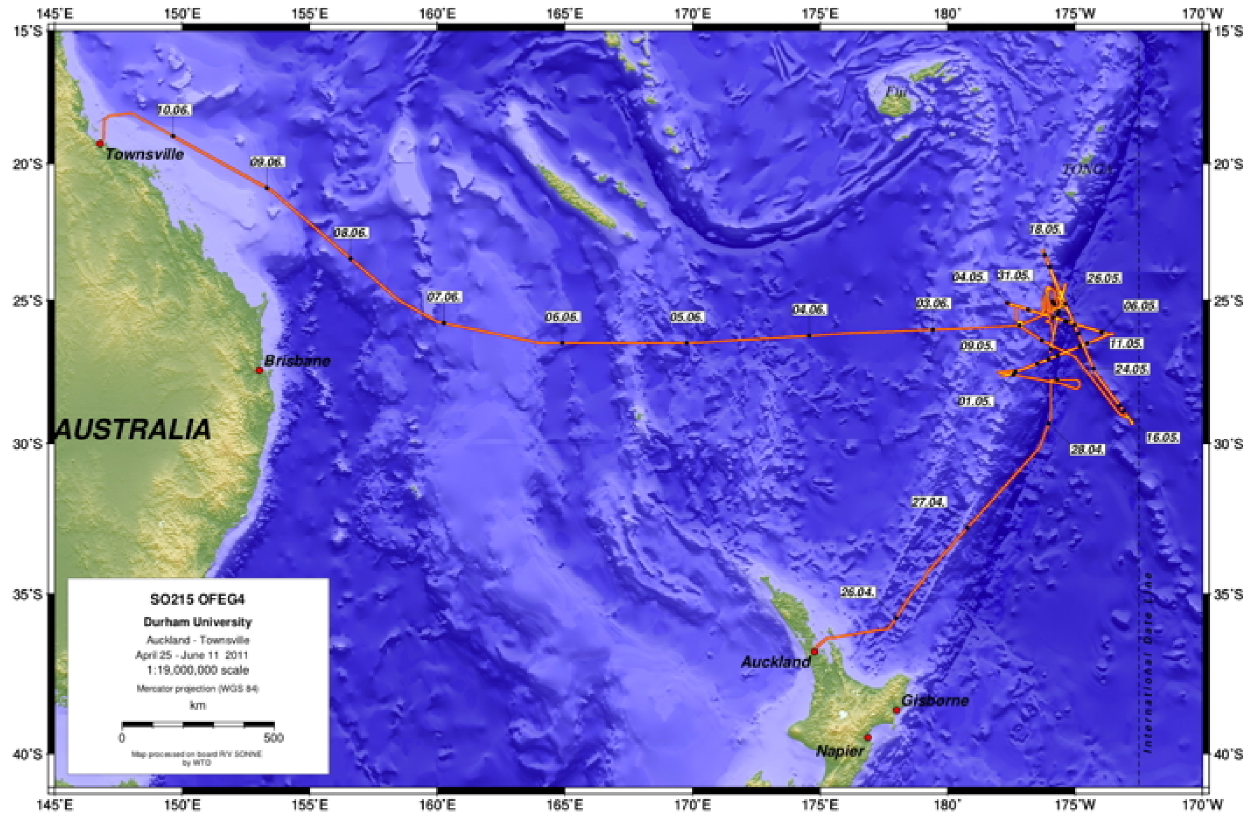
R/V Sonne SO215

Cruise Report

The Louisville Ridge – Tonga Trench collision:

Implications for subduction zone dynamics



25th April – 11th June 2011

Auckland (New Zealand) – Townsville (Australia)

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Chief Scientist
Professor Christine Peirce

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

christine.peirce@durham.ac.uk

Co-Chief Scientist
Professor Anthony Watts

Department of Earth Sciences
University of Oxford
South Parks Road
Oxford
OX1 3LE

tony.watts@earth.ox.ac.uk

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Sea state for much of the cruise!

Summary

We conducted a marine geophysical survey of the Louisville Ridge intersection with the Tonga Trench subduction system onboard R/V Sonne (SO215) during April-June 2011. The data are of high-quality and include multichannel seismic reflection and refraction, gravity and magnetic, swath bathymetry and sub-seabed imaging profiles of the crustal structure of the Louisville Ridge, and the pre- and post-subduction crust of both the down-going and over-riding plates. We were also able to acquire an additional seismic profile trench-parallel in the forearc, undertake a number of instrumentation trials for the NERC's Ocean-Bottom Instrumentation Facility, and swath, gravity, magnetic and XBT survey the Monowai volcanic centre, as it was found to have undergone a recent collapse event and was actively erupting while we were in the work area. Finally, we used any remaining contingency time to complete the regional swath bathymetry coverage in the forearc region between our main survey lines. All equipment worked well throughout the entirety of the cruise, and effectively no downtime was experienced due to either equipment failure or bad weather.

1. Background and cruise objectives

1.1 Introduction

Subduction zones are dynamically evolving features that mark the sites of plate consumption and the recycling of sediment and magmatic material. They are subject to *both* horizontal and vertical motions and so their study results in a better understanding of the driving forces of plate tectonics. Subduction zones are also of societal interest because of their association with explosive volcanism, large-scale slope failure and tsunamigenic earthquakes.

The Tonga island arc–deep-sea trench system is the most linear, fastest converging and most seismically active of any of the world's subduction zones (Fig. 1). The system has also evolved over a long period of geological time (>50 Myr) by successive periods of back-arc spreading, break-up of frontal arc systems, and formation of remnant arcs. A unique feature of this subduction system is that the trench is intersected at ~26ºS by the Louisville Ridge, a 4500 km long chain of seamounts that, together with Hawaii and Easter, are the three 'classic' hotspot trails in the Pacific Ocean. The Tonga Trench is, therefore, the site of a major collision between a seamount chain on a subducting plate and the forearc of an over-riding plate.

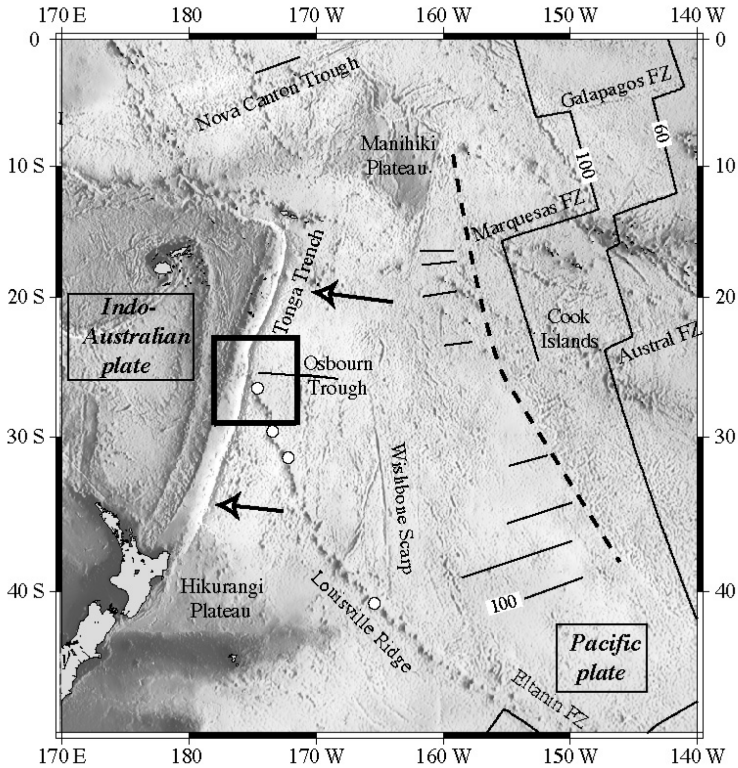


Figure 1: Bathymetry map of the SW Pacific Ocean based on GEBCO data. Thick black box shows the study area and the white dots show IODP 636 drill sites. Dashed line shows the trace of the Tongareva triple junction that connected the Pacific, Farallon and Phoenix plates during the mid-Cretaceous. The E-W trending magnetic lineations to the west are part of the former Pacific-Phoenix system while the N-S trending lineations to the east are part of Pacific-Farallon. Arrows show the direction of convergence between the Pacific plate and the Indo-Australian plate based on NUVEL-1.

The obliqueness of the ridge-trench collision (~30°) is such that the segment of the subducting plate and forearc to the north of the ridge has been affected by the collision, while the segment to the south has not.

The Tonga system was chosen for this study due to its rapid convergence (~80 mm yr^{-1}) which ensures that the ‘signal’ from the collision is large and readily observable with standard geophysical techniques.

The rapidity and obliqueness of convergence make the Louisville Ridge–Tonga Trench an ideal location to determine the mechanical response of the crust and lithosphere to loading and, hence, to determine the integrated strength of the lithosphere. This is important for assessing whether the coupling between the subducting and over-riding plates is ‘soft’ or ‘hard’ as well as informing parameterization and providing constraints on rheological structure required for numerical modelling of subduction zone processes.

At the Tonga Trench, the collision with the Louisville Ridge is also associated with a seismic gap, especially so in shallow seismicity (Fig. 2). This also makes this an ideal locality to test the ‘Kelleher-McCann’ hypothesis [*Kelleher & McCann*, 1976], that bathymetric features on a subducting plate may control aspects of arc seismicity.

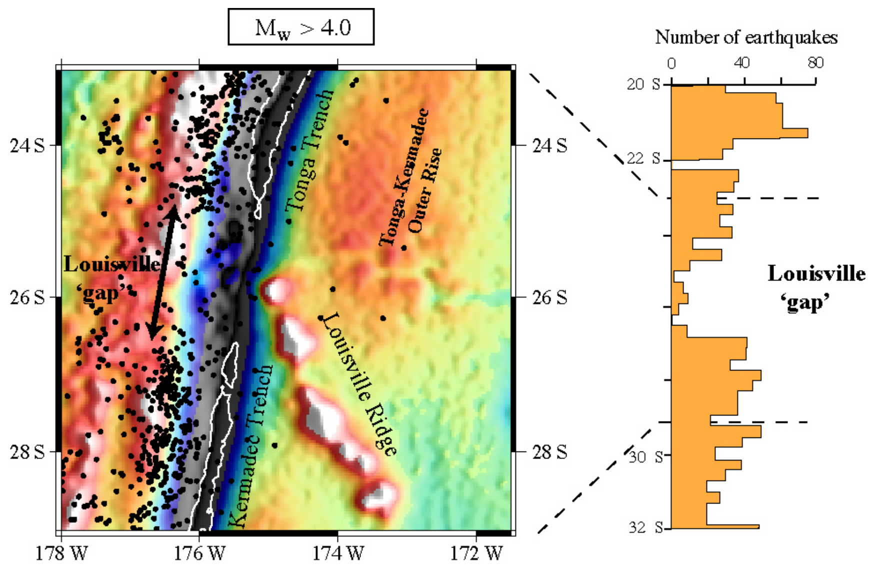


Figure 2: High-pass free-air gravity anomaly field (light shades high values, dark shades low values) with superimposed earthquakes (black dots) based on a USGS catalogue. Graph shows the distribution of earthquakes along the crest of the Tonga Ridge. Note the gap in seismicity between ~25°S-26.5°S correlates with the intersection of the Louisville Ridge and its flanking moat with the Tonga Trench. Triangles show sample sites with ages in Ma [*Koppers et al.*, 2004] while dots show T_e estimates in km [*Watts et al.*, 2006]. The hatchured region shows the weak zone seaward of the trench identified by *Billen & Gurnis* [2005].

1.2 Dynamics of the Louisville Ridge–Tonga Trench collision

The Tonga Trench is a simple, essentially linear subduction system, where the Pacific plate is presently underthrusting the Indo-Australian plate (Fig. 1). The subducting plate is of Cretaceous age and is believed to have been generated by the rifting apart of the Manihiki and Hikurangi plateaus and seafloor spreading at the Osbourn Trough [*Downey et al.*, 2007]. These plateaus, together with the Ontong Java plateau, form one of the world’s largest Large Igneous Provinces (LIPs).

The trench is intersected at ~26°S by the Louisville Ridge (Fig. 1) which was generated at a hotspot, presently located near the intersection of the Eltanin Fracture Zone with the East Pacific Rise [*Watts et al.*, 1988]. Seamount ages progressively increase away from the hotspot, such that the oldest (Osbourn ~78 Ma) is presently located on the seaward wall of the Tonga Trench [*Koppers et al.*, 2004]. Subduction of the Louisville Ridge is currently oblique (~30°) and plate reconstructions show that the point of collision has migrated rapidly ~1150 km southwards at up to 180 $mmyr^{-1}$ [*Ballance et al.*, 1989] over the last 5 Myr [*Lallemand et al.*, 1992]. The collision zone is characterised by a shallowing of the trench [*Scholz & Small*, 1997], pervasive normal faulting on the trench seaward wall [*Lonsdale*, 1986], and uplift of the forearc [*Clift & MacLeod*, 1999]. Behind the arc, the Lau marginal basin is narrowest and it has been suggested that collision may have triggered back-arc extension [*Lallemand et al.*, 1992].

The once flat-top of Osbourn seamount is being tilted arcward as it “rides” the flexural bulge seaward of the trench. Previous flexure studies suggest the elastic thickness (T_e), a proxy for the long-term strength of the lithosphere, increases from about 27 km beneath the Louisville Ridge [*Lyons et al.*, 2000] to ~30-40 km in the bulge region [*Watts et al.*, 2006]. The subducting Pacific plate appears to be relatively strong in its response to the forces associated with trench loading. However, *Billen* & *Gurnis* [2005] suggests that T_e decreases rapidly by ~15 km between the bulge and trench seaward wall. If this is the case, it suggests little strength and that viscous, rather than elastic stresses may play a significant role in transferring slab-pull forces to the subducting plate.

It seems likely that trench loading is also deforming the forearc. Although forearcs are often considered as regions of low cohesion and strength, little is known about the Tonga forearc, except that its collision with the Louisville Ridge correlates with a zone of quiescence in seismicity, called the Louisville 'gap' (Fig. 2). The gap suggests that subducting topographic features may somehow inhibit or even prevent seismicity [*Kelleher & McCann*, 1976], and the current trench shallowing and forearc uplift at its intersection with the Louisville Ridge suggests that a large seamount, ahead of Osbourn, is presently being subducted and is acting as a 'barrier' to seismicity by increasing the recurrence time interval between earthquakes [*Scholz & Small*, 1997].

Consequently, it is important to understand what happens to large seamounts when they subduct. Do they shear off on collision or are they preserved intact to be sheared off after subduction? *Cloos & Shreve* [1996] suggest that this determines whether or not there is a large earthquake. In their model, seamounts may either be truncated aseismically in the low-confining pressure regime of the trench axis and their tops obducted into the accretionary wedge or they are carried into the subduction zone intact and are then sheared off (Fig. 3). As part of this it is also important to understand the nature of the 'root' that supports a seamount. A seamount that is flexurally supported (e.g. one formed on old seafloor), for example, might be expected to lose some of its support as it enters a subduction zone and, therefore, be carried down by the subducting plate. However, a locally supported seamount (e.g. one formed on young seafloor), might be more buoyant and prone to being obducted.

To image deep into the crust beneath a subduction zone requires seismic refraction data. Unfortunately, there is no refraction data available for the Louisville Ridge–Tonga Trench collision zone and so little is known about the structure of the leading edges of the underthrusting and over-riding plates, and the fate and consequences of seamount subduction. Consequently, the primary purpose of this cruise was to acquire seismic refraction and reflection data across the Louisville Ridge–Tonga Trench collision zone and along and across the Louisville Ridge.

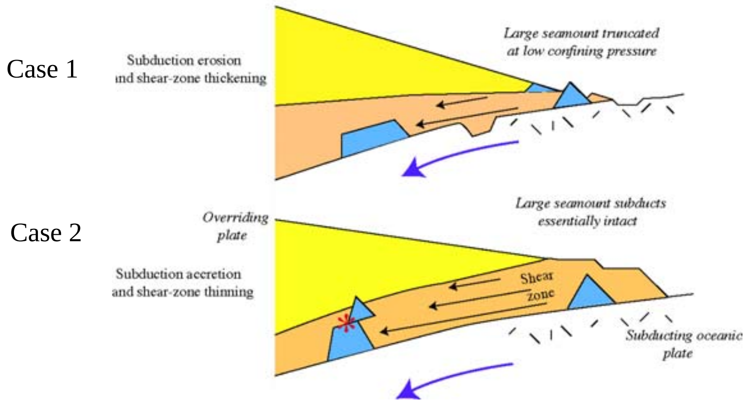


Figure 3: Schematic diagram illustrating the Cloos-Shreve model that links subducting seamounts with earthquakes (* above). Note that in both cases subduction truncates a subducting seamount. However, in Case 1, the truncation occurs in the low-confining pressure regime of the forearc: there is no earthquake and the seamount is obducted. Case 2, in contrast, the seamount is subducted in tact and is then truncated.

1.3 Scientific objectives and key hypotheses to be tested

The data acquired during this cruise will be used to test two main hypotheses:

(1) that the mechanical response to the loads associated with convergence involves inelastic behaviour in the leading edge of both the underthrusting and over-riding plates, and

(2) that bathymetric features on the subducting oceanic plate control aspects of arc seismicity – the 'Kelleher-McCann' hypothesis.

To test the above hypotheses the key scientific objectives for the cruise were as follows:

1) Determine the 'background' crustal and uppermost mantle structure of the subducting plate.
2) Determine the crustal and uppermost mantle structure across and along the Louisville Ridge.
3) Determine the physical properties of the leading edges of the subducting and over-riding plates.
4) Determine the state of isostasy, ridge-related flexure and moat characteristics at the Louisville Ridge, and the mechanical properties of the subducting and over-riding plates.

5) Determine the seafloor morphology and collision-related deformation in the Tonga forearc.

1.4 Acquisition plan

To address the scientific objectives we planned an integrated marine geophysical experiment that comprised simultaneous multichannel reflection (MCS) and wide-angle (WA) refraction seismic, gravity, magnetic, swath bathymetry and sub-seabed high resolution imaging of the Louisville Ridge–Tonga Trench collision system (Fig. 4). The acquisition geometry included:

a) *Profile A* - a 400 km transect across the ridge-trench intersection, designed to determine the across-strike structure of the collision zone between the arc, across the forearc and trench, to the outer rise. Whilst also imaging the crust and uppermost mantle structure in the aseismic zone and high-curvature weak zone in the seaward wall of the trench, this profile would also reveal deformation solely related to collision to allow distinction from that induced by seamount interaction with the over-riding plate.

b) *Profile B* - a 425 km transect across the Louisville Ridge and moat as they ride the trench outer rise, designed to determine the mode of isostatic compensation beneath the ridge at the northernmost part of the chain, and the effect of collision on the mechanical strength and flexural response of the subduction system.

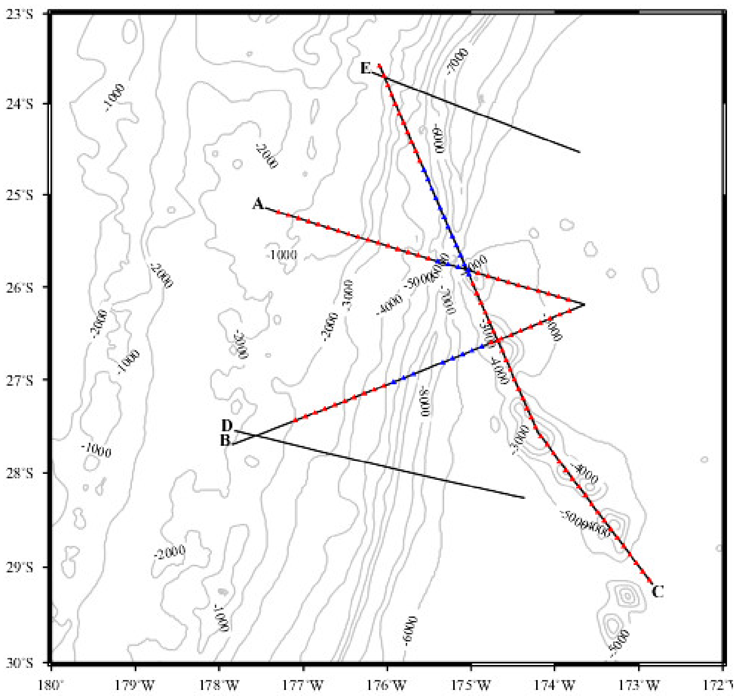


Figure 4: Acquisition geometry showing the location of profiles to be acquired during SO215 (solid black lines) relative to the Louisville Ridge and Tonga Trench. Red and blue triangles show OBS locations.

c) *Profile C* - a 725 km transect along the Louisville Ridge, traversing IODP drill sites. This transect extends across the Tonga Trench, and was designed to determine the structure of the Louisville Ridge (the pre-subduction crust), any along-ridge variation in crustal structure or underplating, how seamounts interact with the over-riding plate upon their subduction, and how along-ridge variation in topography, crust and uppermost mantle structure relate to observed post-collision uplift.

And if the contingency time was not required for weather or equipment downtime:

d) *Profiles D & E* – 350 km and 275 km MCS only transects, which would investigate the pre- and post-subduction crustal structure "background" respectively.

Along each seismic profile ocean-bottom seismographs (OBSs) would be deployed at ~10-15 km intervals, to record airgun shots from an array configured for contemporaneous MCS / WA acquisition. The number of OBSs, [45 from the NERC's Ocean-Bottom Instrumentation Facility (OBIF) and 12 from IFM-Geomar], was required by the planned profile lengths, to ensure full reversal of each along its entire length, minimisation of ship time by avoiding deploying instruments multiple times along the same profile, and to build in redundancy in case of instrument failure. Streamer balancing, array tuning, a sound velocity profile and acoustic release tests would be undertaken on first arrival in the work area. Swath bathymetry data would be acquired port-to-port to image the seabed expression of faulting and the morphology of seamount flanks along the Louisville Ridge.

The port call at the start of the cruise was scheduled to be Auckland (New Zealand) which was 2.25 days from the work area. The entire science programme would take 37 days – 20.5 days of OBS deployment and recovery; 14.5 days of shooting; and 2 days for streamer balancing, array tuning, sound velocity profile and acoustic release tests. The work area was 7.5 days from Townsville (Australia) which would be the end of cruise port call. The entire cruise was, thus, 47 days port-to-port.

The most optimal use of ship time would be obtained by shooting profiles in the order: A & B as WA and MCS data followed by D as MCS data only (all as one activity), followed by C as WA and MCS data. If time allowed, E would be shot as MCS data only. We would also deploy XBTs along each profile and ground-truth these against the sound velocity profile undertaken in deep water at the start of the cruise so that the water column can be profiled throughout the work area for WA refraction data modelling purposes.

2 Territorial waters and diplomatic clearances

The work area for this cruise lay primarily in New Zealand or international waters as shown in Fig. 5, with sections of some profiles lying in Tongan waters. We also planned to run the gravimeter and swath bathymetry acquisition all the way to Townsville to enable an end of cruise base station tie.

Consequently, diplomatic clearance from New Zealand, Tonga and Australia were required. These applications were made in August 2010. In addition, clearance to work in Fijian waters was also requested at the same time to accommodate unforeseen changes in plan which might occur during the cruise. Townsville lies at the edge of the Coral Sea and behind the Great Barrier Reef. To acquire swath bathymetry data in these conservation zones, two further permits were also required. All diplomatic clearances and one of the permits were received prior to sailing from Auckland, with the Great Barrier Reef permit arriving approximately two weeks prior to the end of the cruise.

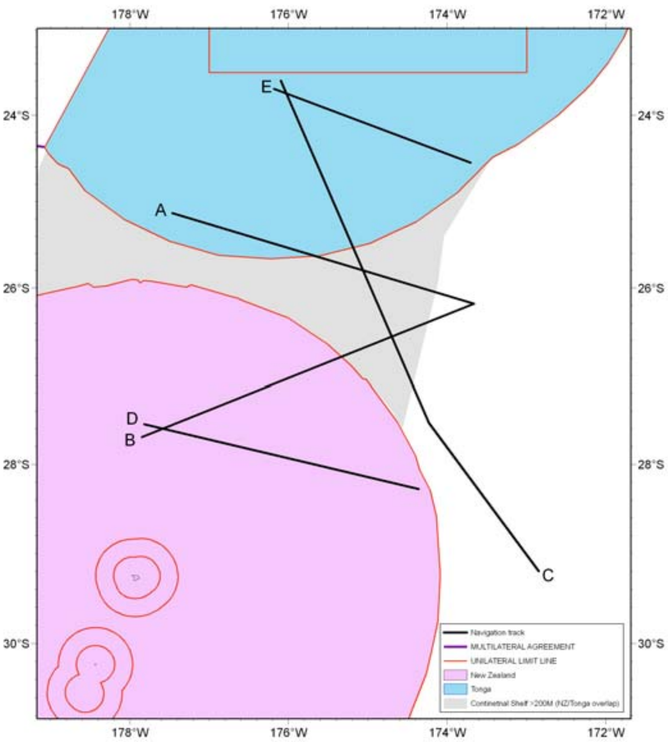


Figure 5: Survey lines plotted with reference to the EEZ of New Zealand, Tonga and Fiji. The territorial waters of New Zealand (pink), Tonga (blue), Fiji (top left white) and international waters (white) and areas of dispute (grey) are colour-shaded.

3 Mobilisation

The pre-cruise port call fell on the Easter bank holiday weekend. Despite this, all equipment containers shipped from the UK were made available by the ship's appointed agent for unloading as and when required, including those containing hazardous materials which were stored at Auckland airport prior to vessel arrival. Mobilisation commenced on the 23rd April with a sailing date of the 25th April. The port call activities divided into three parts: 1) the installation of the MCS system; 2) installation of the marine gravimeter to facilitate the base station tie; and 3) unloading and secure stowage of the OBSs.

To accommodate the MCS streamer winch, a metal deck plate was welded to the stern section of the main deck, and onto this the streamer winch was mounted and securely welded. Once complete, the cheek plates were fitted and the additional streamer sections wound off their shipping drums onto the winch to complete the full 3000m active length. Finally the tow section to the tail buoy was added. The NMFSS compressor container, shipped from the UK to supplement the ship's fitted systems, was then loaded forward of the winch adjacent to the ship compressor's turbo charger container. Forward of this the IFM-Geomar airgun container was loaded, leaving little free deck space remaining.

At planning with the ship's operators, the original intention was to store and operate the OBSs from the hold, due to this lack of deck space. On arrival the hold was found to be full, and consequently OBS storage frames were mounted in any remaining, otherwise unoccupied, space on the main deck.

Mobilisation went without any significant problems except for: one streamer section was damaged during winding, which left no spares; air hose fittings between the UK and German vessel's individual air supply systems were found to be incompatible but adaptors were sourced by the ship's agent; the NMFSS compressor control system suffered irreparable damage during shipping that rendered it unusable for the cruise; and the MCS acquisition system declined to communicate with the streamer. The latter was solved by backing out some recently applied patches to the acquisition system, which had been hired from Exploration Electronics Ltd., and reinitiating a new software licence acquired while still in port.

The Sonne sailed at 13:00 on the 25th April, delayed by a few hours waiting for the air hose fitting adaptors to be delivered.

4. Work conducted and data collected

A track chart for the entire cruise, covering ~10,750 line km, is shown in Fig. 6, a blow-up of the work area only is shown in Fig. 7, and blows-up for individual profiles within the work area are shown in Figs. 21, 23, 24, 29 & 32. The data acquisition comprised: i) wide-angle refraction seismic; ii) multichannel reflection seismic; iii) gravity; iv) magnetics; v) swath bathymetry; and vi) sub-seabed imaging. These data were supplemented by: a) a sound velocity water column profile; and b) expendable bathymetric thermograph water column profiles. Each of these data types and the equipment used will be described in the following sections.

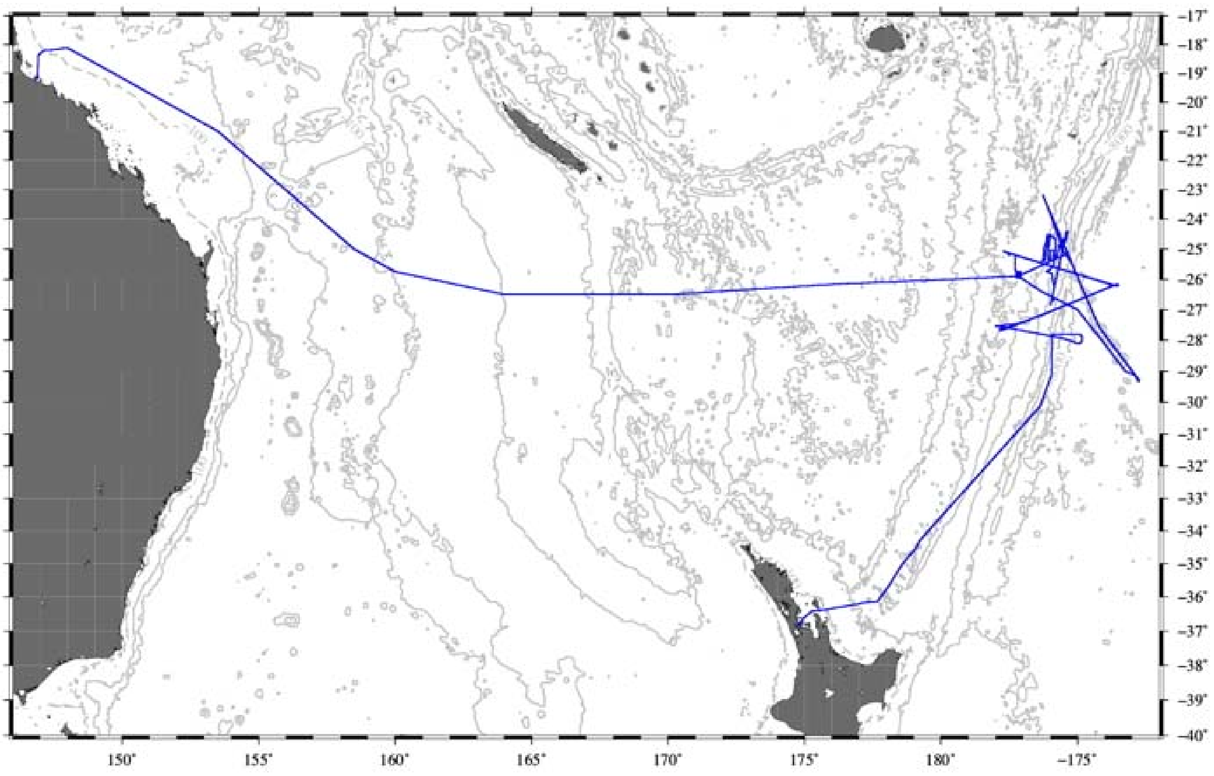


Figure 6: Track chart for SO215 from the pre-cruise port call in Auckland to the end-of-cruise port call in Townsville.

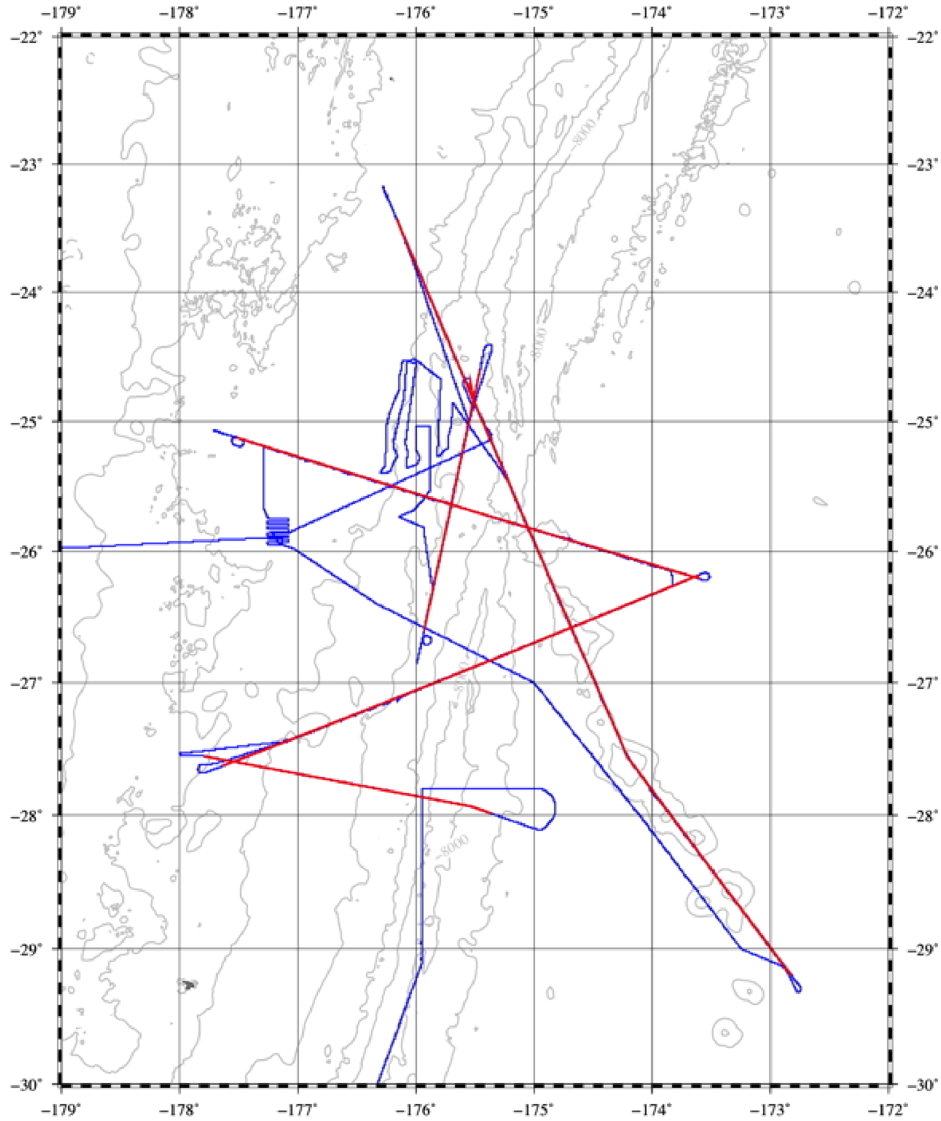


Figure 7: Track chart for SO215 showing all tracks and transits within the work area. Seismic profiles are annotated in red. All other track lines are associated either with instrument deployments and recoveries, transits between profiles or regional swath bathymetry coverage patching.

5.1 Seismic profiles

Seismic acquisition took two forms: multichannel reflection profiling and wide-angle refraction profiling. For profiles A, B, C and G (an intra-cruise addition) both activities were undertaken contemporaneously and, thus, required the design of a seismic source compatible with both types of acquisition.

5.1.1 Seismic source

The seismic source for SO215 comprised 12 Sercel G-guns of 260, 380 and 520 in^3 chamber sizes, arranged into 2 sub-arrays of 6 guns. The total array volume was 5440 in^3, and each sub-array 2720 in^3. Both sub-arrays were designed to be mirror-image identical, such that they could be used singly, maintaining the same signal characteristics as the full array, although at lower power, in the event of gun failure and recovery for repair or maintenance or, if air supply problems precluded firing of the full array volume for any length of time, surveying could still continue. Originally, the array design was as shown in Fig. 8. However, after Profile B it was discovered that the array had been built as shown in Fig. 11, at which point this error was rectified for all subsequent profiles. Sub-array and individual gun separation distances, and tow dimensions relative to the vessel, the navigation antenna and the streamer front-end are shown in Fig. 9. The expected source signature and frequency spectrum are shown in Figs. 12 and 13. The array was designed to operate at

3000 psi (210 bar) pressure, to be towed at 7.5 m depth, and to be fired at 60 s for combined OBS and MCS acquisition and 20 s for MCS only acquisition. See section 7.1 for equipment problems associated with the supply of compressed air. These problems precluded firing of the full array at 3000 psi at 20s and, consequently for Profile D, a 30 s firing rate, at 2400 psi (170 bar) with the two outer 520 in^3 airguns at the rear of the array disabled, was opted for (Fig. 10). In the end, all other profiles were shot as combined MCS/WA profiles and hence the full array at 3000 psi at 60s firing rate was used. Firing intervals of 30 s and 60 s at 4.5 kn resulted in shot intervals of ~75 m and ~150 m, equivalent to 6 and 12 streamer groups respectively. The airgun array was fired using a Longshot gun controller. See section 5.1.4 for details of the shot timing and location determination.

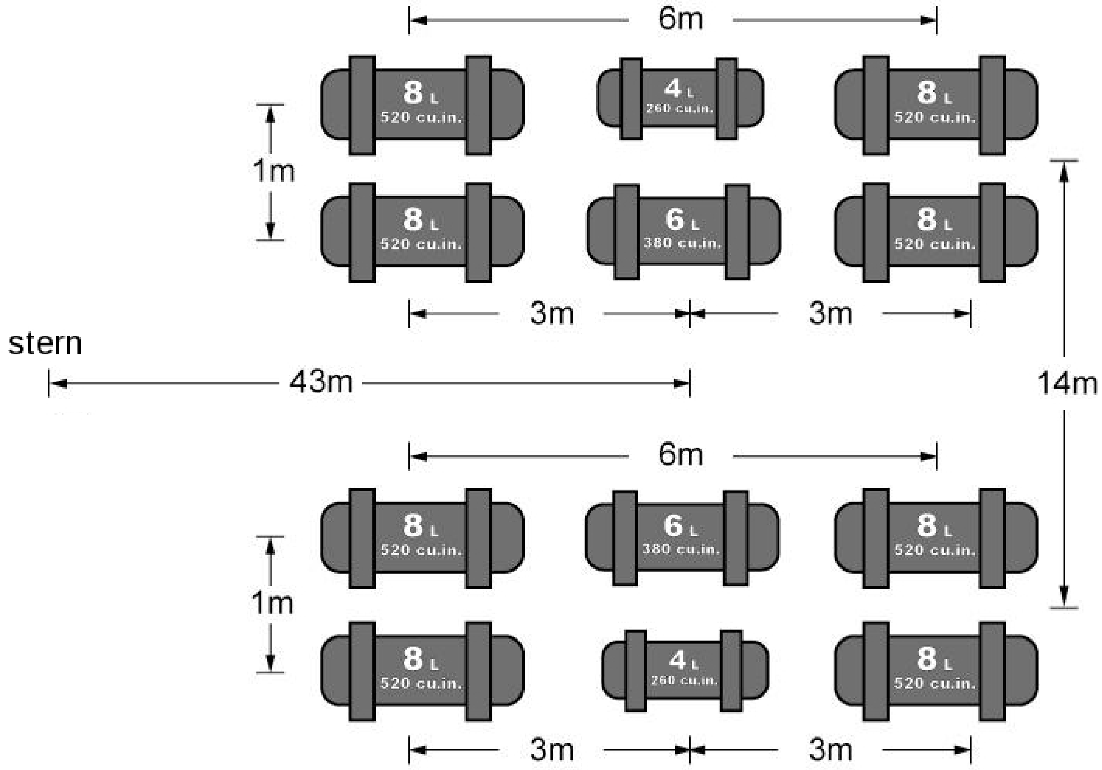


Figure 8: Original airgun array specification used for Profiles C and G. Gun chamber sizes are annotations.

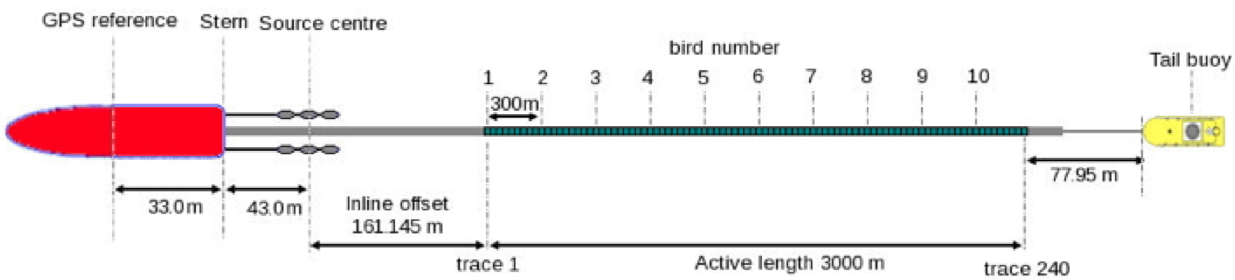


Figure 9: Airgun array dimensions and towing distances relative to the navigation receiver and streamer.

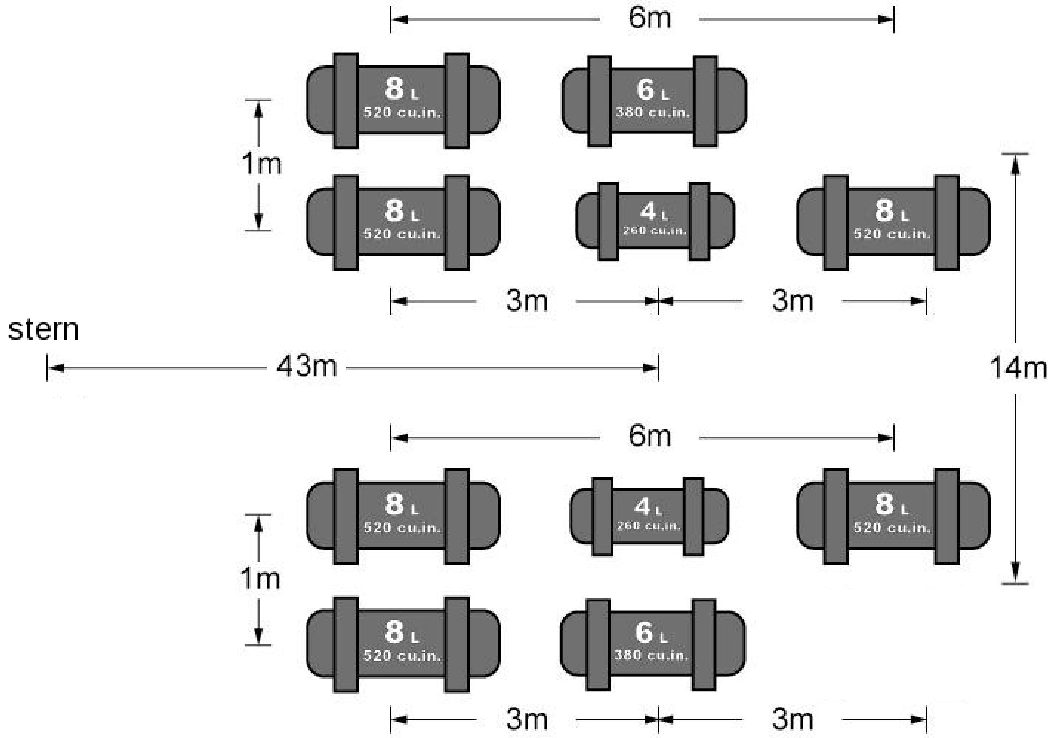


Figure 10: Alternate airgun array specification used for Profile D. Gun chamber sizes are annotations.

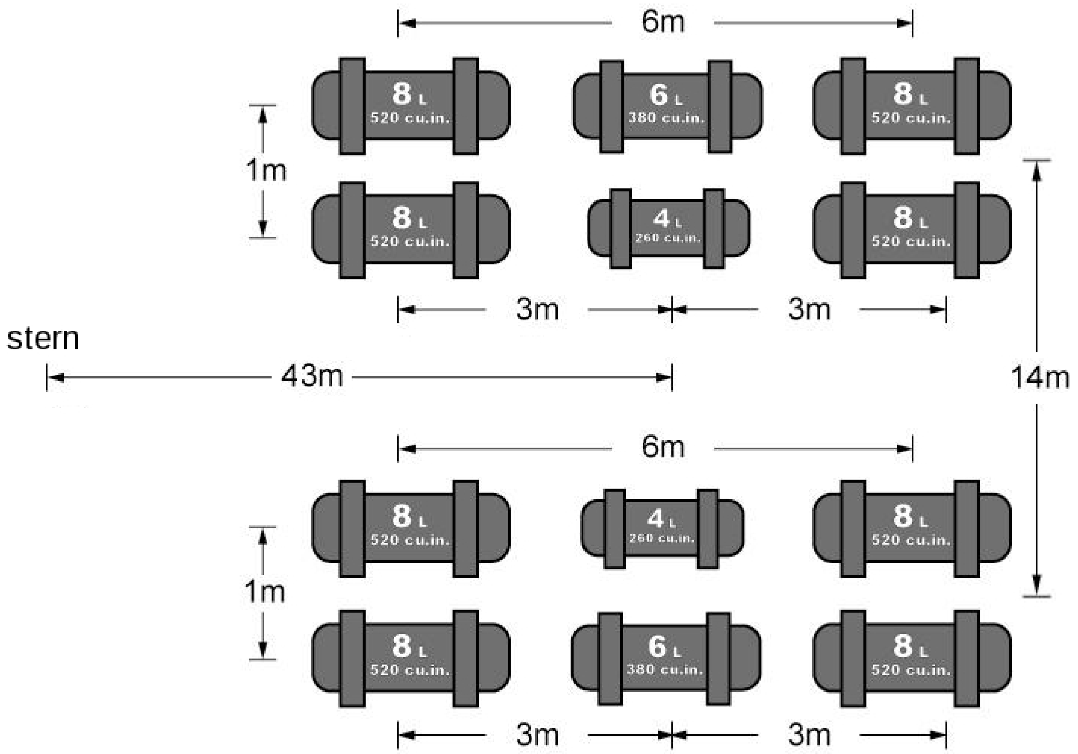


Figure 11: Alternate airgun array specification used for Profiles A and B. Gun chamber sizes are annotations.

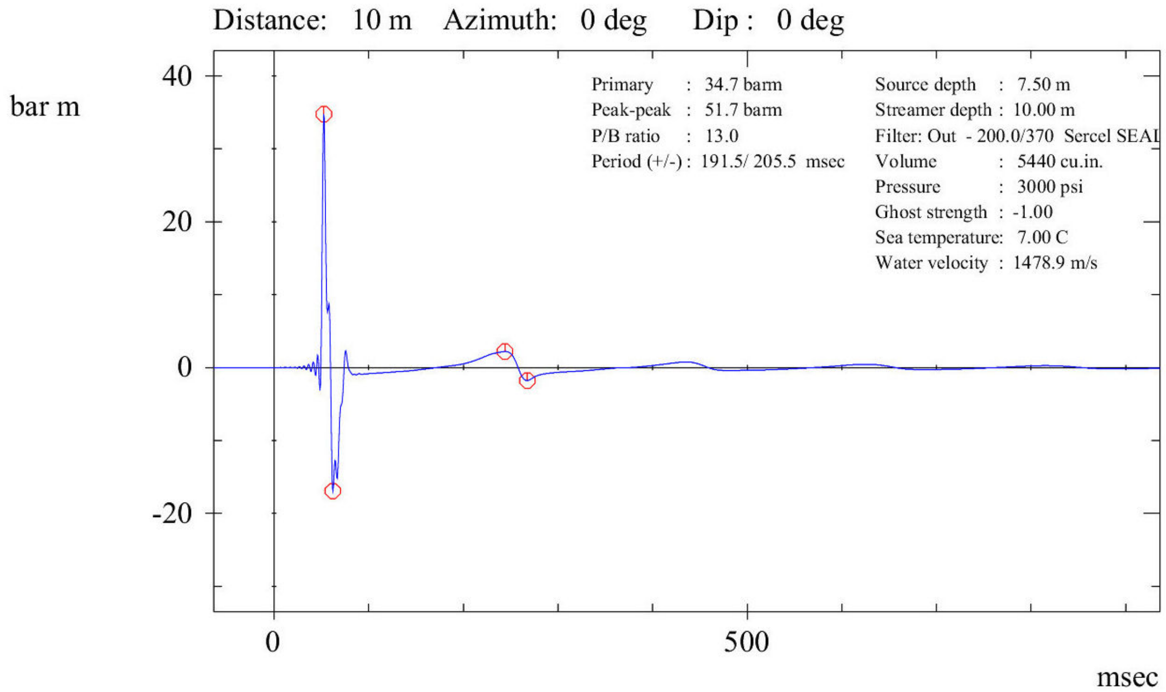


Figure 12: Predicted airgun array source signature obtained from pre-cruise modelling.

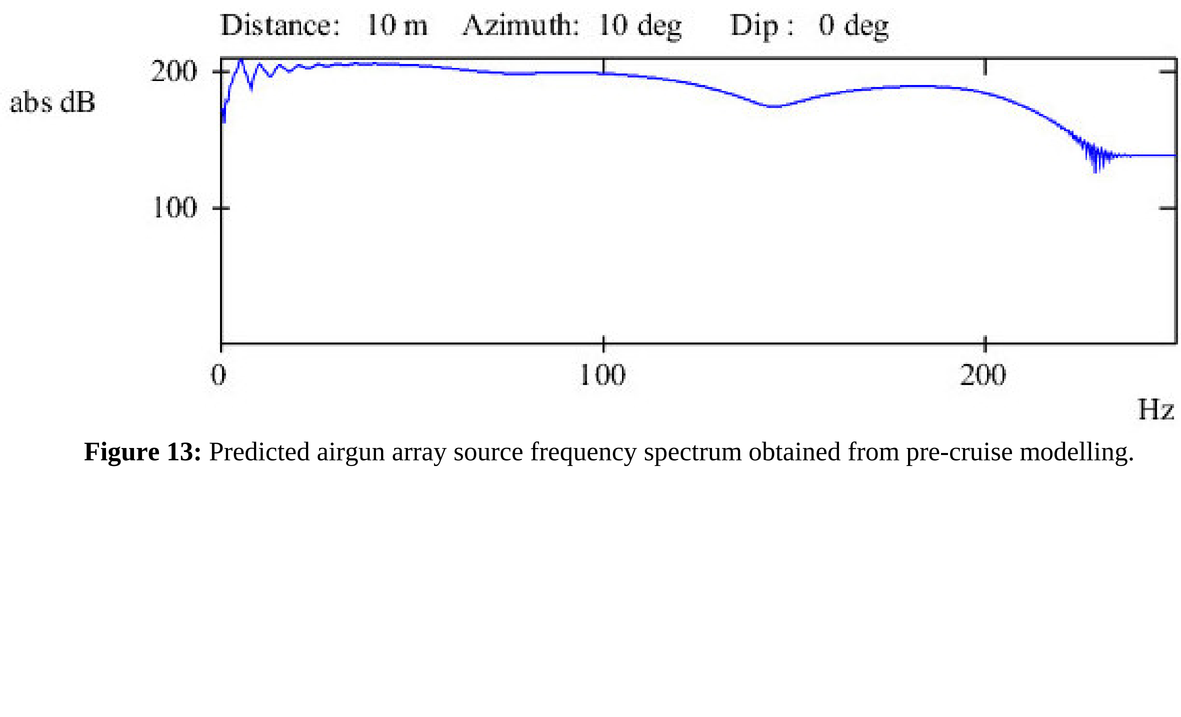


Figure 13: Predicted airgun array source frequency spectrum obtained from pre-cruise modelling.

Figure 14: Airgun array and towing configuration – starboard sub-array.

Figure 15: Two "clusters" of G-guns mounted on their tow frames.

5.1.2 Multichannel streamer

The multichannel seismic acquisition system used for this cruise was a Sercel SEAL system, including a solid, digital, 12.5 m take-out streamer (Fig. 18), and was provided by the NERC's National Marine Facility Sea Systems, with additional parts hired from Exploration Electronics Ltd.. The survey design required the streamer to tow horizontally at 10 m sub-surface which was achieved using Digicourse compass levelling birds. The array configuration is shown in Fig. 16, with distances relative to the navigational receiver annotated.

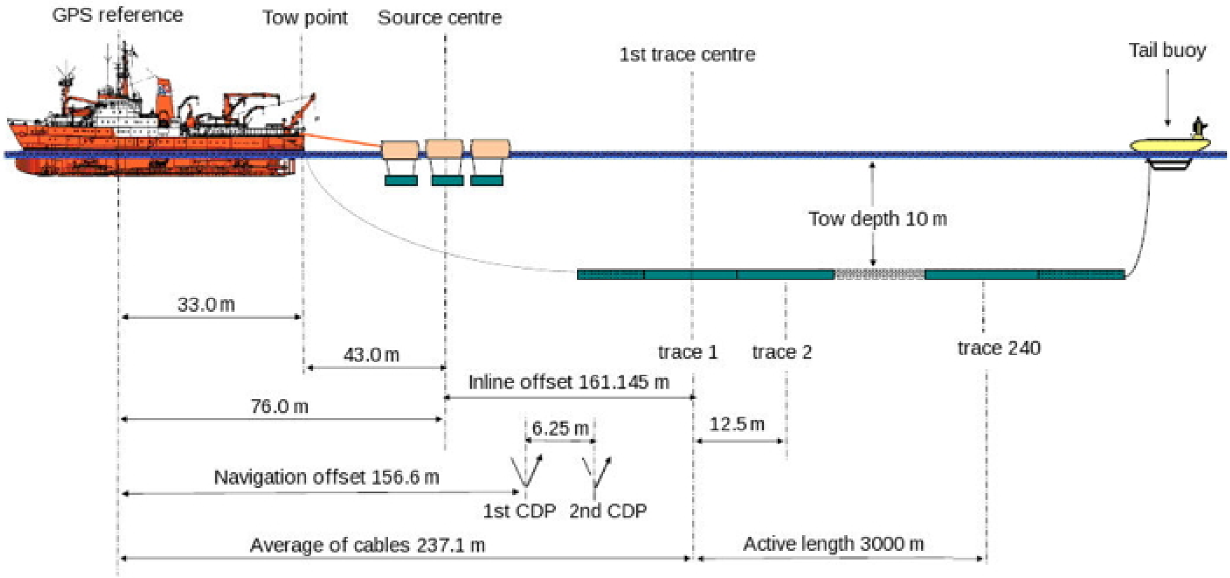


Figure 16: Multichannel streamer configuration, with tow dimensions relative to the navigational receiver annotated.

For the system shake-down period at the start of the cruise, and for Profile D that followed on immediately after, the sampling interval was set to 1 ms with a record length of 29 s. No water break delay was incorporated. Data were stored in SEG-D onto a network attached storage (NAS) device and duplicated in real-time across a local network to an identical NAS device provided by the science party to generate the "untouchable" raw archive which, in-turn, was duplicated off-line to a further NAS to provide the "touchable" raw dataset for underway QC and processing. QC and processing was undertaken using a small network of linux-based computers provided by the science team, with Globe Claritas and Landmark ProMAX installed. For all subsequent profiles the sampling rate was set to 2 ms, with all other parameters remaining the same. SEG-D field file identification (FFID) numbers and the GMT times for the ends each profile are summarised in Table 6.

The SEAL acquisition system also had a view-after-write data QC system attached that allowed monitoring of the data at sub-shot gather level and on a single receiver gather basis as surveying progressed. See Fig. 17. It also allowed monitoring of streamer tension and noise.

Figure 17: Multichannel streamer underway read-after-write data QC system (left) and streamer operation QC (middle and right) showing tow tension (middle, right panel) and streamer noise (left, bottom panel) plus FFID vs. shot number.

Figure 18: NMFSS 3000 m self-spooling multichannel streamer winch used for the first time during SO215. The winch has a 20' container footprint, to allow standard rate sea and road freight shipping, and in its basic mode, can accommodate 1875 m of active streamer length (15 standard 125 m sections), plus the lead-in and tail-out tow sections. With its additional cheek plates, fitted after shipping, a further 9 active sections can be attached, accommodating a total active streamer length of 3000 m. The winch was welded to a steel plate bolted to the R/V Sonne's main deck slightly forward of the stern A-frame.

5.1.3 Ocean-bottom seismographs

For this cruise, two types of 4-channel (hydrophone and three-component geophone) ocean-bottom seismographs were used. Forty-five instruments of the "LC" type (Fig. 19) were provided by the NERC's Ocean-Bottom Instrumentation Facility (OBIF) and a further 12 of the KUM 8000 m, "deep-water" type (Fig. 20) were provided by IFM-Geomar. A total of 126 deployments were made throughout the cruise and individual deployment locations can be found in Tables 2-5. Of these deployments, four LC instruments were deployed (two on Profile A, one on Profile C and one on Profile G) as part of OBIF system development trials which tested heavier ballast weights to improve horizontal geophone component coupling to the seabed and/or 4 kHz sampling rates. Each OBS was synchronised to GPS-derived GMT time before deployment and after recovery and the data corrected for clock drift prior to conversion to SEG-Y format using the shot instants recorded as outlined in section 5.1.4. The shot numbers and locations relative to the start and end of each combined MCS/OBS profile are summarised in Table 6.

Figure 19: "LC"-type ocean-bottom seismograph.

Figure 20: KUM "deep-water"-type ocean-bottom seismograph.

5.1.4 Shot timing

GPS-derived Greenwich Mean Time (GMT) was used as the time standard for the entire cruise. Local time was GMT+12 h. To be able to equate seabed instrument deployment positions to the cruise navigation and to the MCS profile shot gathers, and subsequently common mid-points, in addition to synchronising each OBS to GMT, each shot was also timed against GMT and its location recorded. This was achieved in a very simple way. A Zypher GPS clock was used to generate 0.5 s TTL pulses at the required shot firing rate. This signal was provided to both the MCS acquisition system and initiated recording, and to the Longshot airgun array control system that then fired the array after 60 ms (the “aim point”). The Longshot “fire” pulse was also sent back to the GPS clock which tagged its time against the location at that time and output this to a logging laptop. This file was used as the shot file for subsequent MCS shot location geometry assignment and OBS trace extraction to SEG-Y format and offset calculation. However, during Profile D it was noticed that the MCS system “saw” the rising edge of the TTL pulse, while the Longshot “saw” the falling edge, which resulted in a static advance of 0.56 s of the MCS acquisition system ahead of both the actual fire time and the recorded OBS shot instant. Or put more simply, each shot was fired 0.56 s after the second/minute mark and the MCS data requires a static correction of 0.56 s. As a back-up, the shot instants were also recorded using a Verif-I logger which also has as input a GPS feed.

5.1.5 Profile overview

Each profile was given a unique name no matter when added to the acquisition plan, either prior to the cruise or intra-cruise. Only Profiles A, B, C, D and G were acquired, in the order D, A, B, C and G. Each profile is described below with an accompanying figure showing shot locations and OBS deployment locations where appropriate.

Profile D

This 350 km profile was designed to image the “background” crustal structure associated with the subduction of SW Pacific lithosphere unaffected by the emplacement and loading of the Louisville Ridge. It was originally planned to acquire this profile, as MCS only, after Profiles A and B, carrying on immediately from B without equipment recovery. However, the MCS shake down required less time than allocated, and sea conditions meant that head-to-wind was towards the east end of Profile D’s location, enabling the acquisition plan to be modified to shoot this profile, as MCS only with a 30 s firing rate using 10 guns at 2400 psi, immediately following on from the system tests by enacting a 180° loop-back turn and heading towards the western end of the planned profile location. Although not being located exactly where planned, the actual profile location meets the requirement to perpendicularly traverse the trench and forearc and intersects with Profile B to enable tie-in. Conducting the acquisition in this manner saved approximately 1½ days of acquisition time, which ultimately enabled the shooting of Profile G. A brute stack of Profile D is shown in Fig. 22. Data were acquired shooting east-to-west and were recorded in SEG-D format, one file per shot, at 1 ms sampling rate and 29 s record length.

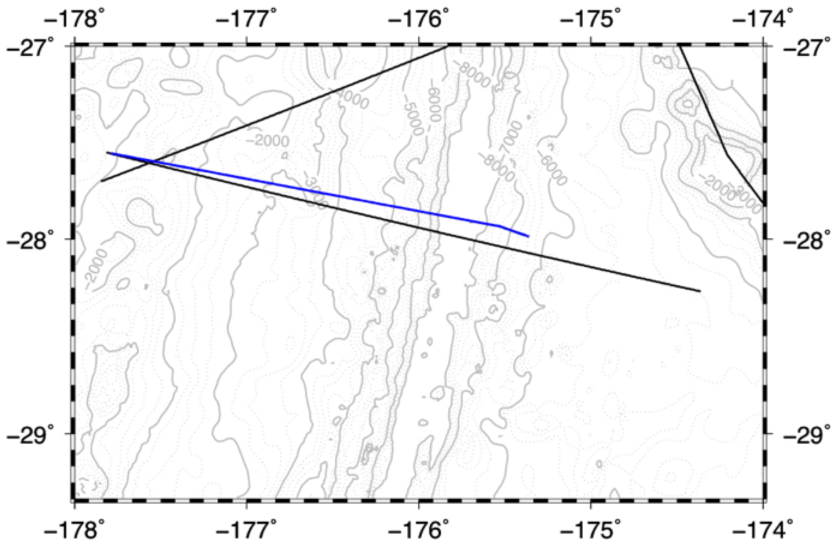


Figure 21: Track chart for SO215 Profile D – an MCS only seismic profile. Black lines show pre-cruise planned profile locations and, for Profile D, the actual shot locations along this profile are plotted in blue.

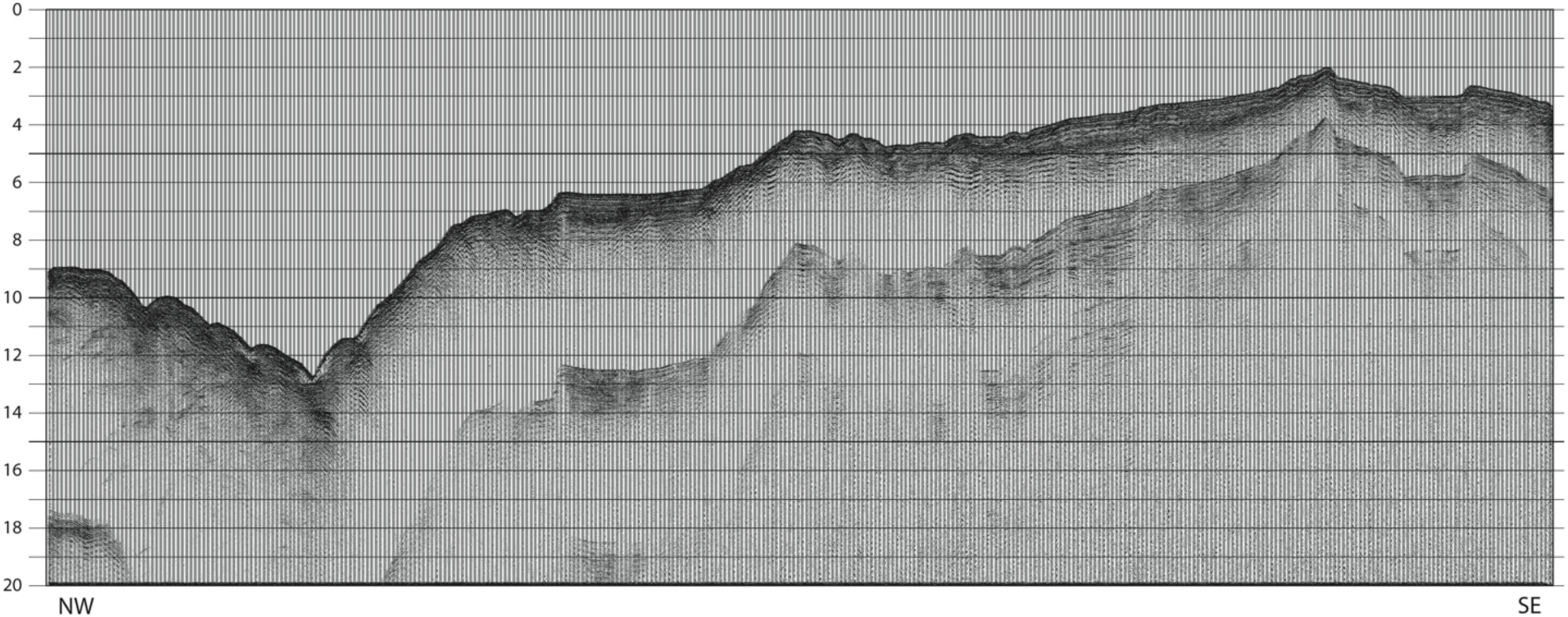


Figure 22: Brute stack of Profile D – MCS-only profile shot with a 10-gun, 4400 in^3 array fired at 2400 psi every 30 s.

Profile A

This 400 km transect across the ridge-trench intersection, was designed to determine the across-strike structure of the collision zone between the arc, across the forearc and trench, to the outer rise and also image the crust and uppermost mantle structure in the seismic gap and high-curvature weak zone in the seaward wall of the trench. Deformation solely related to collision would also be imaged to allow distinction from that induced by seamount interaction with the over-riding plate. Thirty-one OBSs were deployed along this profile as shown in Fig. 23, with one of them (OBS 31) being a trial of the new OBIF 4 kHz sampling datalogger. As this profile was a combined MCS/WA profile, it was acquired with a 60 s firing rate using the full array at 3000 psi. Data were acquired shooting west-to-east and were recorded in SEG-D format, one file per shot, at 2 ms sampling rate and 29 s record length for the MCS data, and in SEG-Y at 4 ms sampling for the OBIF OBS and 5 ms sampling for the IFM-Geomar OBS, both with 60 s trace length. A brute stack of Profile A is shown in Fig. 25 and an example OBS record section shown in Fig. 26.

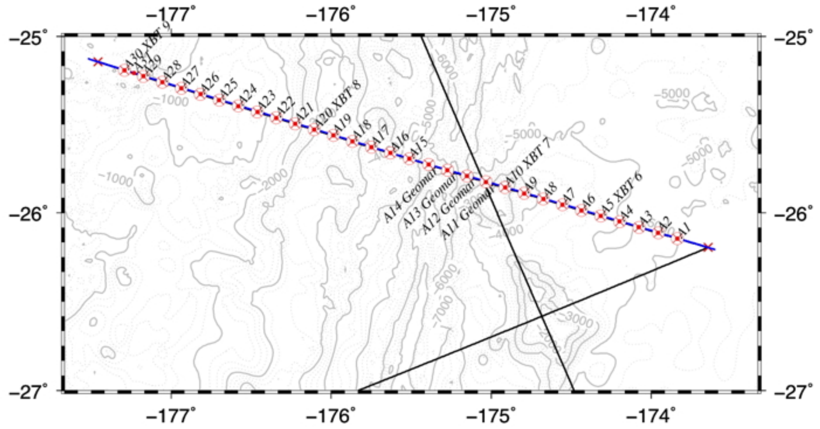


Figure 23: Track chart for SO215 Profile A – a combined OBS and MCS seismic profile acquired at the intersection of the Louisville Ridge and the Tonga Trench. Red crosses show end of profile way points, red targets show planned OBS locations, red dots show actual OBS deployment locations, black lines show pre-cruise planned profile locations and, for Profile A, the actual shot locations along this profile are plotted in blue.

Profile B

This 425 km transect across the Louisville Ridge and moat as they ride the trench outer rise, was designed to determine the mode of isostatic compensation beneath the ridge at the northernmost part of the chain, and the effect of collision on the mechanical strength and flexural response of the subduction system. Twenty-seven OBSs were deployed along this profile as shown in Fig. 24, with the gap in OBS coverage due to water depths in excess of 7500 m in that trench-axis location. As this profile was a combined MCS/WA profile, it was acquired with a 60 s firing rate using the full array at 3000 psi. Data were acquired shooting east-to-west and were recorded in SEG-D format, one file per shot, at 2 ms sampling rate and 29 s record length for the MCS data, and in SEG-Y at 4 ms sampling for the OBIF OBS and 5 ms sampling for the IFM-Geomar OBS, both with 60 s trace length. A brute stack of Profile B is shown in Fig. 27 and an example OBS record section shown in Fig. 28.

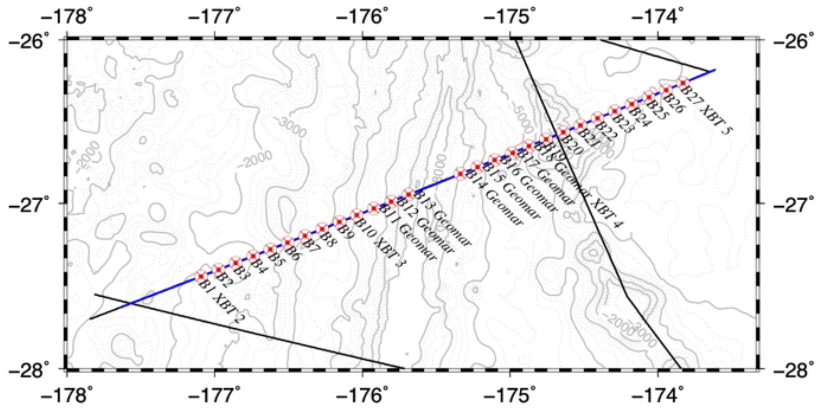


Figure 24: Track chart for SO215 Profile B – a combined OBS and MCS seismic profile acquired across the Tonga Trench and Osborn Seamount, the next seamount along the Louisville Ridge to be subducted. Red crosses show end of profile way points, red targets show planned OBS locations, red dots show actual OBS deployment locations, black lines show pre-cruise planned profile locations and, for Profile B, the actual shot locations along this profile are plotted in blue.

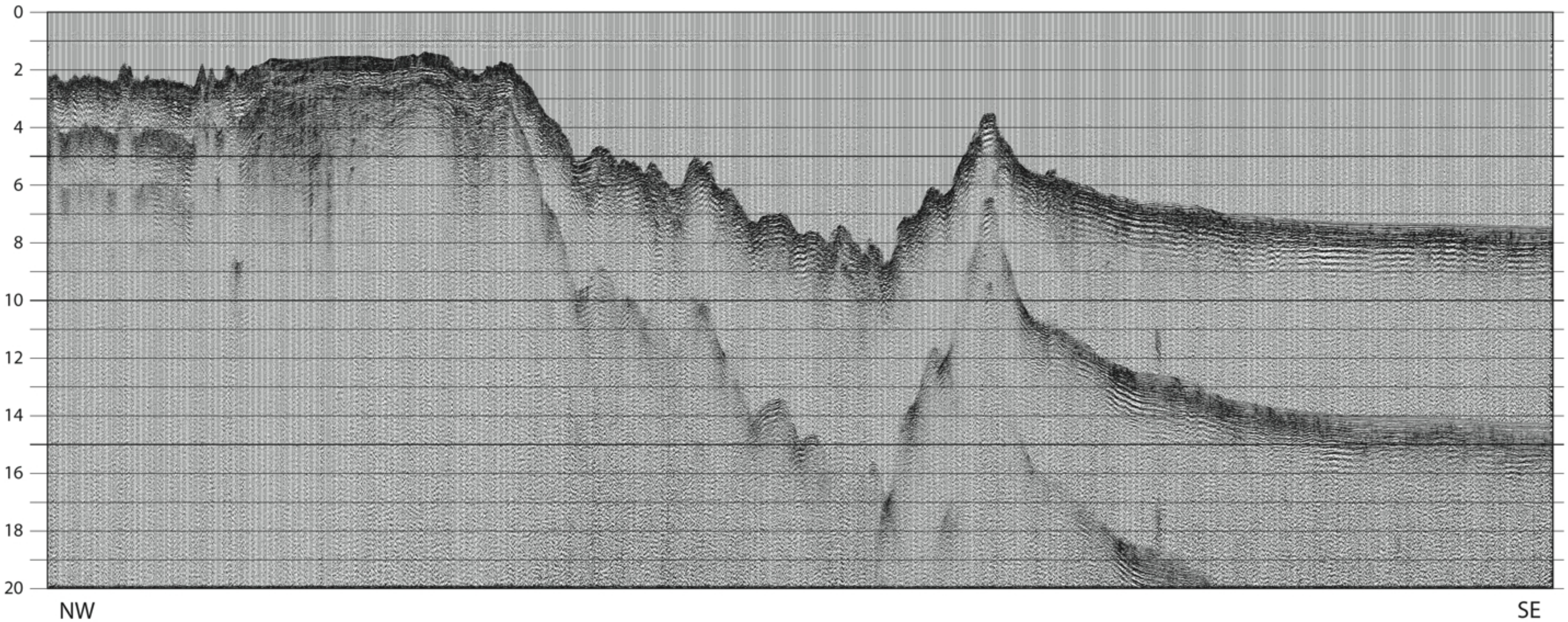


Figure 25: a) Brute stack of Profile A – coincident MCS and OBS profile shot with the full 12-gun, 5440 in^3 array fired at 3000 psi every 60 s.

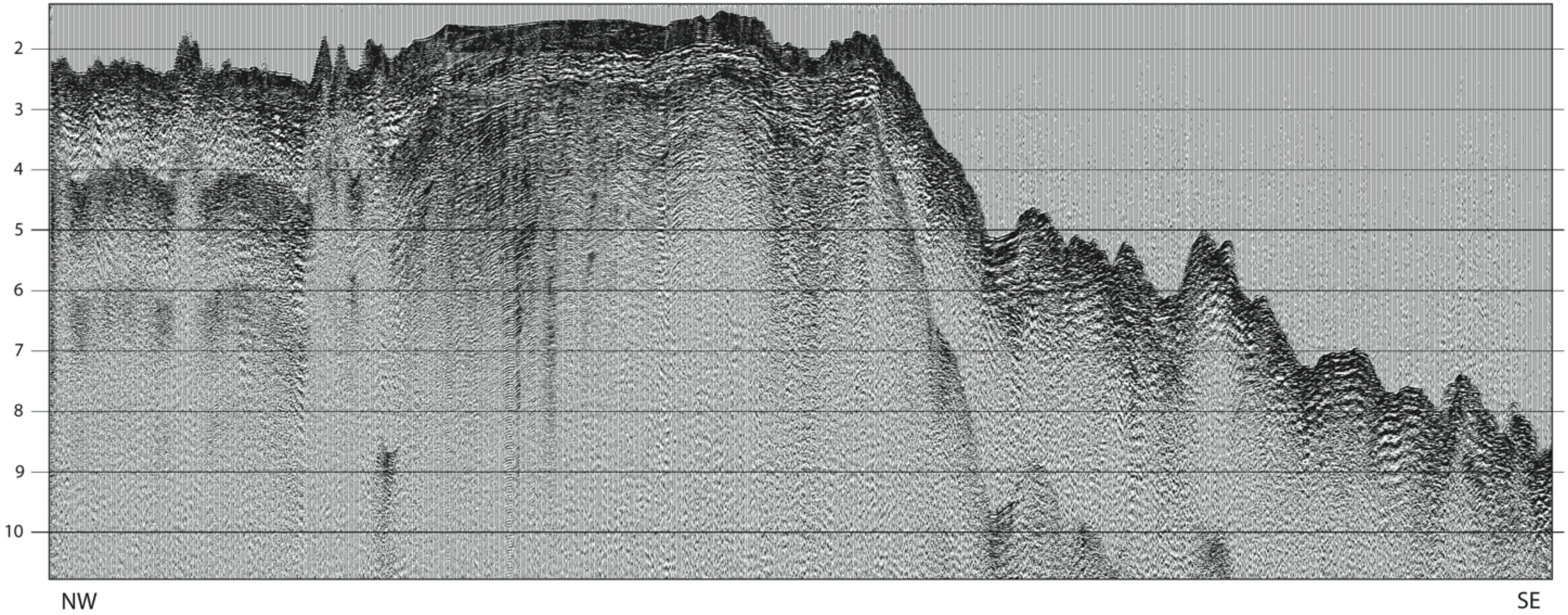


Figure 25 cont.: b) Brute stack of Profile A – zoom-in on the forearc region.

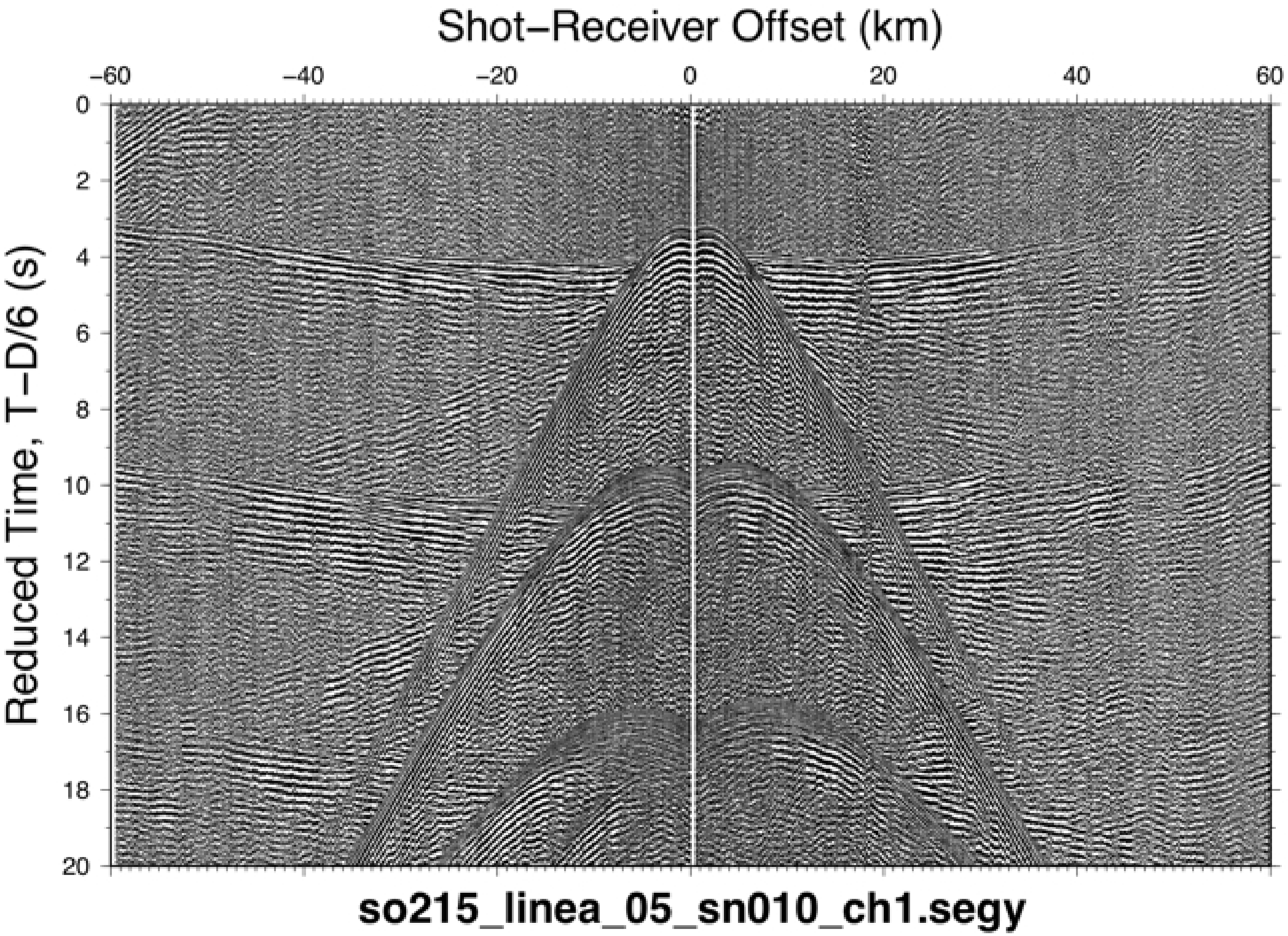


Figure 26: Example OBS data from the hydrophone component of OBS 5 on Profile A. The data are reduced at 6 km s^{-1} and plotted against offset distance from the OBS position.

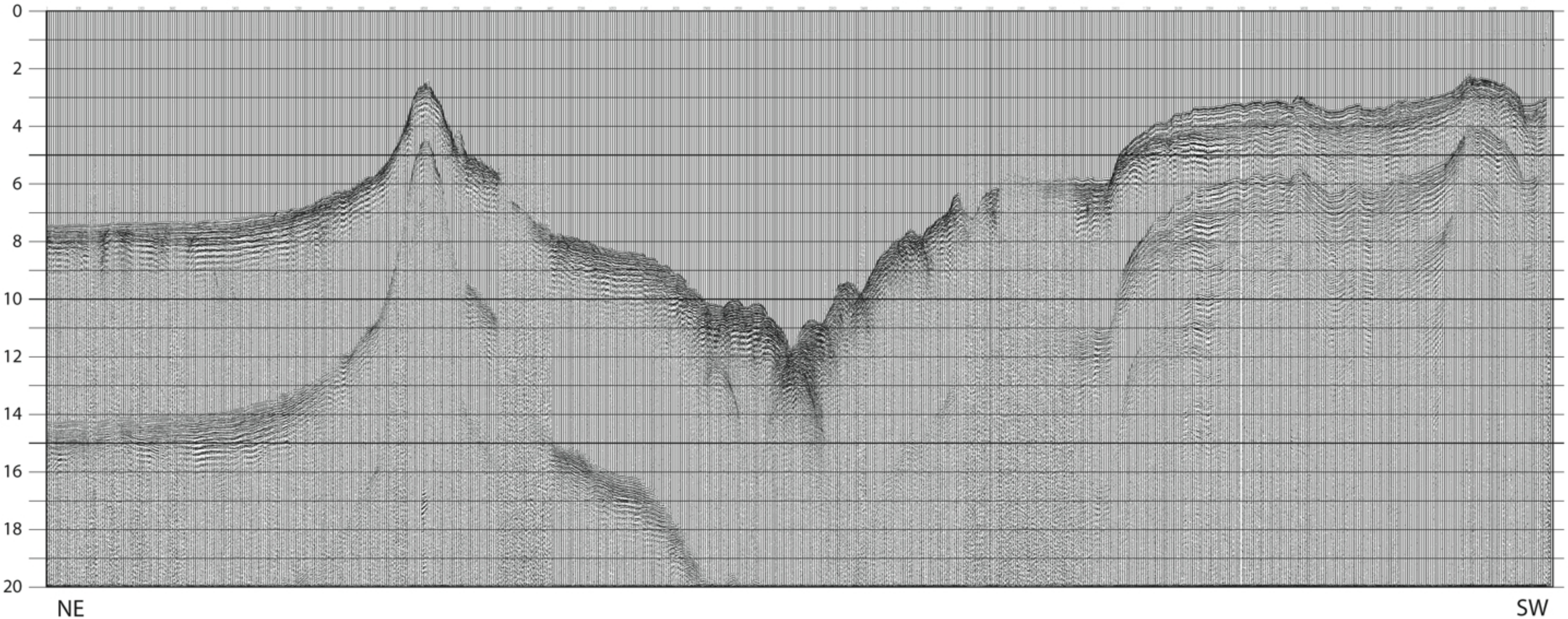


Figure 27: Brute stack of Profile B – coincident MCS and OBS profile shot with the full 12-gun, 5440 in^3 array fired at 3000 psi every 60 s.

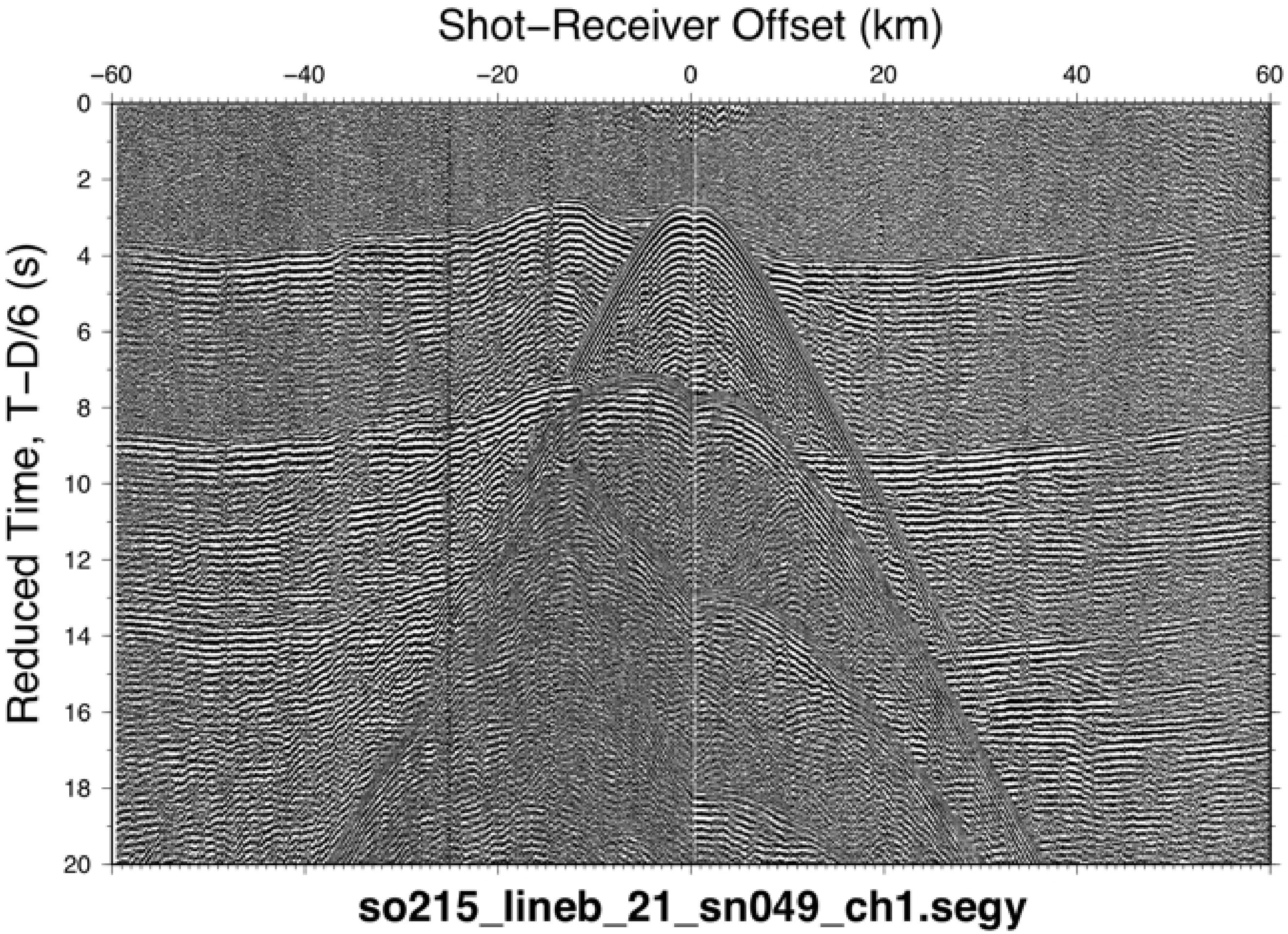


Figure 28: Example OBS data from the hydrophone component of OBS 21 on Profile B. The data are reduced at 6 km s^{-1} and plotted against offset distance from the OBS position.

Profile C

This 725 km transect along the Louisville Ridge, traversing IODP drill sites, extends across the Tonga Trench, and was designed to determine the structure of the Louisville Ridge (the pre-subduction crust), any along-ridge variation in crustal structure or underplating, how seamounts interact with the over-riding plate upon their subduction, and how along-ridge variation in topography, crust and uppermost mantle structure relate to observed post-collision uplift. Fifty-nine OBSs were deployed along this profile as shown in Fig. 29, with one of them (OBS 58) being a trial of the new OBIF 4 kHz sampling datalogger and both OBS 58 and 59 trialling a heavier ballast weight designed to improve horizontal geophone coupling with the seabed. As this profile was a combined MCS/WA profile, it was acquired with a 60 s firing rate using the full array at 3000 psi. Data were acquired shooting northwest-to-southeast and were recorded in SEG-D format, one file per shot, at 2 ms sampling rate and 29 s record length for the MCS data, and in SEG-Y at 4 ms sampling for the OBIF OBS and 5 ms sampling for the IFM-Geomar OBS, both with 60 s trace length. A brute stack of Profile C is shown in Fig. 30 and an example OBS record section shown in Fig. 31.

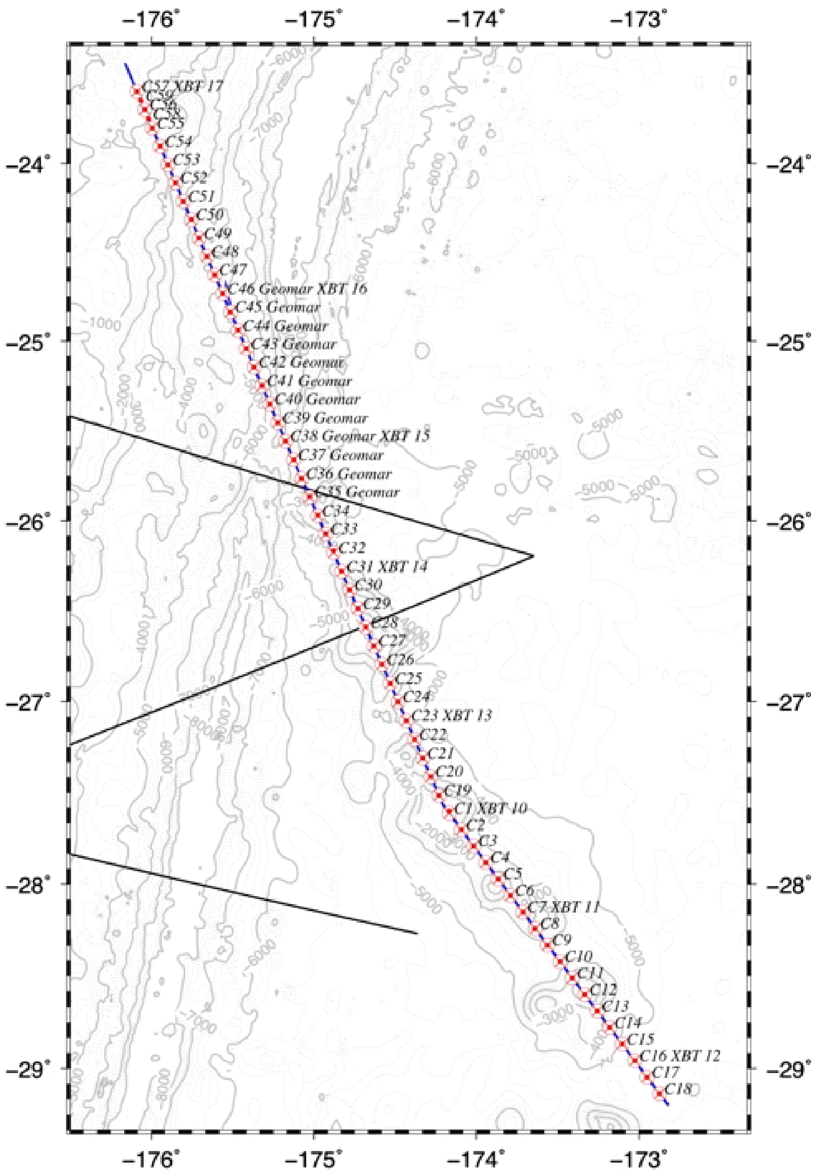


Figure 29: Track chart for SO215 Profile C – a combined OBS and MCS seismic profile acquired along the Louisville Ridge and into the over-riding plate. Red crosses show end of profile way points, red targets show planned OBS locations, red dots show actual OBS deployment locations, black lines show pre-cruise planned profile locations and, for Profile C, the actual shot locations along this profile are plotted in blue.

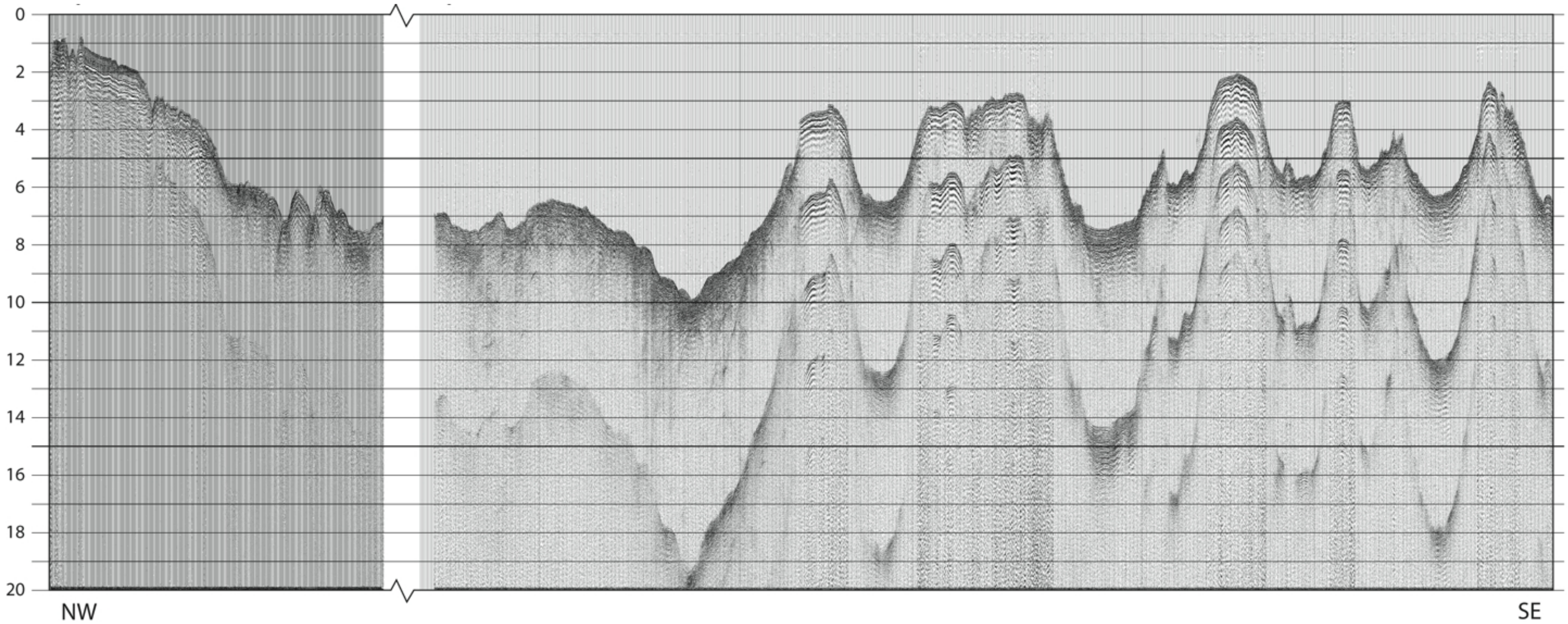


Figure 30: Brute stack of Profile C – coincident MCS and OBS profile shot with the full 12-gun, 5440 in^3 array fired at 3000 psi every 60 s.

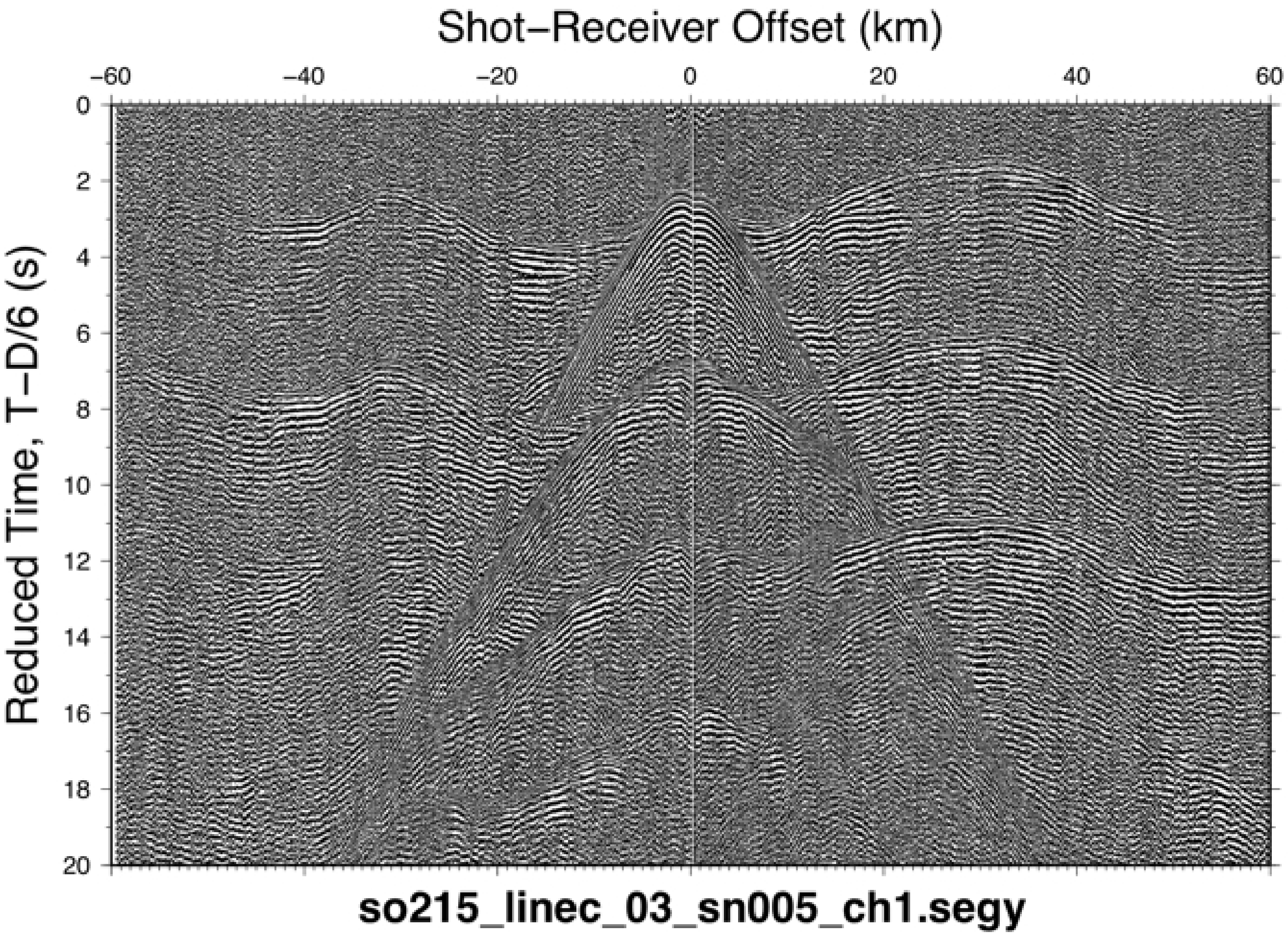


Figure 31: Example OBS data from the hydrophone component of OBS 3 on Profile C. The data are reduced at 6 km s^{-1} and plotted against offset distance from the OBS position.

Profile G

This 240 km transect located trench-parallel on the over-riding Australiasian plate, was added to the acquisition plan intra-cruise to make best-use of remaining ship days in the work area. It was designed to determine the structure of the forearc and locate and determine the depth to the top of the down-going plate. Although not coincidently located, this profile also acted as a reshoot of profile P01 of R/V Sonne cruise SO195, the first cruise of the TOTAL project to which our survey is allied, which did not record data usable for deep crustal imaging. Nine OBSs were deployed along this profile as shown in Fig. 32, with one of them (OBS 9) being a trial of the new OBIF 4 kHz sampling datalogger and with this instrument also trialling a heavier ballast weight designed to improve horizontal geophone coupling with the seabed. As this profile was a combined MCS/WA profile, it was acquired with a 60 s firing rate using the full array at 3000 psi. Data were acquired shooting northeast-to-southwest and were recorded in SEG-D format, one file per shot, at 2 ms sampling rate and 29 s record length for the MCS data, and in SEG-Y at 4 ms sampling for the OBIF OBS and 5 ms sampling for the IFM-Geomar OBS, both with 60 s trace length. A brute stack of Profile C is shown in Fig. 33 and an example OBS record section shown in Fig. 34.

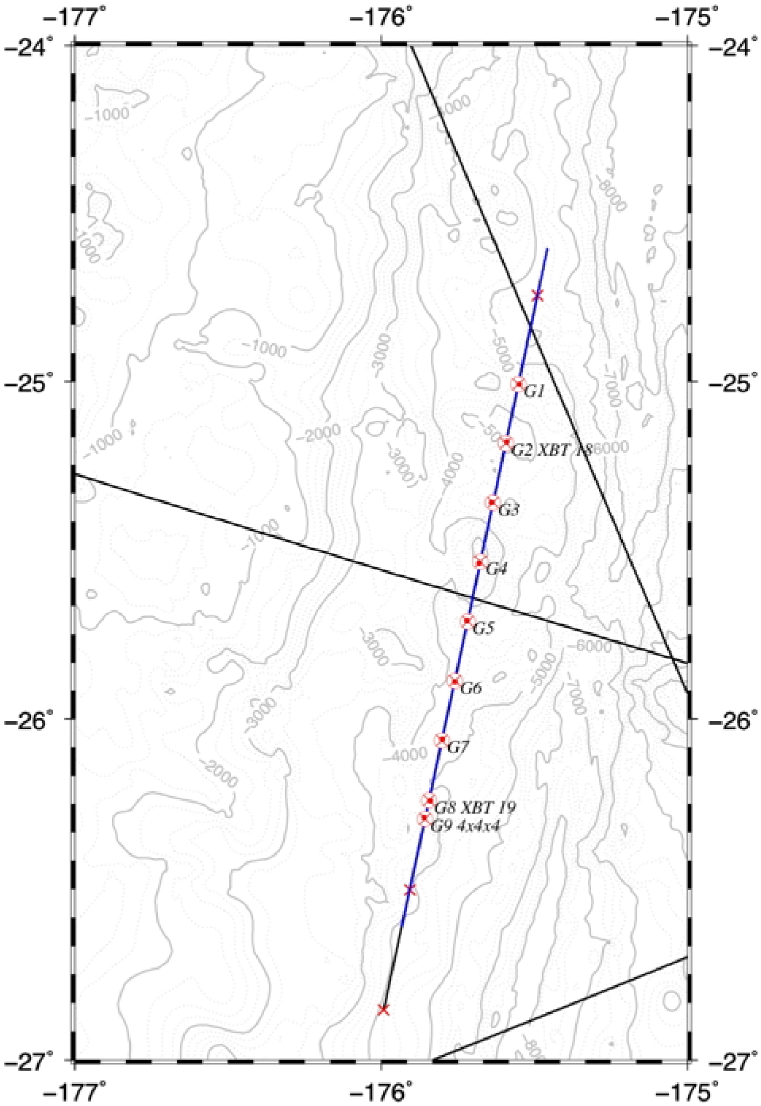


Figure 32: Track chart for SO215 Profile G – a combined OBS and MCS seismic profile acquired trench-parallel in the forearc. Red crosses show end of profile way points, red targets show planned OBS locations, red dots show actual OBS deployment locations, black lines show pre-cruise planned profile locations and, for Profile G, the actual shot locations along this profile are plotted in blue.

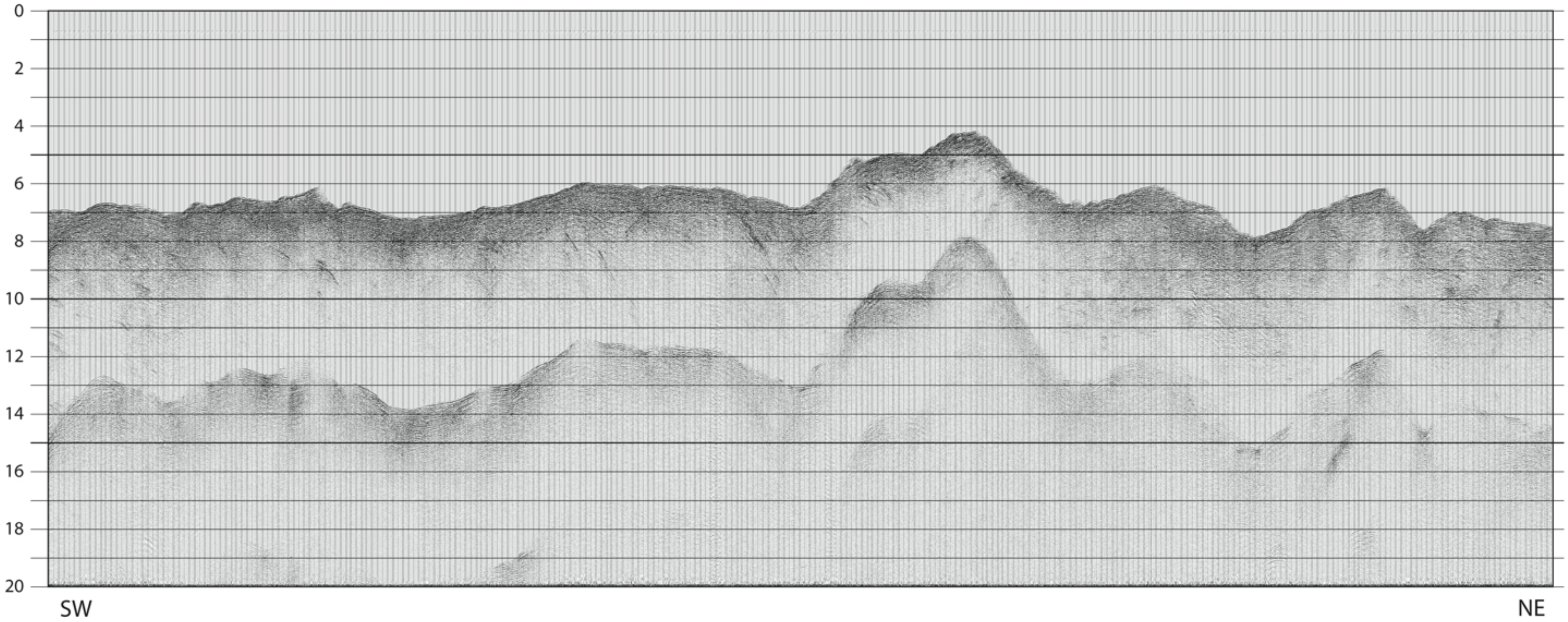


Figure 33: a) Brute stack of Profile G – coincident MCS and OBS profile shot with the full 12-gun, 5440 in^3 array fired at 3000 psi every 60 s.

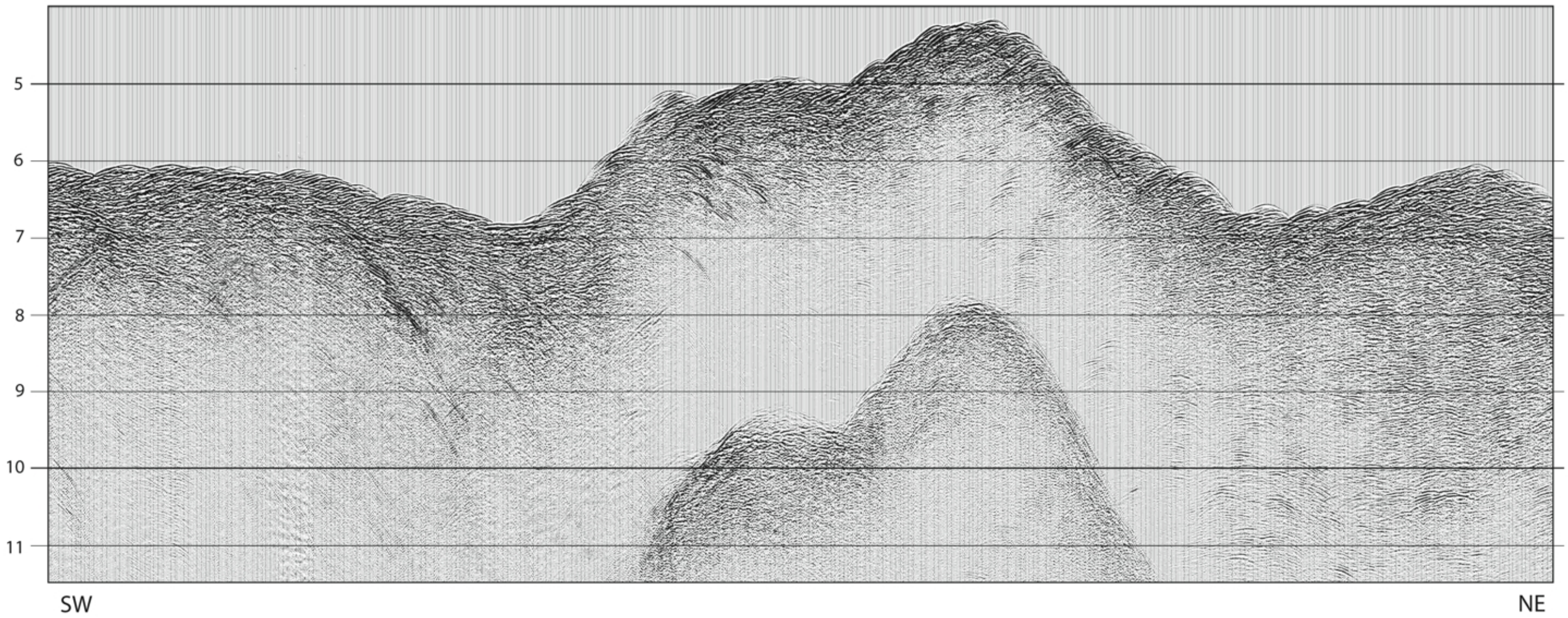


Figure 33 cont.: b) Brute stack of Profile G – zoom-in on possible seamount.

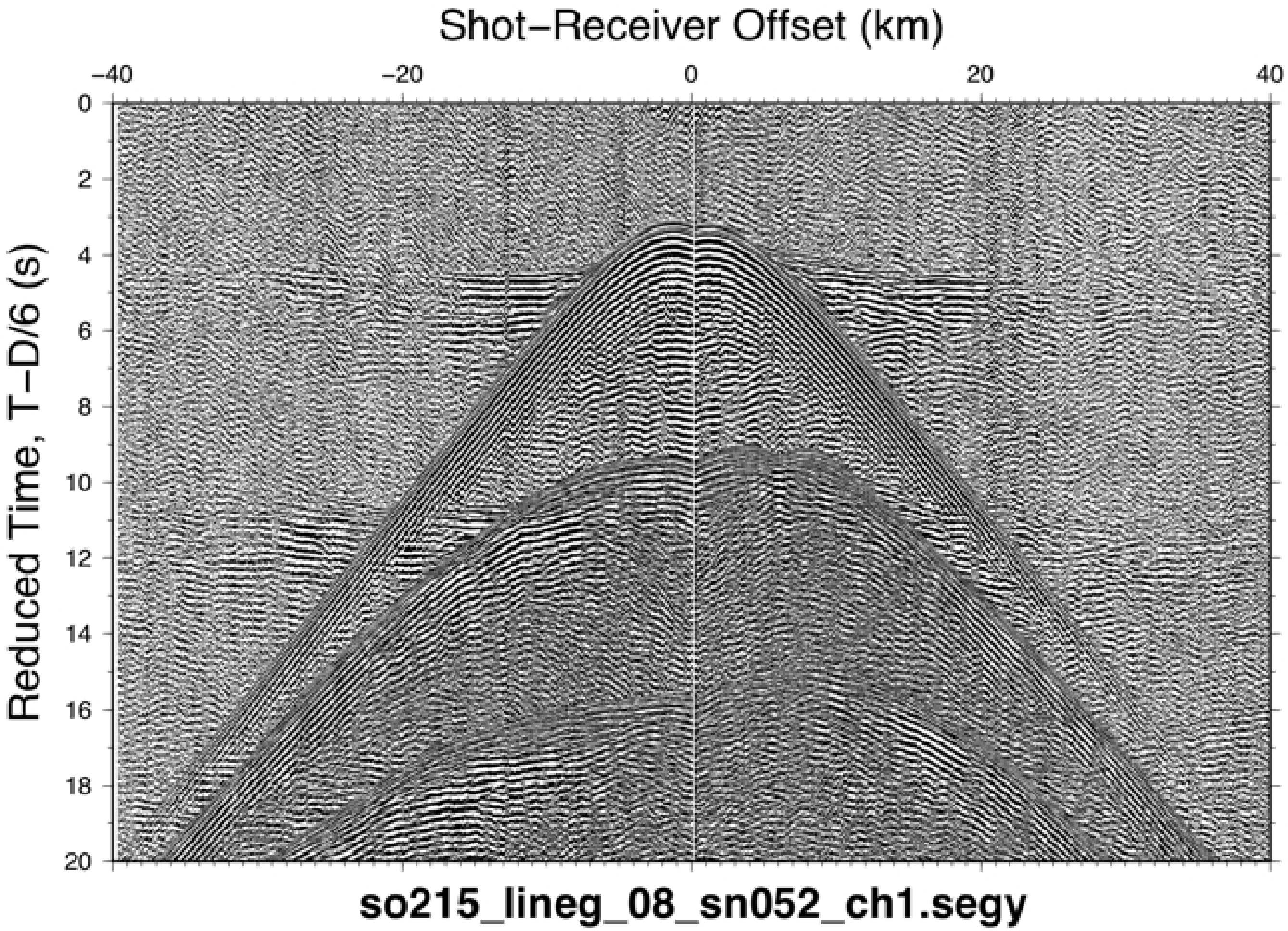


Figure 34: Example OBS data from the hydrophone component of OBS 8 on Profile G. The data are reduced at 6 km s^{-1} and plotted against offset distance from the OBS position.

5.2 Gravity

The recently fully refurbished NMFSS Lacoste & Romberg Air-Sea gravimeter (number S84) was installed in the ‘gravimeter lab’ on the “Kegelbahn” deck (Fig. 35). This instrument was in continuous operation throughout the cruise. The gravimeter has a calibrated range of 12,000 mGal and an accuracy of better than 0.1 mGal. To correct for instrument drift over the duration of the cruise and convert relative to absolute measurements, the gravimeter was tied to absolute gravity reference stations in Auckland and Townsville (See Figs 36-40 and Tables 8-10). A drift of 3.02 mGal per month was calculated which is in accord with the manufacturer’s specifications.

Although the meter’s logging system will automatically calculate the filtered gravity from the spring tension on the beam and correct it for Eotvos using input navigational data, during the cruise the Lacoste-Romberg QC gravity in counter units were independently processed with the underway navigation and bathymetry and satellite-derived gravity data and converted to a free-air gravity anomaly for purposes of quality control. In the processing, we used a low-pass filter of variable width (200-2000 sec) and a delay of 180 sec. Fig. 41 shows an example of the processed data together with the Lacoste-Romberg QC-gravity, the Eotvos correction and the cross-coupling error during a period of OBS deployments along Profiles B and A. The large fluctuations in the Eotvos correction are caused by changes in the speed and heading of the vessel during OBS deployment. The figure shows that our processing scheme recovers a free-air gravity anomaly that satisfactorily accounts for Eotvos and cross-coupling and compares well with what would be expected from the bathymetry and the satellite-derived gravity data.

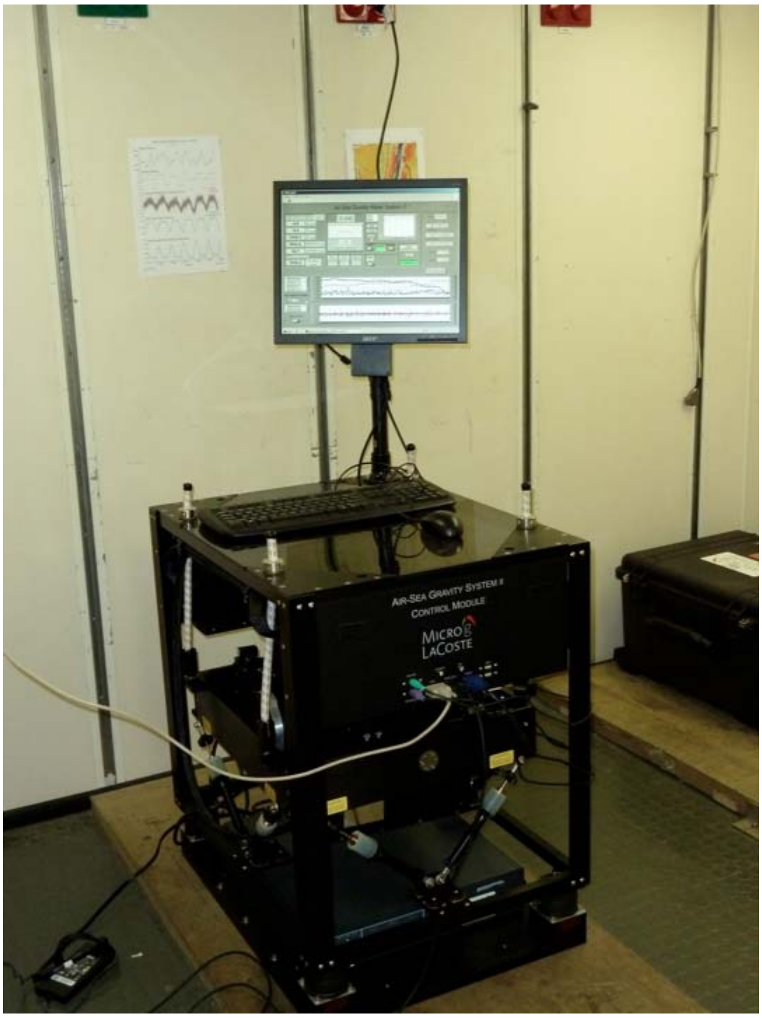


Figure 35: Lacoste & Romberg Air-Sea gravimeter “S84”.

Figure 36: Screen shot of the Lacoste & Romberg Air-Sea gravimeter “S84” system display showing meter instrument and sensor performance as well as raw and processed gravity anomalies, Eotvos correction and spring tension.

Figure 37: Gravity base station location in the container and car import port in Auckland.


Figure 38: Gravity base station location in Townsville on top of Castle Hill.

Figure 40: Gravity base station identification plate on Castle Hill in Townsville.


Figure 39: Undertaking the gravity tie on the quay in Townsville as the R/V Sonne changed berth.

The accuracy of the processed data was assessed by calculating the difference in free-air gravity anomaly at intersecting ship tracks. We found a total of >2200 cross-over errors which yield a mean difference of -0.6 mGal and a Root Mean Square (RMS) difference of +-10.2 mGal. This relatively high RMS is attributed to a large number of intersections in high gradient regions where small changes in bathymetry can cause large changes in gravity. We are presently using the cross-over data to determine the best fit filter parameters to use in the gravity processing.

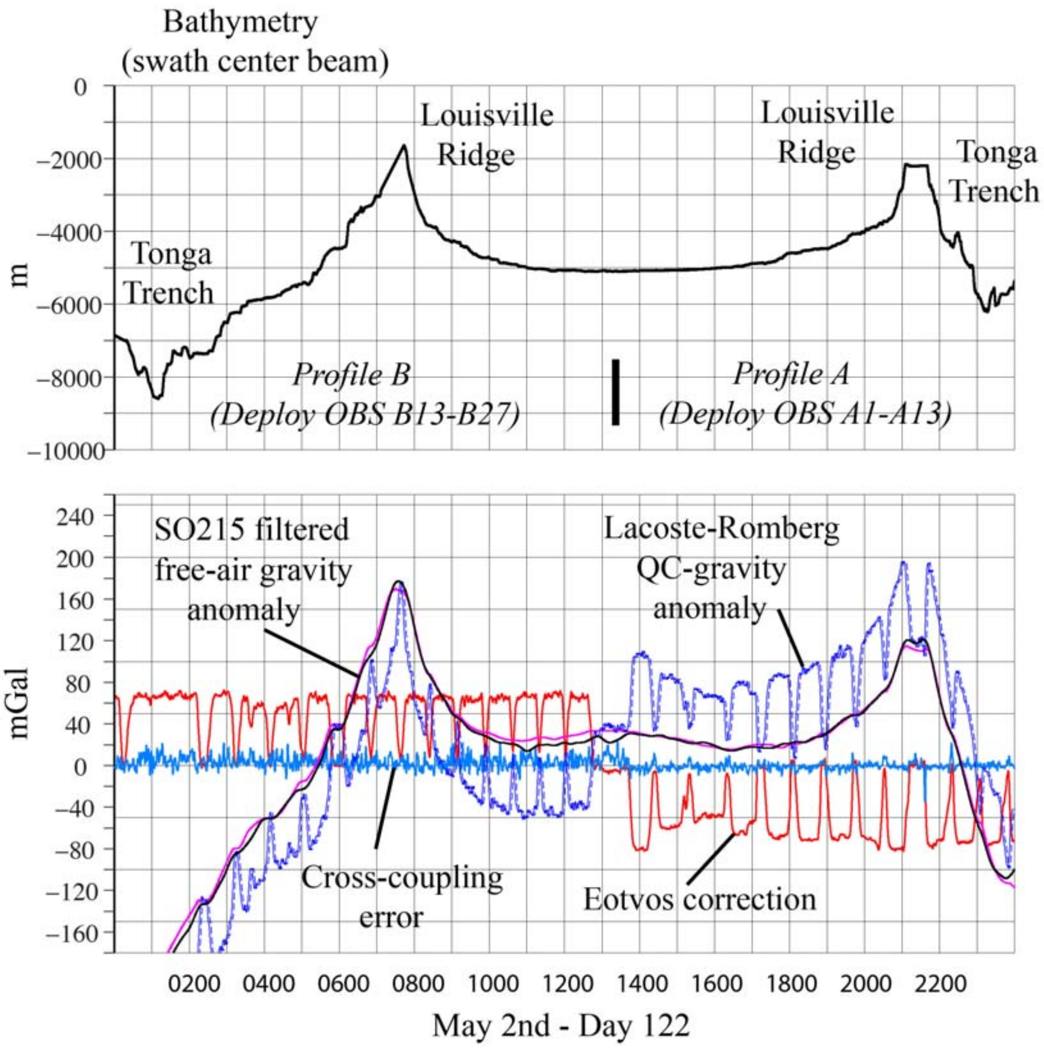


Figure 41: Plot of the filtered free-air gravity anomaly and bathymetry along the eastern end of seismic Profiles A and B. The gravity anomaly has been derived from the QC-gravity in columns 33-41 of the output .DAT files. The sampling interval is 10 sec. The gravity has been converted from counter units to mGal and the anomaly calculated by subtraction of the theoretical gravity. Dark blue dashed lines show the anomaly uncorrected for the delay caused by electrical and mechanical damping of the instantaneous beam motion. The solid dark blue line shows the anomaly with a 180 sec delay applied. The red and light blue lines show the filtered Eotvos correction and cross-coupling error. The filtering is based on a cosine filter of width 200 sec. The black line shows the filtered free-air gravity anomaly, which has been derived from the QC-gravity anomaly by adding the Eotvos correction and subtracting the cross-coupling error. The filtering is based on a cosine filter of width 2000 sec. The solid purple line is the satellite-derived gravity field of Sandwell and Smith (Ver. 18.1). Note how well the filtered free-air gravity anomaly is recovered, even in the presence of speed and heading changes of the vessel during OBS deployment which result in Eotvos correction changes of ±70 mGal.

5.3 Magnetics

An NMFSS SeaSPY marine magnetometer was used to measure and record the Earth's total magnetic field intensity (Fig. 42). The magnetometer operates in a range of 18,000 – 120,000 nT, and is sensitive to ±0.01 nT. The magnetometer was towed ~250 m astern from the port side (Fig. 43). The magnetometer recording PC and power supply were installed in the "Geology lab". Meter readings were recorded against GMT using a terminal logging programme installed on the PC. The logged data comprised of latitude, longitude, sensor depth and total magnetic field. Processing involved the removal of 'rogue' points and magnetic anomalies were calculated using the 2009 International Geomagnetic Reference Field. This field is definitive for years up to 2005 and non-definitive for 2010 and subsequent years.

The magnetometer was towed along all seismic profiles, along the main transits between profiles and for the swath surveying at Monowai. An example of the data recorded over the South Fiji Basin during the transit to Townsville is shown in Fig. 44. The figure shows that the magnetometer recovers well magnetic anomalies 8 through 12 which are approximately 28 to 35 Ma. The magnetometer was towed to the 200 nm limit of Australia.

Unfortunately, there are only a few cross-over points where we can assess the accuracy of the magnetic anomaly data. However, gridding of data over the Monowai volcano suggest accuracies of better than 10 nT.

Figure 42: SeaSPY magnetometer tow fish.

Figure 43: SeaSPY tow cable and deployment winch.

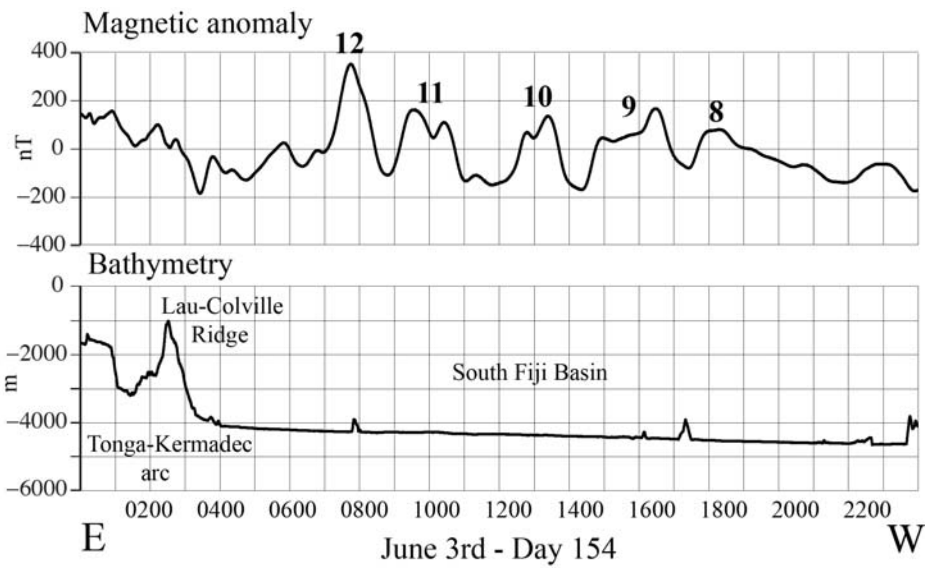


Figure 44: Magnetic anomaly and bathymetry of the South Fiji Basin.

5.4 Swath bathymetry

The R/V Sonne is fitted with a Kongsberg Simrad EM120 multi-beam deep ocean echosounder, with two transducer arrays fixed to the ship's hull and operating at 11.25 to 12.6 kHz. Data acquisition is based on successive transmit-receive cycles of this signal. The transmit beam is 150° wide across track and 2° along track direction and the receive signal is obtained from 191 overlapping beams, with widths of 2° across track and 20° along track. The beam spacing can be defined as equidistant or equiangular, and the maximum seafloor coverage fixed or adjusted according to seabed and weather conditions. Seabed depth and reflectivity are recorded against GMT time and GPS location. The raw depth data are processed to obtain depth-contour maps and the acoustic signal sampled at 3.2 ms and processed to obtain backscatter amplitudes. Swath bathymetry and back-scatter data were acquired port-to-port.

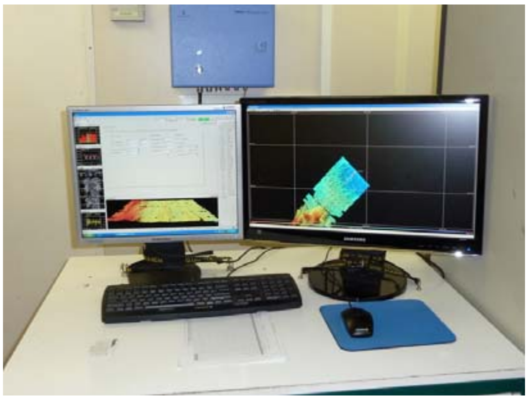


Figure 45: Console display of raw swath bathymetry data looking downwards (right) and sternwards (left).

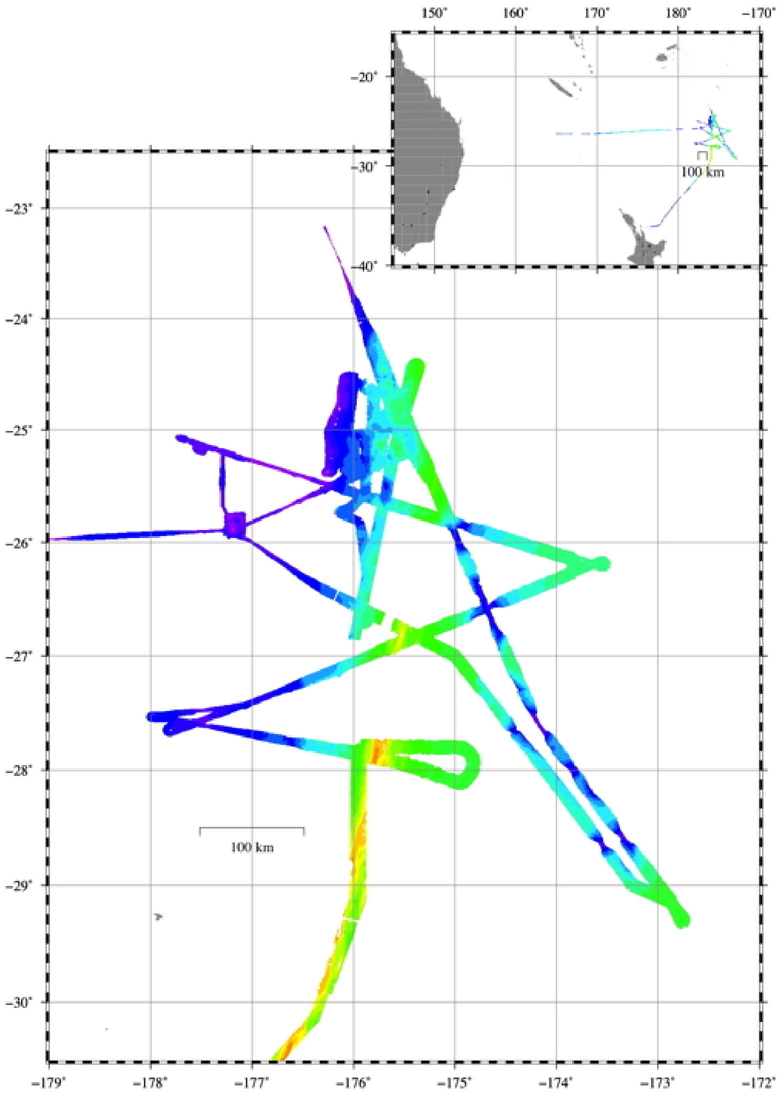


Figure 46: Swath bathymetry data acquired during SO215. Inset shows data acquired along transits from and to the port calls in Auckland and Townsville. Colour palette is the same as for Fig. 47.

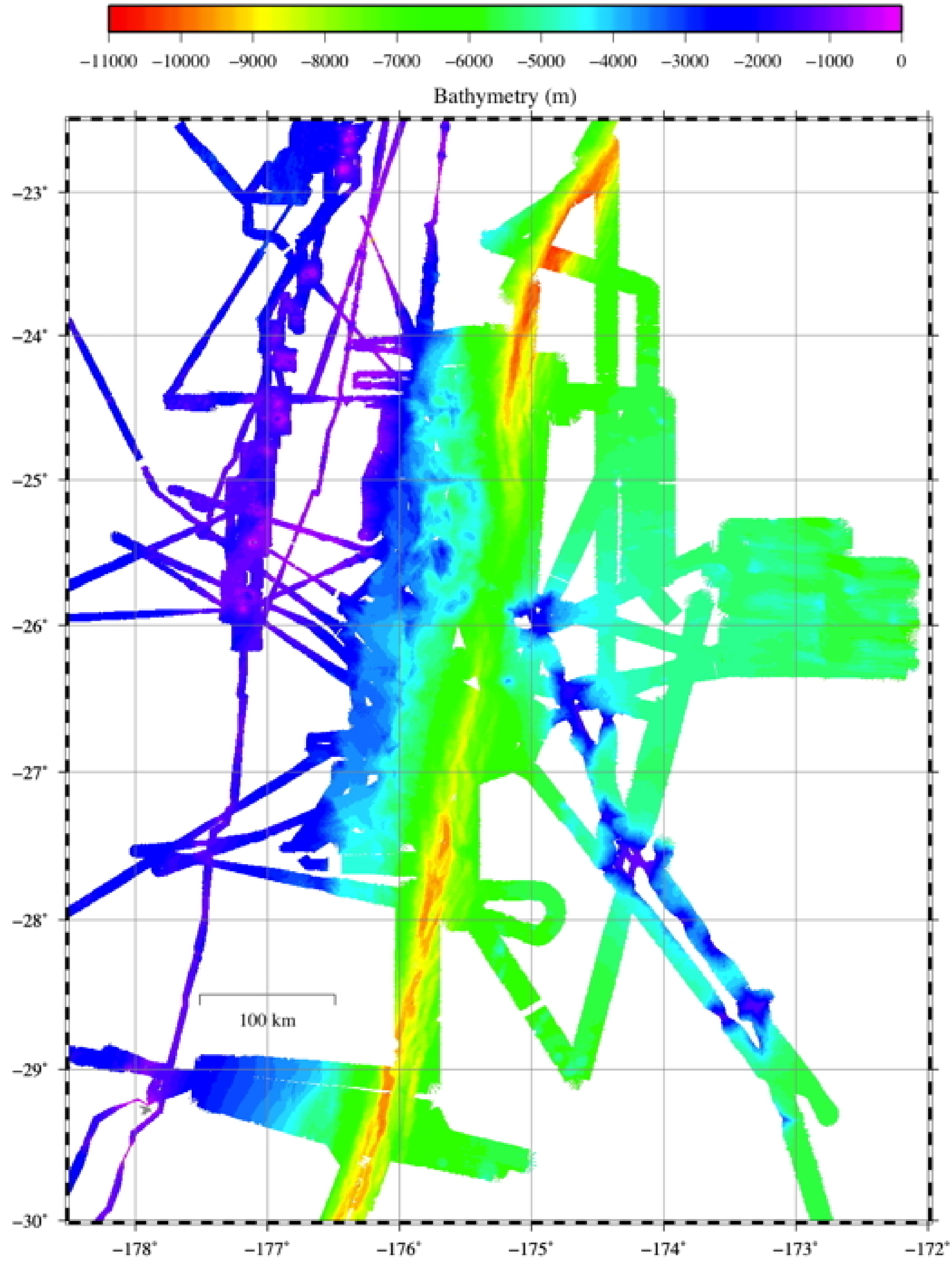


Figure 47: Swath bathymetry data acquired during SO215 merged with that from all previous surveys to the region.

5.5 Sub-bottom profiling – Parasound

The R/V Sonne is fitted with an Atlas Parasound P70 (Fig. 48) which can operate at frequencies of 0.5 to 6.0 kHz and 18 to 33 kHz as a sub-seabed sediment profiler in water depths ranging from 10-11000 m. Sub-seabed imaging can extend to ~200 m depending on seabed conditions and sediment characteristics.

The Parasound was operated continuously throughout the cruise whilst in the work area and recorded data, one trace per ping, into standard SEG-Y format files lasting approximately 3-4 minutes of survey time. Each ping trace has a static lag incorporated into the trace header reflecting the start of data window time, since operation requires a time window to be continuously adjusted to match the seabed arrival time.

Processing applied during the cruise enabled the individual SEG-Y format files to be combined and the individual trace lags removed such that every trace started at 0 s time.

The data is of high quality (Fig. 49) except for sections crossing the deepest parts of the Tonga trench and areas of very steep gradient. Together with the swath bathymetry the data will allow characterisation of the seabed in areas of specific interest and identification and characterisation of tectonic features in the forearc, trench and outer rise.

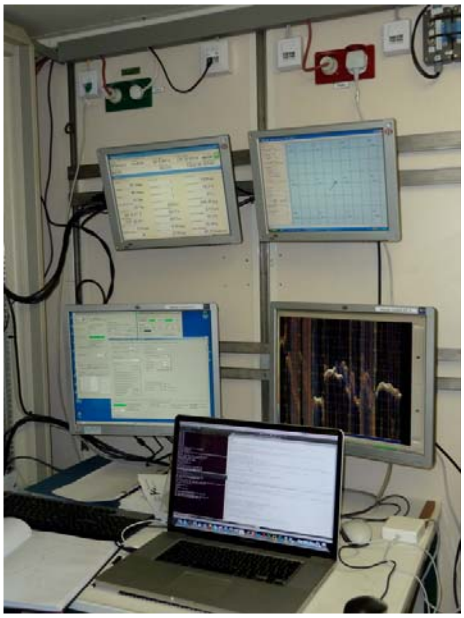


Figure 48: Console display of raw Parasound data (above) in the Hydroacoustic lab and screen display repeater in the Geology lab (below).

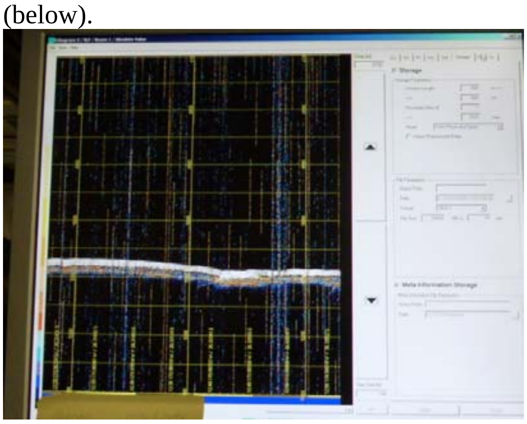
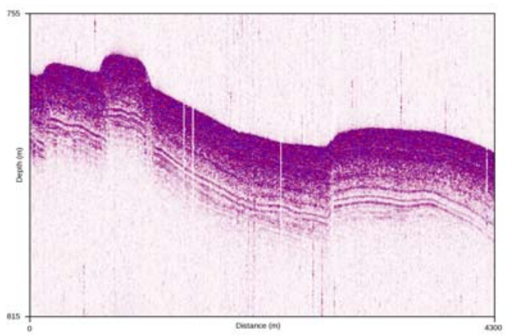


Figure 49: Example Parasound data showing subseabed imaging of up to 50 m. See section 5.9 for an example from the Monowai volcanic centre



5.6 Navigation

The primary navigation system used during SO215 was a Trimble GPS model 4000 DS. This GPS produced positions every second to ~2 m accuracy. Data were logged by the R/V Sonne's Werum data store, and distributed to any workstation on the vessel for download via the "DVS" front-end GUI and also input into the underway track chart plotting system during seismic acquisition and all other vessel systems that required navigational input, including the gravimeter and magnetometer datalogging systems provided by NMFSS.

5.7 Expendable bathymetric thermographs

A series of T5 expendable bathymetric thermographs were deployed throughout the cruise to map the temperature and velocity (once ground-truthed to the sound velocity profile) of the water column in a rapid and more versatile manner than is possible using a sound velocity probe alone. Several probes were deployed along each profile. Once cross-calibrated against the sound velocity profile these could thus provide water column velocity throughout the work area and for every seismic profile. Fig. 50 and Table 12 show deployment locations and Figs 51 and 53 the profiles acquired.

5.8 Sound velocity profiling

A sound velocity profile was undertaken on first arriving in the work area using the R/V Sonne's CTD rosette, providing the water column velocity structure down to 3000 m. The sound velocity profile is shown in Fig. 52 and its deployment location is given in Table 11. As well as providing the ground-truth for the expendable bathymetric thermographs, an accurate sound velocity profile is also needed for the Kongsberg Simrad EM120 swath bathymetry system.

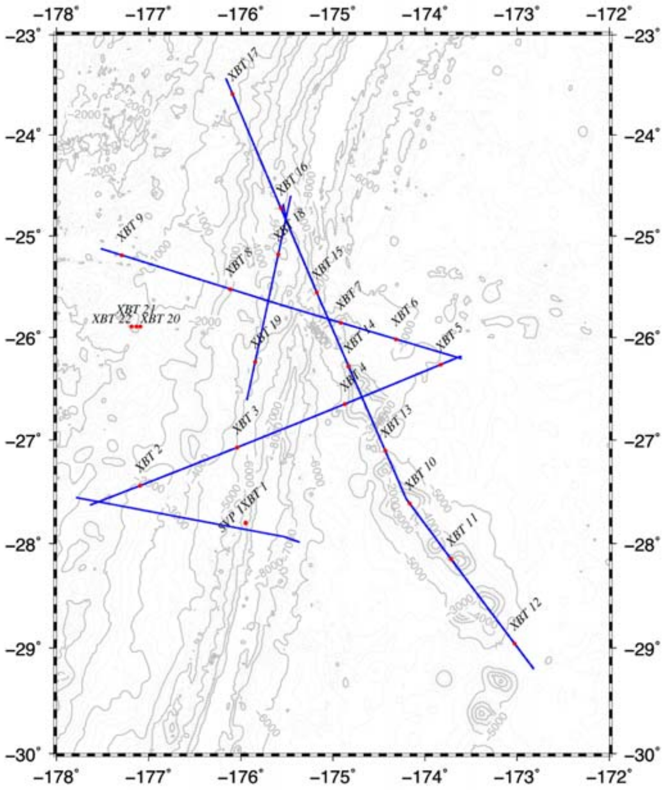


Figure 50: Deployment locations of XBTs and sound velocity profile.

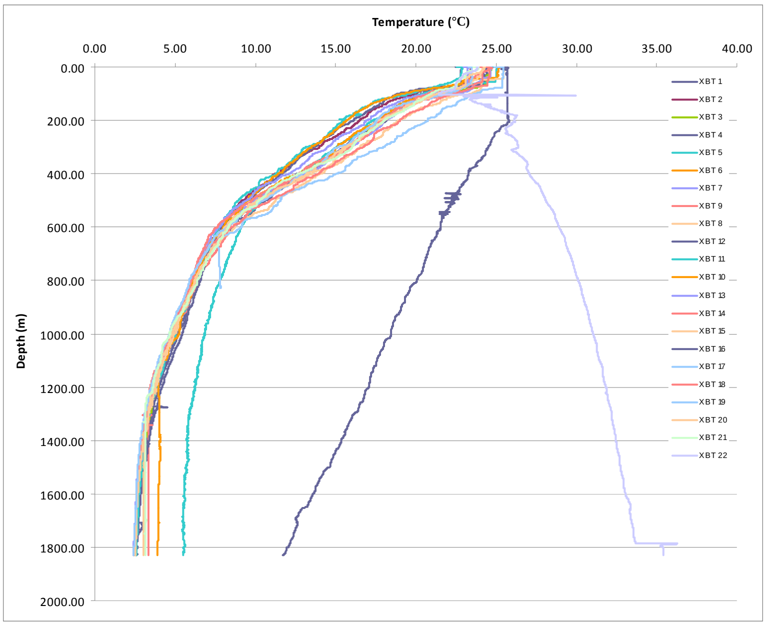


Figure 51: XBT temperature profiles acquired during SO215. Profiles 20, 21 and 22 were deployed at the Monowai Cone and each landed on the seabed in water depths of 1370 m 1330 m and 105 m respectively, although the probes continued to operate until they timed out.

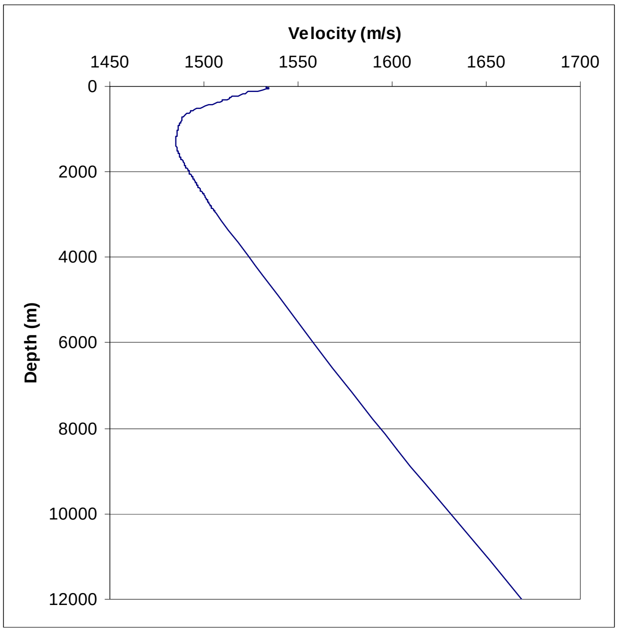


Figure 52: Sound velocity profile used for EM120 swath bathymetry acquisition and XBT ground-truth. The profile has been extrapolated from 3000 m depth.

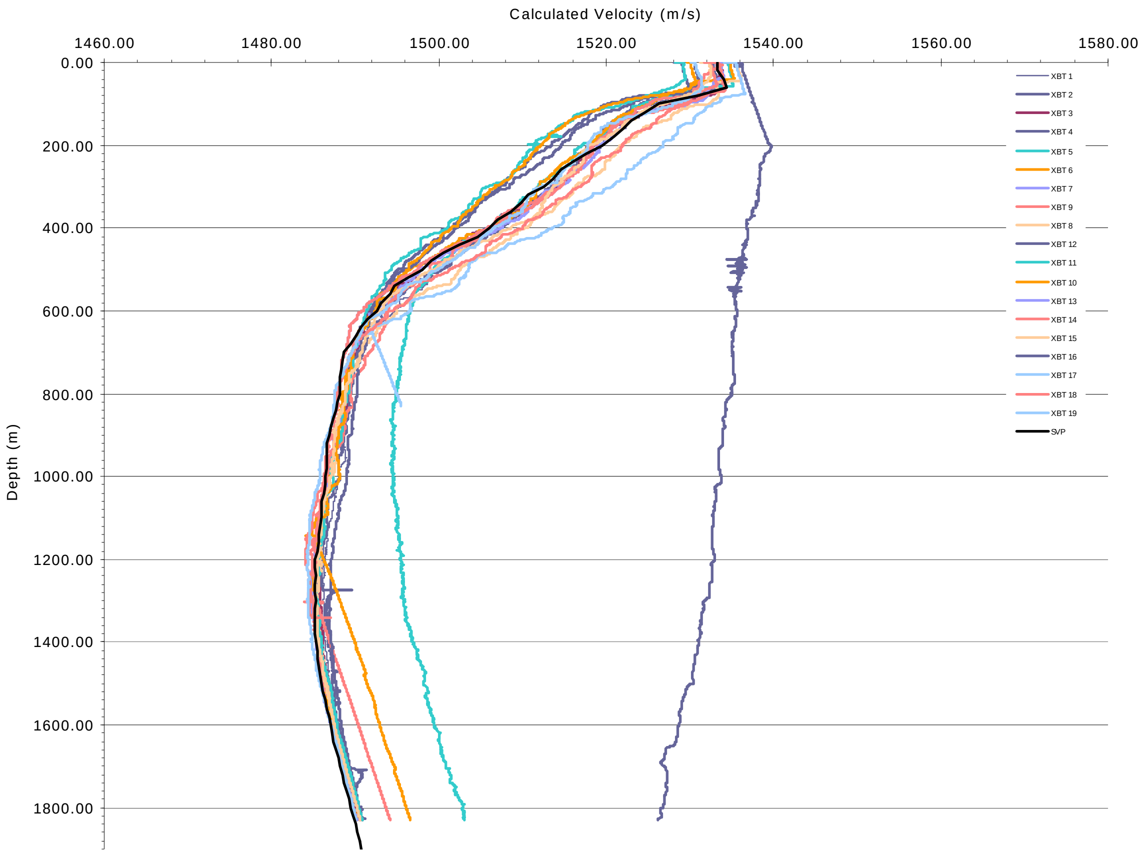


Figure 53: Sound velocity profile (black) compared with water column velocities derived from the XBT probe data.

5.9 Monowai volcanic centre – a unique opportunity to observe an eruption in progress

Monowai is an active submarine volcano located mid-way along the Tonga-Kermadec arc, about 150 km west of the intersection of the Louisville Ridge chain of seamounts with the Tonga-Kermadec trench. First sighted in 1944 from an aircraft [*Davey*, 1980], the volcano has a record of 60+ visual (e.g. shoaling, discoloured water) observations and seismic activity (e.g. as recorded by the Polynesian Seismic Network and locally moored hydrophones) [*Wright et al.*, 2008; *Chadwick et al.*, 2008]. Bathymetric data [*Chadwick et al.*, 2008; *Wright et al.*, 2008] show that the volcano comprises a 10-12 km wide, 1.0 km high, cone that is located ~10 km south-southwest of a 7 -10 km wide, 0.6 km deep, caldera with a central cone. Geological sampling data suggest the volcano comprises mainly of mafic, vesicular and highly glassy lavas that formed from relatively high degrees of partial melting above the subducting Pacific plate [*Haase et al.*, 2002; *Graham et al.*, 2008; *de_Ronde et al.*, 2005; *Timm et al.*, 2011]. The volcano is hydrothermally active and is known to be associated with low temperature vents, a large biomass and seafloor mineralization [*Leybourne et al.*, in press].

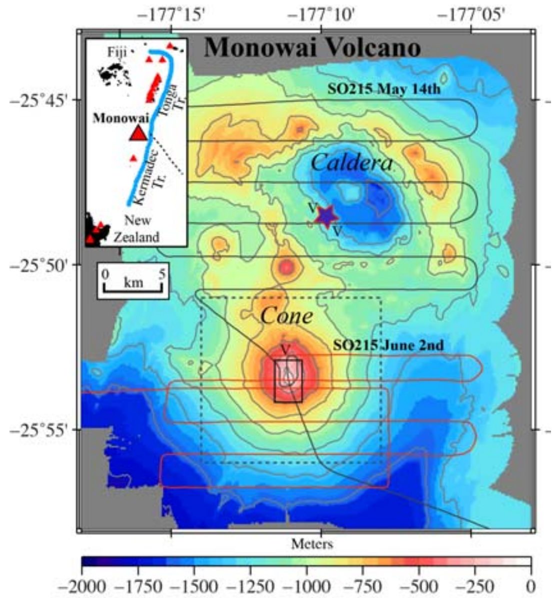


Figure 54: Bathymetry of the Monowai volcano based on SO215 swath data. The solid grey lines show the tracks of SO215 on May 14^{th} and the red solid lines the tracks on June $1^{st}/2^{nd}$. Blue filled star shows the main caldera hydrothermal vent site and V shows the location of other vent sites. The dotted lines locate the maps presented in Figs. 55 and 56.

The cone was first mapped [*Davey*, 1980] using single beam echo sounder data to show that the cone summit in September 1978 was at a depth of 117 m and a location of latitude 25^{o} 53.2’ S, longitude 177^{o} 11.3’ W. The first swath bathymetry survey on R/V Thomas Washington in September 1986 revealed a summit shoal at 115±5 m [*Wright et al.*, 2008]. R/V SONNE surveyed the cone in September 1998, by which time the summit depth had decreased to 49 m and the position had moved about ~700 m south-southeast. R/V Tongaroa re-surveyed the cone in September 2004 and found that the summit depth had deepened to 128 m and the summit had moved south about 200 m. Finally, R/V SONNE re-surveyed the cone in May 2007 and found that the cone summit had dramatically shallowed to 49 m and the summit had moved south about 200 m [*Chadwick et al.*, 2008; *Wright et al.*, 2008].

In order to extend the long history of repeat swath bathymetry surveys, we re-surveyed the Monowai volcano during SO195 (Fig. 54). Fig. 55 compares the results of our survey in the region of the cone to the 2004 and 2007 surveys. The figure shows that in 2004, the cone was characterized by a sector collapse on its south-southeast flank. A small cone had grown in the uppermost part of the collapse. By 2007, the sector collapse had been partially infilled, presumably by lava, and a new sector collapse had formed on the west flank of the cone, downslope of which appears to be a debris flow deposit. A small cone had again formed in the uppermost part of the collapse. In 2011, we observed major changes in the morphology of the cone. There appears to have been a magmatic inflation of the cone summit that resulted in the partial infilling of the sector collapse on the west flank and the deposition of new material, presumably lava, on the south-eastern flank. In addition, two new sector collapses have been identified on the south flank, each of which appears to have generated a debris flow deposit downslope.

The SO215 swath survey of Monowai was carried out in two parts. The first was completed between 10:20 hrs and 20:10 hrs on May 14^{th} while R/V SONNE was en route from recovering the OBS at the northern end of Profile A to deploying OBS at the southern end of Profile C. The second was carried out between 21:50 hrs on June 1^{st} and 07:50 hrs on June 2^{nd} while R/V SONNE was en route from recovering OBS at the northern end of Profile C to the transit across the South Fiji Basin to Townsville. Between the two surveys we learnt from GNS staff on Raoul Island of a burst of explosive activity at Monowai that had been recorded in T-wave data at a seismic station on Rarotonga. The two swath surveys therefore sample the volcano before and after this explosive activity and so potentially provide a unique new data set to study the rates of collapse and growth of an active submarine volcano. Fig. 56 shows the bathymetry of Monowai cone as it appeared on May 14th and June 1st-2nd. The map shows significant differences in seafloor depth between the two shortly spaced surveys. The main differences are growth structures which comprise a partial infilling of a sector collapse, SC3, and the development of at least 4 new cones. Backscatter and Parasound data suggest that the infill material is probably lava and the cones are magmatic constructs. The most prominent cone is ~100 m at its base and up to 40 m high. The total volume of the growth structures is 0.0079 km^3 of which ~37% is infill material and ~63% is cone construct.

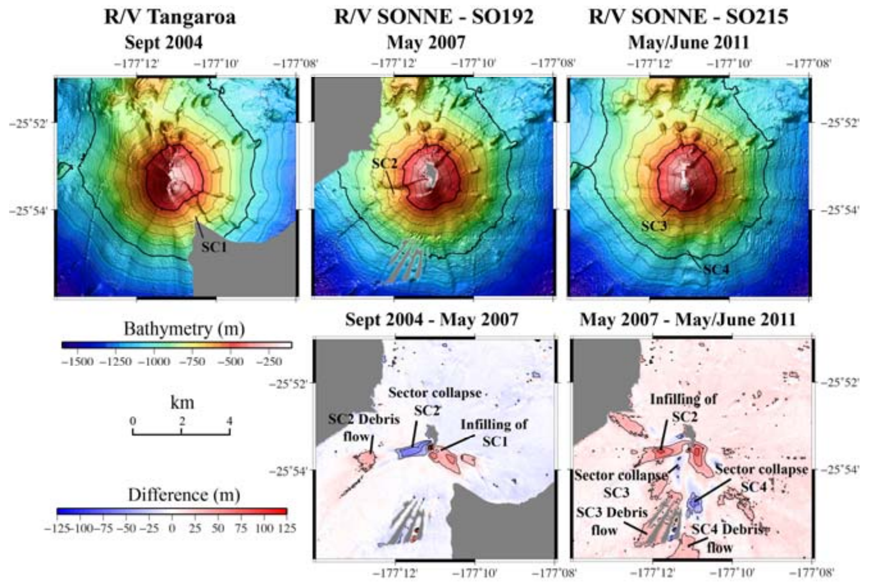


Figure 55: Free-air gravity and magnetic anomaly map of the Monowai volcano. Grey solid lines show SO215 ship tracks. The gravity anomaly map has been contoured at 2.5 mGal interval and shows a broad "high" with superimposed "lows" over the caldera and "highs" over the cone. The magnetic anomaly map has been contoured at 100 nT interval and shows two broad "highs" with a number of superimposed "highs", including one over the cone summit, and "lows" over the caldera.

While we do not know which particular event on the T-wave data was associated with which growth structure, we can attribute the growth structures to the entire 4.6 day long period of explosive activity. The mean growth rate, which is a minimum value, is 0.62 $km^3\ a^{-1}$. These rates are the largest ever recorded at an active submarine volcano, being a factor of ~30-300 higher than those previously reported [*Wright et al.*, 2008; *Chadwick et al.*, 2008] from the 1998, 2004 and 2007 repeat swath surveys at Monowai and a factor of ~1000 higher than implied from repeat swath surveys at Vailulu'u (Samoa) and Kick 'em Jenny (Lesser Antilles).

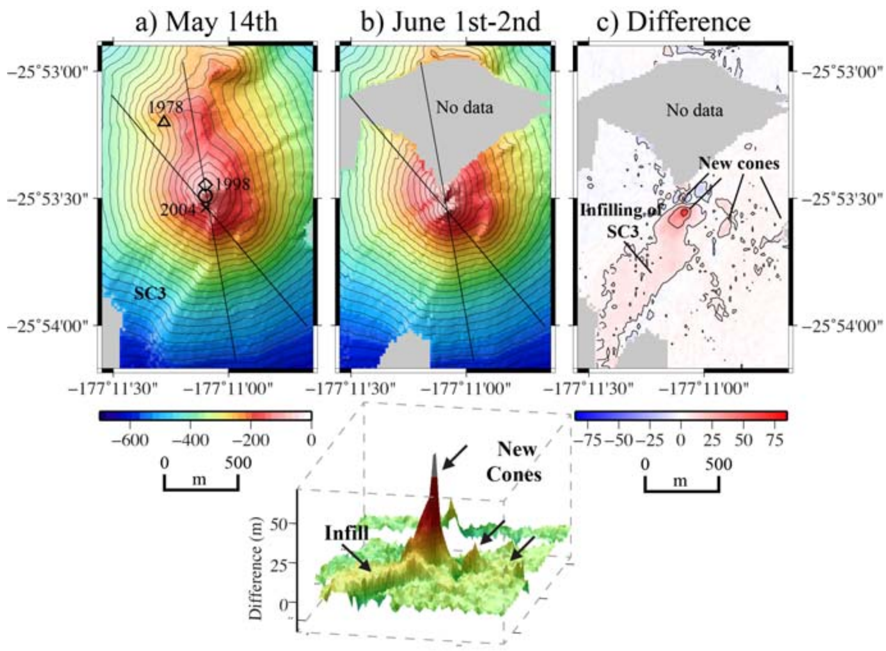


Figure 56: Detailed swath bathymetry maps of the summit of Monowai cone acquired during May 14th and June 1st-2nd on SO215. The unfilled triangle, unfilled diamond and cross show the position of the cone summit in 1978, 1998 and 2004 respectively. The open circle shows the location of discoloured water and gas bubbles observed during SO215 on May 14th.

In addition to swath bathymetry, backscatter and Parasound data, we acquired gravity and magnetic data during the two Monowai surveys. Fig. 57 shows maps of the free-air gravity and magnetic anomaly data that was acquired. The figure shows that the caldera correlates with a free-air gravity and magnetic anomaly "low" of ~10 mGal and ~300 nT respectively. The highest free-air gravity and magnetic anomalies correlate with the cone summit where they reach +134 mGal and +1432 nT respectively.

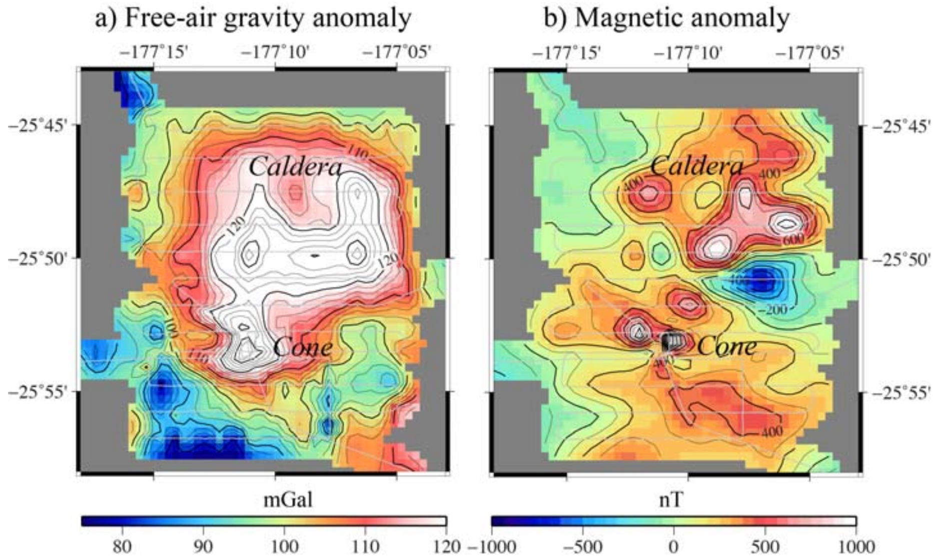


Figure 57: Detailed swath bathymetry maps of the summit of Monowai cone acquired during May 14th and June 1st-2nd on SO215. The unfilled triangle, unfilled diamond and cross show the position of the cone summit in 1978, 1998 and 2004 respectively. The open circle shows the location of discoloured water and gas bubbles observed during SO215 on May 14th.

Figure 58: Discoloured water with gas bubbles and sulphurous smell immediately above the Monowai volcano, observed on the 14th May.

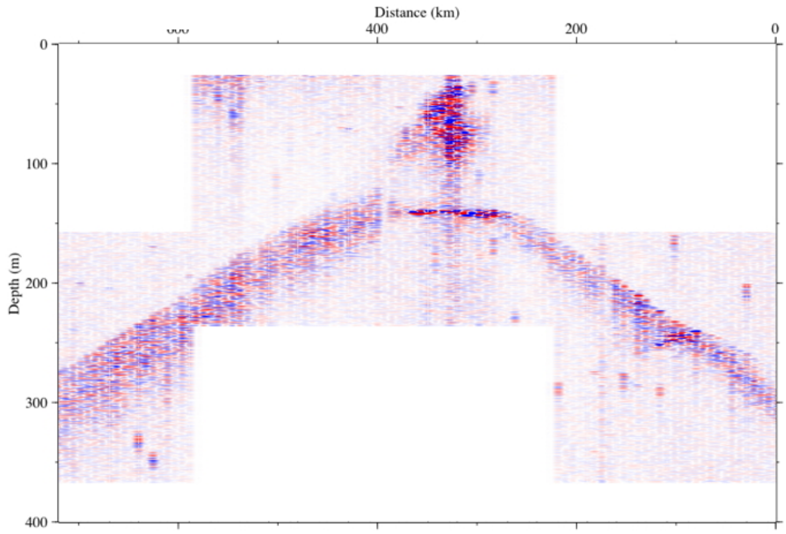


Figure 59: Parasound data from the Monowai volcano showing a plume, most likely warm water and gas bubbles, rising through the water column from the summit.

6. Cruise narrative

The duration of the cruise was 47 days. A summary of the events that took place appears below. All times are in GMT and all way points (WP xxx – where xxx is the way point number) are listed in Table 13 and a cruise track chart shown in Fig. 6.

Julian Day	Local Date	Time (GMT)	Activity
115	Monday 25th April	04:00	Sailed from Auckland - commenced transit to work area. Start of cruise
		04:55	Pilot disembarked
		06:15	Watch-keeping commences
		10:00	Multi-beam surveying commences
		12:16	Arrived at WP NZ1
		14:15	Arrived at WP NZ2
		16:30	Arrived at WP NZ3
		22:15	Muster and boat drill
116	Tuesday 26th April	00:00	In transit
		01:00	Arrived at WP NZ5
		06:45	Arrived at WP NZ6 – surveying seamounts
		12:17	Arrived at WP NZ7
		13:30	Arrived at WP NZ8
		19:00	Crossed international dateline
117	Wednesday 27th April	00:00	In transit
		19:28	Course change to NNE
118	Thursday 28th April	00:00	In transit
		01:00	Arrived at WP T2
		07:45	Reducing speed, arrived at WP SVP1 for SVP, XBT1 and acoustic release tests
		08:00	Commencing deployment of CTD rosette with sound velocity profiler and IFM-Geomar release tubes
		09:11	CTD rosette and sound velocity profiler reached 3000 m
		09:11	Start of IFM-Geomar acoustic tests
		09:32	SVP complete and being recovered, IFM-Geomar acoustic tests complete
		11:25	CTD on surface
		11:49	OBIF acoustic tests - deployment 1 - deployment of transducer rack
		12:41	OBIF acoustic tests - deployment 1 - recovery of transducer rack
		13:18	OBIF acoustic tests - deployment 1 - complete
		13:21	XBT 1 commencing
		13:26	XBT 1 complete
		13:31	OBIF acoustic tests - deployment 2 - deployment of transducer rack
		15:06	OBIF acoustic tests - deployment 2 - complete
		15:12	OBIF acoustic tests - deployment 3 - deployment of transducer rack
		17:00	OBIF acoustic tests - deployment 3 - complete
		17:04	OBIF acoustic tests - deployment 4 - deployment of transducer rack
		18:00	OBIF acoustic tests - deployment 4 - complete
		18:46	OBIF acoustic tests - deployment 5 - deployment of single transducer
		19:00	OBIF acoustic tests - deployment 5 - complete
		20:04	Commencing MCS shake-down tests – tail buoy deployed
119	Friday 29th April	04:05	Streamer being redeployed after extra ballast weight added.
		04:15	Streamer fully deployed - last bird at 5.8 m depth
		04:38	Commencing streamer levelling
		08:00	All 3 km streamer in the water
		08:15	Observing streamer towing behaviour
		10:25	Commencing turn onto Profile D. ETA for end of turn at 15:20 GMT

		18:11	Airguns being deployed at 2 kn - commencing with the port side. Front of streamer wound back onto winch to shorten tow until airguns are fully deployed. MMO commenced
		18:35	Port-side array deployed
		18:45	Commencing deployment of starboard-side array
		19:00	Starboard-side array deployed
		19:13	Soft start commenced - first shot with 260 in^3 firing only - internal triggering
		19:18	Soft start continuing - 2nd 260 in^3 firing
		19:22	Soft start continuing - 1st 380 in^3 firing
		19:25	Soft start continuing - 2nd 380 in^3 firing
		19:30	Soft start complete - full array firing, internal triggering at 60 s
		19:49	Bird 9 appears to have blown airbag and is on surface
		21:45	Testing firing rates vs. pressure and volume of compressors for multichannel optimum fold for MCS-only profiles
		22:15	30 sec 170 bar shooting. Two outer 520 in^3 at rear are switched out
		23:01	First shot on Profile D (# 110), shooting at 30 s interval 170 bar; two outer 520 in^3 guns at rear of array switched out
120	Saturday 30th April	01:00	Magnetometer deployed; shooting Profile D
121	Sunday 1st May	04:58	Acquisition along Profile D complete (3685 last shot)
		05:06	Streamer recovery commences
		05:08	Magnetometer recovery complete
		05:15	Recovery of airgun array commences
		05:35	Starboard sub-array on deck
		05:55	Airgun recovery complete
		06:00	Commencing streamer recovery
		08:22	Streamer recovery complete
		08:45	Transit to WP B1
		13:31	OBS B1 deployed, XBT2
		14:28	OBS B2 deployed
		15:19	OBS B3 deployed
		16:15	OBS B4 deployed
		17:13	OBS B5 deployed
		18:07	OBS B6 deployed
		18:58	OBS B7 deployed
		19:48	OBS B8 deployed
		20:30	OBS B9 deployed
		21:36	OBS B10 deployed, XBT 3
		22:30	OBS B11 deployed
		23:15	OBS B12 deployed
122	Monday 2nd May	00:06	OBS B13 deployed
		02:10	OBS B14 deployed
		02:59	OBS B15 deployed
		04:00	OBS B16 deployed
		04:55	OBS B17 deployed
		05:41	OBS B18 deployed, XBT 4
		06:39	OBS B19 deployed
		07:29	OBS B20 deployed
		08:15	OBS B21 deployed
		09:00	OBS B22 deployed
		09:46	OBS B23 deployed
		10:30	OBS B24 deployed
		11:02	OBS B25 deployed
		11:54	OBS B26 deployed
		12:38	OBS B27 deployed, XBT 5

		13:31	OBS A1 deployed
		14:15	OBS A2 deployed
		15:11	OBS A3 deployed
		16:12	OBS A4 deployed
		17:02	OBS A5 deployed, XBT 6
		17:45	OBS A6 deployed
		18:46	OBS A7 deployed
		19:36	OBS A8 deployed
		20:24	OBS A9 deployed
		21:06	OBS A10 deployed, XBT 7
		22:12	OBS A11 deployed
		22:56	OBS A12 deployed
		23:42	OBS A13 deployed
123	Tuesday 3rd May	00:27	OBS A14 deployed
		01:43	OBS A15 deployed
		02:35	OBS A16 deployed
		03:35	OBS A17 deployed
		06:21	OBS A19 deployed
		07:41	OBS A20 deployed, XBT 8 - failed to log after two attempts
		08:45	OBS A21 deployed
		10:46	OBS A22 deployed
		11:37	OBS A23 deployed
		12:41	OBS A24 deployed
		15:23	OBS A25 deployed
		16:13	OBS A26 deployed
		17:10	OBS A27 deployed
		18:10	OBS A28 deployed
		19:06	OBS A29 deployed
		19:42	OBS A31 deployed
		20:14	OBS A30 deployed; XBT 9
		20:30	Finished deploying OBS – transit to airgun and steamer deployment
		22:49	Commencing streamer deployment – tail buoy deployed
124	Wednesday 4th May	00:15	Four birds deployed
		00:41	Streamer towing too light
		02:00	Commencing a 360° turn at 2° per minute to allow more time for streamer deployment
		02:45	Streamer deployment completed
		03:30	Commencing airgun array deployment - port-side. MMO commencing.
		03:46	Commencing airgun array deployment - starboard-side.
		04:00	Airgun array deployed
		04:08	Commencing soft start
		04:45	Turning to start of Profile A
		05:32	Commencing Profile A – shot number 100; full array, 60 s shot interval, 210 bar
		06:02	Commencing magnetometer deployment
		06:15	Magnetometer deployment complete
125	Thursday 5th May	09:00	Shooting Profile A
126	Friday 6th May	04:00	Arrived at WP AB - end of Profile A; towing full length of streamer past waypoint
		04:32	Last shot on Profile A, (# 2920). Stopped firing to shorten airgun array tow for turn.
		05:10	Commencing turn to Profile B WP BW
		06:48	Turn complete. MMO commencing
		06:58	Airgun tow lengthened
		07:06	Commencing soft start for Profile B

		07:18	Full array firing
		07:32	Commencing Profile B – shot # 100; full array, 60 s interval, 210 bar
		07:57	Crossing Profile A shot # 131
127	Saturday 7th May	00:00	Shooting Profile B
		21:00	Guns switched off for fault diagnosis. Shot # 2354
		21:07	6 missed shots. Restart at shot # 2361
128	Sunday 8th May	00:00	Shooting Profile B
		14:45	Losing air pressure
		16:33	Turbo charger in compressor failed. End of Profile B, last shot # 3527
		17:54	Magnetometer recovered, starting airgun recovery
		19:00	Airguns recovered. Commencing streamer recovery and 180° turn to starboard to course 065°
		21:00	Streamer recovered
129	Monday 9th May	01:30	Arrived at WP B1
		02:52	OBS B1 recovered
		04:30	OBS B2 recovered
		06:45	OBS B3 recovered
		08:45	OBS B4 recovered
		11:00	OBS B5 recovered
		13:04	OBS B6 recovered
		15:51	OBS B7 recovered
		18:57	OBS B8 recovered
130	Tuesday 10th May	01:45	OBS B10 recovered
		04:20	OBS B11 recovered
		05:25	OBS B12 recovered
		07:45	OBS B13 recovered
		09:52	OBS B14 recovered
		11:52	OBS B15 recovered
		15:52	OBS B16 recovered
		16:53	OBS B17 recovered
		18:57	OBS B18 recovered
		21:15	OBS B19 recovered
		22:56	OBS B20 recovered
131	Wednesday 11th May	01:30	OBS B21 recovered
		04:15	OBS B22 recovered
		07:06	OBS B23 recovered
		09:52	OBS B24 recovered
		12:51	OBS B25 recovered
		15:43	OBS B26 recovered
		18:45	OBS B27 recovered
		21:43	OBS A1 recovered
132	Thursday 12th May	00:30	OBS A2 recovered
		03:24	OBS A3 recovered
		07:02	OBS A5 recovered
		08:06	OBS A4 recovered
		11:26	OBS A6 recovered
		13:49	OBS A7 recovered
		16:26	OBS A8 recovered
		17:52	OBS A9 recovered
		19:45	OBS A10 recovered
		21:51	OBS A11 recovered
		22:44	OBS A12 recovered
133	Friday 13th May	00:50	OBS A13 recovered
		01:44	OBS A14 recovered

		04:50	OBS A15 recovered
		07:05	OBS A16 recovered
		10:15	OBS A17 recovered
		11:45	OBS A18 recovered
		12:56	OBS A19 recovered
		15:07	OBS A20 recovered
		15:14	XBT 8 deployed
		17:05	OBS A21 recovered
		18:34	OBS A22 recovered
		19:48	OBS A23 recovered
		21:05	OBS A24 recovered
		22:20	OBS A25 recovered
		23:46	OBS A26 recovered
134	Saturday 14th May	01:07	OBS A27 recovered
		02:52	OBS A28 recovered
		05:20	OBS A29 recovered
		07:19	OBS A31 recovered
		07:44	OBS A30 recovered
		07:53	All OBS recovered. Deploying magnetometer for transit to south end of Profile C
		08:10	Starting transit to Profile C to WP C18, via Monowai
		10:34	Commencing Monowai survey at WP SW1
135	Sunday 15th May	01:18	Completed swath surveying Monowai. Transit to WP C18
		20:43	Arriving at WPC18, slowing to 4 kn to recover magnetometer
		21:06	Heading to OBS C18 to commence OBS deployment
		21:26	OBS C18 deployed
		22:15	OBS C17 deployed
		23:16	OBS C16 deployed, XBT 12
136	Monday 16th May	00:14	OBS C15 deployed
		01:07	OBS C14 deployed
		01:57	OBS C13 deployed
		02:49	OBS C12 deployed
		03:36	OBS C11 deployed
		04:29	OBS C10 deployed
		05:17	OBS C9 deployed
		06:04	OBS C8 deployed
		06:49	OBS C7 deployed, XBT 11
		07:43	OBS C6 deployed
		08:29	OBS C5 deployed
		09:15	OBS C4 deployed
		10:00	OBS C3 deployed
		10:44	OBS C2 deployed
		11:28	OBS C1 deployed, XBT 10
		12:22	OBS C19 deployed
		13:11	OBS C20 deployed
		13:57	OBS C21 deployed
		14:45	OBS C22 deployed
		15:35	OBS C23 deployed, XBT 13
		16:30	OBS C24 deployed
		17:09	OBS C25 deployed
		17:50	OBS C26 deployed
		18:31	OBS C27 deployed
		19:09	OBS C28 deployed
		19:47	OBS C29 deployed
		20:30	OBS C30 deployed

		21:10	OBS C31 deployed, XBT 14
		21:59	OBS C32 deployed
		22:38	OBS C33 deployed
		23:17	OBS C34 deployed
		23:56	OBS C35 deployed
137	Tuesday 17th May	00:38	OBS C36 deployed
		01:19	OBS C37 deployed
		02:01	OBS C38 deployed, XBT 15
		02:49	OBS C39 deployed
		03:40	OBS C40 deployed
		04:19	OBS C41 deployed
		04:55	OBS C42 deployed
		05:31	OBS C43 deployed
		06:08	OBS C44 deployed
		06:44	OBS C45 deployed
		07:18	OBS C46 deployed, XBT 16
		08:01	OBS C47 deployed
		08:39	OBS C48 deployed
		09:17	OBS C49 deployed
		09:55	OBS C50 deployed
		10:34	OBS C51 deployed
		11:12	OBS C52 deployed
		11:52	OBS C53 deployed
		12:34	OBS C54 deployed
		13:23	OBS C55 deployed
		14:17	OBS C58 deployed
		14:50	OBS C56 deployed
		15:34	OBS C59 deployed
		16:02	OBS C57 deployed, XBT 17
		18:00	Transit to 20 nm northwest of the start of Profile C to deploy streamer and airguns
		20:10	Tail buoy deployed
		20:15	Commencing streamer deployment
		23:45	Streamer and airguns deployed. MMO commencing
138	Wednesday 18th May	00:00	Magnetometer deployment complete
		00:46	Soft start complete
		00:58	Commencing Profile C, first shot # 50
		22:25	Losing airgun pressure, 195 bar
		22:28	Failure of valves in compressor turbo charger, stopped shooting, commencing turn to allow time for repair
139	Thursday 19th May	00:45	Compressor turbo charger valves repaired
		00:51	Commencing turn back onto Profile C. MMO commencing
		01:48	Soft start complete
		02:15	Start of recording Profile C pt 2. Shot # 100. Heading towards WP C45 to restart shooting along profile
		04:22	On Profile C. Shot # 216
		05:30	Arrived at WP C45
		05:45	Arrived at break-off point for Profile C pt 1
		18:30	Arrived WP C47
140	Friday 20th May	00:16	Arrived at WP C49
141	Saturday 21st May	01:10	Arrived at WP CB, heading to WP C3
		21:10	Arrived at WP C15
		22:00	Magnetometer system not communicating with tow-fish – recovering for fault finding

142	Sunday 22nd May	02:30	Arrived WP CC - end of Profile C. Continuing past end of line to allow streamer tail buoy to passed end of line WP CC
		02:50	End of Profile C shooting (SP # 4444)
		03:00	Commencing airgun recovery
		03:45	Airguns recovery complete. Commencing streamer recovery
		05:45	Streamer recovery complete
		07:01	Arrival at WP C18 to commence OBS recovery
		09:23	OBS C18 recovered
		11:39	OBS C17 recovered
		14:16	OBS C16 unresponsive – Parasound and swath off
		15:31	Using dunking transducer to try and communicate with OBS C16 – now deemed permanently installed
		18:40	OBS C15 recovered
		20:45	OBS C14 recovered
		21:41	OBS C13 recovered
		22:24	OBS C12 released
		23:17	OBS C12 recovered
143	Monday 23rd May	01:28	OBS C11 recovered
		03:04	Parasound and swath off again for pinging OBS C10
		04:58	OBS C10 deemed permanently installed
		06:58	OBS C9 recovered
		08:14	OBS C8 recovered
		09:33	OBS C7 recovered
		11:32	OBS C6 recovered
		13:25	OBS C5 recovered
		16:01	OBS C4 recovered
		18:22	OBS C3 recovered
		19:37	OBS C2 recovered
		21:09	OBS C1 recovered
		22:42	OBS C19 recovered
144	Tuesday 24th May	00:42	OBS C20 recovered
		03:18	OBS C21 recovered
		05:04	OBS C22 recovered
		07:01	OBS C23 recovered
		10:01	OBS C24 recovered
		12:42	OBS C25 recovered
		14:07	OBS C26 recovered
		15:38	OBS C27 recovered
		17:18	OBS C28 recovered
		18:48	OBS C29 recovered
		18:57	OBS C29 recovered
		20:34	OBS C30 recovered
		22:19	OBS C31 recovered
145	Wednesday 25th May	01:02	OBS C32 recovered
		03:58	OBS C33 recovered
		05:23	OBS C34 recovered
		07:40	OBS C35 recovered
		08:35	OBS C36 recovered
		10:36	OBS C37 recovered
		11:26	OBS C38 recovered
		14:31	OBS C39 has not surfaced, will be left for back-up clock release time
		15:31	OBS C40 recovered
		19:37	OBS C41 recovered
		21:02	Undertaking A-frame repairs while waiting for OBS to surface

146	Thursday 26th May	00:22	OBS C42 not responding, will be left for back-up clock release time
		02:14	OBS C43 recovered
		03:00	OBS C44 recovered
		05:09	OBS C45 recovered
		05:58	OBS C46 recovered
		08:42	OBS C47 recovered
		11:23	OBS C48 recovered
		12:55	OBS C49 recovered
		15:26	OBS C50 recovered
		18:02	OBS C51 recovered
		19:32	OBS C52 recovered
		20:34	Muster and boat drill
		21:19	OBS C53 recovered
		22:51	OBS C54 recovered
147	Friday 27th May	00:31	OBS C55 recovered
		01:36	OBS C58 recovered
		02:41	OBS C56 recovered
		03:38	OBS C59 recovered. OBS recovery complete
		04:51	Magnetometer deployed for transit to Profile G
		13:12	Magnetometer recovery complete
		13:21	OBS G1 deployed
		14:29	OBS G2 deployed
		15:42	OBS G3 deployed
		16:55	OBS G4 deployed
		18:01	OBS G5 deployed
		19:06	OBS G6 deployed
		20:11	OBS G7 deployed
		21:15	OBS G8 deployed
		21:51	OBS G9 deployed
148	Saturday 28th May	00:02	Transit to run-in for Profile G at WPGA Run-in
		01:01	Commencing streamer deployment; tail buoy deployed
		03:21	Streamer not sinking; requires ballast adjustment
		04:16	Starting turn complete reballast of streamer prior to arrival at WP GA
		05:34	Streamer deployment complete
		07:10	Commencing airgun deployment - port-side
		07:21	Airgun array port-side deployment complete. Commencing starboard-side
		07:36	Airgun array deployment complete. MMO commencing
		07:44	Commencing soft start and magnetometer deployment
		08:18	Soft start complete
		22:15	Arrived at WP G4
149	Sunday 29th May	00:30	Arrived at WP G3
		04:40	Arrived at WP G1
		09:00	Profile G complete. Last shot # 1578
		09:10	Magnetometer recovery complete. Airgun recovery commencing
		09:32	Starboard-side airgun recovery complete
		09:45	Port-side airgun recovery complete. Streamer recovery commencing
		18:22	OBS G1 recovered
		20:42	OBS G2 recovered
		23:15	OBS G3 recovered
150	Monday 30th May	01:31	OBS G4 recovered
		04:21	OBS G5 recovered
		07:03	OBS G6 recovered
		10:01	OBS G7 recovered
		12:55	OBS G8 recovered

		14:41	OBS G9 recovered
		14:54	Commencing magnetometer deployment for swath in-fill survey
		15:05	Magnetometer deployment complete
		18:00	Arrived at WP SH1
		19:15	Arrived at WP SH2
		20:04	Arrived at WP SH3
		21:02	Arrived at WP SH4
151	Tuesday 31st May	00:36	Arrived at WP SH5
		00:40	Arrived at WP SH6
		02:31	Arrived at WP SH7, heading to WP SH10
		21:11	Arrived at WP SH10, heading to WP SH12
152	Wednesday 1st June	01:25	Arrived at WP SH12, heading to WP C39
		07:25	Magnetometer recovery commencing
		07:50	Waiting at WP C39 for OBS to surface
		09:45	OBS C39 deemed permanently installed
		11:33	Waiting at WP C42 for OBS to surface
		13:04	OBS C42 deemed permanently installed
		13:15	Commencing deployment of magnetometer for passage to Monowai survey pt 2
		13:25	Magnetometer deployment complete
		22:17	Commencing Monowai survey pt 2 – WP TF18
153	Thursday 2nd June	00:53	Arrival at WP TF30, XBT20, water sample 1
		01:18	Arrival at WP TF31, XBT21, water sample 2
		01:45	Arrival at WP TF32, XBT22, water sample 3 - Monowai summit
		07:27	Arrival at WP TF34. Commencing transit to Townsville
		08:05	Minimal watch - transit commencing - gravity, magnetics and EM120 only
		21:17	Crossed 180° longitude - Eastern Hemisphere
154	Friday 3rd June	All day	Transit to Townsville
		17:00	Passed WP T4
155	Saturday 4th June	All day	Transit to Townsville
156	Sunday 5th June	All day	Transit to Townsville
157	Monday 6th June	All day	Transit to Townsville
158	Tuesday 7th June	All day	Transit to Townsville
159	Wednesday 8th June	All day	Transit to Townsville. Crossed Australian 200 nm limit. MMO during daylight hours
160	Thursday 9th June	All day	Transit to Townsville. MMO during daylight hours
161	Friday 10th June	All day	Transit to Townsville. MMO during daylight hours
162	Saturday 11th June	22:00	Arrived berth 10 - Townsville, Australia. End of Cruise

7. Equipment performance

This cruise went entirely according to plan, with all of the equipment functioning to specification except for that rendered inoperable in Auckland prior to departure due to factors beyond anyone's control. Only issues affecting the data acquisition or data quality and processing are noted below. Everything else functioned according to specification for the entire cruise.

7.1 Seismic equipment

The main equipment casualty pre-departure from Auckland was the control system within the NMFSS Hamworthy compressor container. This proved irreparable at sea and rendered these compressors completely inoperable. The NMFSS compressor container was requested and supplied not only to provide a back-up to the ship's compressors, since this was an entirely seismic cruise, but also, given uncertainties in the air volume vs. pressure vs. recharge rate capabilities of the ship's onboard systems, with respect to the specified airgun array volume and required firing rate and pressure as specified in the cruise agreement and reiterated at cruise planning, would most likely be required to supplement the ship's onboard systems.

Given the uncertainties, and prior to the cruise planning process commencing with NMFSS, a period of trials had been built into the start of the cruise to shake-down the full MCS system, and to trial in particular:

a) the capabilities of the onboard seismic compressors – volume vs. pressure vs. firing rate – uncertain throughout cruise planning despite the best efforts of all concerned;
b) the capability of the new NMFSS seismic winch to tow, deploy and retrieve a 3000m active length of multichannel streamer – untested prior to this; and
c) streamer balancing and tow control – using the newly purchased birds and tail buoy – also untested prior to this cruise.

These tests demonstrated:

a) the ship's onboard compressors and turbo charger could not provide the full array volume at the required pressure at the fastest of the two firing rates required (20 s). A 30 s firing rate, with two of the 520 in^3 guns switched out, could be achieved.
b) the NMFSS seismic winch, apart from its cheek plates which need significant adjustment, does meet the requirements of 3000 m operational capability, although there is no back-up motor and the control panel is not weatherproof. Water ingress into this panel occurs very readily and will similarly render this system inoperable. Operation during the cruise, in the restricted deck area of the Sonne's stern and with blocked lines of direct sight, also demonstrated that the winch needs an operator-mounted remote control system not only to ensure a safe working environment for personnel, but also to prevent streamer damage during spooling.
c) the streamer proved light when towed and required additional ballast which, given the lack of sufficient bespoke streamer ballast weights supplied, was scavenged from throughout the vessel in the form of lengths of chain and chunks of metal, which had to be taped and/or tie-wrapped to individual streamer sections. Once ballasted appropriately, the birds proved capable of achieving a level and controllable streamer tow, and the tail buoy proved capable of producing the necessary sternward drag.

There were only two periods of downtime:

1) 10 km from the end of Profile B, a number of high-pressure air pipes and hoses failed to the extent that surveying had to be terminated. We deemed this normal wear and tear and since the profile was effectively shot to completion at this point, the profile was terminated and the airgun array recovered and the fault repaired. 10 km at MCS/OBS surveying speed is equivalent to ~1 hour of downtime.
2) within a matter of hours of commencing shooting along Profile C, valves in the second stage turbo charger for the ship's compressors failed. A standard practise loop-back turn was undertaken, taking a minimum of 3 hours to complete (circular) at the safe turning rate for a 3000 m streamer. Impressively, the ship's engineers stripped the valves, replaced them and tested the system in less than 2 hours.

Given the 47 day duration of the cruise, 4 hours of downtime (<0.5% of the entire cruise) are considered to be within the operational noise and, thus, that this was a cruise with no downtime for any reason.

7.2 Onboard data quality control and processing

A small network of laptops and desktop computers were provided by the science party to undertake data harvesting from ship's systems and supplied instrumentations, automate replication and back-up to multiple media types and to "push", on a read-only basis, data out to the computers being used for data QC and at-sea processing. Navigation data was extracted from the ship's Werum system on a daily basis and data harvested from non-networked systems (e.g. the gravimeter and magnetometer), both by specified members of the science party, and checked and logged prior to storage on the science "raw" data network storage system (NAS). An automated pick-up was made from the ship's "Wiss" (science storage area, including swath bathymetry, Parasound etc), also on a daily basis, to the "raw" NAS. MCS data was "pushed" out by the SEAL acquisition system on an "after write" basis and stored on the science "raw" NAS in effectively real-time. OBS data were supplied as soon as it had been quality-controlled and passed as final data product. Installations of Seismic Unix, Claritas, ProMAX and GMT were all used for on-going data QC and processing. Despite a few minor pieces of equipment failure, most likely due to temperature and vibration, no major downtime or permanent equipment failure preventing any QC or data processing activity occurred throughout the cruise.

Four sets of data were created prior to arriving in Townsville: 1) the drives from the "raw" NAS were hand carried back to the UK by a member of the science party, with the drive framework shipped in the UK-bound air freight. It was reassembled on arrival, tested and stored in a fire safe; 2) the contents of the "raw" NAS were copied to individual external hard drives and hand-carried back to the UK by the Chief Scientist; 3) two duplicates of the "raw" NAS were shipped home via sea freight together with all of the other science party's and OBIF's equipment; and 4) a complete set of the non-seismic data was copied to two laptops and the seismic data copied to the OBIF raw data store and returned to the UK with members of the science and technical teams. On return to the UK, the "raw" NAS was further duplicated to another network- and RAID-configured NAS device, prior to arrival of the sea freight, for day-to-day use, and a full data inventory created and checked against at-sea records.

7.3 Ocean-bottom seismographs

A total of 126 OBS deployments were made during the cruise of which all recorded usable data except for two OBIF instruments (C10 & C16) and two IFM-Geomar instruments (C39 & C42) which were "permanently installed" along Profile C, and OBIF OBSs B9 and G9 which both suffered water ingress into their pressure tubes destroying the datalogger prior to shooting commencing so that no data were stored (and hence recoverable on instrument recovery) on their SCSI or compact flash storage media. These were the only major OBS equipment failures during the entire cruise, apart from the loss of the odd single channel due to sensor failure (e.g. horizontal geophones on OBS A2, A3, A23, B7 and C23).

7.4 Gravity

The gravimeter functioned to specification from the moment it was installed and base station calibrated in Auckland to the moment it was base station calibrated and then disassembled in Townsville. Despite being supplied with a GPS navigation and time stamp, data were acquired relative to the gravimeter system clock which was, approximately, 7 mins and 33 s ahead of GPS. The gravity data were corrected to GPS as part of QC processing prior to storage in GMT track file format. A Lacoste and Romberg Alliod land gravimeter was used for base station ties, of which details can be found in Tables 8 and 9.

7.5 Magnetics

Figure 60: SeaSPY magnetometer tow fish after shark attack. Note gouges and lost fins.

Two SeaSPY magnetometers and tow cables were provided for the cruise. Only two periods of data loss occurred. The first was at 22:00 on day 134 when approximately 1 hour of data loss occurred due to the accidental shutting down of the acquisition window on the system PC. The second period of data loss occurred at 22:00 on day 141, approximately 4 hours from the end of shooting along Profile C. On this occasion communication was lost with the tow fish due to tow cable failure, which was subsequently replaced. The magnetometer worked perfectly from then on, until it was recovered for the last time on arrival at the Australian EEZ. At this point it was found to have been attacked by sharks, losing all its fins and having teeth embedded in deep gouges in the body of the main tube (Fig. 60).

7.6 Ship's machinery and fitted equipment

No failure of ship's machinery or fitted equipment, apart from the second stage turbo charger for the ship's fitted compressors described above, occurred during the cruise.

7.7 Swath bathymetry

The EM120 swath bathymetry system functioned to specification from departure from Auckland to arrival in Townsville. The only issue experienced with this system was related to the survey area being near and sometimes traversing the 180° line of longitude, which caused the automatic annotation of lines of latitude and longitude to fail on the in-lab slave systems. Only a system reboot solved this. As this took only 2 minutes it was subsequently done on a daily basis as part of house-keeping, which in turn allowed extraction of data files for processing to grid format on a daily basis as well.

7.8 Sub-bottom profiling – Parasound

The Atlas P70 Parasound functioned well for the duration of its use, except for one period towards the end when the system file store became overfull. Once cleared out to the "Wiss" storage area and reset, no further problems occurred.

7.9 Expendable bathymetric thermographs and sound velocity profiler

Only one sound velocity profile was acquired during the cruise and the system functioned according to specification. Although 24 XBT probes were provided, two were deployed at XBT 8 (deployment of OBS A20) without data being recorded. A reset of the acquisition system PC, followed by a restart of the control software and USB interface to the probe gun, restored the XBT system to full functionality and no further problems were experienced. XBT 8 was subsequently acquired at the time of recovery of OBS A20.

7.10 Navigation and underway track plotting

No loss in navigation or other ships fitted sensors were experienced and, similarly no loss of underway track chart plotting, in any lab, occurred throughout the entire cruise.

8. Weather

From the time of leaving Auckland to final departure from the work area the weather consistently blew force 4-6, gusting 7-8, throughout with a significant rolling swell and rain. Fortunately, though, the calmer periods tended to match periods of OBS deployment and recovery, and wind directions were such that, for most of the MCS acquisition itself, the wind direction was mostly on the bow or astern. As such, no downtime occurred due to the weather, although instrument preparations on deck, on occasions, had to be suspended due to taking water onto the deck. On leaving the work area, the weather improved significantly, the sun came out and the seas calmed facilitating a speedy transit to port.

9 Demobilisation

The end of cruise port call in Townsville was also scheduled on a bank holiday weekend. The R/V Sonne was first assigned to No. 10 berth where vessel clearance and Customs processes were completed. The ship then moved to No. 3 berth when it became free where ship's stores, the open-top NMFSS containers shipped from Auckland and a large crane were waiting. The ship's appointed agent proved largely ineffectual and all parties had significant difficulty obtaining empty rental containers for UK and Germany-bound shipping. A significant degree of winging it and mutual cooperation between NMFSS, OBIF and the science party eventually resolved the container problem although, with a significant associated delay in return to the UK.

During the last few days of the transit to Townsville, and assisted by the calm seas, the multichannel seismic winch was cut free from its deck plate ready for a quick lift off the vessel into its open-top container on arrival in port and once the cheek plates and spooling system had been removed, and nine streamer sections had been unwound. A spooling winch was provided by the port service provider for this purpose. Unfortunately, one of the wooden streamer drums collapsed on winding and its sections had to be left on the streamer winch which made it a tight fit into its shipping container.

Due to the delay in acquiring empty containers and due to the change of berthing, demobilisation took two days to complete, instead of the scheduled one day.

10. Achievements

The marine geophysical data acquired during SO215 is of high quality. The highlights of this acquisition are as follows:

- firing 16,006 seismic shots, requiring 85 million in^3 or 1.4 million litres of compressed air;
- completing 126 OBS deployments resulting in 2,710,652 recorded traces and 480 records sections;
- obtaining 2140 km of MCS reflection profile data comprising 3,857,446 individual data traces;
- acquiring 10,750 km of swath bathymetry and gravity data; and
- swath bathymetry, sub-seabed, gravity, magnetic and XBT surveying an actively evolving volcanic centre.

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Tables

Table 1 – Scientific and technical personnel

The RV Sonne carried a crew of 28 and a scientific and technical party of 20 for cruise SO215 as listed below:

Scientific and Technical	
Principal Scientist	Professor Christine Peirce
Co- Principal Scientist	Professor Anthony Watts
Scientist – PDRA - OBS	Dr Wanda Stratford
Scientist – PDRA - MCS	Dr Michele Paulatto
Scientist – IT Data Management	Mr David Stevenson
Scientist – PhD student - watchkeeper	Miss Lara Kalnins
Scientist – PhD student - watchkeeper	Mr Daniel Bassett
Scientist – PhD student - watchkeeper	Mr John Hunter
OBS Support – OBIF	Dr Alejandro Gonzalez-Nakzawa
OBS Support – OBIF	Mr Alan Burchell
OBS Support – IFM	Dr Markus Fink
OBS Support – IFM	Dr Ivonne Arroyo-Eden
Techical Liaison Officer – NMFSS	Mr Darren Young
Technical Support (MCS) – NMFSS	Mr Adam Cox
Technical Support (MCS) – NMFSS	Mr Ben Poole
Technical Support (gravity & magnetics) – NMFSS	Mr Yair Yaniv
Technical Support (MCS) – Exploration Electronic Ltd	Mr Lee Sheldon
Technical Support (seismic source) – IFM Geomar	Mr Klaus-Peter Steffan
Technical Support (seismic source) – IFM Geomar	Mr Thorge Wiskandt
Technical Support (MCS) – CSIC	Mr Marco Ferrer

Ship's Crew

Master	Captain Lutz Mellon
Chief Officer	Mr Detief Korte
2nd Officer	Mr Nils Aden
3rd Officer	Mr Jens Göbel
Chief Engineer	Mr Andreas Rex
2nd Engineer	Mr Dieter Hermesmeyer
2nd Engineer	Mr Sascha Thomsen
Chief Electrician	Mr Lars Maak
2nd Electrician	Mr Jörg Lappin
Motorman	Mr Dirk Dehne
Motorman	Mr Ryszard Krawczak
Engineering Assistant	Mr Rainer Rosemeyer
Trainee	Mr Manuel Grawe
Trainee	Mr Christian Kallenbach
Systems Manager	Mr Rudi Angermann
Systems Manager	Mr Matthias Grossman
Doctor	Dr Wilhelm Schlenker
Boson	Mr Andreas Schrapel
Seaman	Mr Jürgen Kraft
Seaman	Mr Joachim Doilef
Seaman	Mr Günther Stängl
Seaman	Mr Christopher Schröder
Seaman	Mr Reno Roß
Seaman	Mr Ingo Fricke
Chef	Mr Wilhelm Wieden
Assistant Chef	Mr Anthony Ganagaraj
Chief Steward	Mr Harald Schmandtke
Steward	Mr Luis Royo

Table 2 – OBS deployment locations –- Line A

	Deploy Lat Deg (S)	Min	Long Deg (W)	Min	Depth (m)	Logger Number	Instrument Type	Deploy Time	Deploy Jul Day	Recover Time	Recover Jul Day	Recover Lat Deg (S)	Min	Recover Long Deg (W)	Min
A1	26	8.694	173	50.22	5100	0004	LC2000	13:31	122	21:43	131	26	8.935	173	50.567
A2	26	6.770	173	57.44	5078	0043	LC4x4	14:15	122	00:30	132	26	7.045	173	57.732
A3	26	4.877	174	4.71	5060	0018	LC2000	15:11	122	03:24	132	26	5.110	174	5.122
A4	26	2.925	174	11.95	4994	0005	LC2000	16:12	122	08:08	132	26	3.176	174	12.209
A5	26	1.075	174	19.01	4876	0010	LC2000	17:02	122	07:02	132	26	1.214	174	19.239
A6	25	59.175	174	26.15	4592	0007	LC2000	17:57	122	11:14	132	25	59.215	174	26.349
A7	25	57.275	174	33.34	4482	0022	LC2000	18:46	122	13:49	132	25	57.265	174	33.498
A8	25	55.276	174	40.43	4081	0054	LC4x4	19:36	122	16:26	132	25	55.180	174	40.495
A9	25	53.410	174	47.71	3710	0017	LC2000	20:24	122	17:51	132	25	53.278	174	47.672
A10	25	51.423	174	54.81	2194	0020	LC2000	21:06	122	19:45	132	25	51.328	174	54.739
A11	25	49.507	175	1.98	4405	0808	Geomar	22:12	122	21:51	132	25	49.420	175	1.777
A12	25	47.544	175	9.19	5848	0807	Geomar	22:56	122	22:44	132	25	47.568	175	8.986
A13	25	45.562	175	16.45	5614	0809	Geomar	23:42	122	00:50	133	25	45.389	175	16.115
A14	25	43.624	175	23.48	5311	0812	Geomar	00:27	123	01:44	133	25	43.560	175	23.206
A15	25	41.673	175	30.66	4872	0052	LC4x4	01:23	123	04:33	133	25	41.669	175	30.351
A16	25	39.679	175	37.80	4246	0014	LC2000	02:35	123	07:22	133	25	39.734	175	37.242
A17	25	37.724	175	44.95	4302	0053	LC4x4	03:35	123	09:54	133	25	37.812	175	44.755
A18	25	35.755	175	52.05	3838	0002	LC2000	04:27	123	11:32	133	25	36.001	175	51.825
A19	25	33.725	175	59.21	3100	0055	LC4x4	06:21	123	12:56	133	25	34.114	175	58.927
A20	25	31.752	176	6.36	2776	0051	LC4x4	07:41	123	15:08	133	25	32.140	176	5.975
A21	25	29.782	176	13.46	1370	0056	LC4x4	08:45	123	17:05	133	25	30.077	176	12.801
A22	25	27.783	176	20.59	1213	0016	LC2000	10:46	123	18:35	133	25	28.015	176	20.167
A23	25	25.776	176	27.67	664	0011	LC2000	11:37	123	19:49	133	25	25.979	176	27.154
A24	25	23.713	176	34.82	718	0006	LC2000	12:41	123	21:05	133	25	23.932	176	34.325
A25	25	21.705	176	42.03	712	0027	LC2000	15:23	123	22:20	133	25	21.988	176	41.607
A26	25	19.640	176	49.01	737	0019	LC2000	16:13	123	23:46	133	25	20.091	176	48.588
A27	25	17.632	176	56.16	780	0012	LC2000	17:10	123	01:07	134	25	0.810	176	55.821
A28	25	15.594	177	3.25	1235	0009	LC2000	18:10	123	02:52	134	25	16.116	177	2.809
A29	25	13.529	177	10.35	1518	0050	LC4x4	19:06	123	05:04	134	25	14.128	177	9.881
A31	25	12.503	177	13.91	1341	0059	LC4x4x4	19:42	123	07:19	134	25	13.608	177	13.569
A30	25	11.495	177	17.48	1266	0013	LC2000	20:14	123	07:44	134	25	11.930	177	17.086

Table 3 – OBS deployment locations – Line B

	Deploy Lat Deg (S)	Min	Long Deg (W)	Min	Depth (m)	Logger Number	Instrument Type	Deploy Time	Deploy Jul Day	Recover Time	Recover Jul Day	Recover Lat Deg (S)	Min	Recover Long Deg (W)	Min
B27	26	15.890	173	49.80	5098	0021	LC2000	12:38	122	18:45	131	26	16.207	173	49.974
B26	26	18.461	173	56.65	5073	0041	LC4x4	11:54	122	15:43	131	26	18.674	173	56.824
B25	26	21.057	174	3.60	5029	0040	LC4x4	11:12	122	12:51	131	26	21.314	174	3.820
B24	26	23.591	174	10.52	4904	0042	LC4x4	10:30	122	09:52	131	26	23.770	174	10.757
B23	26	26.192	174	17.48	4723	0047	LC4x4	09:46	122	07:06	131	26	26.340	174	17.634
B22	26	28.806	174	24.48	4304	0048	LC4x4	09:00	122	04:15	131	26	28.937	174	24.680
B21	26	31.380	174	31.46	3835	0049	LC4x4	08:16	122	01:30	131	26	31.389	174	31.762
B20	26	33.921	174	38.41	1522	0058	LC4x4	07:30	122	22:56	130	26	33.814	174	38.661
B19	26	36.442	174	45.30	3304	0060	LC4x4	06:39	122	21:15	130	26	36.456	174	45.557
B18	26	39.018	174	52.30	4451	0811	Geomar	05:41	122	18:57	130	26	38.987	174	52.584
B17	26	41.432	174	58.90	5408	0806	Geomar	04:54	122	16:53	130	26	41.599	174	59.649
B16	26	44.130	175	6.23	5818	0810	Geomar	04:00	122	15:52	130	26	44.124	175	6.544
B15	26	46.634	175	13.20	6235	0805	Geomar	03:02	122	13:06	130	26	46.567	175	13.946
B14	26	49.184	175	20.21	7350	0804	Geomar	02:10	122	12:00	130	26	49.193	175	20.662
B13	26	56.738	175	41.22	7069	0806	Geomar	00:06	122	07:57	130	26	56.698	175	41.375
B12	26	59.261	175	48.31	6056	0801	Geomar	23:20	121	05:22	130	26	59.081	175	48.542
B11	27	1.772	175	55.34	5509	0802	Geomar	22:34	121	04:19	130	27	1.711	175	55.325
B10	27	4.269	176	2.36	4337	0045	LC4x4	21:28	121	01:39	130	27	4.516	176	2.430
B9	27	6.769	176	9.34	4215	0015	LC2000	19:48	121	22:29	129	27	7.409	176	9.852
B8	27	9.240	176	16.34	3932	0062	LC4x4	20:39	121	18:57	129	27	10.158	176	16.824
B7	27	11.713	176	23.29	3932	0023	LC2000	18:58	121	15:51	129	27	12.348	176	23.754
B6	27	14.218	176	30.39	3223	0057	LC4x4	18:07	121	13:03	129	27	14.782	176	30.927
B5	27	16.678	176	37.37	2438	0024	LC2000	17:13	121	10:42	129	27	17.243	176	37.886
B4	27	19.163	176	44.42	2056	0044	LC4x4	16:16	121	08:23	129	27	19.516	176	44.795
B3	27	21.604	176	51.47	1930	0028	LC2000	15:19	121	06:26	129	27	21.990	176	51.480
B2	27	24.049	176	58.50	1840	0046	LC4x4	14:28	121	04:24	129	27	24.298	176	58.613
B1	27	26.515	177	5.60	2120	0001	LC2000	13:31	121	02:28	129	27	26.828	177	5.779

Table 4 – OBS deployment locations – Line C

	Deploy Lat Deg (S)	Min	Long Deg (W)	Min	Depth (m)	Logger Number	Instrument Type	Deploy Time	Deploy Jul Day	Recover Time	Recover Jul Day	Recover Lat Deg (S)	Min	Recover Long Deg (W)	Min
C1	27	36.171	174	10.09	1124	0007	LC2000	11:29	136	21:09	143	27	36.869	174	9.910
C2	27	42.105	174	5.59	2173	0010	LC2000	10:46	136	19:37	143	27	42.150	174	5.403
C3	27	47.528	174	1.03	3487	0005	LC2000	10:00	136	18:21	143	27	47.810	174	0.865
C4	27	52.936	173	56.56	3804	0022	LC2000	09:15	136	16:00	143	27	53.190	173	56.434
C5	27	58.288	173	51.99	1986	0054	LC4x4	08:29	136	13:25	143	27	58.500	173	51.972
C6	28	3.694	173	47.42	3453	0017	LC2000	07:44	136	11:32	143	28	3.814	173	47.369
C7	28	9.075	173	42.86	3297	0020	LC2000	06:50	136	09:32	143	28	9.309	173	42.856
C8	28	14.492	173	38.37	3010	0014	LC2000	06:04	136	08:14	143	28	14.705	173	38.262
C9	28	19.926	173	33.82	4563	0052	LC4x4	05:17	136	06:58	143	28	20.159	173	33.706
C10	28	25.247	173	29.13	4195	0009	LC2000	04:29	136	Permanently Installed					
C11	28	30.639	173	24.59	3078	0012	LC2000	03:36	136	01:28	143	28	30.829	173	24.420
C12	28	35.981	173	20.06	1734	0050	LC4x4	02:49	136	23:17	142	28	36.137	173	19.163
C13	28	41.357	173	15.44	2839	0027	LC2000	01:57	136	21:41	142	28	41.430	173	15.421
C14	28	46.747	173	10.85	4303	0051	LC4x4	01:07	136	20:25	142	28	46.771	173	10.707
C15	28	52.100	173	6.25	5148	0019	LC2000	00:14	136	18:39	142	28	51.999	173	5.996
C16	28	57.493	173	1.61	5512	0056	LC4x4	23:16	135	Permanently Installed					
C17	29	2.854	172	57.05	5612	0016	LC2000	22:23	135	11:39	142	29	3.113	172	57.133
C18	29	8.169	172	52.43	5626	0013	LC2000	21:26	135	09:23	142	29	8.405	172	52.696
C19	27	30.957	174	13.88	1652	0055	LC4x4	12:22	136	22:52	143	27	31.075	174	13.815
C20	27	24.773	174	16.90	3779	0053	LC4x4	13:11	136	00:42	144	27	24.861	174	16.850
C21	27	18.592	174	19.87	3788	0018	LC2000	13:58	136	03:20	144	27	18.714	174	19.586
C22	27	12.439	174	22.85	4647	0002	LC2000	14:45	136	05:04	144	27	14.428	174	22.717
C23	27	6.255	174	25.93	5081	0043	LC4x4	15:35	136	07:01	144	27	6.289	174	25.898
C24	27	0.070	174	28.93	5154	0004	LC2000	16:30	136	10:02	144	27	0.257	174	28.896
C25	26	53.908	174	31.87	4273	0021	LC2000	17:10	136	12:41	144	26	53.814	174	31.809
C26	26	47.717	174	34.88	2547	0040	LC4x4	17:51	136	14:06	144	26	47.784	174	34.879
C27	26	41.560	174	37.88	1619	0041	LC4x4	18:31	136	15:38	144	26	41.575	174	37.924
C28	26	35.348	174	40.89	1823	0042	LC4x4	19:09	136	17:18	144	26	35.423	174	40.990
C29	26	29.186	174	43.81	1901	0048	LC4x4	19:48	136	18:57	144	26	29.201	174	43.872
C30	26	22.988	174	46.85	2000	0008	LC2000	20:40	136	20:35	144	26	23.024	174	46.908
C31	26	16.774	174	49.89	4021	0047	LC4x4	21:15	136	22:19	144	26	16.831	174	49.950

C32	26	10.025	174	52.76	4437	0006	LC2000	21:59	136	00:59	145	26	10.563	174	52.905
C33	26	4.374	174	55.70	3050	0023	LC2000	22:38	136	03:32	145	26	4.260	174	55.743
C34	25	58.205	174	58.63	2084	0060	LC4x4	23:17	136	05:23	145	25	58.098	174	58.677
C35	25	52.040	175	1.61	3629	0802	Geomar	23:56	136	07:38	145	25	51.884	175	1.759
C36	25	45.896	175	4.56	5046	0800	Geomar	00:37	137	08:35	145	25	45.699	175	4.826
C37	25	39.664	175	7.48	6049	0812	Geomar	01:19	137	10:50	145	25	39.911	175	7.842
C38	25	33.502	175	10.43	6517	0800	Geomar	02:00	137	10:43	145	25	33.253	175	10.567
C39	25	27.303	175	13.33	6962	0809	Geomar	02:49	137	Permanently Installed					
C40	25	21.044	175	16.24	6109	0806	Geomar	03:46	137	15:31	145	25	19.503	175	16.476
C41	25	14.801	175	19.20	5364	0810	Geomar	04:19	137	19:37	145	25	14.054	175	19.216
C42	25	8.630	175	22.08	4785	0805	Geomar	04:55	137	Permanently Installed					
C43	25	2.443	175	25.04	4540	0804	Geomar	05:31	137	02:11	146	25	1.530	175	25.150
C44	24	56.277	175	27.97	5124	0801	Geomar	06:08	137	03:00	146	24	55.355	175	28.330
C45	24	50.102	175	30.86	5054	0808	Geomar	06:44	137	05:08	146	24	49.403	175	31.160
C46	24	43.860	175	33.65	5110	0811	Geomar	07:19	137	05:58	146	24	43.006	175	33.893
C47	24	37.651	175	36.65	4442	0052	LC4x4	08:01	137	08:40	146	24	37.101	175	36.878
C48	24	31.418	175	39.55	4238	0049	LC4x4	08:39	137	11:06	146	24	31.070	175	39.735
C49	24	25.229	175	42.43	4612	0057	LC4x4	09:17	137	12:55	146	24	24.927	175	42.574
C50	24	18.996	175	45.32	4049	0062	LC4x4	09:57	137	15:26	146	24	18.741	175	45.462
C51	24	12.800	175	48.18	3974	0046	LC4x4	10:34	137	18:02	146	24	12.724	175	48.217
C52	24	6.597	175	51.05	2717	0001	LC2000	11:13	137	19:32	146	24	6.444	175	51.130
C53	24	0.378	175	53.88	2153	0024	LC2000	11:52	137	21:14	146	24	0.237	175	53.893
C54	23	54.184	175	56.76	1938	0044	LC4x4	12:34	137	22:50	146	23	54.154	175	56.859
C55	23	47.982	175	59.63	1292	0028	LC2000	13:23	137	00:10	147	23	47.954	175	59.900
C58	23	44.858	176	1.08	991	0061	LC4x4	14:17	137	01:55	147	23	44.913	176	1.349
C56	23	41.770	176	2.45	874	0045	LC4x4	14:50	137	02:40	147	23	41.852	176	2.725
C59	23	38.645	176	3.95	708	0059	LC4x4	15:34	137	03:36	147	23	38.709	176	4.123
C57	23	35.561	176	5.34	637	0011	LC2000	16:02	137	04:34	147	23	35.663	176	5.506

Table 5 – OBS deployment locations - Line G

	Deploy Lat Deg (S)	Min	Long Deg (W)	Min	Depth (m)	Logger Number	Instrument Type	Deploy Time	Deploy Jul Day	Recover Time	Recover Jul Day	Recover Lat Deg (S)	Min	Recover Long Deg (W)	Min
G1	25	0.550	175	33.12	4336	0011	LC2000	13:21	147	18:22	149	25	0.173	175	33.287
G2	25	11.072	175	35.56	5281	0028	LC2000	14:29	147	20:45	149	25	10.575	175	35.650
G3	25	21.640	175	38.14	4688	0057	LC4X4	15:42	147	23:15	149	25	21.360	175	38.196
G4	25	32.180	175	40.54	2929	0001	LC2000	16:55	147	01:30	150	25	32.150	175	40.345
G5	25	42.746	175	43.09	4697	0016	LC2000	18:01	147	04:21	150	25	42.667	175	43.030
G6	25	53.272	175	45.61	4169	0024	LC2000	19:06	147	07:04	150	25	53.246	175	45.594
G7	26	3.770	175	48.14	4679	0049	LC4X4	20:11	147	09:45	150	26	3.596	175	47.894
G8	26	14.276	175	50.62	4727	0052	LC4X4	21:15	147	12:54	150	26	14.172	175	50.608
G9	26	17.598	175	51.41	4348	0059	LC4X4	21:50	147	14:41	150	26	17.475	175	51.345

Table 6 – Multichannel seismic profile locations vs. FFID numbers and OBS profile shot numbers and locations

Line Number	Line A	Line B	Line C pt 1	Line C pt 2	Line D	Line G
First FFID	100	100	50	100	110	100
Last FFID	2920	3533	1390	4444	3685	1578
First FFID Time (GMT)	05:32 / 124	07:27 / 126	00:58 / 138	02:26 / 139	23:01 / 119	08:22 / 148
	25 07.5485 S	26 10.8901 S	23 26.0283 S	24 41.0783 S	27 59.15871 S	26 36.6071 S
	177 31.1716 W	173 36.4080 W	176 09.7399 W	175 32.3335 W	175 21.7367 W	175 55.9923 W
Last FFID Time (GMT)	04:32 / 126	16:33 / 128	22:28 / 138	02:50 / 142	04:58 / 121	09:00 / 149
	26 12.5096 S	27 37.6763 S	24 51.8385 S	29 11.9922 S	27 33.3495 S	24 36.2279 S
	173 36.0076 W	177 37.9792 W	175 30.0181 W	172 49.1358 W	177 47.4511 W	175 27.3879 W
Total FFIDs for line	2821	3434	1341	4345	2586	1479
OBS shot numbers	100	10100	20001	30001	N/A	100
	2920	13521	21291	34345		1578
Total OBS shots for line	2821	3422	1291	4345	N/A	1479

NOTE: The mismatches between numbers of MCS shots and OBS shots are due to either soft start shots or shots fired while turning onto lines not being used for OBS record sections.

Table 7 – Multichannel seismic acquisition configuration

Parameter	Value
Energy source	Sercel G-guns
Number of guns	10 (MCS only) 12 (combined OBS and MCS)
Total volume	4400 cubic inches (MCS only) 5440 cubic inches (combined OBS and MCS)
Firing pressure	2380 psi / 170 bar (MCS only) 3000 psi / 210 bar (combined OBS and MCS)
Shot point time interval	30 s (MCS only); 60 s (combined OBS and MCS)
Shot point distance interval	30 s – approximately 75 m 60 s – approximately 150 m
Airgun fire delay after GPS trigger	560 ms
MCS acquisition start after GPS trigger	0 ms
MCS static required	560 ms
OBS shot time against GPS time sync	0.56 s after each minute
Source depth	7 m
Distance between sub-arrays	14 m
Distance from navigation point to centre of array	76 m
Streamer depth	10 m
Distance from navigation point to first channel	237.15 m
Number of groups	240
Group interval	12.5m
Near trace offset from centre of airgun array	161.45 m
Far trace offset from centre of airgun array	3148.65 m
Active streamer length	3000 m
CDP interval	6.25 m
Fold	30 s – approximately 20 60 s – approximately 10
Sample interval	30 s – 1 ms 60 s – 2 ms
Record length	29 s

Table 8 – Gravity base station tie in Auckland

Gravity base station calculations - Auckland, New Zealand - April 24th, 2011

Lacoste-Romberg Land Gravimeter Model G-484

Meter conversion factor	1 Counter Unit (CU) =	1.02416	mGal

Gravity at Captain Cook's wharf, eastern side 26 m from the northern end.

979948.52 mGal

(Note: Value is refered to the 1930 IGF and so has been corrected for the Potsdam error)

Mean radius of the Earth	6371	km
Average gravity at 30 degrees S	979500	mGal
Free-air correction =	0.30748705	mGal/m

Average height of Bedisloe Wharf above SONNE main deck	0.27	m
Average height of SONNE main deck above sea gravimeter	1.45	m

	CU	Time
Bedisloe wharf:		
Meter reading =	3407.525	13:52
Captain Cook wharf:	3407.64	"2" - ABW
	3408.11	"3" - ABW
	3407.51	"2" - MP
	3407.59	"3" - MP
Average	3407.7325	
Bedisloe wharf:		
	3407.41	15:17
	3407.45	15:22
	3407.355	15:40
Average	3407.405	
Average Bedisloe Wharf	3407.465	
Average Captain Cook Wharf	3407.7325	
Difference in CU	-0.2675	
Difference in mGal	-0.2739628	
Gravity at Bledisloe Wharf	979948.246 mGal	
Height of Bledisole Wharf above gravimeter		1.72 m
Free air correction	0.52887773 mGal	
Gravity at sea gravimeter	979948.775 mGal	

Table 9 – Gravity base station tie in Townsville

Gravity base station calculations - Townsville, Australia - June 11th, 2011

Lacoste-Romberg Land Gravity Meter Model G-484

Meter conversion factor	1 Counter Unit (CU) =		1.02228	mGal
Gravity at Castle Hill, Captain Towns Monument, Townsville. GA station 1960910251				
		978552.212	mGal	
Mean radius of the Earth =		6371	km	
Latitude of gravity base station =	-19.21	978593.026	mGal	
Free-air correction =		0.30720233	mGal/m	
Height of Wharf above SONNE main deck			2	m
Average height of SONNE main deck above sea gravimeter			1.45	m
Wharf 8 Bollard Number 26	CU		Time	
Meter reading =	2108.05		12:47	
	2107.55		12:40	
	2107.62		12:36	
Average	2107.74			
Captain Towns Monument	CU		Time	
Meter reading =	2046.255		13:20	
	2046.21		13:25	
	2046.2		13:28	
Average	2046.22167			
Wharf 8 Bollard Number 26				
	2108.115		14:20	
	2108.11		!4:25	
	2108.11		!5:20	
Average	2108.11167			
Average Wharf 8	2107.92583			
Average Captain Towns Monument	2046.22167			
Difference in CU	61.7041667			
Difference in mGal	63.0789355			
Gravity at Wharf 8	978615.291	mGal		
Height of Wharf above gravimeter			3.45	m
Free air correction	1.05984804	mGal		
Gravity at sea gravimeter	978616.351	mGal		

Table 10 – Gravity meter drift

Sea gravimeter reading in Auckland		8209.47	CU	
Sea gravimeter reading in Townsville		6869.02	CU	02:00 UTC
Sea gravimeter conversion factor	1 CU =		0.9978	mGal
Gravity at sea gravimeter in Auckland		979948.775	mGal	
Gravity at sea gravimeter in Townsville		978616.351	mGal	
Observed gravity difference		-1332.4242	mGal	
Predicted gravity difference		-1337.501	mGal	
Drift =		5.07679354	mGal	
Drift =		0.10801688	mGal/day	
Drift =		3.24050652	mGal/month	

Check the effect on the drift rate of sensor pressure change due to gas loss

Meter pressure Townsville	0.32	inch-Hg
	7 mGal decrease for every 1 inch-Hg increase	
Meter pressure Auckland	0.37	inch-Hg
Leakage =	-0.05	
Drift =	-0.35	mGal
Corrected drift	4.72679354	mGal
Corrected drift	0.10057008	mGal/day
Corrected drift	3.01710226	mGal/month

Table 11 – Sound velocity profile location

SV Number	Julian Day	Time GMT	Latitude (S)	Longitude (W)
SV01	118 28/4/2011	08:00	27 47.940	175 56.860

Table 12 – Actual expendable bathymetric thermograph deployment locations

XBT Number	Day	Time GMT	Lat (S)		Long (W)	
01	118	13:21	27	48.153	175	56.930
02	121	13:31	27	26.515	177	5.603
03	121	21:36	27	4.272	176	2.357
04	122	05:41	26	39.018	174	52.298
05	122	12:38	26	15.890	173	49.799
06	122	17:04	26	1.061	174	19.008
07	122	21:07	25	51.402	174	54.810
08	133	15:30	25	31.601	176	6.834
09	123	20:16	25	11.469	177	17.476
10	136	11:28	27	36.780	174	10.078
11	136	06:49	28	9.065	173	42.880
12	135	23:16	28	57.491	173	1.608
13	136	15:35	27	6.259	174	25.928
14	136	21:10	26	16.819	174	49.758
15	137	02:01	25	33.503	175	10.430
16	137	07:18	24	43.825	175	33.775
17	137	16:02	23	35.561	176	5.335
18	147	14:29	25	11.070	175	35.564
19	147	21:15	26	14.281	175	50.623
20	153	00:53	25	53.529	177	5.251
21	153	01:18	25	53.520	177	8.005
22	153	01:45	25	53.501	177	11.101

Table 13 – Cruise way points

TRANSIT FROM AUCKLAND WAYPOINTS

	Lat Deg	South Min	Long Deg	West Min	
NZ1	36	17.982	183	43.380	
NZ2	36	14.526	183	18.780	
NZ3	36	10.470	182	55.320	
NZ4	36	7.488	182	19.380	
NZ5	35	40.056	181	55.080	
NZ6	35	8.334	181	31.680	
NZ7	34	54.024	181	18.780	
NZ8	34	31.362	180	55.200	
NZ9	34	19.200	180	48.300	
T1	30	8.010	176	22.920	
T2	29	7.026	175	57.300	
SVP1	27	47.982	175	56.880	XBT 1

SEISMIC PROFILE ENDS WAYPOINTS

AA	25	8.640	177	27.420
AB	26	11.742	173	38.700
BA	27	42.090	177	50.820

BB	26	11.742	173	38.700
CA	23	33.684	176	6.180
CB	27	34.038	174	12.300
CC	29	10.866	172	50.100
DA	27	33.102	177	48.900
DB	28	16.182	174	21.660
GA Run-in	26	51.168	175	59.520
GA	26	30.120	175	54.420
GB	24	44.712	175	29.400

X in tables below indicates the profile shooting way points

OBS DEPLOYMENT AND RECOVERY WAYPOINTS

	Line A	OBS No.	Offset	**Lat Deg**	**South Min**	**Long Deg**	**West Min**	
X	A1	28	20.0	26	8.712	173	50.220	
	A2	29	32.5	26	6.816	173	57.420	
	A3	30	45.0	26	4.908	174	4.620	
	A4	31	57.5	26	3.000	174	11.820	
	A5	32	70.0	26	1.086	174	18.960	XBT 6
	A6	33	82.5	25	59.166	174	26.160	
	A7	34	95.0	25	57.240	174	33.360	
	A8	35	107.5	25	55.308	174	40.500	
	A9	36	120.0	25	53.376	174	47.700	
	A10	37	132.5	25	51.432	174	54.840	XBT 7
	A11	38	145.0	25	49.488	175	2.040	
	A12	39	157.5	25	47.538	175	9.180	
	A13	40	170.0	25	45.582	175	16.380	
	A14	41	182.5	25	43.620	175	23.520	
X	A15	42	195.0	25	41.652	175	30.660	
	A16	43	207.5	25	39.684	175	37.800	
	A17	44	220.0	25	37.698	175	44.940	
	A18	45	232.5	25	35.718	175	52.080	
	A19	46	245.0	25	33.726	175	59.220	
	A20	47	257.5	25	31.734	176	6.360	XBT 8
	A21	48	270.0	25	29.736	176	13.500	
	A22	49	282.5	25	27.732	176	20.640	
	A23	50	295.0	25	25.722	176	27.720	
	A24	51	307.5	25	23.706	176	34.860	
	A25	52	320.0	25	21.684	176	42.000	
	A26	53	332.5	25	19.674	176	49.080	
	A27	54	345.0	25	17.634	176	56.220	
	A28	55	357.5	25	15.594	177	3.300	
	A29	56	370.0	25	13.554	177	10.380	
	A31	58	376.3	25	12.503	177	13.908	
X	A30	57	382.5	25	11.508	177	17.520	XBT 9

	Line B	OBS No.	Offset	Lat Deg	South Min	Long Deg	West Min	
X	B27	1	20.0	26	15.894	173	49.800	XBT 5
	B26	2	32.5	26	18.486	173	56.700	
	B25	3	45.0	26	21.072	174	3.660	
	B24	4	57.5	26	23.652	174	10.620	
	B23	5	70.0	26	26.226	174	17.520	
	B22	6	82.5	26	28.800	174	24.480	
X	B21	7	95.0	26	31.368	174	31.440	
	B20	8	107.5	26	33.924	174	38.400	
	B19	9	120.0	26	36.480	174	45.360	
	B18	10	132.5	26	39.030	174	52.320	XBT 4
	B17	11	145.0	26	41.574	174	59.280	
	B16	12	157.5	26	44.118	175	6.300	
	B15	13	170.0	26	46.650	175	13.260	
X	B14	14	182.5	26	49.182	175	20.220	
	B13	15	220.0	26	56.742	175	41.220	
	B12	16	232.5	26	59.250	175	48.240	
	B11	17	245.0	27	1.752	175	55.260	
	B10	18	257.5	27	4.254	176	2.280	XBT 3
	B9	19	270.0	27	6.750	176	9.300	
X	B8	20	282.5	27	9.240	176	16.320	
	B7	21	295.0	27	11.718	176	23.340	
	B6	22	307.5	27	14.202	176	30.360	
	B5	23	320.0	27	16.674	176	37.380	
	B4	24	332.5	27	19.140	176	44.400	
	B3	25	345.0	27	21.606	176	51.480	
	B2	26	357.5	27	24.060	176	58.500	
X	B1	27	370.0	27	26.514	177	5.580	XBT 2

	Line C	OBS No.	Offset	Lat Deg	South Min	Long Deg	West Min	
	C1	1	6.25	27	36.744	174	10.080	XBT 10
	C2	2	18.75	27	42.144	174	5.580	
X	C3	3	31.25	27	47.544	174	1.020	
	C4	4	43.75	27	52.938	173	56.520	
	C5	5	56.25	27	58.332	173	51.960	
X	C6	6	68.75	28	3.726	173	47.400	
	C7	7	81.25	28	9.114	173	42.900	XBT 11
	C8	8	93.75	28	14.496	173	38.340	
X	C9	9	106.25	28	19.878	173	33.780	
	C10	10	118.75	28	25.260	173	29.160	
	C11	11	131.25	28	30.636	173	24.600	
X	C12	12	143.75	28	36.012	173	20.040	
	C13	13	156.25	28	41.382	173	15.420	
	C14	14	168.75	28	46.746	173	10.860	
X	C15	15	181.25	28	52.116	173	6.240	
	C16	16	193.75	28	57.474	173	1.620	XBT 12
	C17	17	206.25	29	2.832	172	57.060	
	C18	18	218.75	29	8.190	172	52.440	
	C19	19	6.25	27	30.960	174	13.860	
	C20	20	18.75	27	24.792	174	16.860	

	C21	21	31.25	27	18.624	174	19.860	
X	C22	22	43.75	27	12.450	174	22.860	
	C23	23	56.25	27	6.276	174	25.920	XBT 13
	C24	24	68.75	27	0.102	174	28.920	
X	C25	25	81.25	26	53.928	174	31.860	
	C26	26	93.75	26	47.754	174	34.860	
	C27	27	106.25	26	41.574	174	37.860	
X	C28	28	118.75	26	35.394	174	40.860	
	C29	29	131.25	26	29.208	174	43.800	
	C30	30	143.75	26	23.028	174	46.800	
	C31	31	156.25	26	16.842	174	49.740	XBT 14
X	C32	32	168.75	26	10.656	174	52.740	
	C33	33	181.25	26	4.464	174	55.680	
	C34	34	193.75	25	58.278	174	58.620	
X	C35	35	206.25	25	52.086	175	1.620	
	C36	36	218.75	25	45.888	175	4.560	
	C37	37	231.25	25	39.696	175	7.500	
X	C38	38	243.75	25	33.504	175	10.440	XBT 15
	C39	39	256.25	25	27.306	175	13.320	
	C40	40	268.75	25	21.108	175	16.260	
	C41	41	281.25	25	14.904	175	19.200	
X	C42	42	293.75	25	8.706	175	22.080	
	C43	43	306.25	25	2.502	175	25.020	
	C44	44	318.75	24	56.298	175	27.960	
X	C45	45	331.25	24	50.094	175	30.840	
	C46	46	343.75	24	43.890	175	33.720	XBT 16
	C47	47	356.25	24	37.680	175	36.660	
X	C48	48	368.75	24	31.476	175	39.540	
	C49	49	381.25	24	25.266	175	42.420	
	C50	50	393.75	24	19.056	175	45.300	
X	C51	51	406.25	24	12.840	175	48.180	
	C52	52	418.75	24	6.630	175	51.060	
	C53	53	431.25	24	0.414	175	53.880	
X	C54	54	443.75	23	54.198	175	56.760	
	C55	55	456.25	23	47.982	175	59.640	
	C58	58	462.50	23	44.874	176	1.080	
	C56	56	468.75	23	41.766	176	2.460	
	C59	59	475.00	23	38.658	176	3.900	
	C57	57	481.25	23	35.550	176	5.340	XBT 17

	Line G	OBS No.	Offset	**Lat Deg**	**South Min**	**Long Deg**	**West Min**	
X	G1	1	30.00	25	0.540	175	33.120	
X	G2	2	50.00	25	11.082	175	35.580	XBT 18
X	G3	3	70.00	25	21.630	175	38.100	
X	G4	4	90.00	25	32.172	175	40.560	
X	G5	5	110.00	25	42.714	175	43.080	
X	G6	6	130.00	25	53.256	175	45.600	
X	G7	7	150.00	26	3.792	175	48.120	
X	G8	8	170.00	26	14.322	175	50.640	XBT 19
	G9	9	176.25	26	17.616	175	51.420	

SWATH SURVEY PHASE 1 WAYPOINTS

		Lat Deg	South Min	Long Deg	West Min
A30	382.5	25	11.508	177	17.520
SW1	384.5	25	40.020	177	17.520
SW2	385.5	26	0.000	177	0.000
SW3	386.5	26	24.000	176	19.980
SW4	387.5	27	0.000	175	0.000
SW5	388.5	28	0.000	174	6.420
SW6	389.5	29	0.000	173	14.760
C18	218.75	29	8.190	172	52.440

SWATH SURVEY PHASE 2 – MONOWAI VOLCANIC CENTRE WAYPOINTS

	Lat Deg	South Min	Long Deg	West Min
TF1	25	45.000	177	15.000
TF2	25	45.000	177	5.500
TF3	25	46.250	177	5.500
TF4	25	46.250	177	15.000
TF5	25	47.500	177	15.000
TF6	25	47.500	177	5.500
TF7	25	48.750	177	5.500
TF8	25	48.750	177	15.000
TF9	25	49.750	177	15.000
TF10	25	49.750	177	5.500
TF11	25	50.750	177	5.500
TF12	25	50.750	177	14.000
TF13	25	53.050	177	11.430
TF14	25	53.700	177	11.430
TF15	25	53.700	177	11.000
TF16	25	53.450	177	10.750
TF17	25	53.100	177	10.750

SWATH SURVEY PHASE 3 – MONOWAI VOLCANIC CENTRE WAYPOINTS

	Lat Deg	South Min	Long Deg	West Min
TF18	25	51.750	177	5.500
TF19	25	51.750	177	15.000
TF20	25	52.750	177	15.000
TF21	25	52.750	177	5.500
TF22	25	53.750	177	5.500
TF23	25	53.750	177	15.000
TF24	25	54.750	177	15.000
TF25	25	54.750	177	5.500
TF26	25	55.750	177	5.500
TF27	25	55.750	177	15.000
TF28	25	56.750	177	15.000
TF29	25	56.750	177	4.000

TF30	25	53.500	177	4.000	XBT 20
TF31	25	53.500	177	5.000	XBT 21
TF32	25	53.500	177	8.000	XBT 22
TF33	25	53.500	177	11.000	
TF34	25	53.500	177	15.000	

SWATH SURVEY PHASE 4 WAYPOINTS

	Lat Deg	South Min	Long Deg	West Min
SH1	25	49.000	175	56.200
SH2	25	44.100	176	8.700
SH3	25	41.200	176	1.200
SH4	25	32.500	175	53.000
SH5	25	2.500	175	53.000
SH6	25	2.500	176	0.000
SH7	25	20.000	176	0.000
SH8	25	22.500	176	7.200
SH9	24	33.700	176	0.000
SH10	24	40.500	175	47.500
SH11	25	16.200	175	49.000
SH12	25	12.500	175	44.000
SH13	24	50.000	175	42.500

SWATH SURVEY PHASE 5 – TRANSIT TO TOWNSVILLE WAYPOINTS

	Lat Deg	South Min	Long Deg	West Min
T3	25	59.000	179	10.000

	Lat Deg	South Min	Long Deg	East Min
T4	26	10.000	176	0.000
T5	26	29.000	170	26.000
T6	26	30.000	170	0.000
T7	26	30.000	164	0.000
T8	25	45.000	160	0.000
T9	25	0.000	158	30.000
T10	21	0.000	153	30.000
T11	18	7.100	148	0.000