature. S. Levitus, Ed. NOAA Atlas NESDIS 68, U.S. Government Printing Office, Washington, D.C., 184 pp.

Lonsdale, P., 1977. Inflow of bottom water to the Panama Basin, *Deep Sea Research*, 24, Pages 1065-1101, doi:10.1016/0146-6291(77)90514-8.

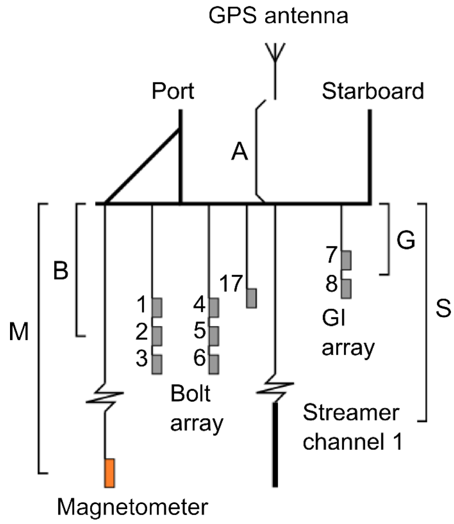
Müller, R.D., Roest, W.R., Royer, J.Y., Gahagan, L.M. and Sclater, J.G., 1997, Digital isochrons of the world's ocean floor, *Journal of Geophysical Research*, 102, 3211-3214, doi:10.1029/96JB01781

Polzin, K.L., Toole, J.M., Ledwell, J.R. And Schmitt, R.W., 1997. Spatial Variability of Turbulent Mixing in the Abyssal Ocean, Science, 276 (5309), 93-96, doi:10.1126/science.276.5309.93

Stein, C.A. and Stein, S., 1992. A model for the global variation in oceanic depth and heat flow with lithospheric age , *Nature* , 359 , 123 -129 , doi:10.1038/359123a0

Appendix A - airgun array and streamer layouts

Airgun configuration



All airguns were fired at 2000 psi
GI-to-Bolt firing delay of 6 s

A = 46 m
B = 40 m (47 m for configuration 1)
G = 24 m
M = 254 m

Bolt array tow depth = 8 m
GI array tow depth = 5 m (3 m for configuration 5)

Configuration	Gun number							
	1	2	3	4	5	6	7	8
	Gun volume (cu. in.)							
1	500	100	120	300	100	200	210*	210*
2	120	100	500	200	100	300	210*	210*
3	120	100	300	200	100	300	210*	210*
4	120	100	300	200	100	300	210*	210*
5	-	-	-	-	-	-	210*	210*
6	120	100	300	200	100	300	-	-

*GI gun with 2 x 105 cu. in. chambers

Gun 17 is single Bolt 500 cu in towed without a buoy, estimated position is 20 m behind stern at a depth of 8 m used in conjunction with configuration 3 for the EX, SG (labelled as "Airgun configuration 3+") and RS_B profile (labelled as "Airgun configuration 6+").

Streamer configuration

SEAL streamer system with a 12.5 m group interval and 3-200 Hz bandpass filter. During acquisition, several configurations were used according to the source parameters. The MCS summary includes the relevant configuration for each profile.

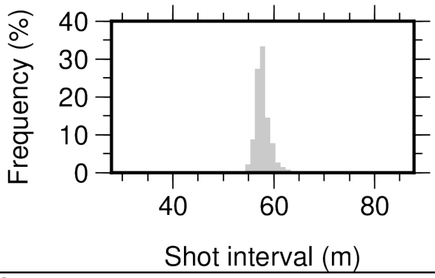
Configuration	Number of channels	Length (km)	Stern-to-channel 1 offset, S (m)	Tow depth (m)
1	120	1.5	103	10
2	360	4.5	170	10
3	360	4.5	170	3/5*

*Front 1.5 km towed at 3 m depth. Transition to 5 m tow depth between birds 6 and 7.

Appendix B - profile acquisition configurations

MCS Acquisition Summary

NG_A.5

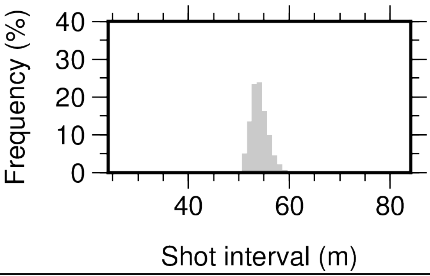


Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots 570
Mean shot interval 57.8 m
Expected fold (25 m bin) 51

FFID	Time	Latitude	Longitude	Comment
101	2015:027:15:58:34	3.365440	-83.929545	FSP
303	2015:027:17:39:40			Gun 1 off
670	2015:027:20:43:04	3.364860	-83.633921	LSP

NG_B.3

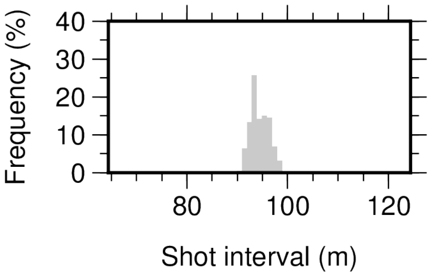


Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots 609
Mean shot interval 54.1 m
Expected fold (25 m bin) 55

FFID	Time	Latitude	Longitude	Comment
101	2015:027:02:06:04	3.329328	-83.929402	FSP, Gun 1 off
709	2015:027:07:10:34	3.328473	-83.633804	LSP

NG_C.6

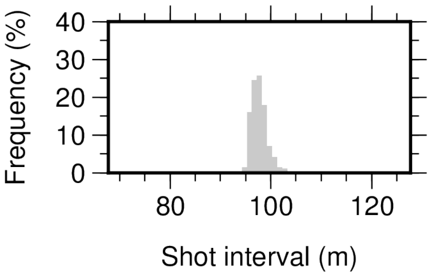


Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots 346
Mean shot interval 94.4 m
Expected fold (25 m bin) 31

FFID	Time	Latitude	Longitude	Comment
101	2015:027:23:22:34	3.284943	-83.637756	FSP
446	2015:028:02:15:04	3.284177	-83.930507	LSP

NG_D.4



Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

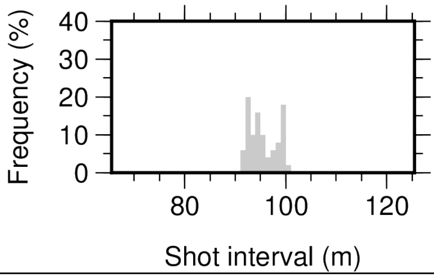
Total number of shots 335
Mean shot interval 97.7 m
Expected fold (25 m bin) 30

FFID	Time	Latitude	Longitude	Comment
101	2015:027:10:00:34	3.239809	-83.637440	FSP, Gun 1 off
435	2015:027:12:47:34	3.238970	-83.930898	LSP

NG_E.1

Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots 51
Mean shot interval 95.5 m
Expected fold (25 m bin) 31

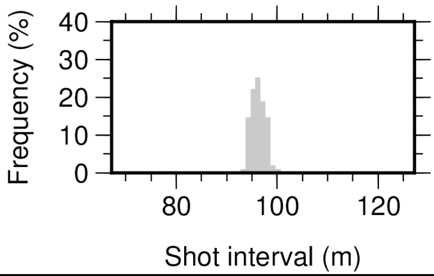


FFID	Time	Latitude	Longitude	Comment
101	2015:026:19:58:34	3.194681	-83.637701	FSP
104	2015:026:20:00:10			Gun 1 off
151	2015:026:20:23:34	3.194947	-83.680625	LSP

NG_EA.2

Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots 97
Mean shot interval 97.2 m
Expected fold (25 m bin) 30

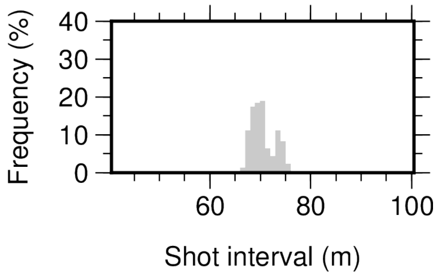


FFID	Time	Latitude	Longitude	Comment
1001	2015:026:21:59:34	3.196961	-83.846972	FSP
1097	2015:026:22:48:04	3.197477	-83.930833	LSP

NG_F.8

Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots 433
Mean shot interval 70.5 m
Expected fold (25 m bin) 42

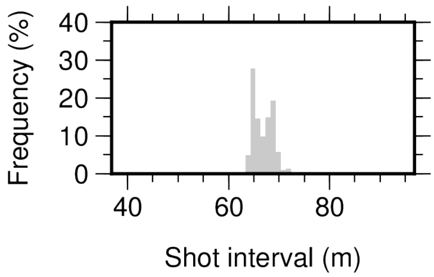


FFID	Time	Latitude	Longitude	Comment
101	2015:028:15:07:04	3.157412	-83.871771	FSP
533	2015:028:18:43:04	3.432400	-83.872555	LSP

NG_G.10

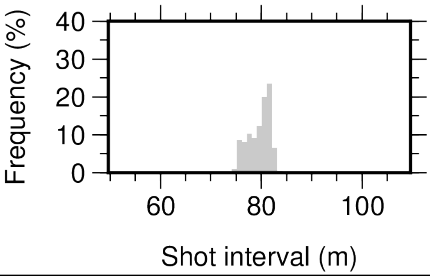
Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots 490
Mean shot interval 66.8 m
Expected fold (25 m bin) 44



FFID	Time	Latitude	Longitude	Comment
103	2015:029:03:41:34	3.137794	-83.827134	FSP
592	2015:029:07:46:04	3.432968	-83.827616	LSP

NG_H.7

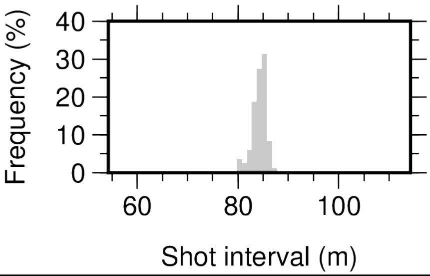


Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots	408
Mean shot interval	79.6 m
Expected fold (25 m bin)	37

FFID	Time	Latitude	Longitude	Comment
101	2015:028:09:19:34	3.429017	-83.782577	FSP
508	2015:028:12:43:04	3.136221	-83.782091	LSP

NG_I.9

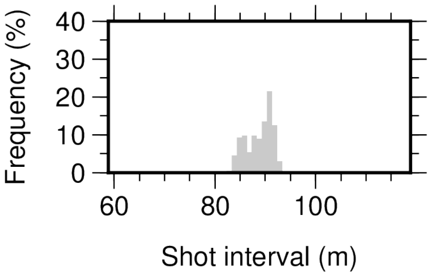


Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots	359
Mean shot interval	84.3 m
Expected fold (25 m bin)	35

FFID	Time	Latitude	Longitude	Comment
102	2015:028:22:32:04	3.409617	-83.737645	FSP
460	2015:029:01:31:04	3.137057	-83.736780	LSP

NG_J.11

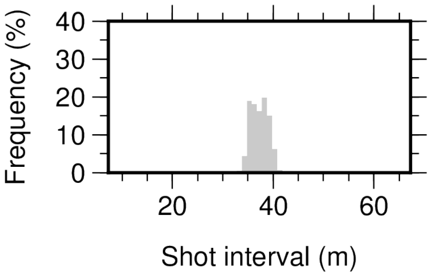


Airgun configuration 1; Shot interval 30 s
Streamer configuration 1; 27 s record at 500 Hz

Total number of shots	368
Mean shot interval	88.8 m
Expected fold (25 m bin)	33

FFID	Time	Latitude	Longitude	Comment
101	2015:029:11:20:04	3.430860	-83.692557	FSP
468	2015:029:14:23:34	3.136269	-83.691806	LSP

NG_Bb.13

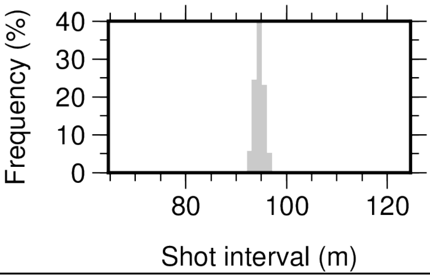


Airgun configuration 1; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots	920
Mean shot interval	37.3 m
Expected fold (25 m bin)	241

FFID	Time	Latitude	Longitude	Comment
101	2015:030:20:12:20	3.332137	-83.942163	FSP
1020	2015:031:01:18:40	3.325618	-83.634457	LSP

NG_EE.12

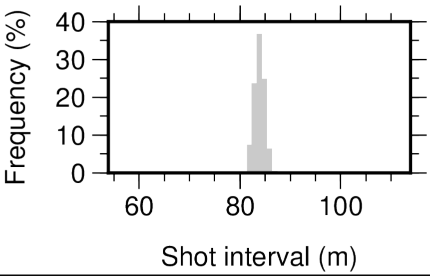


Airgun configuration 1; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots	347
Mean shot interval	94.6 m
Expected fold (25 m bin)	95

FFID	Time	Latitude	Longitude	Comment
101	2015:030:13:48:00	3.194504	-83.637517	FSP
447	2015:030:16:41:00	3.193728	-83.931776	LSP

NG_FF.16

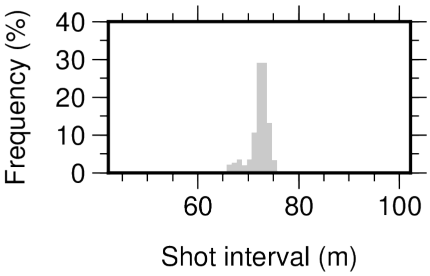


Airgun configuration 1; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots	390
Mean shot interval	83.9 m
Expected fold (25 m bin)	107

FFID	Time	Latitude	Longitude	Comment
101	2015:031:21:46:30	3.138445	-83.871878	FSP, Gun 3 off
490	2015:032:01:01:00	3.433204	-83.872535	LSP

NG_II.15

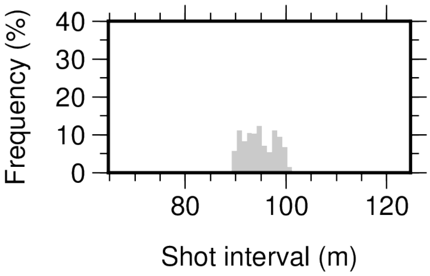


Airgun configuration 1; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots	450
Mean shot interval	72.2 m
Expected fold (25 m bin)	124

FFID	Time	Latitude	Longitude	Comment
101	2015:031:15:26:30	3.428635	-83.737751	FSP, Gun 3 off
550	2015:031:19:11:00	3.135688	-83.736968	LSP

NG_K.14



Airgun configuration 1; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

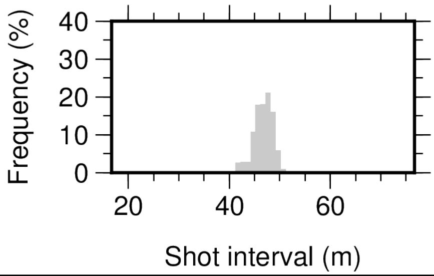
Total number of shots	521
Mean shot interval	94.7 m
Expected fold (25 m bin)	95

FFID	Time	Latitude	Longitude	Comment
101	2015:031:06:32:00	3.117374	-83.613760	FSP
621	2015:031:10:52:00	3.427438	-83.930964	LSP

EX_A.1

Airgun configuration 2; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 3604
Mean shot interval 46.7 m
Expected fold (25 m bin) 192

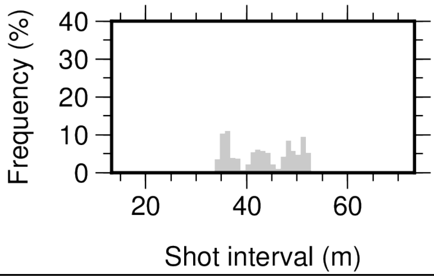


FFID	Time	Latitude	Longitude	Comment
101	2015:035:17:41:00	1.730222	-83.682134	FSP, Guns 1 & 8 off
952	2015:035:22:24:46			Gun 3 off
1055	2015:035:23:00:00			Gun 8 on
3704	2015:036:13:42:04	1.727780	-85.190720	LSP

EX_B.2

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 2260
Mean shot interval 43.2 m
Expected fold (25 m bin) 208

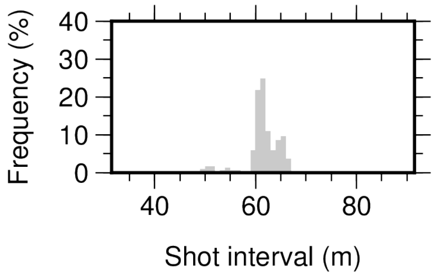


FFID	Time	Latitude	Longitude	Comment
101	2015:036:19:53:20	1.808382	-84.960249	FSP
2360	2015:037:08:26:20	0.926847	-84.959486	LSP

EX_C.3

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 302
Mean shot interval 61.5 m
Expected fold (25 m bin) 146

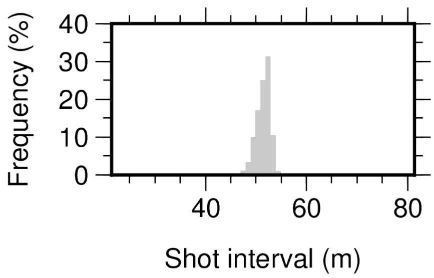


FFID	Time	Latitude	Longitude	Comment
101	2015:037:13:13:20	1.249777	-85.076154	FSP
370	2015:037:14:43:06			Gun 17 off
402	2015:037:14:53:40	1.416745	-85.076100	LSP

EX_CA.4

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 657
Mean shot interval 51.4 m
Expected fold (25 m bin) 175

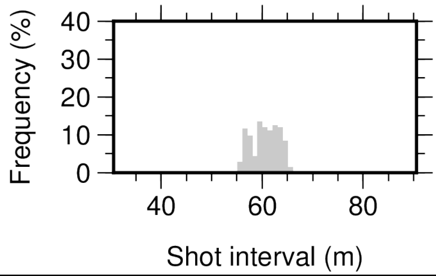


FFID	Time	Latitude	Longitude	Comment
101	2015:037:16:24:40	1.517817	-85.076123	FSP
757	2015:037:20:03:20	1.821946	-85.076250	LSP

EX_D.5

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 855
Mean shot interval 60.6 m
Expected fold (25 m bin) 148

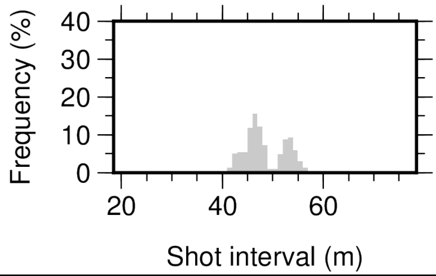


FFID	Time	Latitude	Longitude	Comment
101	2015:037:21:08:00	1.842389	-84.985351	FSP
955	2015:038:01:52:40	1.842517	-84.521384	LSP

EX_E.6

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 1919
Mean shot interval 48.4 m
Expected fold (25 m bin) 185

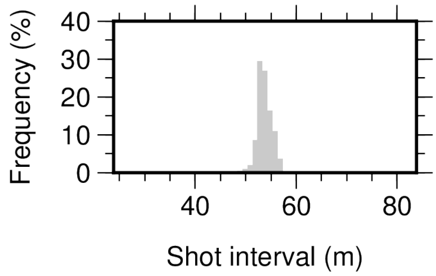


FFID	Time	Latitude	Longitude	Comment
101	2015:038:03:16:40	1.761963	-84.475498	FSP
2019	2015:038:13:56:00	0.939465	-84.639554	LSP

EX_F.7

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 1375
Mean shot interval 53.8 m
Expected fold (25 m bin) 167

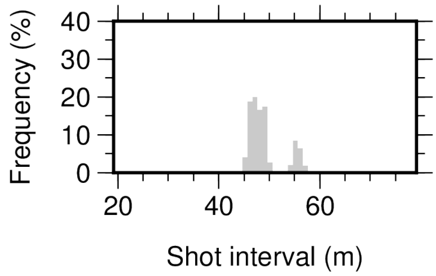


FFID	Time	Latitude	Longitude	Comment
101	2015:038:15:23:38	0.874320	-84.720362	FSP
698	2015:038:18:42:40			Break for pilot whales
807	2015:038:19:19:00			Continued on full power after soft start
1475	2015:038:23:02:00	0.874175	-85.383247	LSP

EX_G.8

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 1802
Mean shot interval 49.1 m
Expected fold (25 m bin) 183

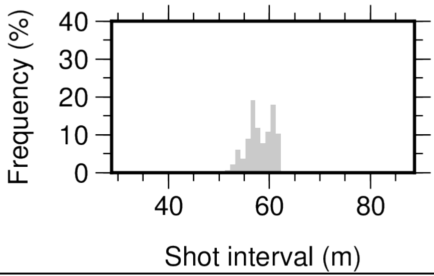


FFID	Time	Latitude	Longitude	Comment
101	2015:039:00:09:40	0.943597	-85.427234	FSP
1902	2015:039:10:10:00	1.741876	-85.416641	LSP

EX_H.9

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 1822
Mean shot interval 58.1 m
Expected fold (25 m bin) 154

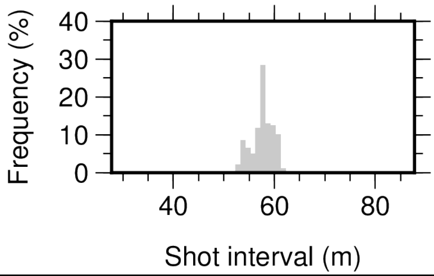


FFID	Time	Latitude	Longitude	Comment
101	2015:039:11:21:40	1.791547	-85.347399	FSP
1940	2015:039:21:34:40	1.748212	-84.389823	LSP

EX_I.10

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 1281
Mean shot interval 57.8 m
Expected fold (25 m bin) 155

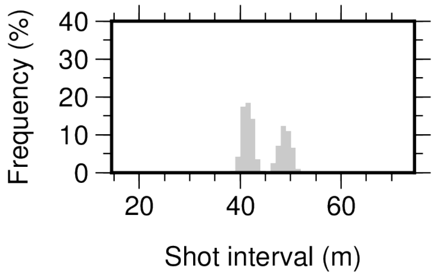


FFID	Time	Latitude	Longitude	Comment
101	2015:039:22:26:40	1.694692	-84.346601	FSP
1381	2015:040:05:34:20	1.047936	-84.510865	LSP

EX_II.11

Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 1074
Mean shot interval 44.5 m
Expected fold (25 m bin) 202

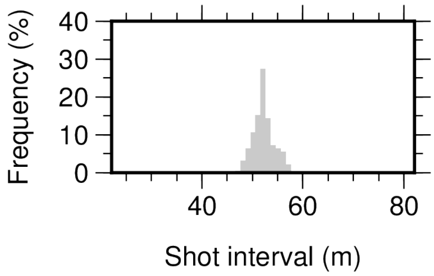


FFID	Time	Latitude	Longitude	Comment
101	2015:040:06:49:00	0.979297	-84.581778	FSP
1174	2015:040:12:46:40	1.193310	-84.866613	LSP

EX_J.12

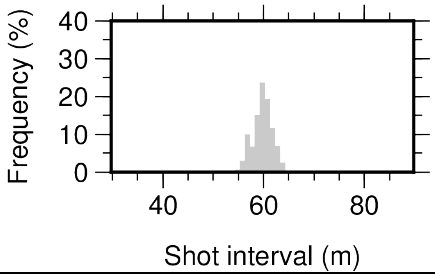
Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 2483
Mean shot interval 52.1 m
Expected fold (25 m bin) 172



FFID	Time	Latitude	Longitude	Comment
101	2015:040:13:42:40	1.233113	-84.813738	FSP
2583	2015:041:03:30:00	1.226781	-83.654862	LSP

EX_K.13

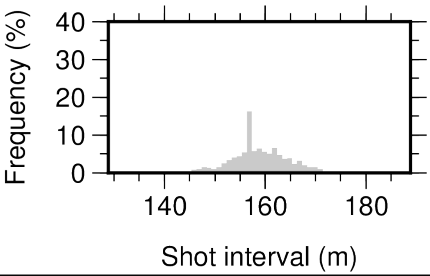


Airgun configuration 3+; Shot interval 20 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots	657
Mean shot interval	59.8 m
Expected fold (25 m bin)	150

FFID	Time	Latitude	Longitude	Comment
101	2015:041:05:02:20	1.093907	-83.607469	FSP
757	2015:041:08:41:00	0.740338	-83.589742	LSP

SAP_A.3

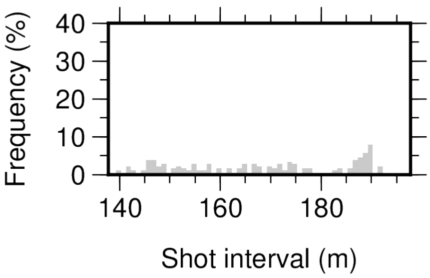


Airgun configuration 4; Shot interval 60 s
Streamer configuration 2; 44 s record at 500 Hz

Total number of shots	1877
Mean shot interval	158.8 m
Expected fold (25 m bin)	56

FFID	Time	Latitude	Longitude	Comment
101	2015:043:19:04:00	3.599614	-83.684937	FSP
245	2015:043:21:30:00			Change to 42.5 s record
1474	2015:044:18:00:00			Change to 41 s record
1977	2015:045:02:23:00	0.907625	-83.739531	LSP

SAP_AA.4 (turn)

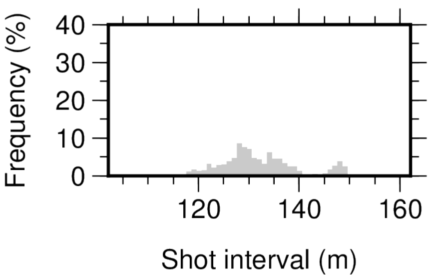


Airgun configuration 4; Shot interval 60 s
Streamer configuration 2; 41 s record at 500 Hz

Total number of shots	178
Mean shot interval	167.8 m
Expected fold (25 m bin)	53

FFID	Time	Latitude	Longitude	Comment
101	2015:045:02:27:00	0.901529	-83.739881	FSP
278	2015:045:05:24:00	0.926785	-83.874442	LSP

SAP_B.1



Airgun configuration 4; Shot interval 60 s
Streamer configuration 2; 47 s record at 500 Hz

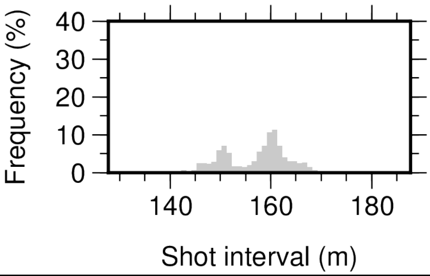
Total number of shots	530
Mean shot interval	132.1 m
Expected fold (25 m bin)	68

FFID	Time	Latitude	Longitude	Comment
101	2015:041:14:04:00	0.956635	-83.721653	FSP
630	2015:041:22:53:00	1.587468	-83.749111	LSP, streamer problems after this

SAP_BB.1

Airgun configuration 4; Shot interval 60 s
Streamer configuration 2; 47 s record at 500 Hz

Total number of shots	1613
Mean shot interval	157.5 m
Expected fold (25 m bin)	57

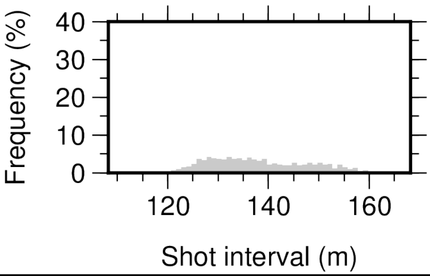


FFID	Time	Latitude	Longitude	Comment
101	2015:042:13:05:00	1.433885	-83.742307	FSP
253	2015:042:15:45:00			Change to 41 s record
1713	2015:043:16:05:00	3.721872	-83.819630	LSP

SAP_C.5

Airgun configuration 4; Shot interval 60 s
Streamer configuration 2; 41 s record at 500 Hz

Total number of shots	2192
Mean shot interval	138.2 m
Expected fold (25 m bin)	65

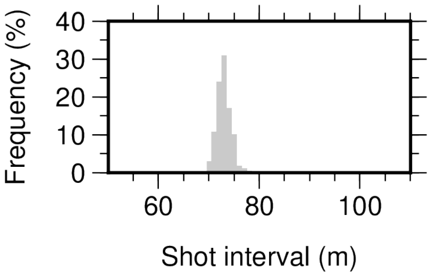


FFID	Time	Latitude	Longitude	Comment
102	2015:045:05:30:00	0.934662	-83.874404	FSP
2073	2015:046:14:24:00			Guns 7 & 8 off
2293	2015:046:18:01:00	3.669144	-83.820638	LSP

SG_A.10

Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots	435
Mean shot interval	73.2 m
Expected fold (25 m bin)	122

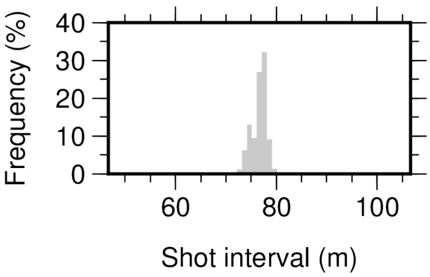


FFID	Time	Latitude	Longitude	Comment
101	2015:053:14:33:30	1.323462	-83.915691	FSP
437	2015:053:17:21:30			No record
445	2015:053:17:25:30			Bad record to FFID 455, streamer off
456	2015:053:17:50:30			Resumed recording after ~4 km gap
536	2015:053:18:30:30	1.323875	-83.603882	LSP

SG_B.12

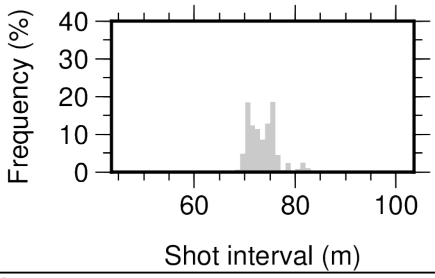
Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots	446
Mean shot interval	76.6 m
Expected fold (25 m bin)	117



FFID	Time	Latitude	Longitude	Comment
101	2015:054:04:14:30	1.278464	-83.909344	FSP
546	2015:054:07:57:00	1.278945	-83.603211	LSP

SG_C.7

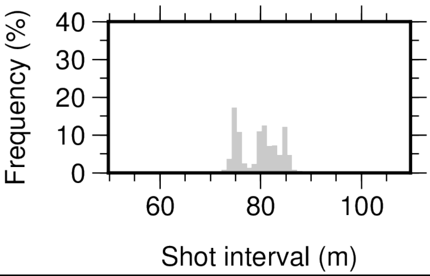


Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots	468
Mean shot interval	73.6 m
Expected fold (25 m bin)	122

FFID	Time	Latitude	Longitude	Comment
101	2015:052:18:25:30	1.234315	-83.645068	FSP
568	2015:052:22:19:00	1.233552	-83.953424	LSP

SG_D.9

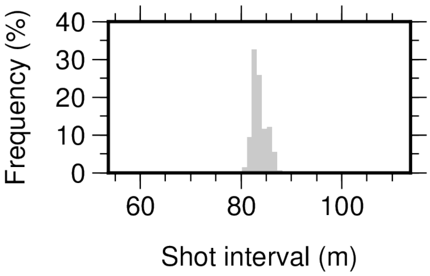


Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots	437
Mean shot interval	79.7 m
Expected fold (25 m bin)	112

FFID	Time	Latitude	Longitude	Comment
101	2015:053:08:29:30	1.188424	-83.641347	FSP
537	2015:053:12:07:30	1.187868	-83.953345	LSP

SG_E.11

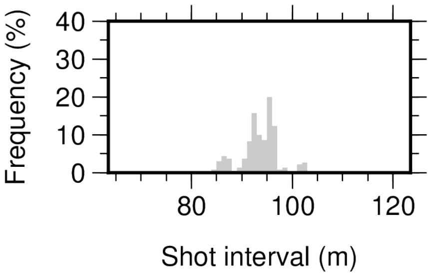


Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots	411
Mean shot interval	83.6 m
Expected fold (25 m bin)	107

FFID	Time	Latitude	Longitude	Comment
101	2015:053:22:09:00	1.143258	-83.645414	FSP
511	2015:054:01:34:00	1.142823	-83.953234	LSP

SG_F.2



Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

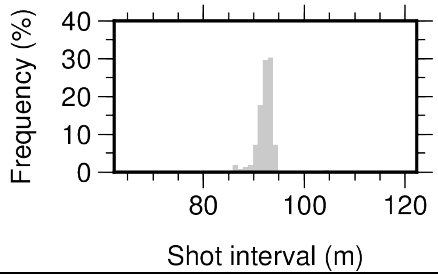
Total number of shots	371
Mean shot interval	93.5 m
Expected fold (25 m bin)	96

FFID	Time	Latitude	Longitude	Comment
101	2015:051:05:59:30	1.097563	-83.867935	FSP
471	2015:051:09:04:30	1.410101	-83.868196	LSP

SG_G.4

Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots 373
Mean shot interval 92.3 m
Expected fold (25 m bin) 97

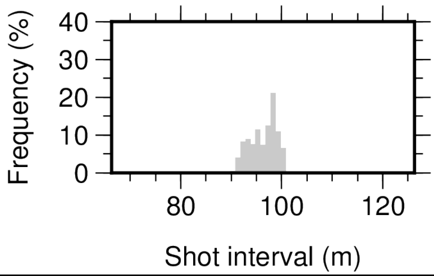


FFID	Time	Latitude	Longitude	Comment
101	2015:051:19:29:00	1.099300	-83.822955	FSP
473	2015:051:22:35:00	1.409559	-83.823187	LSP

SG_H.6

Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots 366
Mean shot interval 96.3 m
Expected fold (25 m bin) 93

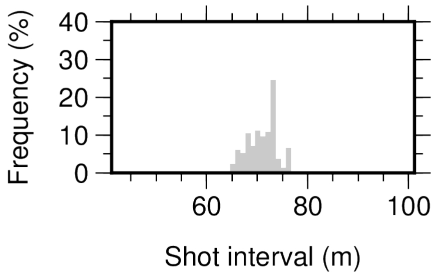


FFID	Time	Latitude	Longitude	Comment
101	2015:052:09:16:30	1.091852	-83.778120	FSP, Gun 17 off
466	2015:052:12:19:00	1.409442	-83.778395	LSP

SG_I.1

Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots 491
Mean shot interval 71.2 m
Expected fold (25 m bin) 126

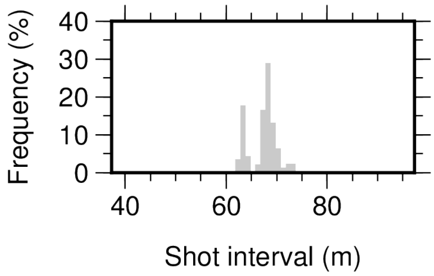


FFID	Time	Latitude	Longitude	Comment
101	2015:050:23:30:00	1.368365	-83.733551	FSP
591	2015:051:03:35:30	1.053310	-83.733139	LSP

SG_J.3

Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots 515
Mean shot interval 67.3 m
Expected fold (25 m bin) 133

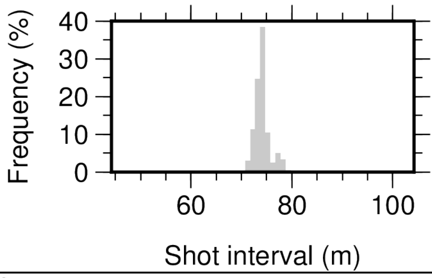


FFID	Time	Latitude	Longitude	Comment
101	2015:051:12:25:00	1.370098	-83.688622	FSP
615	2015:051:16:42:00	1.057555	-83.688307	LSP

SG_M.8

Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots 466
Mean shot interval 74.2 m
Expected fold (25 m bin) 121

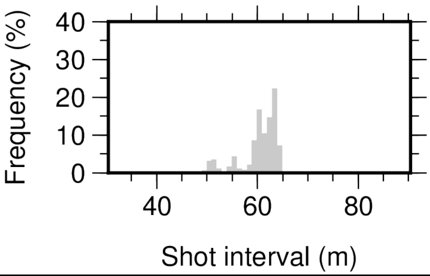


FFID	Time	Latitude	Longitude	Comment
101	2015:053:01:02:48	1.368788	-83.912870	FSP
566	2015:053:04:55:30	1.369088	-83.603084	LSP

SG_N.5

Airgun configuration 3+; Shot interval 30 s
Streamer configuration 2; 27 s record at 500 Hz

Total number of shots 572
Mean shot interval 60.4 m
Expected fold (25 m bin) 149

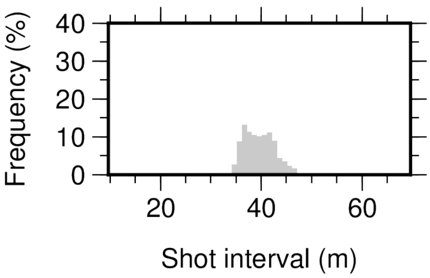


FFID	Time	Latitude	Longitude	Comment
101	2015:052:01:51:30	1.368443	-83.643754	FSP
191	2015:052:02:36:36			Gun 17 off
672	2015:052:06:37:00	1.056865	-83.643401	LSP

RS_A.1

Airgun configuration 5; Shot interval 15 s
Streamer configuration 3; 10 s record at 1000 Hz

Total number of shots 5250
Mean shot interval 39.6 m
Expected fold (25 m bin) 227

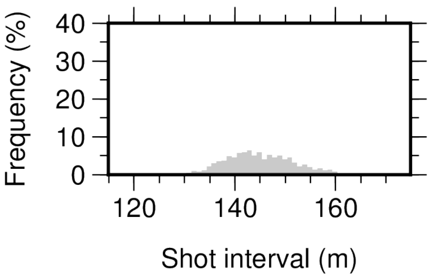


FFID	Time	Latitude	Longitude	Comment
101	2015:054:14:10:15	1.096659	-83.735906	FSP
5350	2015:055:12:02:30	2.975441	-83.697125	LSP

RS_B.2

Airgun configuration 6+; Shot interval 60 s
Streamer configuration 2; 17 s record at 500 Hz

Total number of shots 1426
Mean shot interval 144.9 m
Expected fold (25 m bin) 62



FFID	Time	Latitude	Longitude	Comment
101	2015:055:19:15:00	2.963541	-83.697828	FSP
269	2015:055:22:03:00			Gun 2 off
1526	2015:056:19:00:00	1.099502	-83.735746	LSP

Appendix C - OBS deployment

North Grid OBS deployment summary

Area	Site	Latitude	Longitude	Depth	Deployment time	Recovery time	Logger number	OBS type	Sample rate (Hz)
NG	NG_01	3.364833	-83.689833	2939.0	2015:025:08:49:00	2015:032:15:34:00	69	LC4x4	500
NG	NG_02	3.369267	-83.734733	2985.0	2015:025:09:26:00	2015:032:14:20:00	62	LC4x4	500
NG	NG_03	3.369025	-83.780011	3013.1	2015:025:10:18:40	2015:032:12:44:45	72	LC4x4	500
NG	NG_04	3.369235	-83.824064	2954.7	2015:025:10:45:16	2015:047:00:53:00	57	LC4x4	500
NG	NG_05	3.368930	-83.869448	2911.7	2015:025:11:19:36	2015:032:10:59:30	58	LC4x4	500
NG	NG_06	3.332790	-83.869530	2979.3	2015:025:11:47:10	2015:032:21:45:00	67	LC4x4	500
NG	NG_07	3.331251	-83.824747	2914.8	2015:025:12:21:30	2015:047:17:47:00	63	LC4x4	500
NG	NG_08	3.333187	-83.779434	2893.3	2015:025:12:57:30	2015:032:20:05:00	46	LC4x4	500
NG	NG_09	3.342175	-83.734820	2957.8	2015:025:13:27:27	2015:032:18:17:00	47	LC4x4	500
NG	NG_10	3.329046	-83.689653	3086.8	2015:025:13:58:20	2015:032:16:57:00	65	LC4x4	500
NG	NG_11	3.284860	-83.690450	2973.0	2015:025:14:27:00	2015:033:02:57:00	76	LC4x4	500
NG	NG_12	3.289117	-83.733950	3111.4	2015:025:14:59:00	2015:032:01:48:00	73	LC4x4	500
NG	NG_13	3.284300	-83.779133	2973.2	2015:025:15:24:59	2015:033:00:14:00	70	LC4x4	500
NG	NG_14	3.288100	-83.825983	2973.2	2015:025:15:54:50	2015:048:02:40:00	40	LC4x4	500
NG	NG_15	3.287800	-83.869300	2927.1	2015:025:16:20:26	2015:032:22:56:00	54	LC4x4	500
NG	NG_16	3.243267	-83.869600	2881.0	2015:025:16:55:00	2015:033:08:50:00	74	LC4x4	500
NG	NG_17	3.247067	-83.824383	2831.8	2015:025:17:26:55	2015:047:16:02:00	44	LC4x4	500
NG	NG_18	3.241750	-83.774783	2963.9	2015:025:18:10:14	2015:032:07:02:00	68	LC4x4	500
NG	NG_19	3.247317	-83.735283	3024.0	2015:026:04:57:00	2015:033:05:37:00	51	LC4x4	500
NG	NG_20	3.241917	-83.689050	3125.0	2015:026:05:30:00	2015:033:04:22:00	66	LC4x4	500
NG	NG_21	3.193033	-83.688906	2767.3	2015:026:13:33:55	2015:032:14:26:00	55	LC4x4	500
NG	NG_22	3.201986	-83.734111	2877.9	2015:026:13:05:00	2015:033:12:45:00	61	LC4x4	500
NG	NG_23	3.188354	-83.778672	2862.6	2015:026:12:37:10	2015:033:11:34:00	53	LC4x4	500
NG	NG_24	3.197386	-83.823513	2650.6	2015:026:12:09:11	2015:048:09:29:00	75	LC4x4	500
NG	NG_25	3.197432	-83.868668	2696.7	2015:026:11:42:25	2015:033:10:08:00	71	LC4x4	500

Synthetic Aperture Profile OBS deployment summary

Area	Site	Latitude	Longitude	Depth	Deployment time	Recovery time	Logger number	OBS type	Sample rate (Hz)
SAP	SAP_01	3.532167	-83.836733	2589.0	2015:032:08:06:35	2015:047:21:28:00	60	LC4x4	500
SAP	SAP_02	3.450733	-83.833033	2672.0	2015:032:09:01:00	2015:047:22:39:00	50	LC4x4	500
SAP	SAP_08	3.105267	-83.815800	2804.0	2015:033:15:37:00	2015:048:07:46:00	58	LC4x4	500
SAP	SAP_09	3.026150	-83.813317	2688.0	2015:033:16:16:00	2015:048:05:55:00	72	LC4x4	500
SAP	SAP_10	2.941133	-83.809767	2939.0	2015:033:16:56:00	2015:048:12:14:00	22	LC2000	250
SAP	SAP_11	2.864467	-83.806217	3158.0	2015:033:17:32:00	2015:048:13:54:00	62	LC4x4	500
SAP	SAP_12	2.783750	-83.802983	3170.0	2015:033:18:13:26	2015:048:15:36:00	23	LC2000	250
SAP	SAP_13	2.702900	-83.799050	3213.0	2015:033:19:01:00	2015:048:17:39:00	69	LC4x4	500
SAP	SAP_14	2.621367	-83.795450	3342.0	2015:033:19:47:00	2015:048:19:01:00	05	LC2000	250
SAP	SAP_15	2.540267	-83.791900	3197.0	2015:033:20:33:00	2015:048:21:09:00	65	LC4x4	500
SAP	SAP_16	2.459417	-83.788131	3298.0	2015:033:21:16:50	2015:048:23:08:00	17	LC2000	250
SAP	SAP_17	2.378052	-83.784625	3296.0	2015:033:22:01:35	2015:048:01:11:00	47	LC4x4	500
SAP	SAP_18	2.296720	-83.780814	3460.0	2015:033:22:41:48	2015:049:03:18:58	01	LC2000	250
SAP	SAP_19	2.215980	-83.776990	3151.0	2015:033:23:21:11	2015:049:05:17:00	46	LC4x4	500
SAP	SAP_20	2.134609	-83.773484	3302.0	2015:034:00:01:50	2015:049:07:18:00	07	LC2000	250
SAP	SAP_21	2.053401	-83.769690	3382.0	2015:034:00:42:33	2015:049:08:56:00	67	LC4x4	500
SAP	SAP_22	1.972540	-83.765967	3311.0	2015:034:01:23:40	2015:049:10:56:00	08	LC2000	250
SAP	SAP_23	1.892067	-83.762633	3422.0	2015:034:02:06:00	2015:049:12:55:00	54	LC4x4	500
SAP	SAP_24	1.810383	-83.758867	3256.0	2015:034:02:50:00	2015:049:19:23:00	20	LC2000	250
SAP	SAP_25	1.728767	-83.755150	3210.0	2015:034:03:31:00	2015:049:16:37:00	70	LC4x4	500
SAP	SAP_26	1.648817	-83.751750	3247.0	2015:034:04:13:00	2015:049:18:52:00	13	LC2000	250
SAP	SAP_27	1.567083	-83.747850	3428.0	2015:034:04:50:00	2015:049:21:11:00	73	LC4x4	500
SAP	SAP_28	1.487900	-83.743917	3434.0	2015:034:05:29:00	2015:049:23:51:00	16	LC2000	250
SAP	SAP_29	1.405267	-83.740700	3560.0	2015:034:06:00:00	2015:057:18:54:00	76	LC4x4	500
SAP	SAP_35	1.062650	-83.725933	3416.0	2015:034:09:46:00	2015:058:11:55:00	53	LC4x4	500

South Grid OBS deployment summary

Area	Site	Latitude	Longitude	Depth	Deployment time	Recovery time	Logger number	OBS type	Sample rate (Hz)
SG	SG_01	1.323948	-83.688732	3498.5	2015:050:01:14:10	2015:057:20:45:20	61	LC4x4	500
SG	SG_02	1.324327	-83.733148	3452.0	2015:034:07:04:00	2015:057:15:21:00	66	LC4x4	500
SG	SG_03	1.324558	-83.777492	3430.9	2015:050:01:59:49	2015:057:22:31:52	55	LC4x4	500
SG	SG_04	1.324167	-83.823367	3419.0	2015:050:02:43:00	2015:058:22:12:00	60	LC4x4	500
SG	SG_05	1.323783	-83.867217	3437.0	2015:050:03:04:00	2015:058:23:39:00	50	LC4x4	500
SG	SG_06	1.278683	-83.868283	3477.0	2015:050:03:35:00	2015:058:01:07:00	57	LC4x4	500
SG	SG_07	1.279117	-83.823533	3302.0	2015:050:04:05:00	2015:058:20:39:00	63	LC4x4	500
SG	SG_08	1.279067	-83.779517	3472.0	2015:050:04:40:00	2015:057:00:00:00	40	LC4x4	500
SG	SG_08_A	1.273850	-83.777917	3477.0	2015:050:04:49:00	2015:058:01:35:00	N/A	Proto	500
SG	SG_09	1.279017	-83.732850	3472.0	2015:034:07:33:00	2015:057:14:02:00	51	LC4x4	500
SG	SG_10	1.279367	-83.688783	3446.0	2015:050:05:33:00	2015:057:12:36:00	44	LC4x4	500
SG	SG_11	1.234283	-83.688467	3452.0	2015:050:06:08:00	2015:057:10:57:00	75	LC4x4	500
SG	SG_12	1.233817	-83.733100	3452.0	2015:034:08:03:00	2015:058:16:13:51	68	LC4x4	500
SG	SG_13	1.233617	-83.777733	3443.0	2015:050:06:54:00	2015:057:04:29:07	58	LC4x4	500
SG	SG_13_A	1.237433	-83.778600	3446.0	2015:050:07:05:00	2015:058:03:06:00	N/A	Proto	500
SG	SG_14	1.233583	-83.821583	3462.0	2015:050:07:36:00	2015:058:19:05:00	52	LC4x4	500
SG	SG_15	1.233350	-83.867583	3495.0	2015:050:08:02:00	2015:059:02:41:51	62	LC4x4	500
SG	SG_16	1.188750	-83.867950	3437.0	2015:050:08:31:00	2015:059:04:20:33	69	LC4x4	500
SG	SG_17	1.188317	-83.823267	3431.0	2015:050:08:58:00	2015:058:17:42:36	65	LC4x4	500
SG	SG_18	1.188597	-83.778883	3354.0	2015:050:09:19:00	2015:058:05:55:51	47	LC4x4	500
SG	SG_19	1.188917	-83.733367	3385.0	2015:034:08:32:00	2015:058:14:44:50	74	LC4x4	500
SG	SG_20	1.188750	-83.688833	3419.0	2015:050:10:03:00	2015:057:09:14:00	45	LC4x4	500
SG	SG_21	1.143150	-83.688167	3440.0	2015:050:10:34:00	2015:057:07:43:00	67	LC4x4	500
SG	SG_22	1.143333	-83.733033	3465.0	2015:034:08:59:00	2015:058:13:20:00	71	LC4x4	500
SG	SG_23	1.143067	-83.778167	3425.0	2015:050:11:17:00	2015:058:07:33:00	54	LC4x4	500
SG	SG_24	1.143017	-83.822983	3428.0	2015:050:11:43:00	2015:058:09:04:00	70	LC4x4	500
SG	SG_25	1.143117	-83.868017	3484.0	2015:050:12:07:00	2015:059:05:51:06	73	LC4x4	500

Vertical Hydrophone Array deployment summary

Area	Site	Latitude	Longitude	Depth	Deployment time	Recovery time	Logger number	OBS type	Sample rate (Hz)
VA	VA_01_BOT	3.214750	-83.828510	2312.5	2015:025:06:40:38	2015:048:14:00:00	45	LC4x4	500
VA	VA_01_MID	3.214750	-83.828510	2296.0	2015:025:06:40:38	2015:048:14:00:00	52	LC4x4	500
VA	VA_01_TOP	3.214750	-83.828510	2275.0	2015:025:06:40:38	2015:048:14:00:00	64	LC4x4	500
VA	VA_02_BOT	1.300200	-83.733683	2935.0	2015:034:14:27:00	2015:057:17:08:00	49	LC4x4	500
VA	VA_02_MID	1.300200	-83.733683	2913.0	2015:034:14:27:00	2015:057:17:08:00	42	LC4x4	500
VA	VA_02_TOP	1.300200	-83.733683	2891.0	2015:034:14:27:00	2015:057:17:08:00	43	LC4x4	500

Sandra Ridge OBS deployment summary

Area	Site	Latitude	Longitude	Depth	Deployment time	Recovery time	Logger number	OBS type	Sample rate (Hz)
SR	SR_01	5.348883	-81.901667	3881.0	2015:024:02:48:00	2015:063:22:17:00	19	LC2000	250
SR	SR_02	5.299662	-81.341014	3412.0	2015:024:06:31:00	2015:063:17:01:00	18	LC2000	250
SR	SR_03	4.829750	-81.340400	3824.0	2015:024:09:28:00	2015:063:11:47:00	06	LC2000	250
SR	SR_04	4.499579	-82.000970	3993.1	2015:024:13:35:35	2015:063:03:36:00	12	LC2000	250

Appendix D - marine mammal observer watches

Times of Marine Mammal Observer (MMO) Watches

Julian Day	Date	Time start	Time end
26	26/01/2015	14:30	18:38
26	26/01/2015	20:28	22:06
27	27/01/2015	11:33	16:20
27	27/01/2015	19:51	22:42
30	30/01/2015	11:40	13:10
31	31/01/2015	11:35	15:07
35	04/02/2015	11:58	17:33
36	05/02/2015	18:18	19:55
37	06/02/2015	11:37	13:17
37	06/02/2015	14:57	16:36
37	06/02/2015	18:58	21:10
38	07/02/2015	18:42	19:42
41	10/02/2015	11:40	13:31
42	11/02/2015	11:34	13:11
50	19/02/2015	16:07	16:59
50	19/02/2015	20:04	22:55
52	21/02/2015	14:11	15:42
54	23/02/2015	11:30	13:20
55	24/02/2015	17:35	19:04

Appendix E - swath survey way points

NAME	TRANSIT AND SWATH	Lat	Log	Distance (approx) nm	Lat Deg	Lat Min	Long West Deg	Long West Min
SG_25	OBS	1.1433 N	83.8680 W		01	08.600 N	083	52.081 W
T_1		0.9667 N	83.9833 W	14	00	58.000 N	083	59.000 W
T_2		0.9667 N	85.3333 W	92	00	58.000 N	085	20.000 W
T_9		1.1250 N	85.3083 W	10	01	07.500 N	085	18.500 W
T_8		1.6917 N	85.3083 W	39	01	41.500 N	085	18.500 W
T_7		1.6917 N	85.5167 W	13	01	41.500 N	085	31.000 W
T_6		0.8250 N	85.5167 W	52	00	49.500 N	085	31.000 W
T_5		0.7667 N	85.4833 W	4	00	46.000 N	085	29.000 W
T_4		0.0167 S	85.5500 W	9	00	01.000 S	085	33.000 W
T_3		0.0167 S	85.4333 W	67	00	01.000 S	085	26.000 W
T_2	REPEATED	0.9667 N	85.3333 W	92	00	58.000 N	085	20.000 W
T_31	ADDITIONAL	1.1667 N	85.2333 W	17	01	10.000 N	085	14.000 W
T_10	UPDATED	1.3333 N	84.7167 W	33	01	20.000 N	084	43.000 W
T_11		3.3000 N	84.4000 W	95	03	18.000 N	084	24.000 W
T_12		3.3000 N	84.2500 W	9	03	18.000 N	084	15.000 W
T_13		1.8833 N	84.4667 W	97	01	53.000 N	084	28.000 W
T_14		1.8417 N	84.3667 W	7	01	50.500 N	084	22.000 W
T_15		3.3917 N	84.1333 W	106	03	23.500 N	084	08.000 W
T_16		4.1333 N	82.7833 W	104	04	08.000 N	082	47.000 W
T_17		4.5500 N	82.1167 W	53	04	33.000 N	082	07.000 W
SR_04	OBS	4.4996 N	82.0010 W	8	04	29.975 N	082	00.058 W
T_18		4.6333 N	82.0000 W	9	04	38.000 N	082	00.000 W
T_19		4.8417 N	81.5500 W	34	04	50.500 N	081	33.000 W
SR_03	OBS	4.8298 N	81.3404 W	15	04	49.785 N	081	20.424 W
T_20		4.8833 N	81.4500 W	8	04	53.000 N	081	27.000 W
T_21		5.1917 N	81.4750 W	22	05	11.500 N	081	28.500 W
SR_02	OBS	5.2997 N	81.3410 W	11	05	17.980 N	081	20.461 W
T_22		5.2167 N	81.5500 W	16	05	13.000 N	081	33.000 W
T_23		5.2167 N	81.9000 W	24	05	13.000 N	081	54.000 W
T_24		5.2417 N	81.9500 W	4	05	14.500 N	081	57.000 W
SR_01	OBS	5.3489 N	81.9017 W	8	05	20.933 N	081	54.100 W
T_32	UPDATED	5.0417 N	81.9017 W	18	05	02.500 N	081	54.100 W
T_33	UPDATED	5.1333 N	81.4333 W	28	05	08.000 N	081	26.000 W
T_27	SWATH OFF	6.9917 N	79.7500 W	175	06	59.500 N	079	45.000 W
	TRANSIT TO ANCHORAGE AT BALBOA							