National Oceanography Centre, Southampton

Cruise Report No. 31

RV *Sonne* Cruise 198-1

03 MAY-14 JUN 2008

Singapore – Merak, Indonesia.

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ABSTRACT

All plate boundaries are divided into segments - pieces of fault that are distinct from one another, either separated by gaps or with different orientations. The maximum size of an earthquake on a fault system is controlled by the degree to which the propagating rupture can cross the boundaries between such segments. A large earthquake may rupture a whole segment of plate boundary, but a great earthquake usually ruptures more than one segment at once.

Earthquakes offshore of Sumatra on December 26th 2004 (M_W=9.3) and March 28th 2005 (M_W=8.7) ruptured, respectively, 1200-1300 km and 300-400 km of the subduction boundary between the Indian-Australian plate and the Burman and Sumatra blocks. Rupture in the 2004 event started at the southern end of the fault segment, and propagated northwards. The observation that the slip did not propagate significantly southwards in December 2004, even though the magnitude of slip was high at the southern end of the rupture strongly suggests a barrier at that place. Maximum slip in the March 2005 earthquake occurred within ~100 km of the barrier between the 2004 and 2005 ruptures, confirming both the physical importance of the barrier, and the loading of the March 2005 rupture zone by the December 2004 earthquake.

Cruise SO198-1, from Singapore to Merak between 3rd May and 14th June 2008 is the first of three cruises, funded by the Natural Environment Research Council (NERC), which will form a coherent set of geophysical observations in the source regions of the 2004 and 2005 great Sumatra earthquakes. Arrays of 50 ocean-bottom seismometers (OBS) were deployed at each of two locations – between the 2004 and 2005 ruptures, and at the southern end of the 2005 rupture - to record shots from a large-capacity airgun array. Approximately 7 days of continuous airgun shooting at 60s interval was completed at each location. 10 OBS were reconfigured for earthquake recording and deployed with a planned retrieval in early 2009. Gravity, Parasound, and swath bathymetry data were recorded continuously while in the permitted area, with magnetic field data recorded throughout the airgun shooting, and 101 XBT casts taken at the OBS deployment locations.

KEYWORDS

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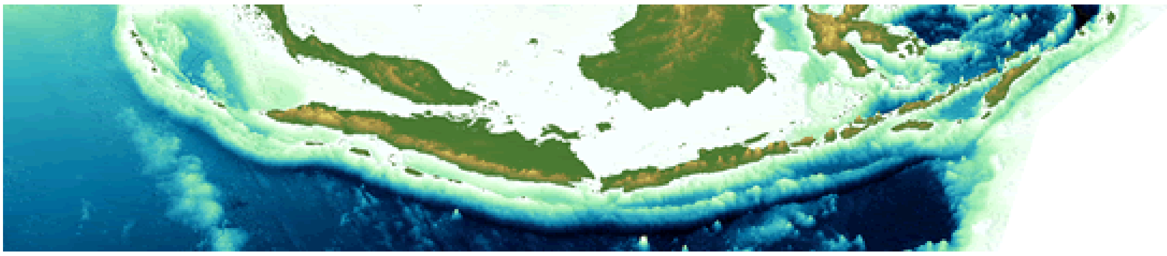

Cruise Report: SO198-1

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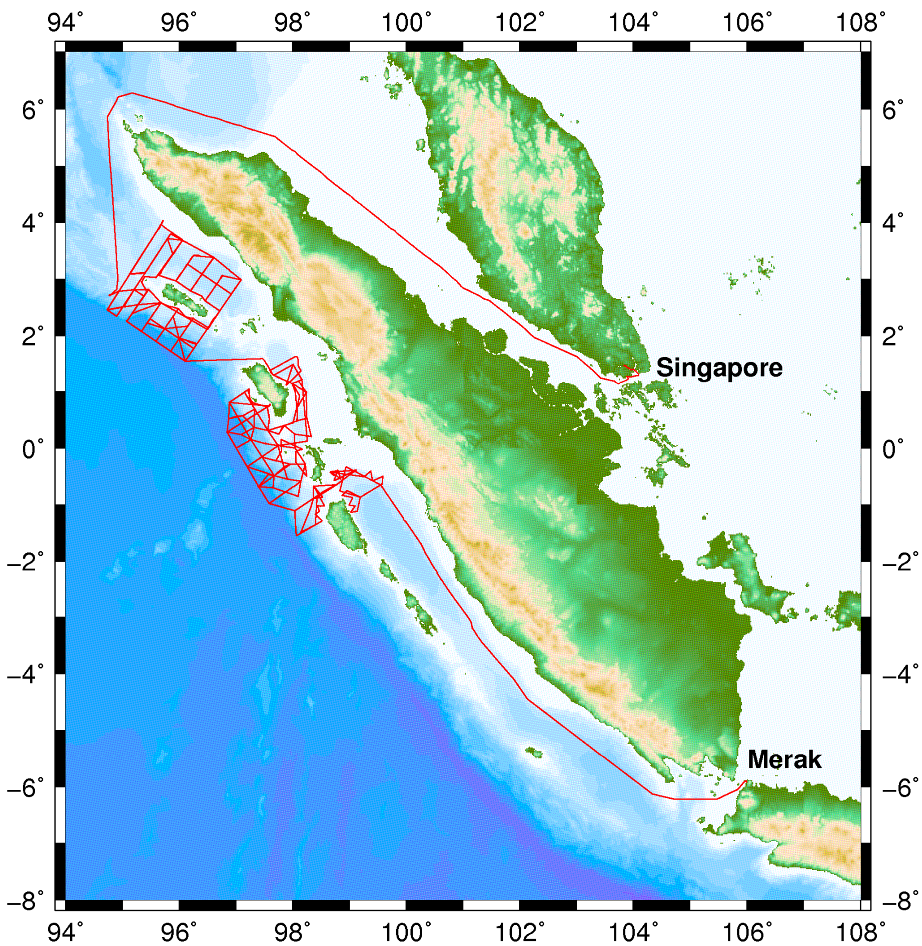
Singapore to Merak



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Introduction

All plate boundaries are divided into segments – pieces of fault that are distinct from one another, either separated by gaps or with different orientations. The maximum size of an earthquake on a fault system is controlled by the degree to which the propagating rupture can cross the boundaries between such segments. A large earthquake may rupture a whole segment of plate boundary, but a great earthquake usually ruptures more than one segment at once.

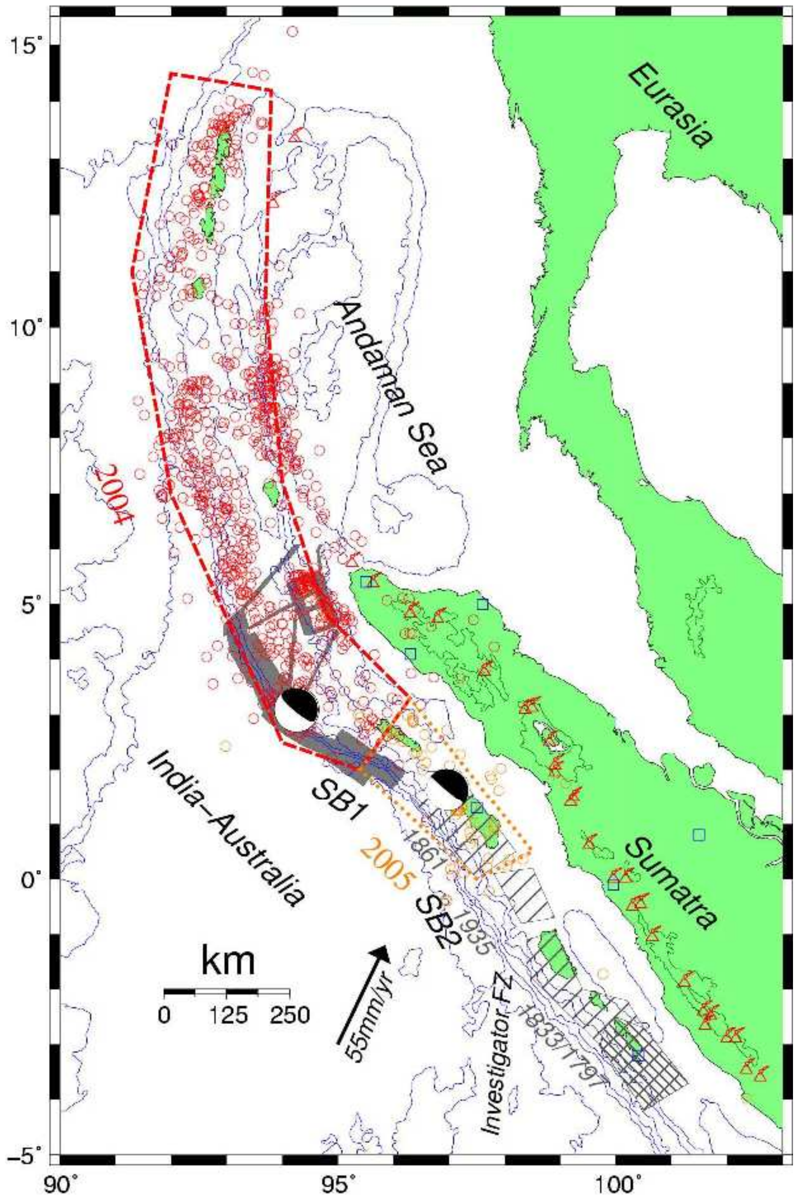

Figure 1: Regional setting of the Sumatra subduction zone. Approximate mainshock rupture extents and the first ten days of aftershocks with M>5 are shown in red (26th December, 2004) and orange (28th March, 2005) respectively, with Harvard CMT solutions. Hatching – estimated extent of major previous earthquakes, cross-hatching where constrained by coral uplift. Grey shading – HMS Scott bathymetry coverage. Blue squares – location of new permanent seismic stations. Elevation contoured at 1000 m intervals. Active arc volcanoes also marked.

The December 26th 2004 M_W 9.3 earthquake and the March 28th 2005 M_W 8.7 earthquake ruptured, respectively, 1200–1300 km and 300–400 km of the subduction boundary between the Indian-Australian plate and the Burman and Sumatra blocks. Rupture in the 2004 event started at the southern end of the fault segment, and propagated northwards. The observation that the slip did not propagate significantly southwards in December 2004, even though the magnitude of slip was high at the southern end of the rupture strongly suggests a barrier at that place. Maximum slip in the March 2005 earthquake occurred within ~100 km of the barrier between the 2004 and 2005 ruptures, confirming both the physical importance of the barrier, and the loading of the March 2005 rupture zone by the December 2004 earthquake.

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Explanatory Notes

Navigation

The RV Sonne operates a number of GPS navigation receivers, including an Ashtech GG24 Glonass GPS, an Ashtech MicroZ GPS and a Trimble NT200DS. The main GPS antennas are located on the mast directly above the bridge, 28 m from the waterline (Figure 2). This antenna location is the origin for all the navigation data acquired during SO198-1.

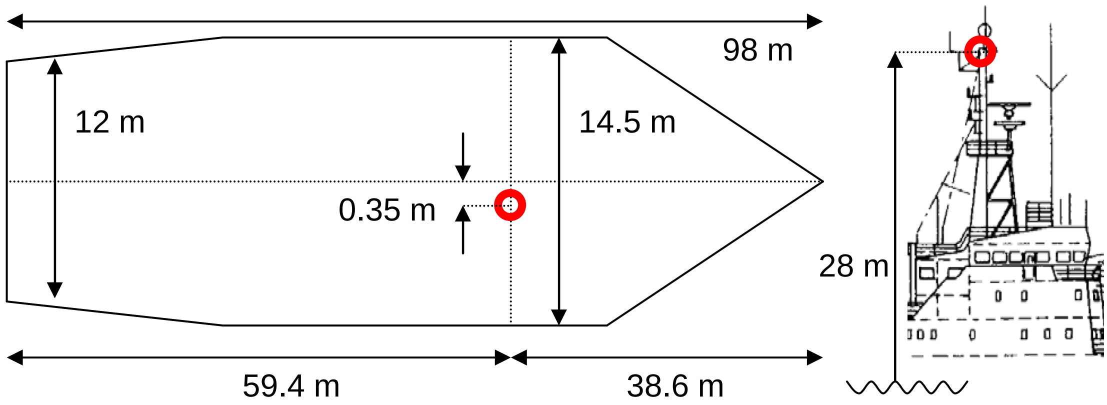

Figure 2: The location of the GPS antenna (red circle) on the mast above the bridge of the RV Sonne, 28 m from the water line.

The data from each GPS receiver are logged independently in the ship's database, but one of the GPS receivers is manually selected to be the *System GPS*, the data from which is used by all the scientific equipment onboard that can take a navigation input including the swath bathymetry system, the sub-bottom profiler and the laboratory displays (Figure 3). During SO198-1 the Ashtech GG24 Glonass GPS receiver was selected to be the *System GPS*.

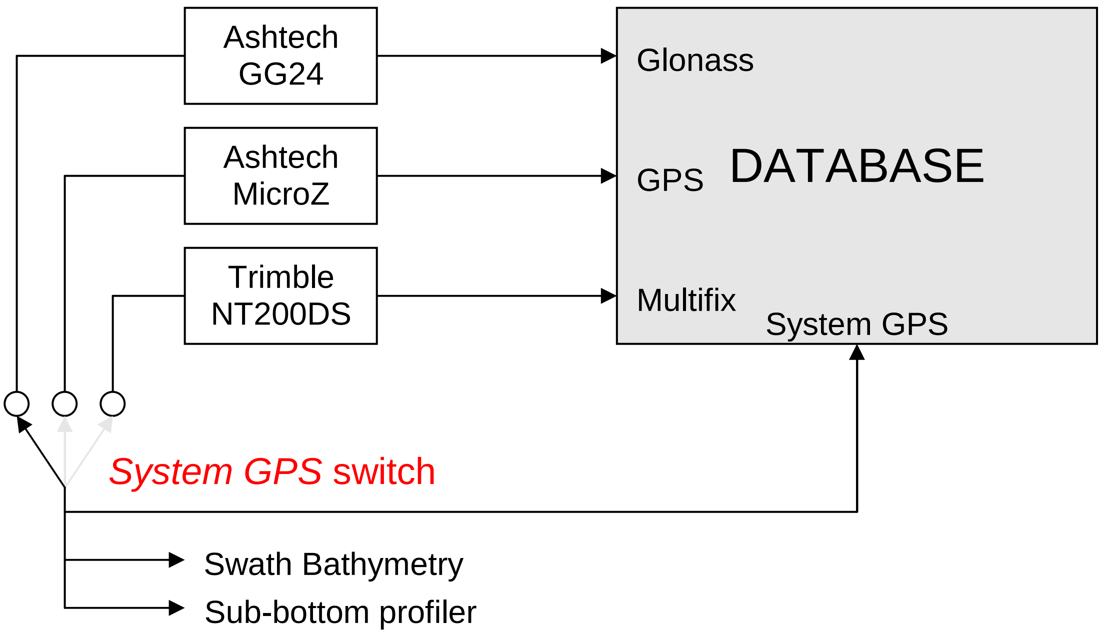

Figure 3: The relationship between the Ashtech GG24, MicroZ and Trimble GPS receivers, System GPS, and the data logged in the ship's database.

Seismic source

Airguns

The seismic source employed for SO198-1 consisted of a twelve airgun tuned array with a total capacity of 5420 cu. in. The Sonne's fixed compressors provided the air supply at a pressure of 150 bar (2174 psi) to a second stage containerised compressor, fixed to the afterdeck, that fed the airguns at a pressure of 210 bar (3046 psi). The airguns were SSI Sodera G-guns with capacities of 8x520 cu. in., 2x380 cu. in., and 2x250 cu. in. The airguns were clustered into pairs of like-sized guns (Figure 4).

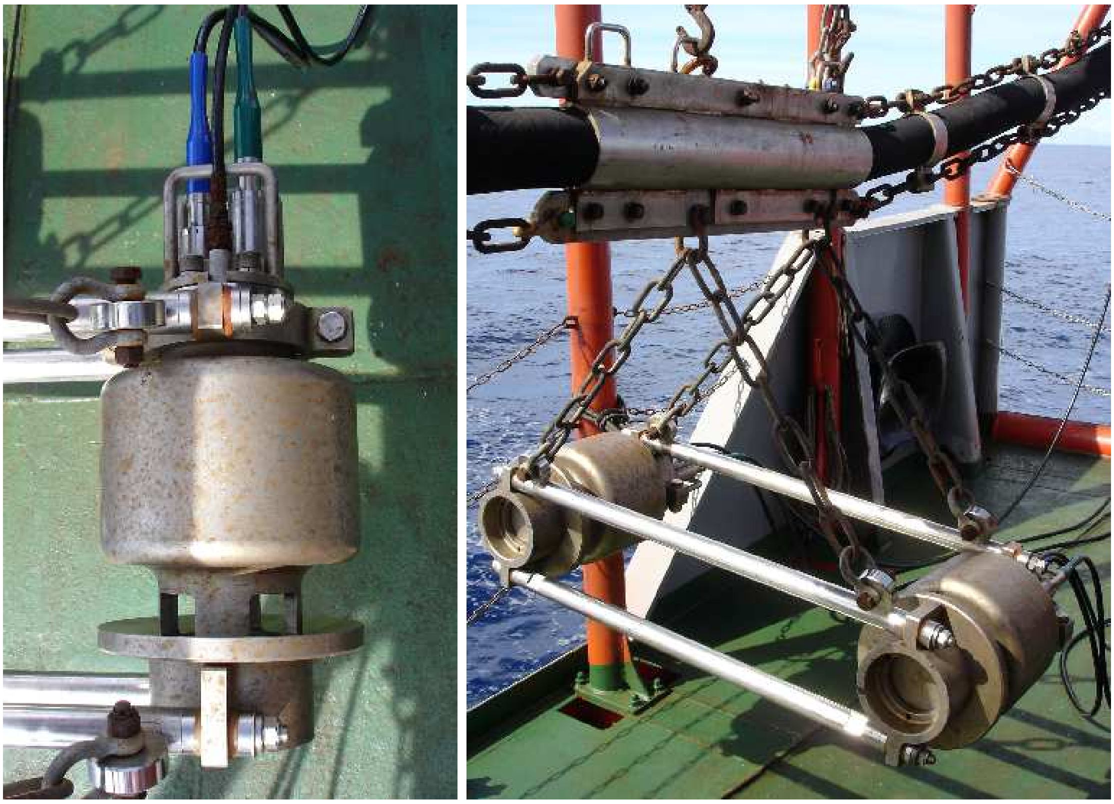

Figure 4: An Sodera G-gun (left panel) with air hose, solenoid valve and M/P time break connectors (top), chamber (middle) and ports (bottom). Airguns were clustered in pairs of like-sized guns (right panel), each suspended by chains beneath a flexible towing frame to which the flotation buoys were attached.

Two sets of three airgun-clusters were towed from the afterdeck, one set either side of the vessel; a total of eight buoys, four for each set of clusters, supported the airguns ~12 m below the sea surface. The air hoses were marked with tape after the airguns were deployed and the distance from the back of the ship to the airguns was measured after recovery with a tape measure. The dimensions measured are summarised in Figure 5.

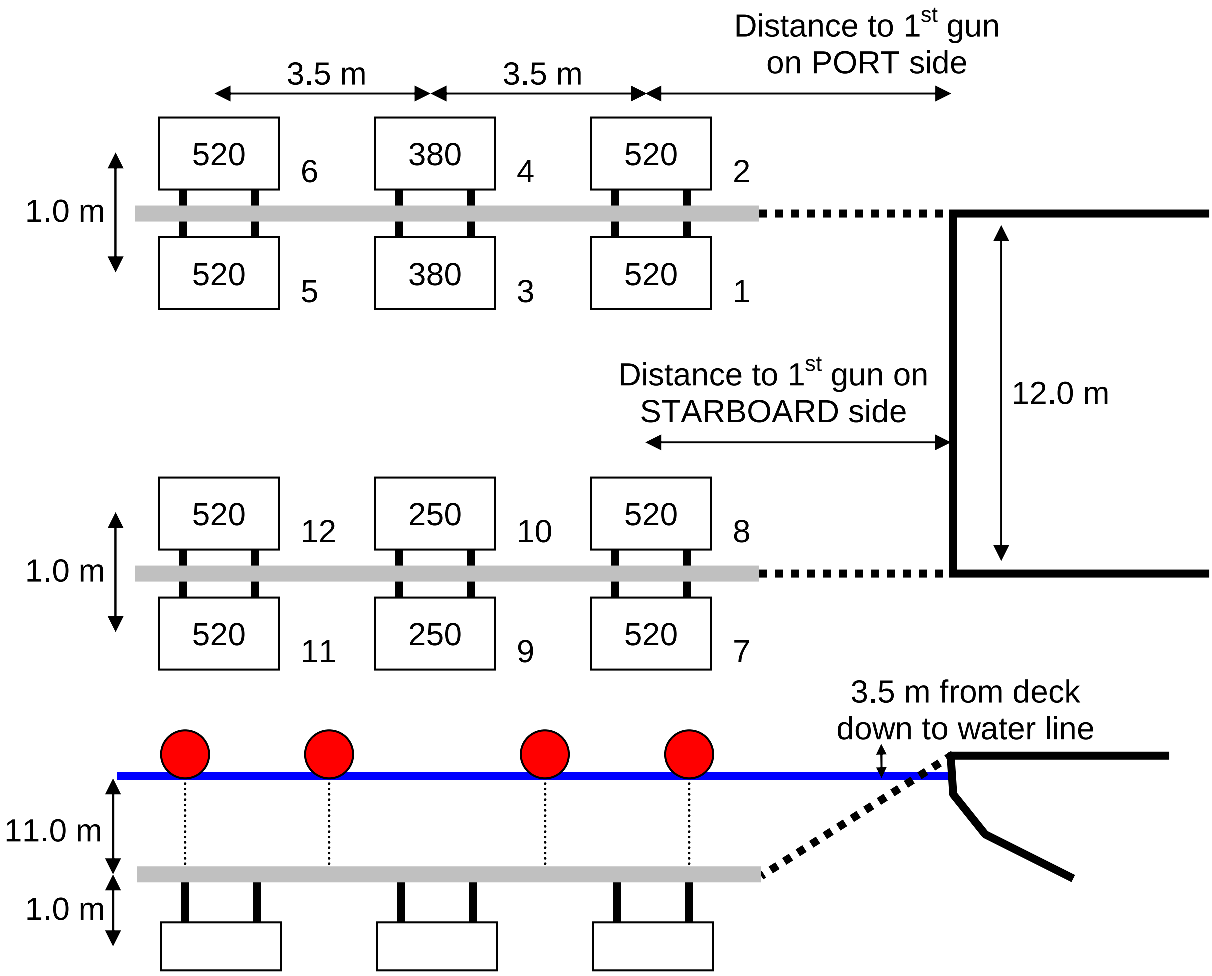

Figure 5: Schematic diagram showing the dimensions of the airgun array towed during SO198-1, and the airgun numbers, as used by the gun controller. Airgun volumes are given in cubic inches, all other dimensions are in metres. The distance between the back of the ship and the first airgun in the port and starboard array varied during the cruise and are given in Table 1.

The distance to the first gun on the port and starboard side varied slightly during the cruise since the guns had to be redeployed between survey areas and to allow for maintenance during the shooting periods. During shooting in Survey Box 1, the total hose length was 40.65 m on the port side and 42.1 m on the starboard side until shot number 5975; at shot number 6164 the starboard hose reduced in length to 40.5 m. During shooting in Survey Box 2, the total hose length was 40.65 m on the port side and 40.3 m on the starboard side. Given that the GPS antenna used for navigation is 59.4 m from the stern of the vessel, the variations in layback to the centre of the airgun array are summarised in Table 1.

Survey Box	Time period (ddd/hh:mm:ss.ss)	Shot numbers	Distance to 1st gun on port side	Distance to first gun on starboard side	Distance from source centre to GPS antenna
1	133/02:25:30.56–137/06:00:30.56	0–5975	37.58	39.14	101.26
1	137/06:01:30.56–137/09:08:30.56	5976–6163	37.58	N/A	100.48
1	137/09:09:30.56–140/08:46:30.56	6164–10461	37.58	37.42	100.40
2	149/14:52:30.56–155/23:17:30.56	20000–29133	37.58	37.20	100.29

Table 1: Distances from the back of the ship to the first gun for the port and starboard airgun arrays.

LongShot gun controller

The airguns were fired using a Real Time Systems Controller Module, running *LongShot* V7.08,0705 software, and four *FourShot* Solenoid Power Supply modules (Figure 6). Only three of the *FourShot* modules were required for the twelve airguns. The Controller Module was triggered using a Zyfer GPStarplus model 565 clock, identical to the one used as the time-base for the OBS instruments, although connected to its own GPS antenna located on the rail above the Geology Lab.

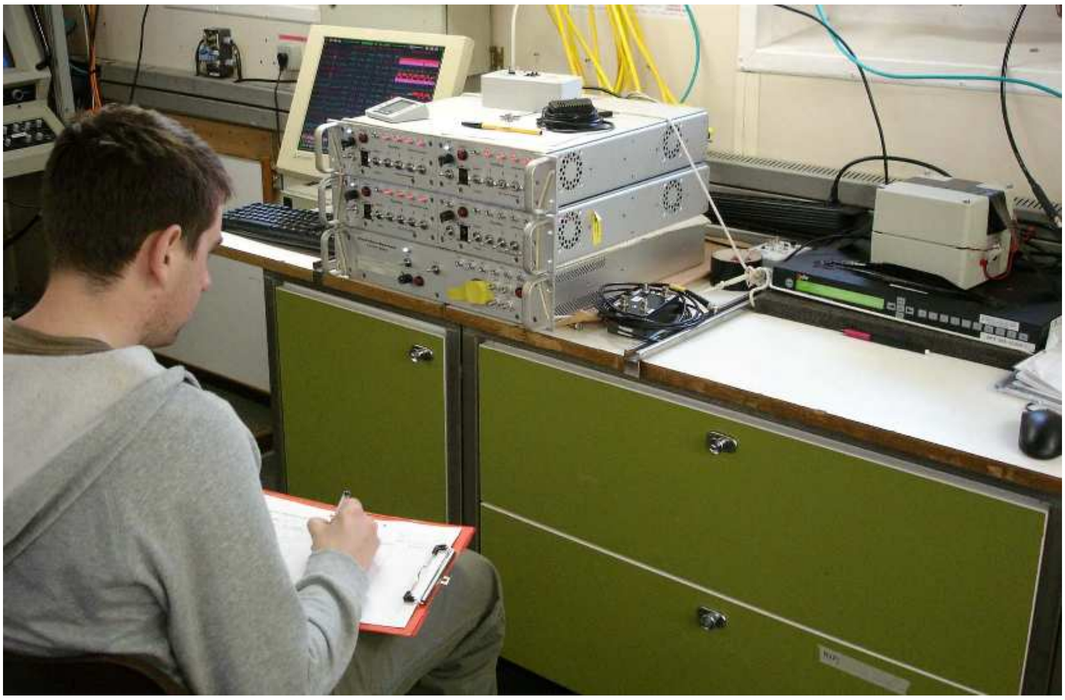

Figure 6: The airgun controller and logging system. A pulse from the Zyfer GPS clock (black box, right) triggers the Real Time Systems Controller Module (lowest of the three silver boxes, centre) that fires each airgun through the *FourShot* Solenoid Power Supply modules (two upper-most silver boxes, centre). The Controller Module optimises the firing of each airgun using LongShot software that is displaying on the screen (obscured, left; Figure 7). Trigger pulses from the Zyfer clock are recorded on the modified OBS logger (grey box, right). Shot times and numbers are noted by hand.

The gun firing system has two goals: 1) to synchronise all the guns in the array to fire constructively; 2) to produce a seismic source that occurs at a time instance with an error significantly less than the sample rate of the OBS instruments. Synchronising the gun pulses is the purpose of the *LongShot* software (Figure 7). Each gun in the array responds slightly differently, providing maximum power at a different time after it is triggered to fire. *LongShot* uses data from hydrophones located adjacent to each gun to measure the signal produced every time it fires and adjust each individual gun's timing so that the peak energy from all the guns occurs at the same time. In order to allow *LongShot* to fire some guns earlier than others, a delay is set between the time the system is triggered and the time the guns are aimed to achieve peak energy. During SO198-1 this delay was set to 60 ms.

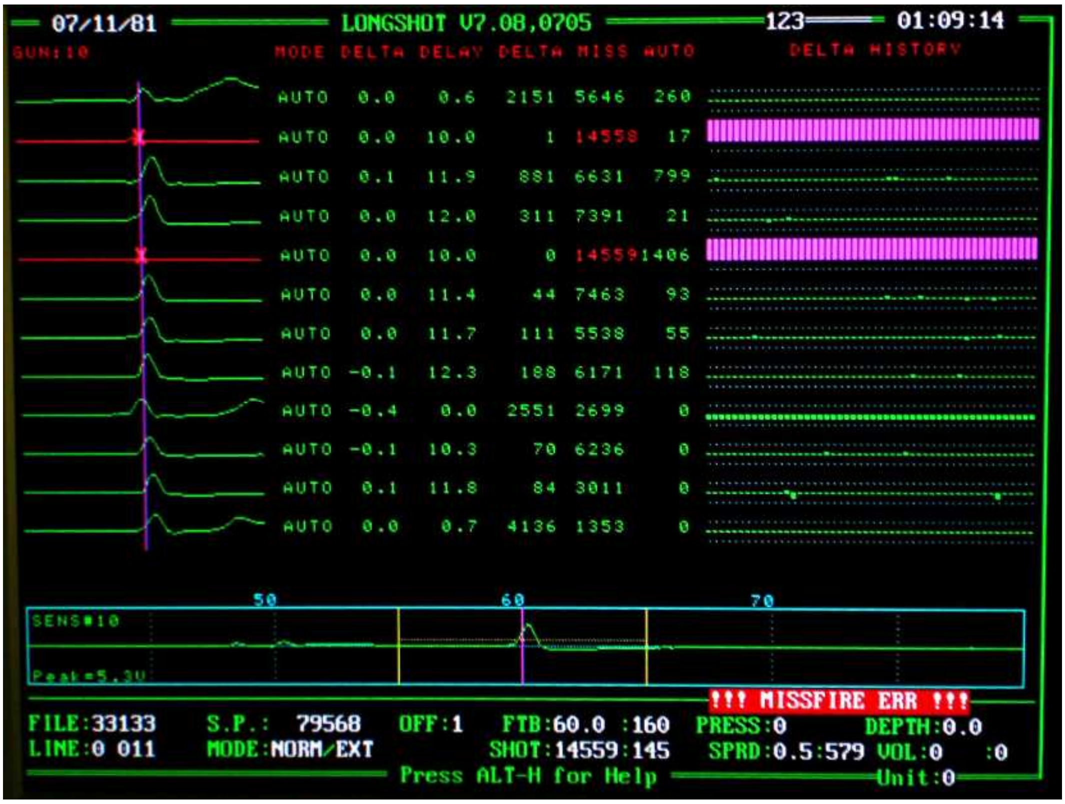

Figure 7: A typical screen from the *LongShot* software running on the Real Time Systems Controller Module. The signal from each individual airgun from the previous shot is displayed left, the vertical pink line identifying the target time for the leading edge of each pulse. Delay times and other gun statistics are given for each gun as text. The firing history for the previous 50 shots of each gun, in terms of its accuracy relative to the target time, is shown graphically on the right: small green bars mean the leading edge of the gun's signal matches the target time; larger green bars (e.g., for gun 9, counting down from the top of the display) indicate a small time discrepancy; large pink or purple bars indicate serious misfires. Note that at this point in the survey gun 5 is turned off and the sensor on gun 2 has failed. At the bottom of the screen is a detailed display for one gun (gun 10 in this example), and the shot number is displayed bottom-centre.

The timing of the gun trigger pulses came from a GPS time base. The Zyfer GPStarplus clock uses a GPS disciplined ovenized quartz oscillator and is accurate to better than 1 μs indicated by a Time Figure Of Merit value (TFOM; Table 2). The clock provided a 500 ms-wide trigger pulse to the Real Time Systems Controller Module, once a minute on the 30-second mark. Initially unknown, the Controller Module triggers on a falling pulse edge, which meant the guns were triggered every minute at:

30 seconds + 500 ms pulse width delay + 60 ms *LongShot* delay = 30.560 s

TFOM value	Time Error
4	≤1 µs
5	>1 µs to ≤10 µs
6	>10 µs to ≤100 µs
7	>100 µs to ≤1 ms
8	>1 ms to ≤10 ms
9	>10 ms

Table 2: Time Figure Of Merit (TFOM) values for the Zyfer GPStarplus model 565 clock, and their meaning in terms of timing accuracy (Zyfer GPStarplus Model 565 User's Manual).

In case of an instability or failure in the GPS clock, the trigger pulses from the Zyfer GPStarplus were recorded by an OBS logger (4x4 type) modified to fit into an instrument case (Figure 6). This logger was set up in the same way as all the equivalent OBS instruments.

Figure 8: The airgun source. This sequence of photographs shows, from left to right, the evolution of the guns firing from the shot through the air bubble rising and spreading out at the surface.

Operational issues with the seismic source

The seismic source proved effective and reliable. However, a number of issues were apparent that affected the operation of the source:

1. A number of airgun failures occurred as a result of burst hoses (Figure 9). Since the air pressure was 210 bar during SO198-1, the failures may have occurred due to higher than normal pressure. However, the equipment was not being used outside of its specification and the more likely cause for the failures was by abrasion of the hoses against the

towing equipment (Figure 4). This may be avoided by either rerouting/shortening the hoses or by using armoured hoses.

2. Time break sensors on the airguns were not reliable. During the shooting periods, at best two sensors failed altogether with one or two others producing suspect signals. The airgun array would often be deployed with many sensors initially failing to work, but for them to gradually start working over a period of 6-12 hours use. Attempts were made to rectify the problem by checking the sensors between deployments, but the problem was not fully resolved. The affect of these failures was that the source could not be satisfactorily tuned, and a number of the airguns had to be fired using manual ‘best guess’ timing.
3. The lack of depth sensors on the airgun array meant that the source depth could only be estimated from the length of the ropes attached to the flotation buoys. The tow-depth has a significant affect on the source signature, and it is important to keep this constant during data acquisition, but no quality control was possible due to the lack of sensors.

Figure 9: Damage to the air hose to gun 2 (port array) sustained during shooting in Survey Box 1. Note: the hose is ~1 cm in diameter.

Ocean Bottom Seismometer (OBS) instruments

The Ocean Bottom Instruments (OBS) used during SO198-1 were supplied by the Ocean Bottom Instrument Consortium (OBIC) based in Durham and Southampton, U.K., and the Institut de Physique du Globe de Paris (IPGP), France. A total of six different configurations of instrument were deployed: four configurations with fundamentally the same data logger but varying sensor packages and pressure cases (LC2000 and LASSI instruments); and two configurations with LC2000 pressure cases but the latest '4x4' loggers and two different sensor packages, one identical to the 4-channel LC2000 instruments for the controlled source experiment, one with a Differential Pressure Gauge (DPG) for the long-term deployment experiment. The instrument configurations are summarised in Table 3.

Instrument name	Hydrophone	Differential Pressure Gauge (DPG)	Vertical geophone	Horizontal geophone (x2 orthogonal)
LC2000 2-channel	X		X	
LC2000 4-channel	X		X	X
LC2000 Broadband (BB)		X	X	X
LASSI	X		X	X
LC4x4	X		X	X
LC4x4 Long-term deployment		X	X	X

Table 3: OBS instrument names and sensor configurations.

The OBS instruments were prepared in the Seismik/Abfül laboratory, and deployed and recovered from the starboard side of the main deck using a crane (Figure 10). There was sufficient space on deck to have up to four instruments lined up simultaneously, ready for direct deployment.

Figure 10: The location of the Seismik/Abfül laboratory and the deck area from which the OBS instruments were deployed and recovered.

LC2000 instruments (OBIC/IPGP)

Three configurations of LC2000 instruments were deployed: 2-channel comprising a hydrophone and a vertical geophone; 4-channel comprising a hydrophone and three-component geophone (one vertical and two orthogonal horizontal); 4-channel comprising a differential pressure gauge and a broadband geophone package (Figure 12).

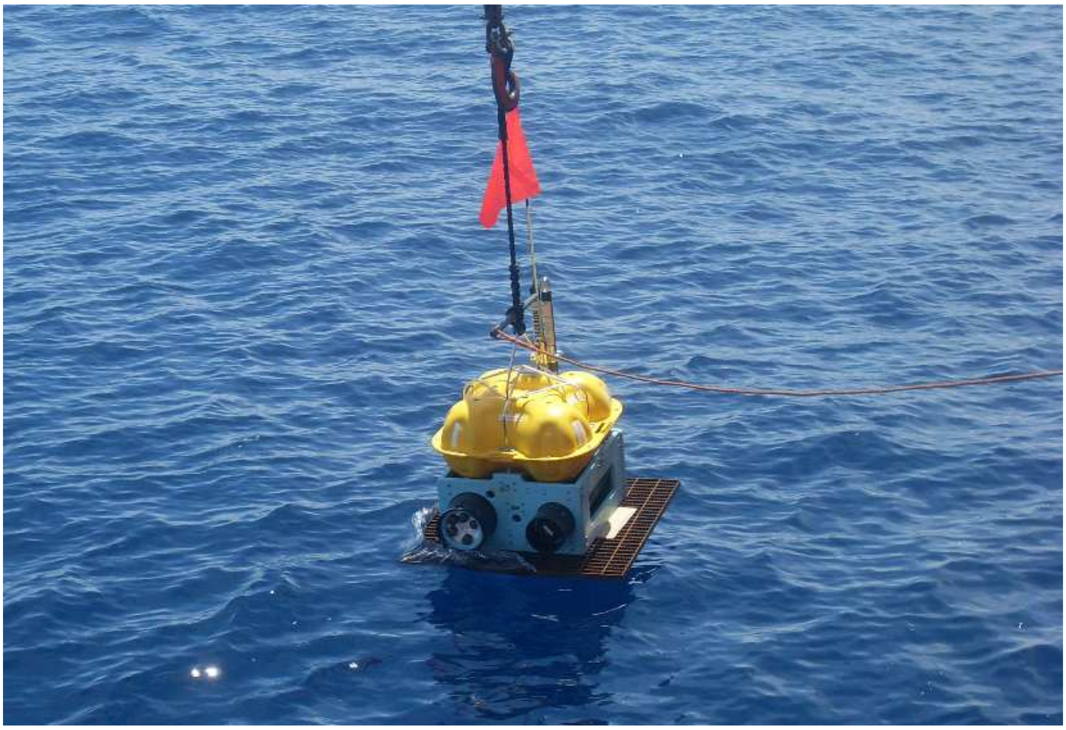

Figure 11: An LC2000 instrument being deployed. The blue section contains the data logger (left cylinder) and the release tube (right cylinder); the hydrophone, geophone and release mechanism are located between the cylinders. The yellow section contains four glass spheres for flotation and a flag, strobe light and radio beacons are attached to the top. Photo by D. Sobaruddin.

Figure 12: The LC2000 broadband (BB) instrument being deployed. This instrument has many components in common with an LC2000: the data logger (right white cylinder); the release tube (centre cylinder); flotation (yellow packages, double that of an LC2000); flag, strobe light and radio beacons. In addition, the broadband instrument has the trillium sensor in a separate pressure case (green sphere, right) and an additional battery package (left white cylinder). Photo by L. Beguery.

Data logger specifications for the LC2000 (all models):

Data type:	24 bit	
Sampling rates:	4-channels	@ 32.25/64.5/125/250 Hz
	2-channels	@ 500 Hz
	1-channel	@ 1000 Hz
Data storage:	3.5" hard drive (9 GB)	
Clock:	Seascan MCXO SISMTB4SC	

Mechanical specifications for the LC2000 2- and 4-channel:

Dimensions: 1m x 1m x 1m
Maximum depth rating: 6000 meters
Weight:

In air without drop weight: 72 Kg
In air with drop weight: 110 Kg
In water without drop weight: -14 Kg
In water with drop weight: 19 Kg

Mechanical specifications for the LC2000 Broadband (BB):

Dimensions: 1m x 1.5m x 1.30m
Maximum depth rating: 6000 meters
Weight:

In air without drop weight: 230 Kg
In air with drop weight: 310 Kg
In water without drop weight: -15 Kg
In water with drop weight: 40 Kg

Sensor specifications for the LC2000:

Hitech HYI-90-U hydrophone (LC2000 2-channel and 4-channel)
Mark Products L-22E geophone (LC2000 2-channel only)
Mark Products L-28LB geophone (LC2000 4-channel only)
Differential pressure gauge (LC2000 BB only)
Nanometrics Trillium T240 broadband geophone (LC2000 BB only)

Note: The L-28LB geophones in the OBIC and IPGP LC2000 4-channel instruments use a slightly different mechanism to level the package and different pressure cases; in other respects they are fundamentally identical.

The frequency response for the geophone sensors are shown in Figure 13, Figure 14 and Figure 15. The frequency response for the hydrophone sensor was not available.

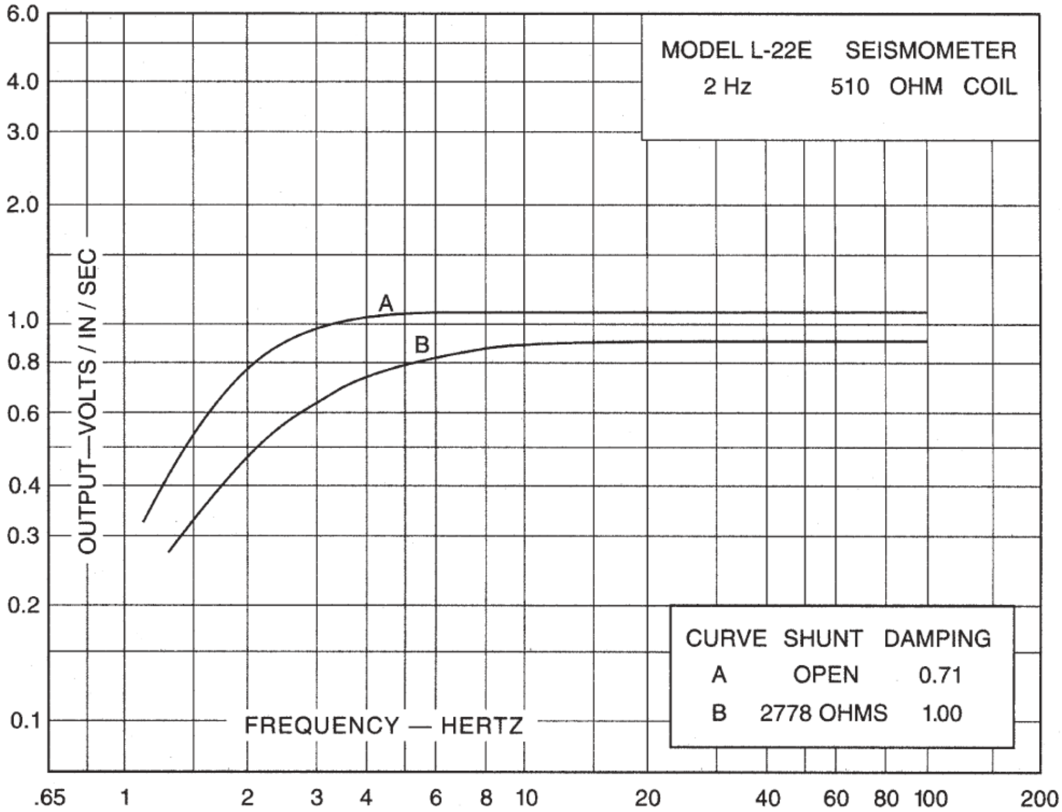

Figure 13: Frequency response for the Mark Products (Sercel) L-22E geophone (curve A) used in the 2-channel LC2000 instruments.

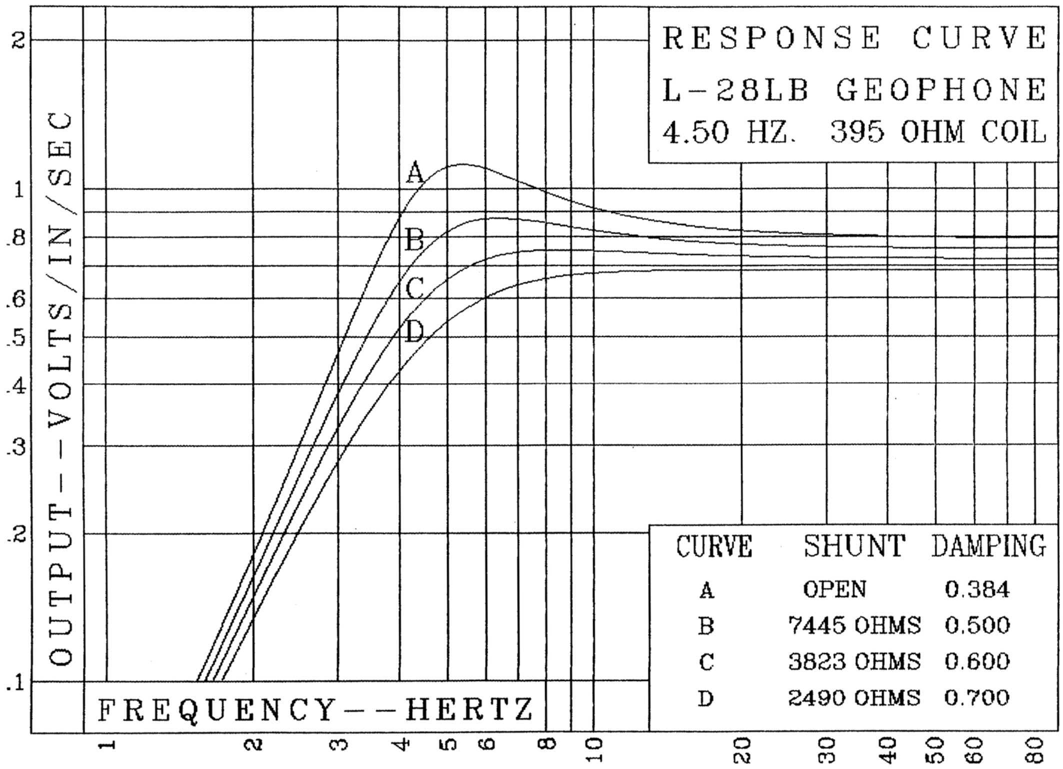

Figure 14: Frequency response for the Mark Products (Sercel) L-28LB geophone (curve A) used in the 4-channel LC2000 instruments.

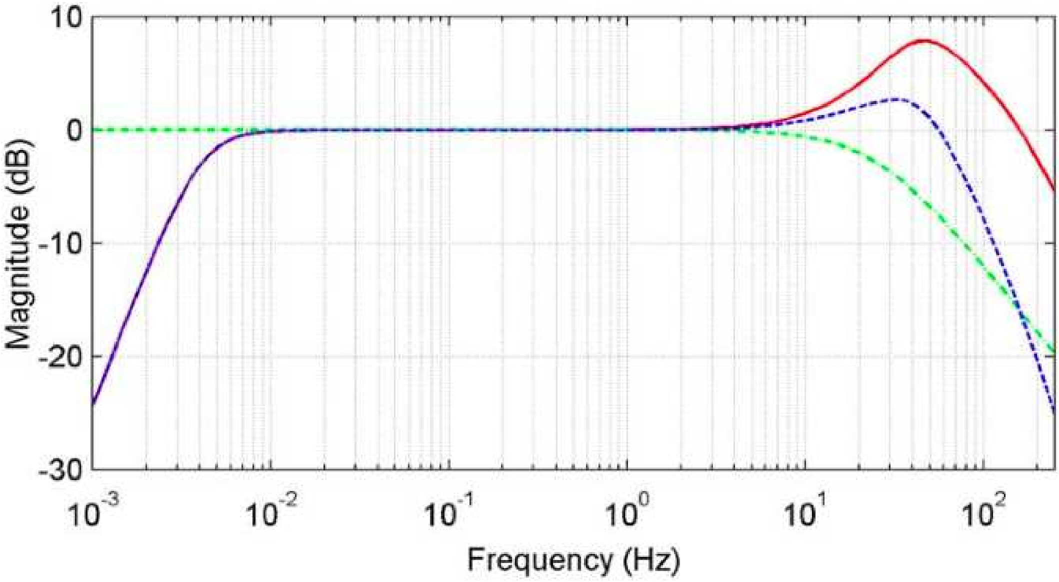

Figure 15: Frequency response for the Nanometrics Trillium T240 geophone used in the 4-channel LC2000 broadband (BB) instrument.

LASSI (OBIC)

The LASSI (Large Aluminium Seafloor Seismic Instrument; Figure 16) uses virtually the same logger as the LC2000s. The main difference is an additional pre-amp board and the three orthogonal geophones mounted internally in a self-levelling case in the bottom of the pressure vessel.

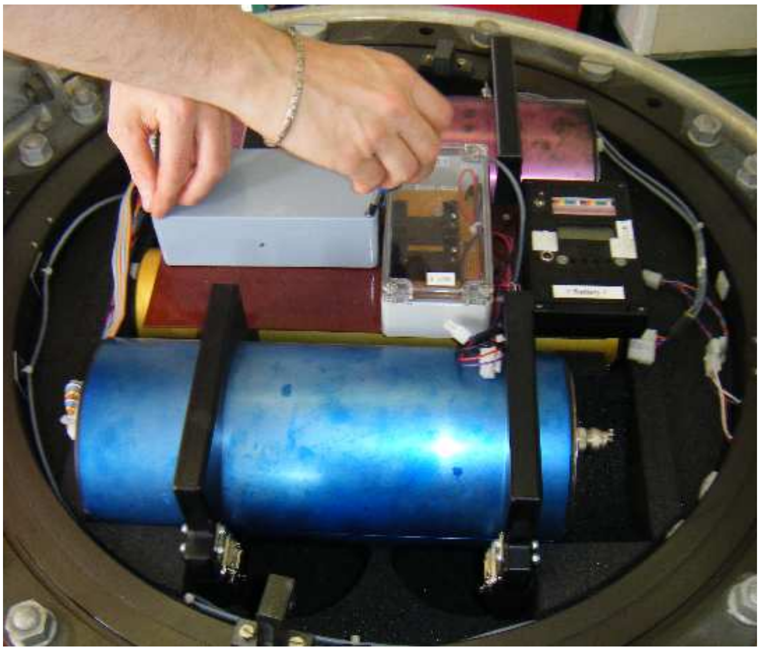

Figure 16: The LASSI OBS instrument. Inside the pressure case (left photo; O. Lewis) the data logger is modified from a 4-channel LC2000 split into two shorter tubes (blue and purple) with an additional hydrophone pre-amp (grey box) and the release electronics (gold tube, obscured); the geophone is beneath the electronics package. The LASSI is deployed (right photo; D. Sobaruddin) with a concrete anchor weight above which is wrapped a rope stray line that deploys when the instrument releases the anchor. The acoustic transducer is visible as an inverted cone above the pressure case, along with strobe light and radio beacons.

Data logger specifications for the LASSI
As LC2000 specifications

Mechanical specifications for the LASSI:
Dimensions: 1m x 1m x 1.35m
Maximum depth rating: 6000 meters
Weight:
  In air without drop weight: 195 Kg
  In air with drop weight: 263 Kg
  In water without drop weight: -25 Kg
  In water with drop weight: 14 Kg

Sensor specifications for the LASSI:
Benthos AQ-11 hydrophone with AQ-202 preamp
Mark Products L-18B geophone

The frequency response for the geophone sensor is shown in Figure 17. The frequency response for the hydrophone sensor was not available.

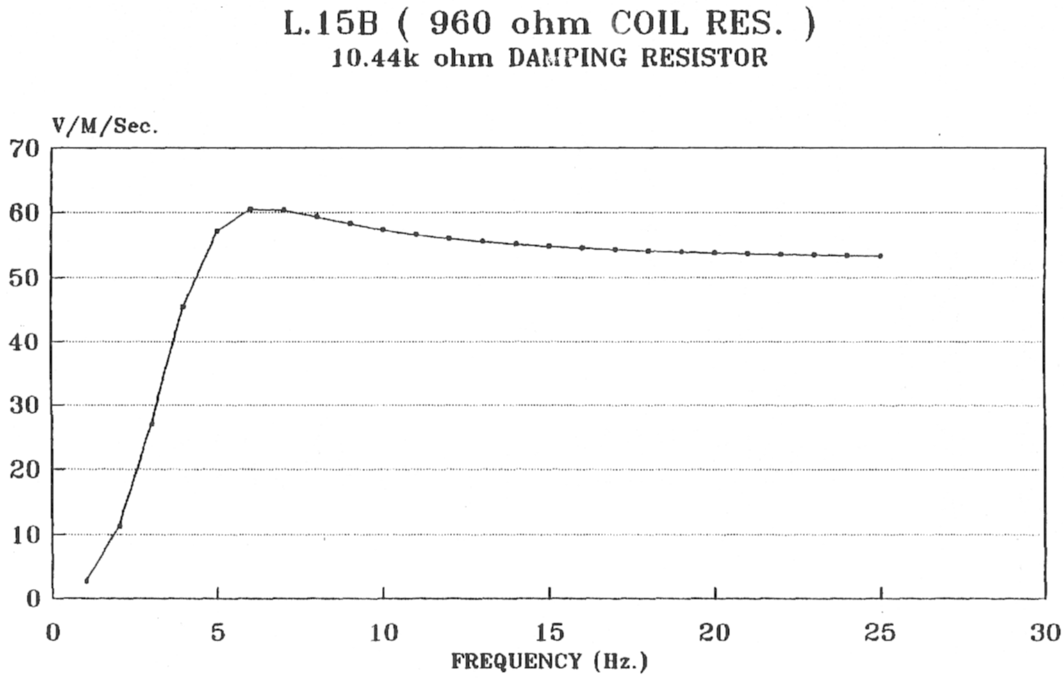

Figure 17: Frequency response for the Mark Products (Sercel) L-18B geophone used in the LASSI instruments.

LC4x4 instruments (OBIC)

The LC4x4 loggers represent the latest development of the LC-OBS family. The physical design of the instrument is largely unchanged, using the same pressure tubes and sensor package as the LC2000 4-channel OBS. However, the data logger has undergone a major revision: the electronic package is considerably smaller compact; the hard disk drive has been eliminated for data storage, replaced by solid state Compact Flash (CF) memory cards (). These advances mean that the LC4x4 has more space in the pressure case for batteries and uses less power than the LC2000, vital improvements for long-term deployment.

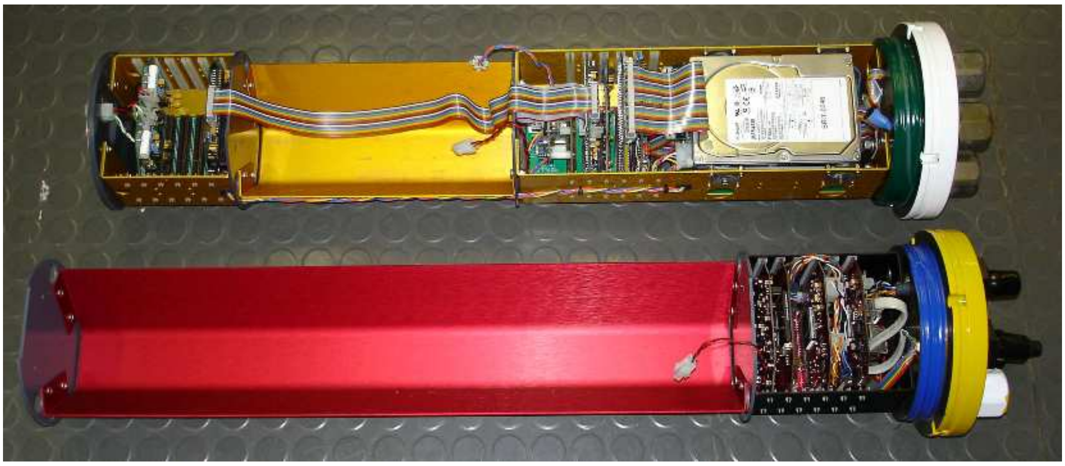

Figure 18: An LC2000 2-channel logger (top) and an LC4x4 logger (bottom) without pressure tubes. The LC4x4 electronics package is considerably smaller than that of the LC2000 and eliminates the use of a hard disk drive (right-hand end with a white sticker). The extra spare space is available to be packed with batteries for long-term deployment. Note that the LC4x4 logger fits inside the same pressure tube as the LC2000 logger – the LC2000 data logger requires external connectors at both ends of the tube, the LC4x4 uses only connectors at one end and can therefore be slightly longer.

Data logger specifications for the LC4x4 (all models):

Data type:	24 bit
Sampling rates:	4-channels @ ≤4000 Hz
Data storage:	Compact Flash (24 GB)
Clock:	Seascan MCXO SISMTB4SC

Mechanical specifications for the LC4x4 (standard deployment):

Dimensions: 1m x 1m x 1m
Maximum depth rating: 6000 meters
Weight:

- In air without drop weight: 72 Kg
- In air with drop weight: 110 Kg
- In water without drop weight: -14 Kg
- In water with drop weight: 19 Kg

Mechanical specifications for the LC4x4 (long-term deployment):

Dimensions: 1.2m x 1.2m x 1.3m
Maximum depth rating: 6000 meters
Weight:

- In air without drop weight: 105 Kg
- In air with drop weight: 185 Kg
- In water without drop weight: -10 Kg
- In water with drop weight: 25 Kg

Sensor specifications for the LC4x4:

Hitech HYI-90-U Hydrophone (standard deployment)

Mark Products L-28LB geophone (standard and long-term deployment)
Differential Pressure Gauge (long-term deployment)

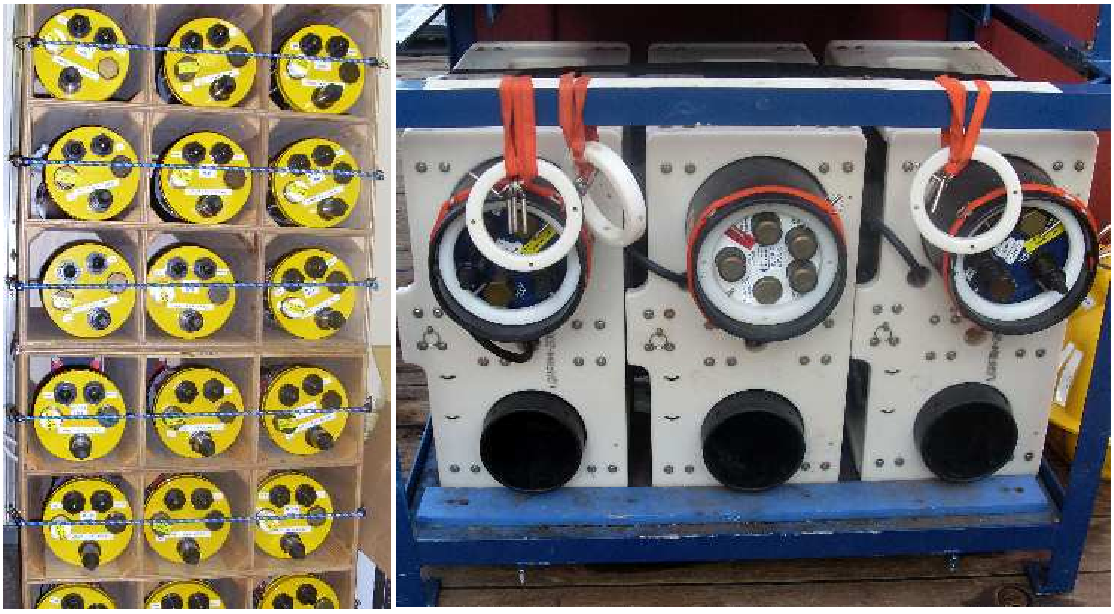

Figure 19: The LC4x4 OBS instruments. British LC4x4 loggers (left) are distinguished from LC2000 loggers by yellow end caps. US LC4x4 loggers, hired by OBIC, have blue end caps (right; an OBIC LC2000 is lurking in the middle deployment frame). Photos by D. Sobaruddin.

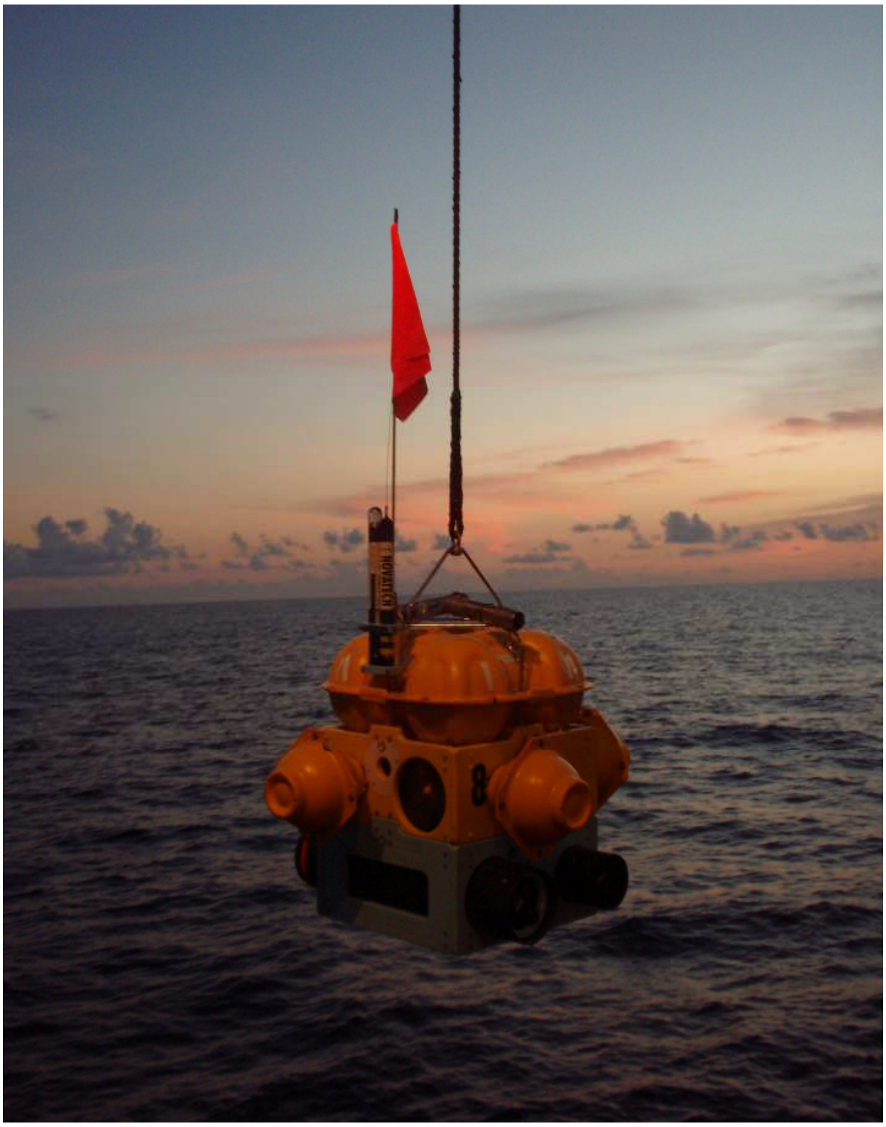

Figure 20: An LC4x4 long-term instrument. This instrument is being tested for buoyancy without an anchor weight and with a pair of 5 kg depressor weights (borrowed from the CTD) attached horizontally on top of the instrument. The blue section is similar to the other LC instruments but without a hydrophone. The yellow middle section contains a Differential Pressure Gauge and extra buoyancy to compensate for the different sensor and the extra batteries required to run the instrument for nearly a year.

Sound-Velocity (SVP) and Current-Temperature-Density (CTD) probes

Prior to starting acquisition of swath bathymetry, an acoustic velocity profile of the water column was measured using both a Sound-Velocity Probe (SVP) and a Current-Temperature-Density probe (CTD).

The SVP instrument (Figure 21) was an Applied Microsystem LTD SVPlus, which uses an acoustic transducer to directly measure the speed of sound through water.

The CTD instrument (Figure 22) was a Sea-bird Electronics Carousel Water Sampler fitted with an SBE 911plus CTD system; the entire water sampler frame was deployed although none of the bottles were used. The CTD provides data for water pressure, temperature, salinity, conductivity, density, and acoustic velocity.

The SVP and CTD were deployed simultaneously on a single winch cable from the starboard extending gantry; the CTD, being substantially heavier, was placed at the end of the cable and the SVP was attached ~30 m above it. Both instruments have an integral data logger and calculate their depth using a pressure sensor. The cable-out measurement on the winch was zeroed when the CTD was at the surface and then a length of cable, appropriate for the water depth, was run out.

Figure 21: The Applied Microsystems SVPlus sound-velocity profiler being recovered. The winch cable extends a further 30 m below this instrument, with the CTD (Figure 22) on the end. Photo by D. Sobaruddin.

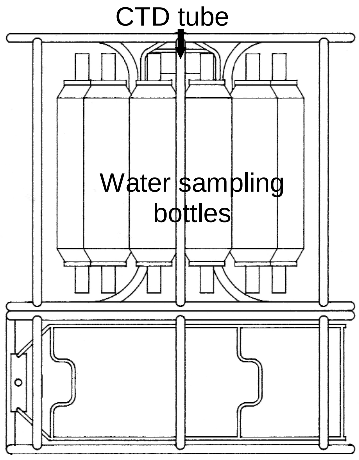

Figure 22: The Sea-bird Electronics Carousel Water Sampler and 911plus CTD being recovered (left), and in schematic form (right); the CTD is in a vertically oriented tube located in the centre of the water sampling bottles. The water sampling system was not used during SO198-1. Photo by D. Sobaruddin.

Expendable Bathythermographs (XBTs)

Expendable bathythermograph probes provide a measure of water temperature versus depth, which is used to calculate the acoustic velocity structure of the water beneath the vessel. The acoustic velocity structure of the water column is the main control on the path followed by any acoustic energy produced by equipment located on, or towed by, the vessel including the swath bathymetric system and the seismic airguns. An XBT probe was launched after the deployment of each OBS instrument in order to provide an even distribution of measurement locations over each survey area.

An XBT probe consists of a weighted temperature sensor, hydro dynamically shaped to descend at a constant known velocity. The probe has a metal nose that provides a grounding path to the data acquisition system on the ship, which is triggered when the probe hits the water. Temperature is measured with an integrated thermistor and sent to the data acquisition system along a two-conductor insulated wire. Probe depth is calculated from the time elapsed since the probe entered the water. Acoustic velocity is calculated from temperature using Equation 1 (Chen and Millero, 1977; Fofonoff and Millard, 1983), which also requires the salinity of the water. Since salinity is not measured by an XBT, an average value of 35 ppt was estimated from the CTD drop (see previous section).

$$Velocity = C + (A + B \times \sqrt{S} + D \times S) \times S$$

Equation 1

Where:

$$salinity(S) = 35\,ppt$$
$$pressure(p) = depth \times 3.2808 \times 0.03048$$

$$A = ((A_3 p + A_2)p + A_1)p + A_0$$
$$A_0 = (((-3.21t \times 10^{-8} + 2.006 \times 10^{-6})t + 7.164 \times 10^{-5})t - 0.01262)t + 1.389$$
$$A_1 = (((-2.0122t \times 10^{-10} + 1.0507 \times 10^{-8})t - 6.4885 \times 10^{-8})t - 1.258 \times 10^{-5})t + 9.4742 \times 10^{-5}$$

$$A_2 = ((7.988t \times 10^{-12} - 1.6002 \times 10^{-10})t + 9.1041 \times 10^{-9})t - 3.9064 \times 10^{-7}$$
$$A_3 = (-3.389t \times 10^{-13} + 6.649 \times 10^{-12})t + 1.1 \times 10^{-10}$$

$$B = B_0 + B_1 p$$
$$B_0 = -0.01922 - 4.42t \times 10^{-5}$$
$$B_1 = 7.3637 \times 10^{-5} + 1.7945t \times 10^{-7}$$

$$C = ((C_3 p + C_2)p + C_1)p + C_0$$
$$C_0 = (((3.1464t \times 10^{-9} - 1.478 \times 10^{-6})t + 3.342 \times 10^{-4})t - 0.0580852)t + 5.03711)t + 1402.388$$
$$C_1 = (((-6.1185t \times 10^{-10} + 1.3621 \times 10^{-7})t - 8.1788 \times 10^{-6})t + 6.8982 \times 10^{-4})t + 0.153563$$
$$C_2 = (((1.0405t \times 10^{-12} - 2.5335 \times 10^{-10})t + 2.5974 \times 10^{-8})t - 1.7107 \times 10^{-6})t + 3.126 \times 10^{-5}$$
$$C_3 = (-2.3643t \times 10^{-12} + 3.8504 \times 10^{-10})t - 9.7729 \times 10^{-9}$$

$$D = 1.727 \times 10^{-3} - 7.9836p \times 10^{-6}$$

XBT launcher and data acquisition system

The XBT system comprised of a hand-held launcher (Figure 23) and Lockheed Martin Sippican, Inc. MK21 I/O module (serial number 00157, running June 14th 2007 firmware) connected via USB to the same PC used to run the *Caris HIPS and SIPS* swath bathymetry processing software (Figure 24).

Figure 23: The XBT hand-held launcher ready with a T-7 probe in its launch tube (bottom), and an unused T-5 probe (top).

The data acquisition software was WinMK21 SURFACE version 2.10.1 that includes MK21COEF version 2.9.1 and MK21AL version 2.13.1. The software was configured to automatically save an Export Data File (EDF) and automatically backup data as it was acquired. The workstation was connected to the vessel's NMEA GPS feed to provide the location of each launch. The clock on the workstation was manually synchronised to GPS at the start of the cruise and provided the time-tag for each launch.

The hand-held launcher was connected to a deck connection box located on the main deck directly behind the *luftpulserstation* (Figure 25). The probes were deployed over the port rail adjacent to the deck connection box (Figure 26).

The launch of each probe creates two files on the workstation, for example:

T7_00051.RDF	–	WinMK21 format file
T7_00051.EDF	–	Export Data File in plain text format

The first two characters in the name identify the probe type followed by the *Sequence Number*, which increments with the deployment of every probe regardless of type. The EDF file contains all the

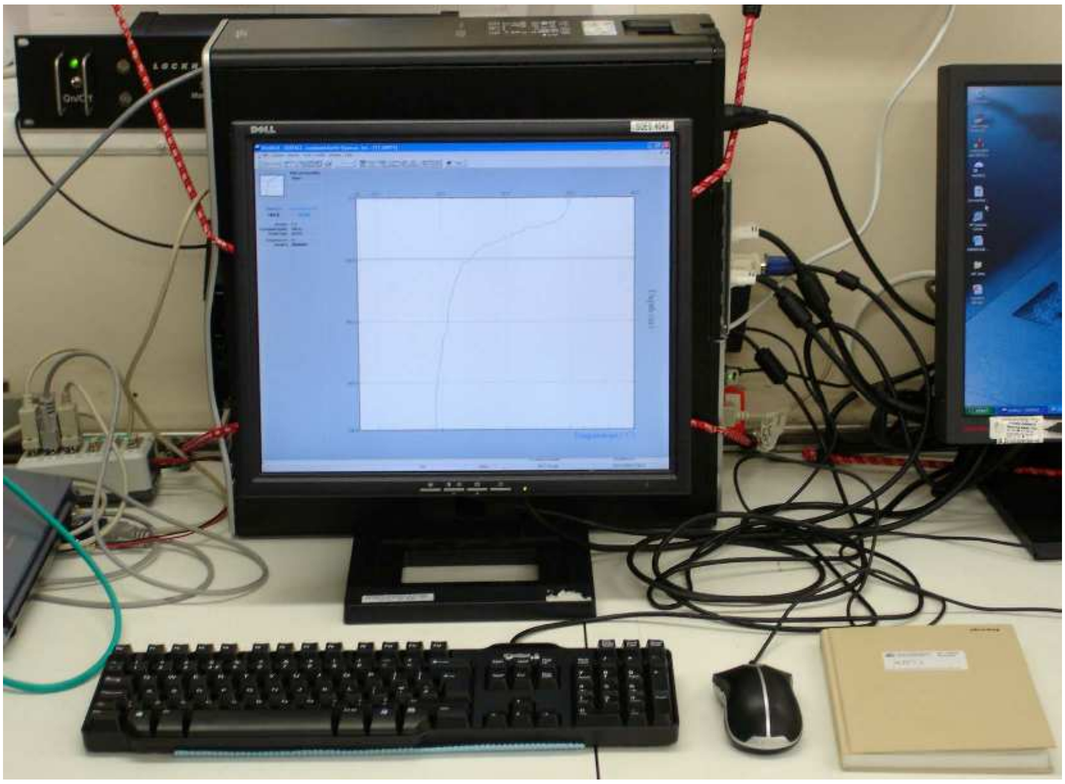

Figure 24: The XBT data acquisition system with the WinMK21 SURFACE software displaying the temperature profile resulting from the launch of a T-7 probe to the maximum depth of 760 m. The MK21 I/O module is visible behind the workstation, toward the top-left of the picture.

Two types of XBT probe were deployed during SO198-1: T-7 probes capable of providing data to a maximum depth of 760 m; and T-5 probes with a maximum depth of 1860 m (Figure 23). Specifications for each type of probes, provided by the logging software, dictated that T-5 probes could only be deployed while the vessel was travelling at less than 6 knots through the water; T-7 probes could be deployed at up to 15 knots, i.e. at any operating speed for the Sonne.

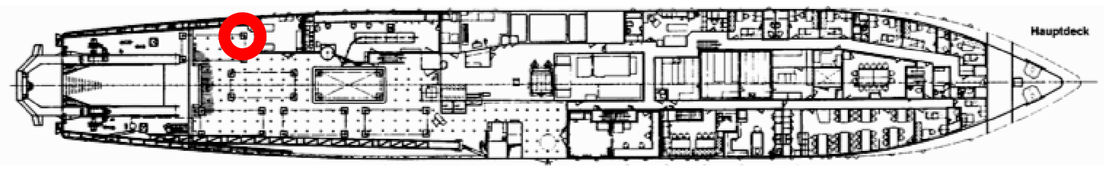

Figure 25: The launch location for XBT probes, on the main deck directly behind the *luftpulserstation*.

Figure 26: An XBT probe being deployed using the hand-held launcher. Photo by P. Barton.

Operational issues with the XBT system

1. The relatively short length of cable hard-wired to the launcher dictated that the probes could not be launched over the stern of the vessel, which would be the most desirable location to ensure a clear path for the trailing signal cable while the vessel is underway. A 10-metre extension cable between the launcher and the deck connection box would solve this problem.
2. The deck connection box is not rain/waterproof.
3. The WinMK21 has a couple of issues:
    a. The sequence number, displayed when loading a new probe, is one less than will be written to the final data file for that probe.
    b. The software expects administrative rights on the workstation and a normal user is not permitted to write data files to the default storage locations.

Swath bathymetry (Simrad EM120)

The Simrad EM120 system acquires swath bathymetric and backscatter data. The EM120 system is a 12 kHz multibeam echosounder designed for deep-water mapping. It forms 191 beams using of an array of transducers built into the hull of the Sonne (Figure 27).

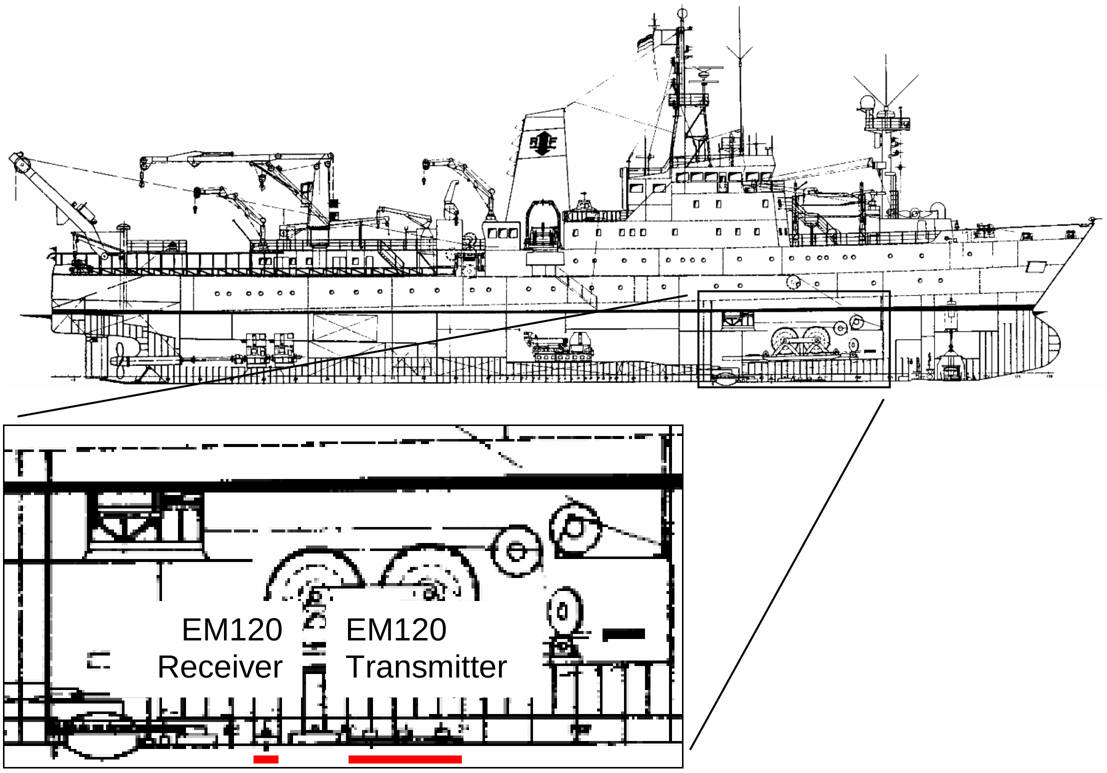

Figure 27: Location of the EM120 transmitter and receiver transducers in the Sonne's hull.

The EM120 system incorporates data from the GPS navigation system and the Motion Reference Unit (MRU) to account for the location and orientation of the ship (Figure 28). The system provides a 1° beam wid th resulting in a seafloor resolution of, for example, 50 m x 50 m in ~3000 m water depth.

The swath data were loaded into Caris HIPS & SIPS (version 6.1) software for gridding and display using the following scheme:

1. The Caris Conversion Wizard was used to load the raw data
2. A sound-velocity correction was applied based on the profile acquired by XBT sequence number 1 located at OBS site A05 (Figure 60)
3. A zero-tide correction was applied
4. Data were gridded at 50 m and interpolated using a 5x5 grid where at least 10 grid nodes are populated

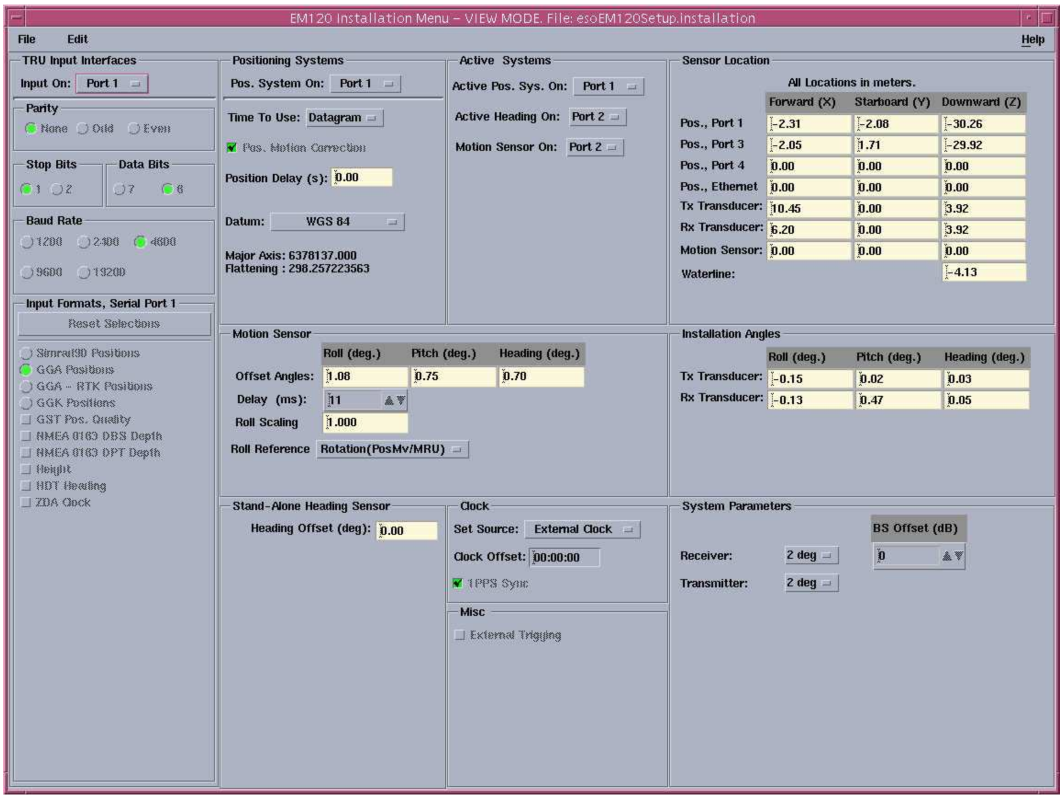

Figure 28: The EM120 Installation Menu, showing the settings used during data acquisition on SO198-1.

Sub-bottom profiler (Parasound)

The *Parasound* system from Krupp Atlas Electronik is a high-resolution sub-bottom profiler fitted to the Sonne. The system is comprised of a transducer unit built into the hull (Figure 29), a heave sensor, and an electronic control, data processing and logging system called *ParaDigMA*.

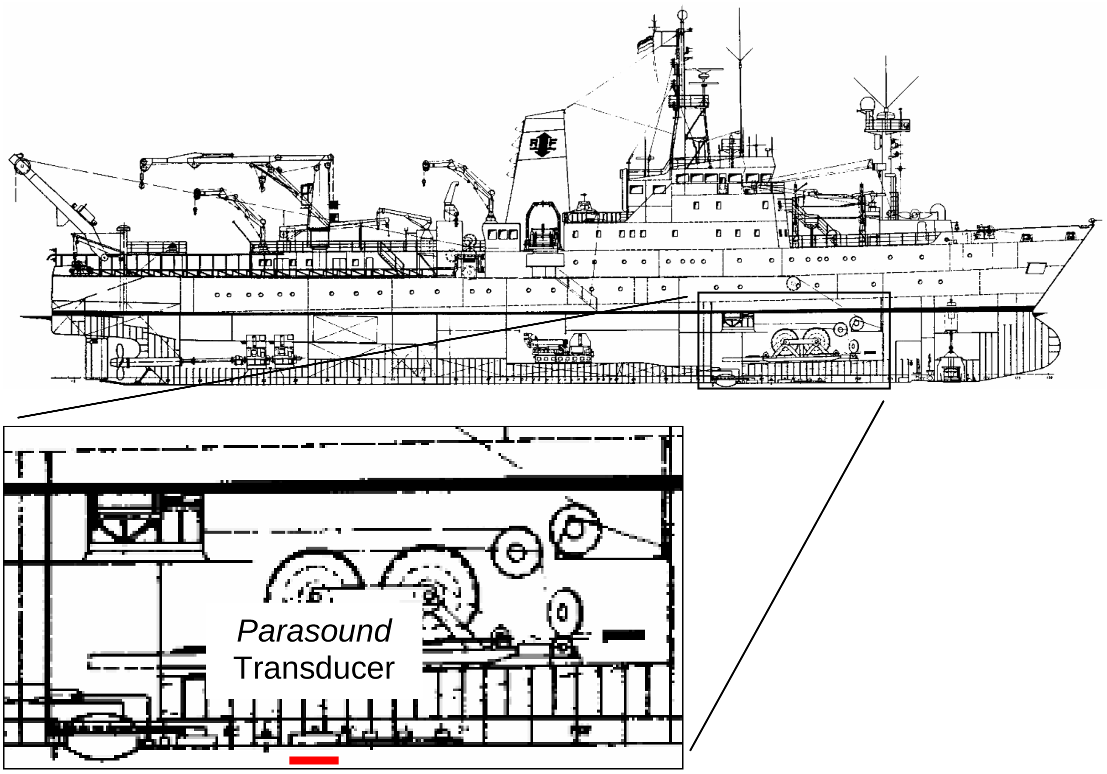

Figure 29: Location of the *Parasound* transducer in the Sonne's hull.

The *Parasound* system uses the parametric effect that results from the non-linearity of the motion of acoustic waves in a fluid when signals with two different frequencies are transmitted simultaneously. One transmission frequency is fixed at 18 kHz while the second can be varied between 20.5 kHz and 23.5 kHz in increments of 0.5 kHz. The parametric signal in the water column has a frequency equal to the difference between the two transmitted frequencies, and this is the signal used for sub-bottom profiling.

The advantage of a parametric signal is that it has a relatively high lateral resolution; the signal is emitted within a cone as narrow as 4° and samples an area of the seafloor with a diameter approximately equal to 7% of the total water depth. The disadvantage of a parametric system is that it cannot detect a signal reflected from a layer dipping at more than 2°; this is a significant problem in areas with steep slopes such as continental margins.

During SO198-1 the second signal was set to a frequency of 22 kHz resulting in a parametric signal with a frequency of 4 kHz. The system was set up to assume an acoustic water velocity of 1.5 km/s. The depth to the transducer was set to 6.5 m in the *ParaDigMA* software; this value is slightly different to that used by the EM120 (4.13 m). The *Parasound* system obtains heave data from the Sonne's MRU and uses its own dedicated pitch and roll sensor to automatically correct the data for the motion of the ship.

A data sample rate of 40 kHz (25µs sample interval) is required to record the high frequency source wavelet. The high data sample rate and large range of depths over which the *Parasound* system can be operated would result in huge volumes of data being produced. To keep the volume of data to a manageable level, the *Parasound* system employs windowed recording. The recording window is 200 m long (10640 samples assuming 1.5 km/s) and the start of the window is set in depth on the Operator Console (Figure 30). Unfortunately the recording window does not automatically track the seafloor reflection and must be adjusted manually by the operator as the water depth changes.

Figure 30: The *Parasound* Operator Console (left), and the *ParaDigMA* data processing and logging system display (right).

Converting *Parasound* data to SEG-Y format

The *Parasound* system stores data in a format similar to SEG-Y where each record consists of a trace header containing pertinent information such as date, time, location, etc., followed by the trace data as a series of floating point numbers. While the trace header does conform to the SEG-Y standard, the extended header (bytes 181-240) is used to store information vital to the use of the data (see Table 4). However, there are a couple of crucial incompatibilities to SEG-Y in the rest of the format:

1. The SEG-Y EBCDIC and binary reel headers are missing from the start of the file.
2. The trace data are stored in a compressed 2-byte integer format.

The trace time-series data format saves data space by separating each sample into a 12-bit mantissa, 1-bit sign, 2-bit exponent used to represent four different gain ranges, and an overflow bit (Figure 31).

Bit number:	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Content:	Ov.	Exponent		Sign		Mantissa									

Figure 31: The compressed 2-byte integer format employed by the *Parasound* system to store each data sample.

The following FORTRAN code, based on the suggested scheme in Appendix B of the ParaDigMA User and Reference manual (Atlas Elektronik GmbH, 1994), was used to convert trace data into an array of 4-byte floating-point numbers:

```
      program paraconv
      integer a, samples
      integer*2 idata
      real*4 output
      open(unit=10,file='wiggle_para',form='unformatted',
    & access='direct', recl=2)
      open(unit=11,file='samples')
      read(11,*) samples
      do 20 a=1,samples,1
        read(10, rec=a) IDATA
        call decpack(idata, output)
        write(6,*) output
20    continue
      end

      SUBROUTINE DECPACK ( IDATA, VOLT )
      REAL*4 F, VOLT
      INTEGER*2 IDATA, NGESAMT, IA, J, IBB
      INTEGER*2 IMANT, ISIG, IRANG, IB
      DIMENSION F(4)
      SAVE F
      DATA F / 256., 32., 4., 1. /
      IBB = IDATA
      IB = IBCLR ( IBB,15 )
      IMANT = MOD ( IB,4096 )
      ISIG = MOD ( IB / 4096 , 2 )
      IRANG = IB / 8192
      VOLT=FLOAT(IMANT)*(2.5/F(IRANG+1))*FLOAT(1-ISIG*2)
      RETURN
      END
```

Trace header values

The *Parasound* system makes extensive use of the trace header in order to store many useful system settings. The full set is listed in Appendix B of the ParaDigMA User and Reference manual (Atlas Elektronik GmbH, 1994), and reproduced in a modified form with the actual start-byte for each header value in Table 4.

Start byte (format)	Value (v=variable)	Description
1 (I4)	v	Shotpoint
5 (I4)	v	Shotpoint
9 (I4)	v	Shotpoint
17 (I4)	0	Source type
29 (I2)	1	Trace indicator: Seismogram
31 (I2)	1	No. of vertically summed traces
33 (I2)	1	No. of horizontally summed traces
35 (I2)	1	Data use: production
37 (I4)	0	Distance source point to receiver group
41 (I4)	0	Receiver group elevation
45 (I4)	0	Surface elevation at source
49 (I4)	0	Source depth below surface
53 (I4)	0	Datum elevation at receiver group
57 (I4)	0	Datum elevation at source
61 (I4)	v	Depth *Parasound* in metres x10
65 (I4)	v	Depth *Hydrosweep* in metres x10
69 (I2)	-10	Scaler (divisor) for depth
71 (I2)	-10	Scaler (divisor) for coordinates
73 (I4)	v	Source coordinate – longitude: in arc seconds x10
77 (I4)	v	Source coordinate – latitude: in arc seconds x10
81 (I4)	v	Source coordinate – longitude: in arc seconds x10
85 (I4)	v	Source coordinate – latitude: in arc seconds x10
89 (I2)	2	coordinates in seconds of arc x10
105 I2)	0	Lag time A
107 (I2)	0	Lag time B
109 (I2)	v	Additional delay in ms
115 (I2)	v	Number of samples
117 (I2)	v	Sample rate in µs
119 (I2)	0	Gain type floating: no
127 (I2)	v	*Parasound* frequency in Hz
129 (I2)	v	*Parasound* frequency in Hz
131 (I2)	v	Signal length in ms
157 (I2)	v	Year
159 (I2)	v	Month x100 + Day
161 (I2)	v	Hour
163 (I2)	v	Minute
165 (I2)	v	Second x100 + hundreds of ms
167 (I2)	2	Time = GMT
181 (I4)	v	*Parasound* – Depth x10 in m
185 (I2)	v	Range in m
187 (I2)	v	Ship's speed x10 in knots
189 (I2)	v	Course [º] x10
191 (I2)	v	Heading [º] x10
193 (I2)	v	Reception window in m
195 (I2)	v	0/1 x10 – parametric mode
197 (I2)	v	Source frequency in kHz x10
199 (I2)	v	No. of pulses x10
201 (I2)	v	Bottom TVC x10
203 (I2)	v	0/1 x10 – NBS mode
205 (I2)	v	NBS frequency in kHz (18/33) x10
207 (I2)	v	NBS opening angle (2/4/20)x10
209 (I2)	v	NBS pulse length (up to 25ms) x10
211 (I2)	v	NBS gain (1-5 for 1, 10, 100, >, >>)
213 (I2)	v	0/1 x10 – Pilot tone mode

Table 4: Parasound SEG-Y header values.

Data processing

A basic processing sequence for *Parasound* data should include a static correction to align the variable recording window in time. The static correction is derived from the *Reception Window* setting, in metres, on the Operator Console, and stored as a 2-byte integer format starting at byte 193 of the trace header. The data benefit substantially from an Instantaneous Amplitude calculation (Taner, Kohler and Sheriff, 1979), which removes the ‘ringyness’ inherent in the raw data although at the expense of all signal polarity (Figure 32).

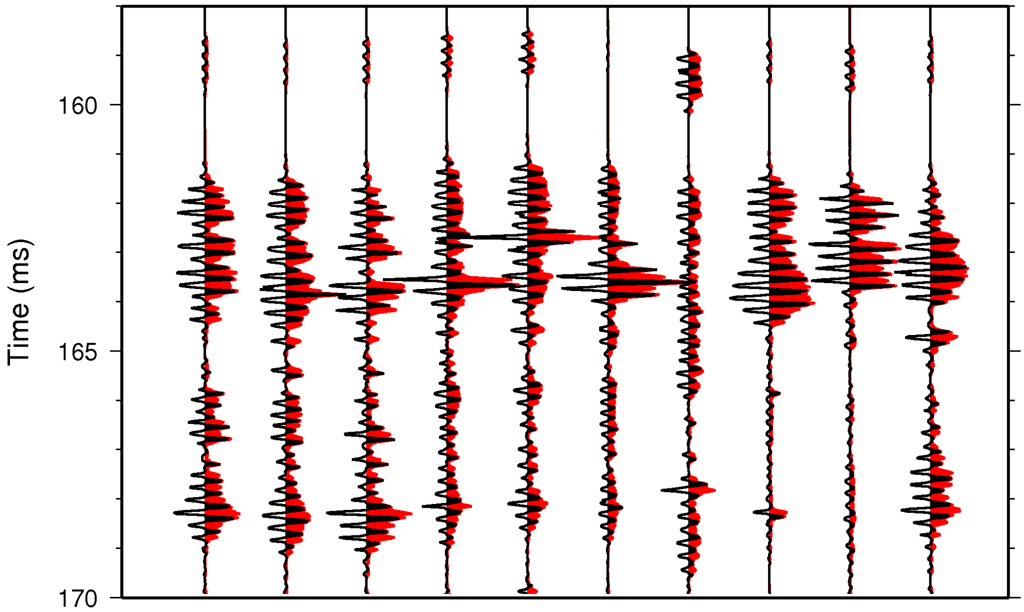

Figure 32: An example of raw *Parasound* data (black) superimposed on the same data after calculating instantaneous amplitude (red).

Gravity meter

Gravity was recorded continuously during SO198-1 on a LaCoste and Romberg marine gravity meter (S40). The meter was installed in the *Gravimeterraum* on deck II of the Sonne (Figure 33). The meter is mounted in a gyro-stabilised platform to keep it level at all times. The meter measures tension on a zero-length spring that is converted to digital gravity using a calibration constant of 0.992 and applies corrections for lateral accelerations. The logged data have a 5-minute averaging filter applied. Data are displayed every 10 seconds on the instruments control console and logged every 1 second to an internal hard disk. The control console could not be connected to the ship's systems and logs data versus an internal time base from a 200 Hz precision oscillator. The data were also logged every 2-minutes using *HyperTerminal* software on a laptop PC connected to the serial output of the console.

Figure 33: The gravity meter S40 (left) installed in the *Gravimeterraum* on deck II of the Sonne with the control and logging console (centre) and the laptop PC used to capture 2-minute gravity data via an RS-232 serial connection (right; on the bench).

Singapore base station tie (Julian Day 124)

The gravity base station tie in Singapore was performed using the LaCoste and Romberg portable gravity meter. Three sets of four measurements were made: (1) on the quay adjacent to the Sonne (Figure 34; 1º27'43.7"N, 103º50'03.2"E measured by handheld GPS); (2) in the Singapore National Museum (Figure 35; 1º17'48.4", 103º50'56.0"E measured by handheld GPS); (3) a repeat measurement back at the quay adjacent to the Sonne. The measurements and time of acquisition are given in Table 5, Table 6 and Table 7. The Singapore National Museum is published as station number 1391 located at 1.29667ºN (1º17'48.012"N), 103.85ºE (103º51'E), altitude 8.20 m, with a gravity value of 978,066.040 mGal.

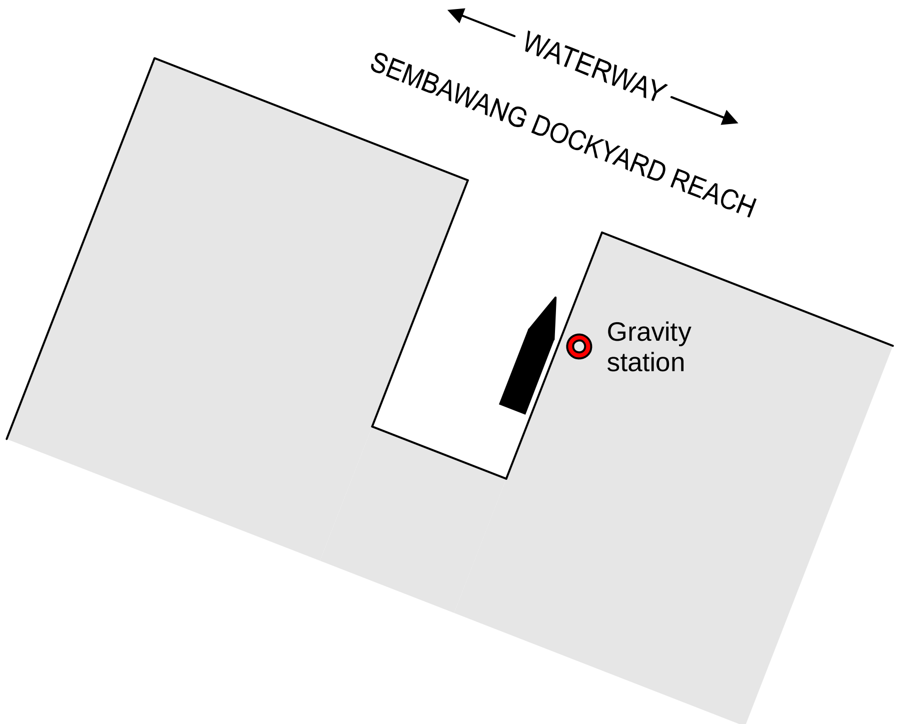

Figure 34: Gravity station location in Sembawang Dockyard (1º27'43.7"N, 103º50'03.2"E measured by handheld GPS), on the quay adjacent to the Sonne.

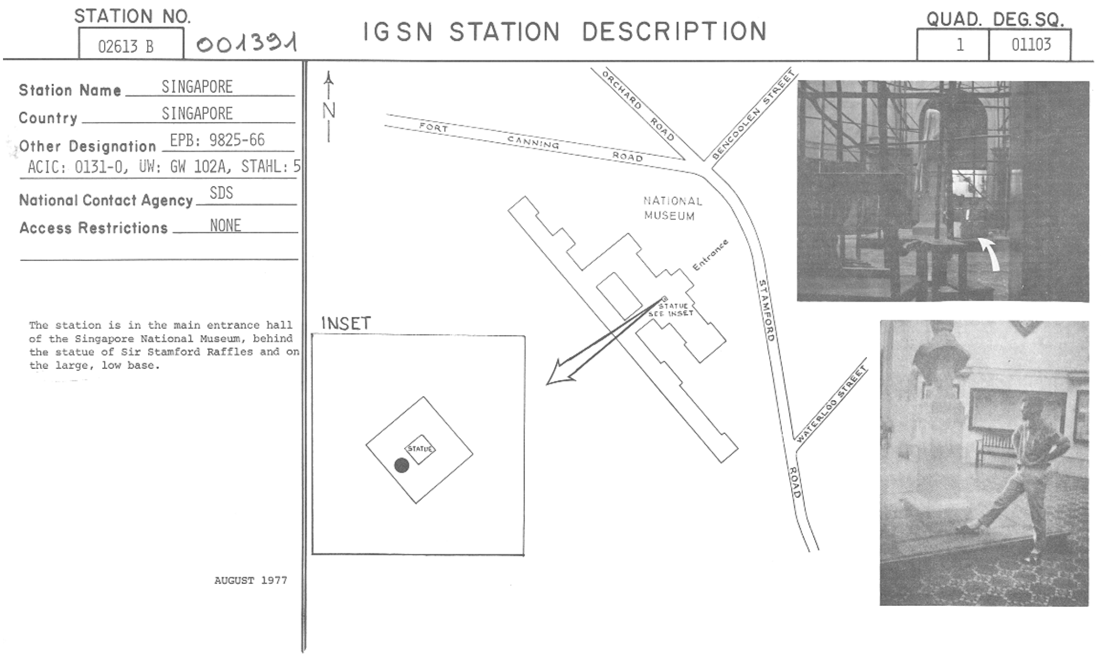

Figure 35: Singapore National Museum base station location

Reading number	Counter reading	Local time	UTC time
1	1636.58	14:46	06:46
2	1636.40	14:48	06:48
3	1636.49	14:50	06:50
4	1636.46	14:53	06:53

Table 5: Sembawang Dockyard reading 1.

Reading number	Counter reading	Local time	UTC time
1	1633.77	15:47	07:47
2	1633.82	15:49	07:49
3	1633.65	15:51	07:51
4	1633.76	15:54	07:54

Table 6: Singapore National Museum.

Reading number	Counter reading	Local time	UTC time
1	1636.55	16:52	08:52
2	1636.67	16:54	08:54
3	1636.12	16:56	08:56
4	1636.65	16:58	08:58

Table 7: Sembawang Dockyard reading 2.

The results of the gravity tie at 08:55 UTC on 03/05/08 (Julian Day 124) are as follows:

Absolute gravity at the quay	=	978068.86 mGal
Free air correction from quay to ship	=	0.84 mGal (3.8 m – 1.1 m)
Absolute gravity at the ship	=	978069.70 mGal
Ship's digital gravity meter reading	=	6312.8 mGal

Cigading base station tie (Julian Day 167)

Two gravity base stations were established in Indonesia prior to cruise SO198, by LIPI. The base stations, CDG1 & CDG2, are both located in the port of Cigading (Figure 36), ~20 km south of Merak.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 36: Location of gravity base stations CGD1 and CGD2 in the port of Cigading. Detailed station locations are given in Figure 37 and Figure 38.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 37: Details for gravity base station CGD1 in Cigading, Indonesia.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure 38: Details for gravity base station CGD2 in Cigading, Indonesia.

Four sets of measurements were taken with the portable LaCoste and Romberg gravity meter: (1) on the quay alongside the Sonne in Merak (6°00’52.3”S, 108°57’28.1”E measured by handheld GPS); (2) at base station

CGD2; (3) at base station CGD1; (4) a repeat measurement back at the quay alongside the Sonne in Merak.

Reading number	Counter reading	Local time	UTC time
1	1710.79	08:00	01:00
2	1710.74	08:03	01:03
3	1710.85	08:05	01:05
4	1710.87	08:07	01:07
5	1710.89	08:09	01:09

Table 8: Merak Dockyard reading 1.

Reading number	Counter reading	Local time	UTC time
1	1713.3	09:37	02:37
2	1713.26	09:38	02:38
3	1713.21	09:39	02:39
4	1713.24	09:40	02:40
5	1713.2	09:41	02:41

Table 9: Cigading base station CGD2.

Reading number	Counter reading	Local time	UTC time
1	1713.06	09:49	02:49
2	1713.16	09:50	02:50

Table 10: Cigading base station CGD1.

Reading number	Counter reading	Local time	UTC time
1	1710.85	10:33	03:33
2	1710.8	10:34	03:34
3	1710.83	10:35	03:35
4	1710.73	10:35	03:35
5	1710.75	10:36	03:36

Table 11: Merak Dockyard reading 2.

The results of the gravity tie at 03:34 UTC on 15/06/08 (Julian Day 167) are as follows:

Absolute gravity at the quay	=	978145.57 mGal
Free air correction from quay to ship	=	0.775 mGal (3.6 m – 1.1 m)
Absolute gravity at the ship	=	978146.35 mGal
Ship's digital gravity meter reading	=	6388.2 mGal

The total drift values for SO198-1 are thus:

Total drift	=	1.250881494 mGal
Drift rate	=	0.029312859 mGal/day

Gravity meter clock drift

The clock on the gravity meter was found to drift significantly versus UTC time against which all other systems on the ship were logged. Since the gravity data was logged on meter itself, the time offset between the meter's clock and UTC was measured and recorded approximately every hour during SO198-2. This was achieved by observing the 10-second update interval on the gravity meter's logging console and, using a watch or stopwatch, synchronising the update to a UTC display provided by a laptop PC in the *Gravimeterraum*, connected to the ship's clock. With practice, the time offset measured is estimated to be correct to ~1 second. The gravity meter's clock tended to lose time relative to UTC. The measured time offset is shown in Figure 39.

It should be noted that prior to Julian Day 126, when the gravity meter clock was synchronised to UTC for the entirety of the experiment, the instrument's clock was incorrectly set to Julian Day-1. The clock was therefore incorrectly set for the base station tie.

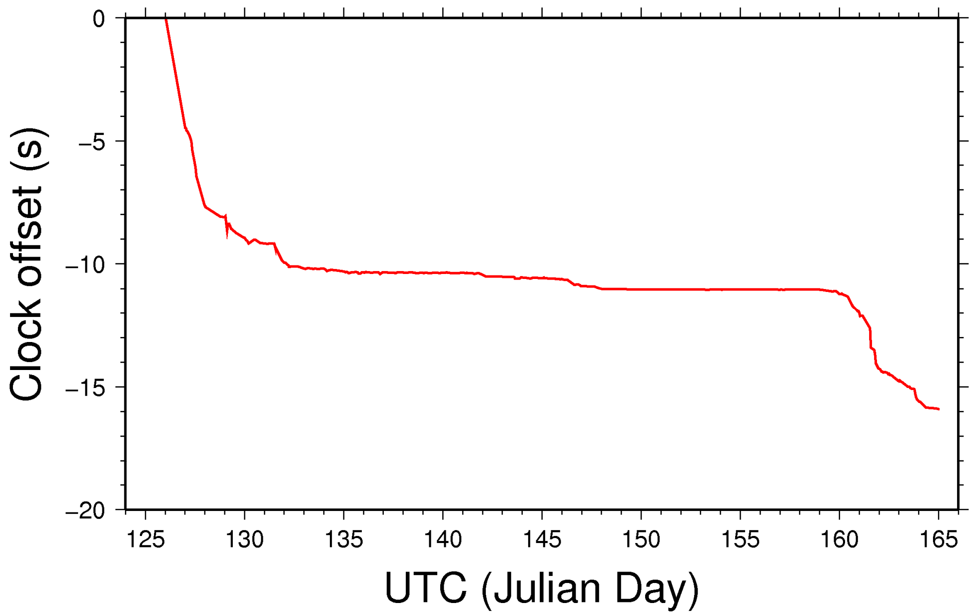

Figure 39: Time offset between the gravity meter clock and UTC during SO198-1. A negative offset means that the instrument's clock is behind UTC.

Gravity data reduction

The 10-second gravity data logged on the S40 internal disk was post-processed using the following scheme:

1. Meter clock drift corrected to UTC
2. Meter gravity drift corrected and resampled at 10 s interval UTC
3. Data merged with 1-second navigation data filtered with a 5-second Gaussian filter
4. Eötvos correction calculated using 1-second course and speed over ground data filtered with a 30-second median filter
5. Eötvos correction filtered using a 5-minute Gaussian filter and applied
6. Remove the regional gravity anomaly using the International Gravity Formula (IGF 1967).

Magnetometer

A *SeaSPY* proton precession magnetometer system was used to measure the total magnetic field. The system consists of a fish unit containing an Overhauser sensor, a deck mounted winch and tow cable, a *Smart Transceiver* interface module and a computer running *SeaLINK* software to visualise and log the data (Figure 40).

The logging PC was connected to the vessel's NMEA GPS feed to provide navigation information. Data were acquired at 1 Hz sampling. The clock used to tag the logged data, located in the *Smart Transceiver* interface, was manually synchronised to GPS time at the start of the survey.

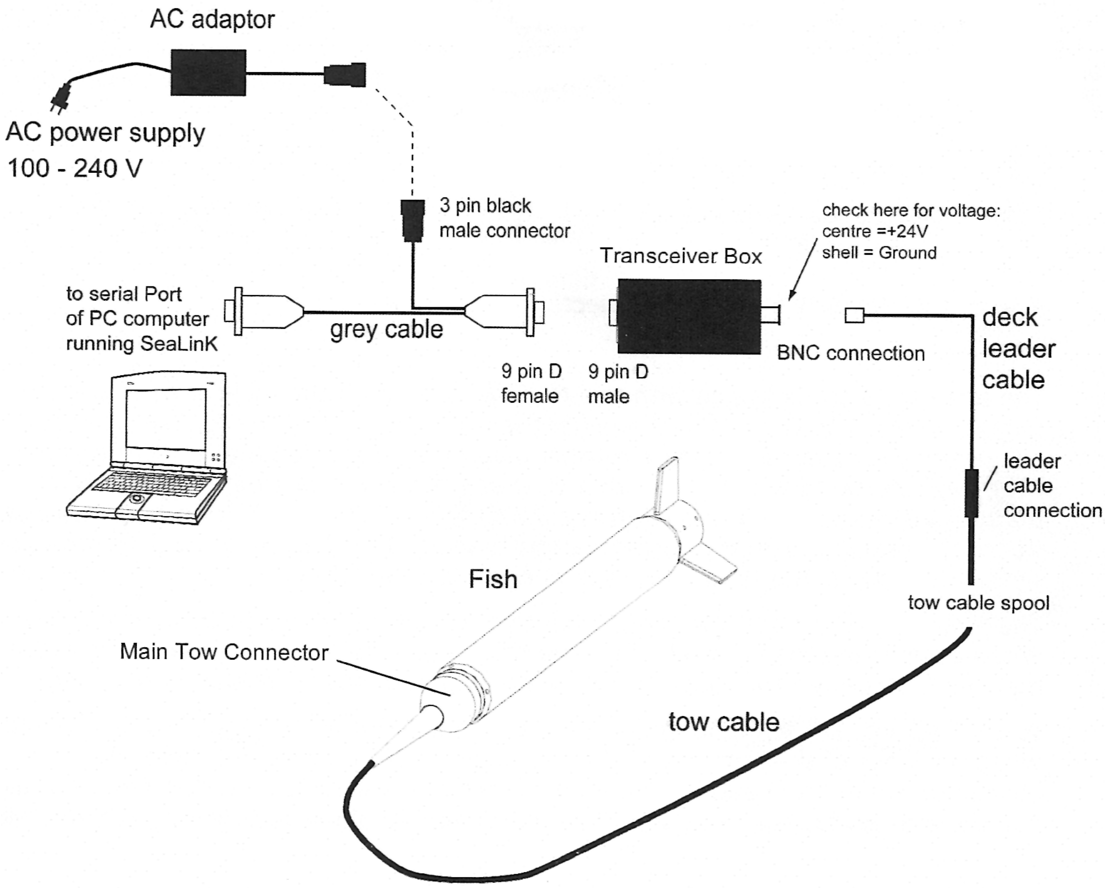

Figure 40: The *SeaSPY* total field magnetometer system (after Marine Magnetics Corporation, 2008).

Tow configuration

The fish was towed, using a set of pulley wheels tied to the end of the boom on the back-boat deck, on a 300 m cable from an electric winch attached to the deck (Figure 41). The location of the winch drum and the end of the boom that formed the towing point were measured using a tape (Figure 42 and Figure 43).

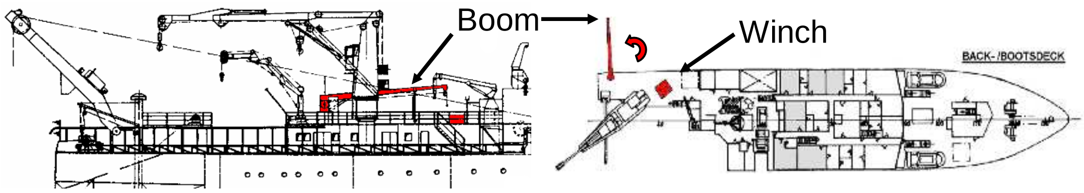

Figure 41: Location of the magnetometer winch and deployment boom on the port side of the back-boat deck, one deck above the main deck.

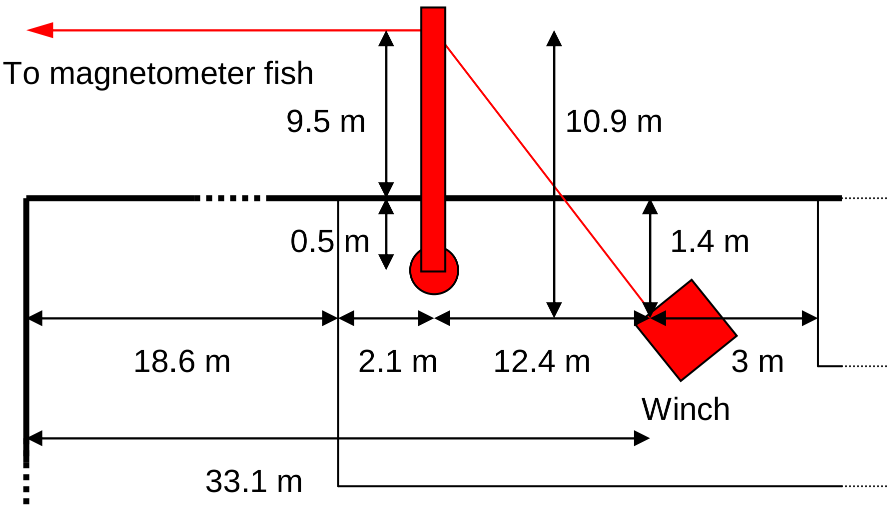

Figure 42: The location of the magnetometer winch and the towing point at the end of the rotating boom on the port side of the back-boat deck. Distances are given in metres relative to the tow point at the end of the extended boom, the point at which the cable leaves the winch drum, and the stern and port rail of the Sonne.

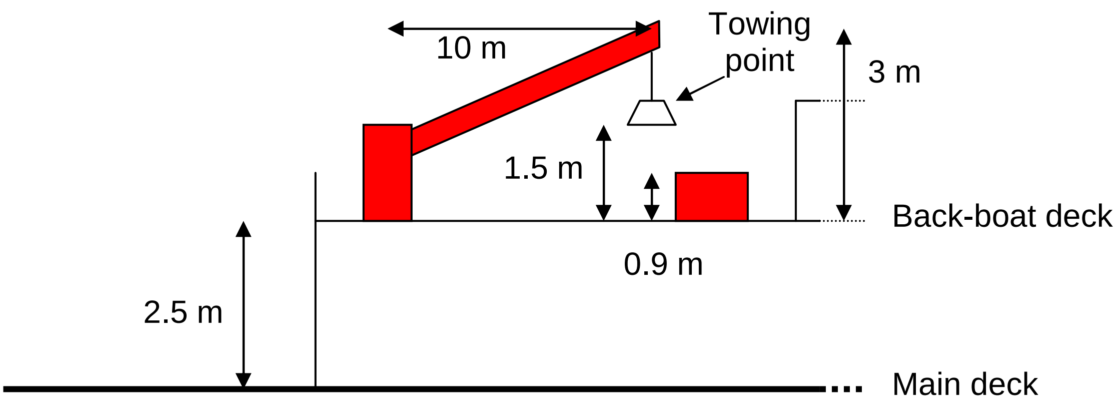

Figure 43: The height of the magnetometer winch, cable on the winch drum, and the towing point on the boom (not extended in this diagram) above the main deck of the Sonne. The water line is a further 3.5 m below the main deck.

Of the 300 m of tow cable, 19.5 m remained on the winch drum (circumference 0.75 m x 26 turns) and 16.5 m lies between the winch and the towing point on the end of the boom, leaving 264 m of cable between the towing point and the fish. At a nominal tow speed of 5 kt the fish will tow at ~7.5 m with 120 m of tow cable (Figure 44); assuming the same rate of increase in tow depth with cable length at 3 kt (Figure 45) and extrapolating to 264 m estimates a fish depth of 26 m. Given that this fish depth calculation ignores the length of cable that is not in the water, and therefore not acting to depress the fish, between the towing point and the water line, the minimum estimate for the distance of the fish behind the towing point is 262 m.

In summary, including the distances in Figure 2, the magnetometer fish is:

1. ~17 m to port of the GPS navigation fixes
2. ~300 m behind the GPS navigation fixes

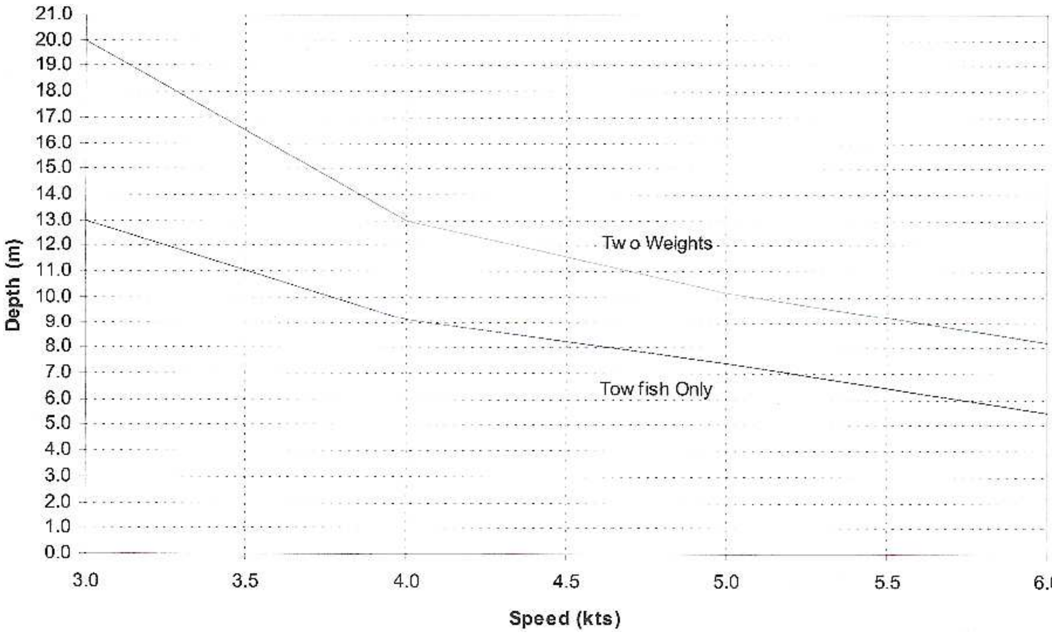

Figure 44: Towing depth of the *SeaSPY* tow fish versus towing speed with a 120 m tow cable. The un-weighted tow fish (bottom curve) represents the sensor used during SO198-1 (after Marine Magnetics Corporation, 2008).

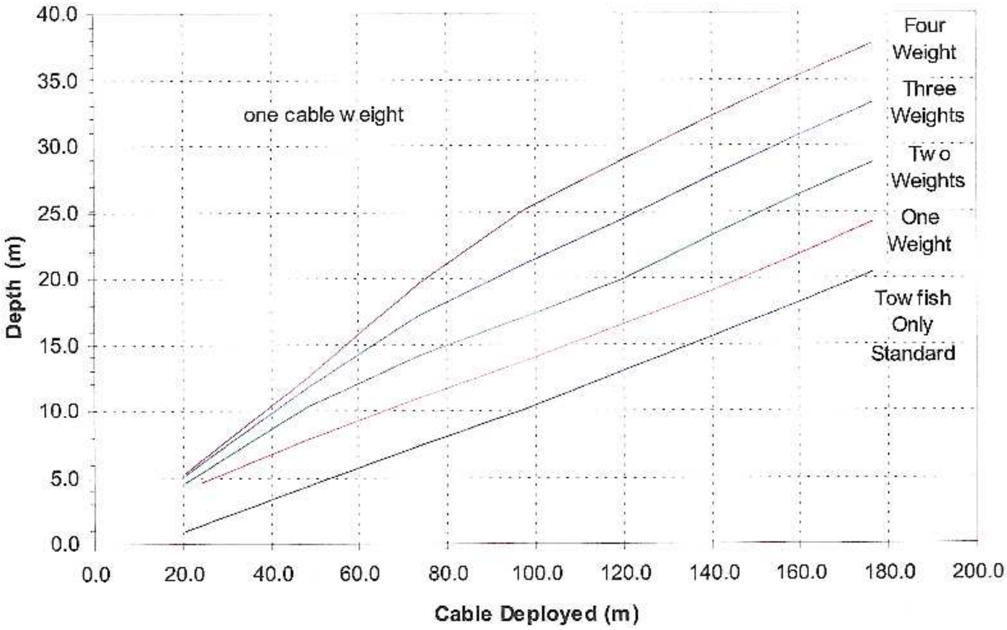

Figure 45: Towing depth of the *SeaSPY* tow fish at 3 kt towing speed. The un-weighted (standard) tow fish (bottom curve) represents the sensor used during SO198-1 (after Marine Magnetics Corporation, 2008).

Figure 46: Magnetometer winch and deployment boom. The magnetometer is fully deployed leaving one layer of cable on the winch drum. Photo by D. Sobaruddin.

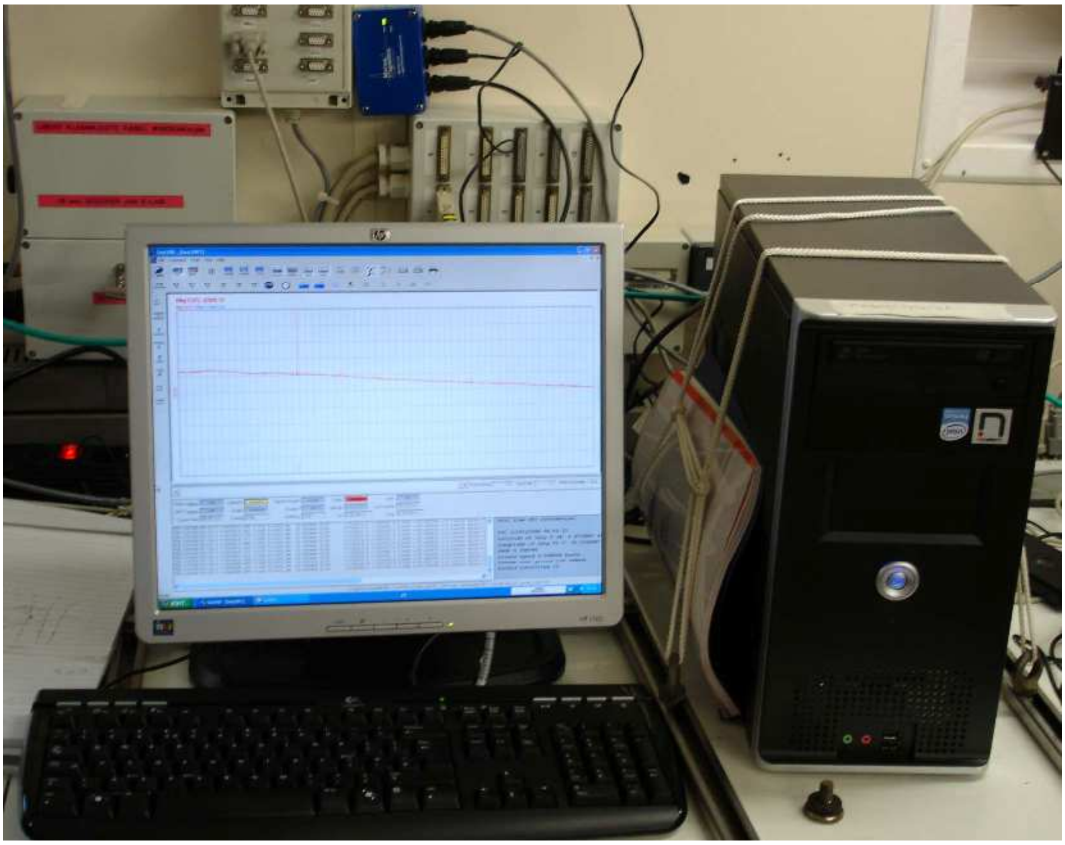

Figure 47: The magnetometer logging PC running *SeaLINK* software. The *Smart Transceiver* interface module is visible behind the monitor (blue box, centre top).

Data format

The *SeaLINK* software (version 8.00017) can record three output data streams; all are in ASCII text format:

1. *SeaLINK* raw data log (.mag)
2. XYZ data log (.XYZ)
3. NMEA log (.txt)

Since the NMEA log is a repeat of the GPS navigation stream, already logged in the Sonne's database, only the .mag and .XYZ files were recorded during SO198-1.

The .mag file contains all the possible data fields available, including any commands issued to the fish (Figure 48). Each record starts with a "*" then year (yy), Julian Day and time (hh:mm:ss.s), followed by each data values identified by prefix:

F:	field value (nT)
S:	field strength
D:	fish depth
L:	leak detector value
Q:	signal quality
X:	UTM Easting (m)
Y:	UTM Northing (m)
Z:	UTM zone
x:	Longitude (decimal degrees)
y:	Latitude (decimal degrees)
NOLBX/Y/Z/x/y:	as X/Y/Z/x/y but with no layback correction
<REAL>	The co-ordinates for this data point recorded by the GPS
<INTERP>	The co-ordinate for this point was interpolated by software – GPS sampling rate is less than the instrument sampling rate
<LAYBACK INTERPOLATION>	Layback calculation has started – treat fish positions with caution!

```
*08.135/03:00:47.5  F:041892.453  S:153  D:+317.7m    L0  0465ms  Q:99
X:172248.3  Y:406668.6  Z:47N  x:96.049854  y:3.674312  NOLBX:171948.4
NOLBY:406675.2 NOLBZ:47N NOLBx:96.047157 NOLBy:3.674363 <REAL>
*08.135/03:00:48.5  F:041892.432  S:151  D:+311.4m    L0  0465ms  Q:99
X:825640.2  Y:392168.0  Z:46N  x:95.930737  y:3.543362  NOLBX:825940.2
NOLBY:392161.3 NOLBZ:46N NOLBx:95.933433 NOLBy:3.543293 <INTERP>
*08.135/03:00:49.5  F:041892.528  S:153  D:+311.4m    L0  0465ms  Q:99
X:172245.9  Y:406664.7  Z:47N  x:96.049832  y:3.674277  NOLBX:171945.9
NOLBY:406671.4 NOLBZ:47N NOLBx:96.047135 NOLBy:3.674328 <REAL>
```

Figure 48: Three lines from an example *SeaLINK* raw data log (.mag) file.

The .XYZ file contains a 6-line header detailing the date and time at which the log started, where the log was recorded, and gives the title headings for all subsequent columns of data. This file is basically a simplified version of the .mag file, with minimal formatting for importing into another program. The locations recorded in this file are only those with a layback correction applied.

```
/ -----------------------------------------------------------------
-------------------------
/ Marine Magnetics Corp. SeaLINLK Magnetometer Data Log [ 2008/05/14
03:00:47.5 ]
/ Filename -- [ C:\so198-1\sl_info_so198_1_002.XYZ ]
/ -----------------------------------------------------------------
-------------------------
/
/Date   Time   Field_Mag1   Alt_Mag1   Depth_Mag1   Longitude   Latitude
UTM_Easting UTM_Northing UTM_Zone
2008/05/14  03:00:47.5  41892.453  0.00m  317.7m  96.049854  3.674312
172248.3 406668.6 47N
2008/05/14  03:00:48.5  41892.434  0.00m  311.4m  95.930737  3.543362
825640.2 392168.0 46N
2008/05/14  03:00:49.5  41892.527  0.00m  311.4m  96.049832  3.674277
172245.9 406664.7 47N
```

Figure 49: The header and first three lines from an example .XYZ data log file.

Layback correction

The SeaLINK software, when a GPS navigation input is available, can automatically calculate a layback correction to the position logged with each field measurement to account for the distance offset between the GPS antenna and the fish. This option was enabled during SO198-1, using a value of 300 m. Both antenna and layback-corrected positions are recorded in the .mag files.

Operational issues with the *SeaSPY* system

A number of issues were identified with the *SeaSPY* system, mainly with the *SeaLINK* software, that seriously affected its functionality.

1. It proved impossible to sync the fish/transceiver clock with either GPS or the PC clock.
2. Manually setting the time on the fish/transceiver clock requires the current date to be supplied in YYMMDD format yet returns a confirmation date in Julian Day which is one less than the true value. Since only the SeaLINK software logs the Julian Day, when manually setting the time the following days date must be entered.
3. A time delay occurs (~2x per day) in the GPS NMEA data stream displayed in the *SeaLINK* software resulting in the navigation time tags to lag behind the fish time tags. Once the lag reaches ~20 seconds GPS positions are no longer appended to either the .mag or .XYZ log files. Independently viewing the incoming NMEA data stream confirms that the lag originates within the logging PC.
4. The depth sensor on the fish must be calibrated on deck by zeroing the pressure sensor. The calibration is lost when power is removed from the fish. Due to the design of the winch, the fish must be disconnected

from the power in order to be deployed. Without calibration the depth sensor calculates a fish depth of ~350 m, when it should not exceed 30 m (see earlier).

The NMEA data stream delay was suspected to be the result of using an RS232-to-USB adapter. Only a single conventional RS232 socket was available on the *SeaSPY* PC and this was occupied with the connection to the *Smart Transceiver*.

The Julian Day date and time synchronisation issues are probably related – the time can only be set correctly by supplying the wrong date and the automatic sync methods probably check that the Julian Day returned by the sync operation actually matches the real date. The fault is suspected to lie in the *Smart Transceiver* module software not accounting for 2008 as a leap year.

Results: Survey Box 1

The basic order of scientific operations in Survey Box 1, after transit from Singapore, was as follows:

1. An SVP and CTD drop to calibrate the swath bathymetry system.
2. Deploy 50 OBS instruments, with an XBT drop at each site.
3. Survey with airguns throughout the Survey Box.
4. Recover the OBS instruments.

Where possible, the following systems were also operated during this period:

- Swath bathymetry
- Sub-bottom profiler
- Gravity meter
- Magnetometer

Survey narrative

Julian Day 123, Friday 2nd May

Singapore port. First party of scientists arrived at the ship at 11:30 (PB, SD, PV, NF, AB, DW and Alan Sherring from NMFSS). Containers alongside. These were loaded on board or unstuffed on the dockside and everything put away. Plenty of assistance. All returned to the hotel.

Julian Day 124, Saturday 3rd May

Singapore port. Scientists as above plus Chris Hunter (NMFSS) arrived at ship 09:15. Ship had been due to go to anchorage but this was not possible due to the need to make a gravity base station tie. The base station information had to be downloaded via the very slow satellite link, and the station in the National Museum selected. The tie was completed around 17:00 and all except PB departed for the hotel again. At 18:00 the ship sailed along the river to the anchorage offshore ‘downtown’ Singapore, to the east of the island. The remaining UK and Indonesian scientists arrived by launch at around 23:00, direct from their flights.

Julian Day 125, Sunday 4th May

Anchor off Singapore. Party from the hotel embarked in morning. Chris Hunter and Alan Sherring spent the day on board checking over the gravimeter, magnetics, XBT and compressor arrangements for next leg. A short science meeting and ship’s safety briefing were held.

Julian Day 126, Monday 5th May

Transit Singapore – Survey Box 1. Left anchorage off Singapore at 07:45 and set off NW up the Straits of Malacca, an extremely busy shipping lane. Began watches at 08:00 and a problem with interrupts on the gravity screen noted immediately. Lots of preparation work done on the OBS.

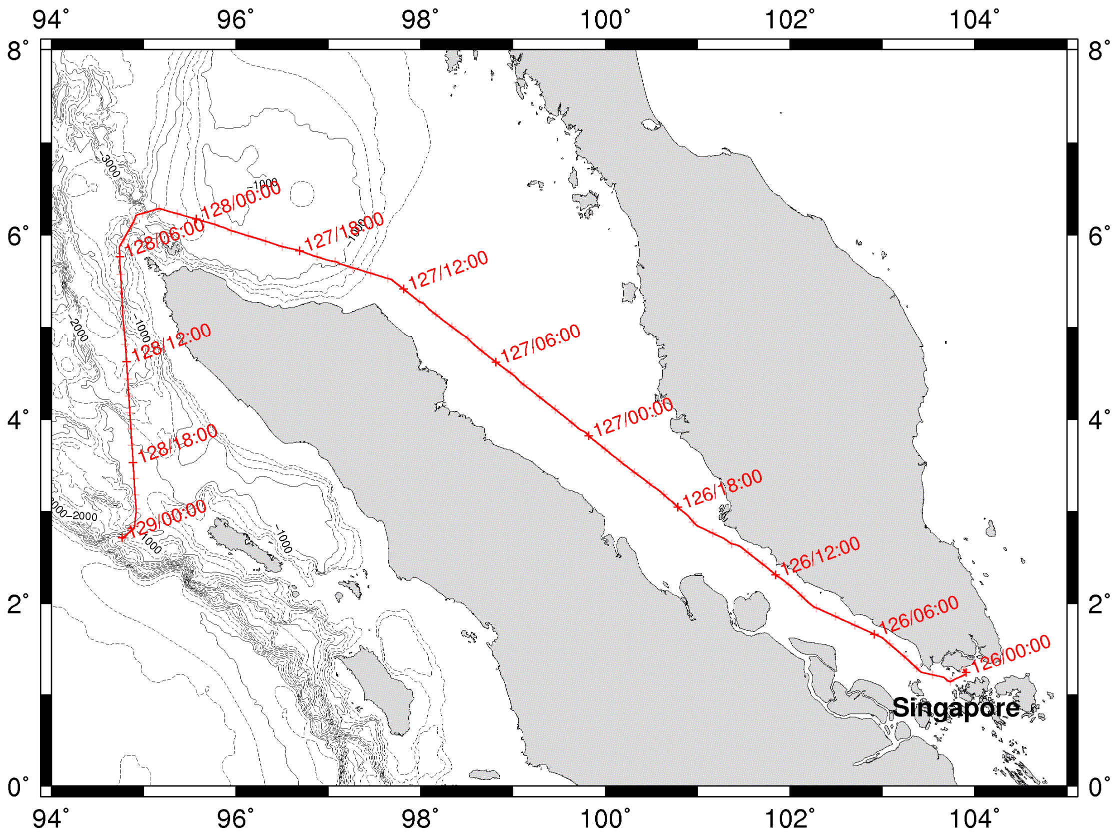

Figure 50: Map of the transit route taken from Singapore to Survey Box 1. Crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 127, Tuesday 6th May

Transit Singapore – Survey Box 1. Gravimeter clock galloping ahead - testing to see if this is related to the number of interrupts. Discussed arrangements for guns, 12 m towing depth agreed, and triggering. As the Sonne uses a box that cycles every 0-99 seconds without a clock base, decided to trigger off a GPS pulse from a borrowed spare OBIC GPS clock. A short science presentation held. Clocks put back one hour.

Julian Day 128, Wednesday 7th May

Transit Singapore – Survey Box 1. Passed around north end of Sumatra. Entered work area and switched on multibeam swath and sub-bottom profiler. Problems with gravimeter clock continued. Organised OBS shifts. OBS preparation work continued.

Julian Day 129, Thursday 8th May

Arrived in work area Survey Box 1 at 06:15. CTD and sound velocity meter drop (2 hours), which worked well despite pessimism. Tested 3 OBS release rosettes. Tested new long-deployment OBS configuration and found it needed more flotation. Began OBS deployments (see Table 13). We will carry out an XBT at each OBS station to ensure good spatial coverage. Further long-term OBS test with 4 small floats instead of 2 proved successful.

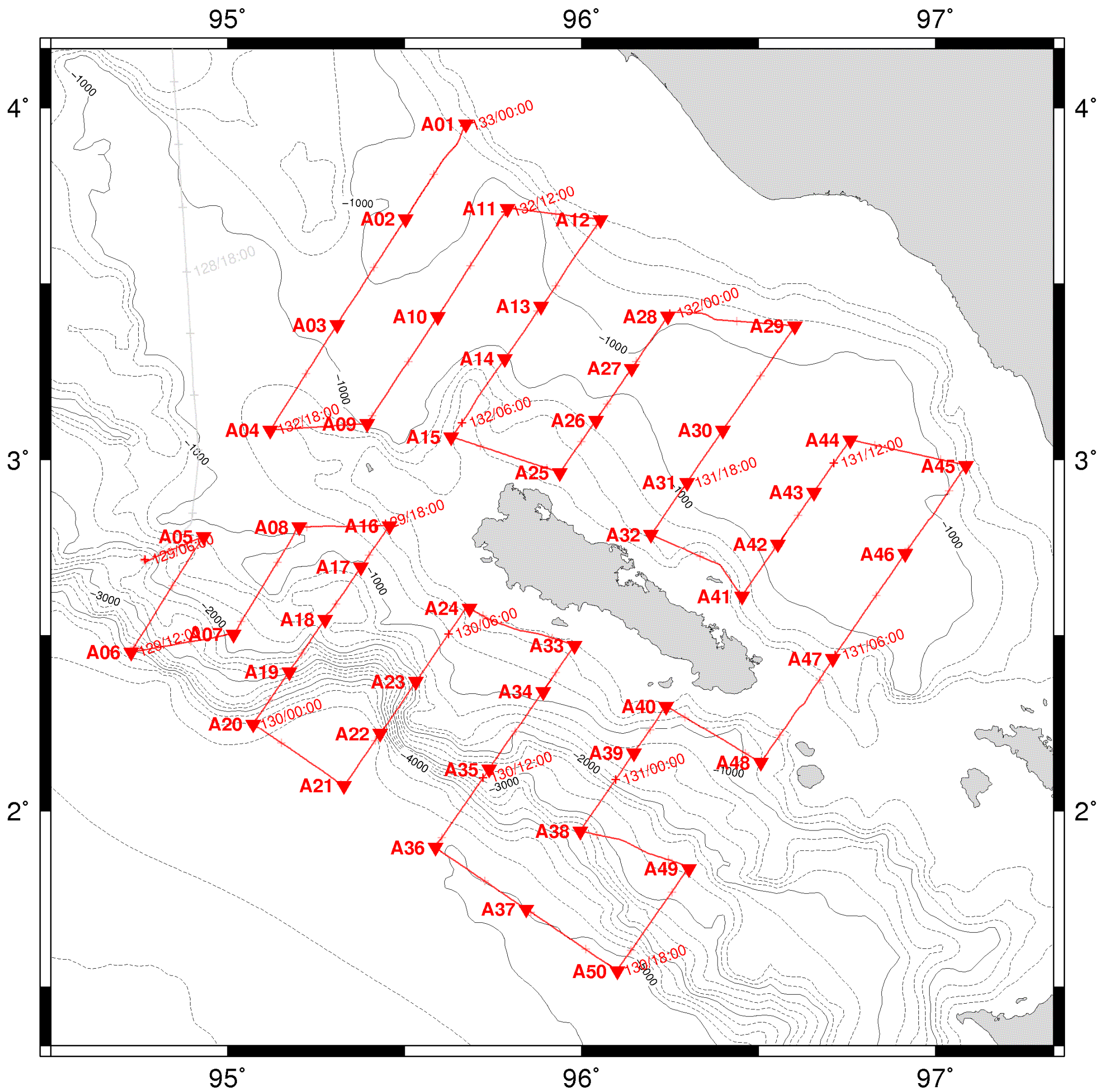

Figure 51: Deployment location for the OBS instruments in Survey Box 1 (triangles) labelled with the Site Number. The red line shows the route taken; crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 130, Friday 9th May

Continued OBS deployment in Survey Box 1. The LC instruments take only 5-10 minutes on station, whereas LASSIs need about 45 minutes, as they must be lowered to 500 m for individual release tests. The ship does not provide electronic or printed logging of shot number against time/position, so we are devising a system of logging shots manually every minute, allocating a number after they had been triggered by the GPS clock. They will also be recorded on an OBIC LC4x4 logger (analogue signal of trigger pulse against logger clock), but this cannot be viewed or replayed until after the shooting (at the moment we do not have the software anyway), and does not record a shot number.

Julian Day 131, Saturday 10th May

Continued OBS deployment in Survey Box 1. Concern over borrowed US LC4x4 instruments' release systems after one dropped its weight as it was deployed.

Julian Day 132, Sunday 11th May

Continued OBS deployment in Survey Box 1. US LC4x4 instruments were supplied without lights or radios so some instruments had to be deployed with one only or neither.

Figure 52: Shooting profiles SUMAA to SUMAP in Survey Box 1. Crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 133, Monday 12th May

Completed OBS deployment in Survey Box 1 at 07:00 and began airgun deployment. This was very efficient and took 40 minutes. Went through testing/rampup procedure and were ready to start before we were fully ready to begin logging. Guns are being fired through a *LongShot* firing system, which shows gun sensors against firing time, but these were not tuned at this time. Began line SUMAA (see Table 12). We are logging shots manually every minute on pre-prepared sheets. The GPS clock is set to give a half-second pulse at the 30-second mark and the gun are triggered at the end of this pulse, and fired by *LongShot* 60 ms after this, so firing times are at 30.56 seconds after each GPS minute.

Julian Day 134, Tuesday 13th May

Continued shooting in Survey Box 1. Got most of the guns tuned in properly. Gun 12 on the starboard side is leaking (trail of bubbles) but this only reduced the pressure to 206 bar so continued with it turned on.

Julian Day 135, Wednesday 14th May

Continued shooting in Survey Box 1.

Julian Day 136, Thursday 15th May

Continued shooting in Survey Box 1.

Julian Day 137, Friday 16th May

Continued shooting in Survey Box 1. One of the four buoys disappeared from the starboard side array. Starboard side guns brought in for repair and buoy replacement. Redeployed guns greatly improved until about 21:00 local time, when gun 2 (port side) began leaking catastrophically and had to be turned off.

Julian Day 138, Saturday 17th May

Continued shooting in Survey Box 1. Still awaiting software from Scripps for new LC4x4 instruments, so have decided to use same number of LC4x4s in the next deployment, but with different logger units, to test the maximum number of units ready for the long-term deployment, with minimum exposure for this survey.

Julian Day 139, Sunday 18th May

Continued shooting in Survey Box 1. Sensor on gun 8 stopped working.

Julian Day 140, Monday 19th May

Finished shooting in Survey Box 1 at 15:45, recovered the guns in less than an hour and began OBS recovery.

Julian Day 141, Tuesday 20th May

Continued OBS recovery in Survey Box 1. Used the RIB for a few recoveries as the grapple iron was dangerous for OBS connectors and the instruments were often out of reach of the poles. However, the RIB tended to drag them too much, and move them from their pop-up point. Used the RIB one last time for the broad-band instrument, picked up in the moonlight. Initial OBS data playback looks excellent. Broadband instrument shows fine recording of 12th May earthquake in China.

Julian Day 142, Wednesday 21st May

Continued OBS recovery in Survey Box 1. Problem with French acoustic release box traced to broken plug assembly. Lifeboat tests (45 minutes). Visited by armed police from Simeulue but our Security Officer was able to reassure them without them boarding.

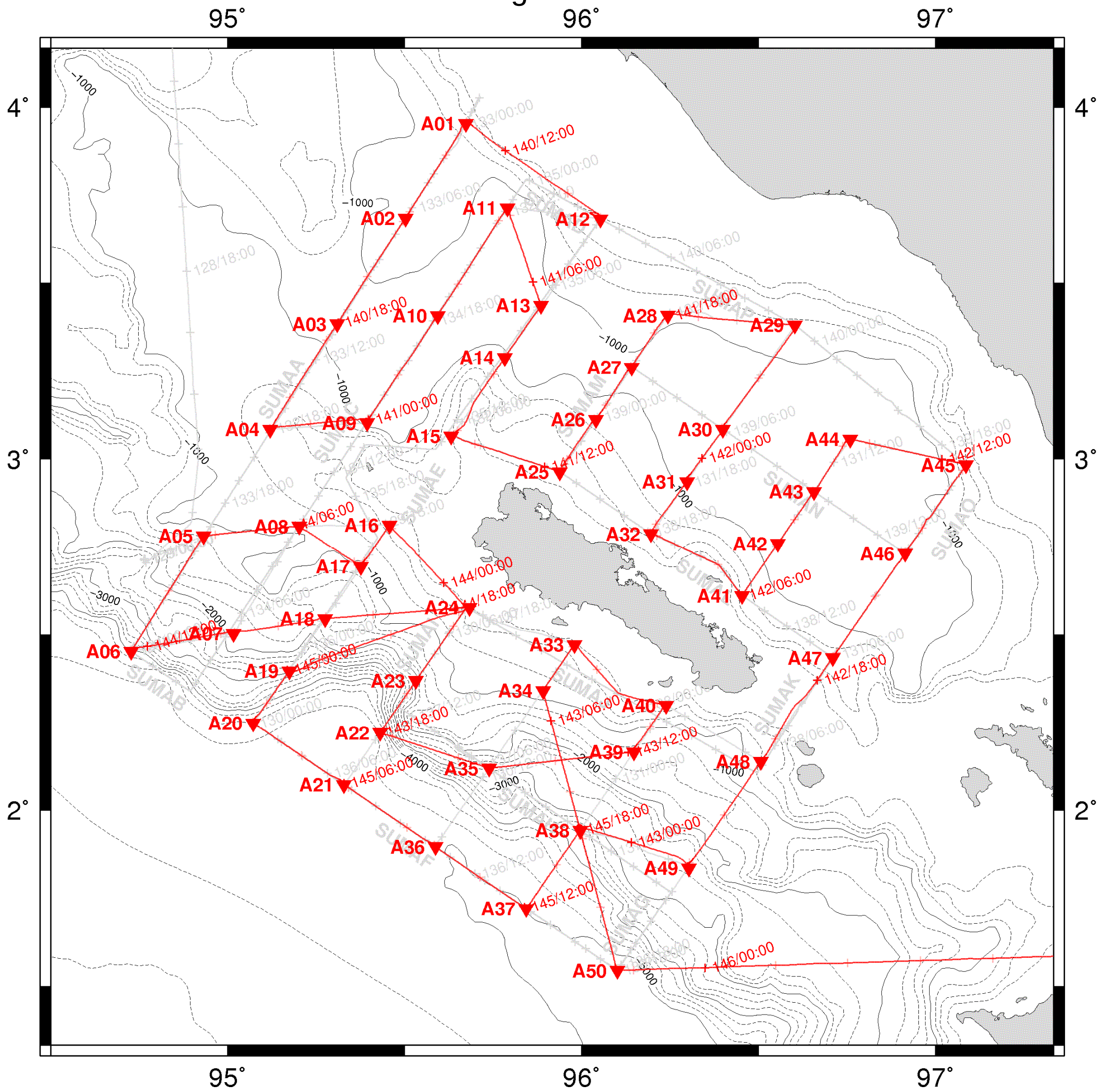

Figure 53: The recovery route for OBS instruments in Survey Box 1; crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. Triangles identify OBS deployment locations, labelled with the Site Number. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 143, Thursday 22nd May

Continued OBS recovery in Survey Box 1. LASSI 25 at site A38 was completely unresponsive. Spent 3-4 hours pinging at it from different directions as there are extreme variations in bathymetry nearby, but got no response. Went straight to the next LASSI recovery in case of a consistent problem, but this was fine. There have been several M5-5.5 earthquakes nearby in the last few days, and there was concern that perhaps the instrument had been covered in sediment.

Julian Day 144, Friday 23rd May

Continued OBS recovery in Survey Box 1. Problem with French OBS at site A24 that was pinging but did not release. A second site (A16) was also recalcitrant for a long time, but released when the repaired French deck unit was used. Pouring with rain. Returned to site A24 overnight and instrument still pinged but did not release. Another instrument was difficult to release and both burn wires had to be burned before it released. An intrepid snail was found on deck and adopted as Bryan.

Julian Day 145, Saturday 24th May

Continued OBS recovery in Survey Box 1. Returned to LASSI at site A38 and spent 2 hours doing a swath survey and then sitting stationary immediately above it with the overside transducer. Some faint intermittent pings were probably noise and nothing appeared.

Julian Day 146, Sunday 25th May

Completed OBS recovery in the early hours of the morning. Start passage to Survey Box 2.

Seismic source

Start					End					Line
Julian Day	UTC Time	Shot No.	Lat.	Long.	Julian Day	UTC Time	Shot No.	Lat.	Long.	
133	02:25:30.56	0	3.958	95.675	134	00:06:30.56	1301	2.451	94.727	SUMAA
134	00:07:30.56	1302	2.450	94.728	134	00:10:30.56	1305	2.448	94.731	Turn
134	00:11:30.56	1306	2.447	94.732	134	02:36:30.56	1451	2.340	94.891	SUMAB
134	02:15:30.56	1430	2.354	94.870						Starboard pressure loss
134	02:37:30.56	1452	2.340	94.892	134	02:39:30.56	1454	2.341	94.894	Turn
134	02:40:30.56	1455	2.342	94.895	134	23:48:30.56	2723	3.791	95.840	SUMAC
134	23:49:30.56	2724	3.792	95.841	134	23:56:30.56	2731	3.794	95.849	Turn
134	23:57:30.56	2732	3.794	95.850	135	02:49:30.56	2904	3.685	96.045	SUMAD
135	02:50:30.56	2905	3.684	96.046	135	03:03:30.56	2918	3.672	96.045	Turn
135	03:04:30.56	2919	3.670	96.045	135	13:17:30.56	3532	3.028	95.589	SUMAE-1
135	13:18:30.56	3533	3.027	95.588	135	13:27:30.56	3542	3.026	95.576	Turn
135	13:28:30.56	3543	3.026	95.574	135	15:44:30.56	3679	3.039	95.399	SUMAE-2
135	15:45:30.56	3680	3.039	95.397	135	15:54:30.56	3689	3.037	95.387	Turn
135	15:55:30.56	3690	3.036	95.386	135	17:15:30.56	3770	2.948	95.335	SUMAE-3
135	17:16:30.56	3771	2.947	95.335	135	17:23:30.56	3778	2.938	95.337	Turn
135	17:24:30.56	3779	2.936	95.338	135	19:36:30.56	3911	2.777	95.422	SUMAE-4
135	19:37:30.56	3912	2.776	95.423	135	19:41:30.56	3916	2.771	95.421	Turn
135	19:42:30.56	3917	2.770	95.420	136	02:59:30.56	4354	2.252	95.074	SUMAE-5
136	03:00:30.56	4355	2.251	95.074	136	03:04:30.56	4359	2.246	95.074	Turn
136	03:05:30.56	4360	2.245	95.075	136	17:48:30.56	5243	1.550	96.104	SUMAF
136	17:49:30.56	5244	1.551	96.105	136	17:55:30.56	5250	1.557	96.108	Turn
136	17:56:30.56	5251	1.558	96.109	136	21:19:30.56	5454	1.766	96.251	SUMAG
136	21:20:30.56	5455	1.767	96.252	136	21:22:30.56	5457	1.769	96.252	Turn
136	21:23:30.56	5458	1.769	96.251	137	08:12:30.56	6107	2.180	95.646	SUMAH-1
137	06:01:30.56	5976	2.133	95.719						Starboard airguns turned off
137	08:13:30.56	6108	2.179	95.645	137	09:20:30.56	6175	2.150	95.695	Loop
137	09:09:30.56	6164	2.147	95.688						Starboard

137	09:21:30.56	6176	2.151	95.694	137	12:34:30.56	6369	2.293	95.484	airguns turned on SUMAH-2
137	12:35:30.56	6370	2.293	95.483	137	12:39:30.56	6374	2.298	95.482	Turn
137	12:40:30.56	6375	2.299	95.483	137	17:04:30.56	6639	2.575	95.673	SUMAI
137	13:20:30.56	6415	2.340	95.513						Airgun 2 turned off
137	17:05:30.56	6640	2.576	95.674	137	17:13:30.56	6648	2.572	95.683	Turn
137	17:14:30.56	6649	2.571	95.684	138	04:34:30.56	7329	2.107	96.492	SUMAJ
138	04:35:30.56	7330	2.106	96.494	138	04:38:30.56	7333	2.107	96.497	Turn
138	04:39:30.56	7334	2.108	96.498	138	09:55:30.56	7650	2.431	96.707	SUMAK
138	09:56:30.56	7651	2.432	96.708	138	10:02:30.56	7657	2.437	96.706	Turn
138	10:03:31.56	7658	2.438	96.705	138	13:56:30.56	7891	2.609	96.455	SUMAL-1
138	13:57:30.56	7892	2.609	96.454	138	14:00:30.56	7895	2.612	96.451	Turn
138	14:01:30.56	7896	2.613	96.451	138	15:16:30.56	7971	2.696	96.389	SUMAL-2
138	15:17:30.56	7972	2.697	96.388	138	15:19:30.56	7974	2.699	96.386	Turn
138	15:20:30.56	7975	2.699	96.385	138	17:51:30.56	8126	2.786	96.197	SUMAL-3
138	17:52:30.56	8127	2.787	96.196	138	17:52:30.56	8127	2.787	96.196	Turn
138	17:53:30.56	8128	2.787	96.194	138	21:37:30.56	8352	2.960	95.942	SUMAL-4
138	21:38:30.56	8353	2.961	95.940	138	21:42:30.56	8357	2.966	95.939	Turn
138	21:43:30.56	8358	2.967	95.940	139	02:03:30.56	8618	3.256	96.139	SUMAM
139	02:04:30.56	8619	3.257	96.140	139	02:07:30.56	8622	3.259	96.143	Turn
139	02:08:30.56	8623	3.258	96.144	139	13:00:30.56	9275	2.737	96.903	SUMAN
139	13:01:30.56	9276	2.737	96.904	139	13:09:30.56	9284	2.732	96.914	Turn
139	13:10:30.56	9285	2.733	96.915	139	16:51:30.56	9506	2.981	97.084	SUMAO
139	16:52:30.56	9507	2.982	97.084	139	16:54:30.56	9509	2.984	97.084	Turn
139	16:55:30.56	9510	2.985	97.083	140	00:05:30.56	9989	3.381	96.601	SUMAP-1
140	00:06:30.56	9990	3.382	96.600	140	00:06:30.56	9990	3.382	96.600	Turn
140	00:07:30.56	9991	3.382	96.599	140	08:46:30.56	10461	3.681	96.052	SUMAP-2

Table 12: The start and end time for each shooting profile in Survey Box 1, versus shot number. The pressure loss to the starboard airgun array, starting on Julian Day 134, was rectified on Julian Day 137. Airgun 2, turned off on Julian Day 137, was not turned back on for the remainder of the shooting. Navigation locations are for the vessel, not the source.

OBS data

A total of 50 OBS instruments were deployed in Survey Box 1 (Table 13, Figure 51).

Due to incorrectly set jumpers on the pre-amplifier circuit boards, the only LC4x4 OBS to record hydrophone data was US68.

Site No.	OBS No.	OBS type	Julian Day	UTC Time	Lat.	Long.	Depth (m)
A01	FR20	LC2000/2	133	00:07	3.95318	95.67213	653
A02	FR19	LC2000/2	132	21:59	3.68322	95.50175	1109
A03	FR06	LC2000/4	132	19:55	3.38315	95.30895	1290
A04	FR18	LC2000/2	132	17:57	3.08313	95.12010	654
A05	UK03	LC2000/4	129	09:06	2.78112	94.93107	972
A06	UK19	LASSI	129	11:50	2.45260	94.72737	4550
A07	UK28	LASSI	129	14:36	2.50333	95.01663	1979
A08	US68	LC4x4	129	16:46	2.80848	95.20130	460
A09	UK17	LC2000/2	132	16:14	3.10163	95.39313	1033
A10	UK42	LC4x4	132	14:04	3.40668	95.59335	864
A11	US72	LC4x4	132	11:51	3.71290	95.79032	988
A12	UK15	LC2000/2	132	10:12	3.68113	96.05258	479
A13	UK08	LC2000/4	132	08:32	3.43587	95.88478	1149
A14	UK12	LC2000/2	132	07:07	3.28758	95.78260	1067
A15	UK10	LC2000/4	132	05:37	3.06418	95.63055	431
A16	FR07	LC2000/2	129	18:20	2.81185	95.45717	290
A17	FR08	LC2000/2	129	19:16	2.69343	95.37628	1012
A18	UK22	LASSI	129	21:19	2.54492	95.27480	1203
A19	FR09	LC2000/2	129	22:26	2.39637	95.17355	2032
A20	UK23	LASSI	130	00:25	2.24762	95.07175	4837
A21	UK16	LC2000/2	130	02:09	2.07217	95.32855	4880
A22	UK21	LASSI	130	03:59	2.22070	95.43067	2704
A23	UK04	LC2000/4	130	05:10	2.36902	95.53180	1597
A24	FR10	LC2000/2	130	06:37	2.57702	95.68325	387
A25	FR17	LC2000/2	132	03:45	2.96255	95.93812	364
A26	FR23	LC2000/BB	132	02:32	3.11097	96.04008	932
A27	US74	LC4x4	132	01:16	3.25950	96.14167	1026
A28	UK09	LC2000/4	132	00:07	3.40763	96.24352	954
A29	UK11	LC2000/2	131	22:02	3.38015	96.60230	955
A30	UK13	LC2000/2	131	20:01	3.08352	96.39893	1080
A31	UK41	LC4x4	131	18:54	2.93510	96.29733	884
A32	FR16	LC2000/2	131	16:56	2.78673	96.19592	533
A33	UK40	LC4x4	130	08:24	2.47132	95.97945	484
A34	UK27	LASSI	130	10:13	2.34033	95.89110	1353
A35	FR11	LC2000/2	130	11:45	2.11902	95.73850	2905
A36	UK20	LASSI	130	13:59	1.89637	95.58625	4966
A37	UK06	LC2000/4	130	15:49	1.72077	95.84330	5023
A38	UK25	LASSI	130	23:04	1.94300	95.99567	3576
A39	US71	LC4x4	131	00:31	2.16527	96.14750	679
A40	UK14	LC2000/2	131	01:35	2.29892	96.23887	618
A41	UK05	LC2000/4	131	14:59	2.61048	96.45235	422
A42	FR15	LC2000/2	131	13:52	2.75890	96.55417	1101
A43	US69	LC4x4	131	12:32	2.90670	96.65605	1106
A44	FR05	LC2000/4	131	11:30	3.05552	96.75802	1092
A45	FR14	LC2000/2	131	09:31	2.98252	97.08568	820
A46	FR13	LC2000/2	131	07:47	2.73117	96.91317	1100
A47	US73	LC4x4	131	05:50	2.43405	96.70972	760
A48	UK02	LC2000/4	131	03:25	2.13777	96.50598	797
A49	FR12	LC2000/2	130	20:34	1.83637	96.30302	2773
A50	UK24	LASSI	130	18:32	1.54470	96.10017	5018

Table 13: OBS deployment details for Survey Box 1.

Site No.	OBS No.	Julian Day	UTC Time	Lat.	Long.	Depth (m)	Data Quality			
							1	2	3	4
A01	FR20	140	13:17	3.958	95.668	618	1	2a	-	-
A02	FR19	140	15:49	3.684	95.503	1110	1	2a	-	-
A03	FR06	140	18:33	3.384	95.311	1285	1	2a	1/2	1/2
A04	FR18	140	21:14	3.088	95.115	635	1	2b	-	-
A05	UK03	144	07:46	2.782	94.933	952	1	2a	1/2	1/2
A06	UK19	144	11:38	2.457	94.730	4451	2a	2a	1/2	1/2
A07	UK28	144	14:08	2.509	95.016	2033	1	1	1	1
A08	US68	144	05:27	2.813	95.200		2a	2a	2a	2a
A09	UK17	141	00:15	3.117	95.401	1067	1	1	-	-
A10	UK42	141	02:23	3.409	95.593	860	1	2a	1	4
A11	US72	141	04:42	3.714	95.790	985	2a	2a	2a	4
A12	UK15	140	10:21	3.687	96.054	542	1	2a	-	-
A13	UK08	141	06:51	3.438	95.887	1142	1	2a	1/2	1/2
A14	UK12	141	08:32	3.290	95.783	1072	1	2a	-	-
A15	UK10	141	10:32	3.067	95.632	422	1	2b	2	2
A16	FR07	144	02:07	2.814	95.458	253	1	1	-	-
A17	FR08	144	03:43	2.695	95.375	1003	1	1	-	-
A18	UK22	144	16:10	2.548	95.276	1291	1	2a	1/2	1/2
A19	FR09	145	00:17	2.400	95.175	1857	1	2b	-	-
A20	UK23	145	03:0	2.251	95.071	4817	2a	2a	1/2	1/2
A21	UK16	145	06:47	2.075	95.327	4880	2b	3	-	-
A22	UK21	143	18:18	2.225	95.431	2675	3	3	3	3
A23	UK04	143	20:01	2.371	95.532	1615	1	2b	1/2	1/2
A24	FR10	LOST								
A25	FR17	141	12:41	2.963	95.934	361	1	1	-	-
A26	FR23	141	14:23	3.112	96.039	923	2a	2a	1	2a
A27	US74	141	16:17	3.260	96.142	1028	2a	2a	2a	4
A28	UK09	141	18:27	3.410	96.245	950	1	2a	2a	2a
A29	UK11	141	20:55	3.378	96.604	955	1	2a	-	-
A30	UK13	141	23:25	3.083	96.400	1079	1	2b	-	-
A31	UK41	142	01:08	2.936	96.297	884	2a	2a	2a	4
A32	FR16	142	03:49	2.788	96.197	550	1	2a	-	-
A33	UK40	143	08:25	2.473	95.980	473	2a	1	1	4
A34	UK27	143	07:08	2.342	95.889	1323	2b/3	1	2	1
A35	FR11	143	15:25	2.122	95.737	2916	1	1	-	-
A36	UK20	145	10:09	1.897	95.586	4965	2a	2b	1/2	1/2
A37	UK06	145	14:03	1.721	95.842	5027	1	1/2	1/2	1/2
A38	UK25	LOST								
A39	US71	143	11:48	2.165	96.148	685	4	2a	2b	4
A40	UK14	143	10:33	2.300	96.237	607	1	2a	-	-
A41	UK05	142	05:57	2.611	96.454	464	4	4	1/2	1/2
A42	FR15	142	07:31	2.761	96.555	1102	2a	2a	-	-
A43	US69	142	09:13	2.910	96.659	1108	1	1	2a	4
A44	FR05	142	10:39	3.056	96.760	1095	1	1	-	-
A45	FR14	142	12:48	2.983	97.086	889	3	3	-	-
A46	FR13	142	15:05	2.733	96.916	1097	4	4	-	-
A47	US73	142	17:31	2.435	96.706	758	2a	2a	2a	4
A48	UK02	142	19:57	2.138	96.505	802	1	2b	1/2	1/2
A49	FR12	142	23:02	1.840	96.301	2775	1	1	-	-
A50	UK24	145	22:39	1.544	96.100	5015	2a	2a	1/2	1/2

Table 14: OBS recovery times and locations in Survey Box 1. The quality of the data recorded on each channel (1-2 or 1-4 depending on instrument sensor configuration) is indicated in the left four columns: 1 - excellent data quality; 2a - fair data quality, can be picked; 2b - poor data quality, some data can be picked; 3 - data recorded, cannot be picked; 4 - nothing recorded.

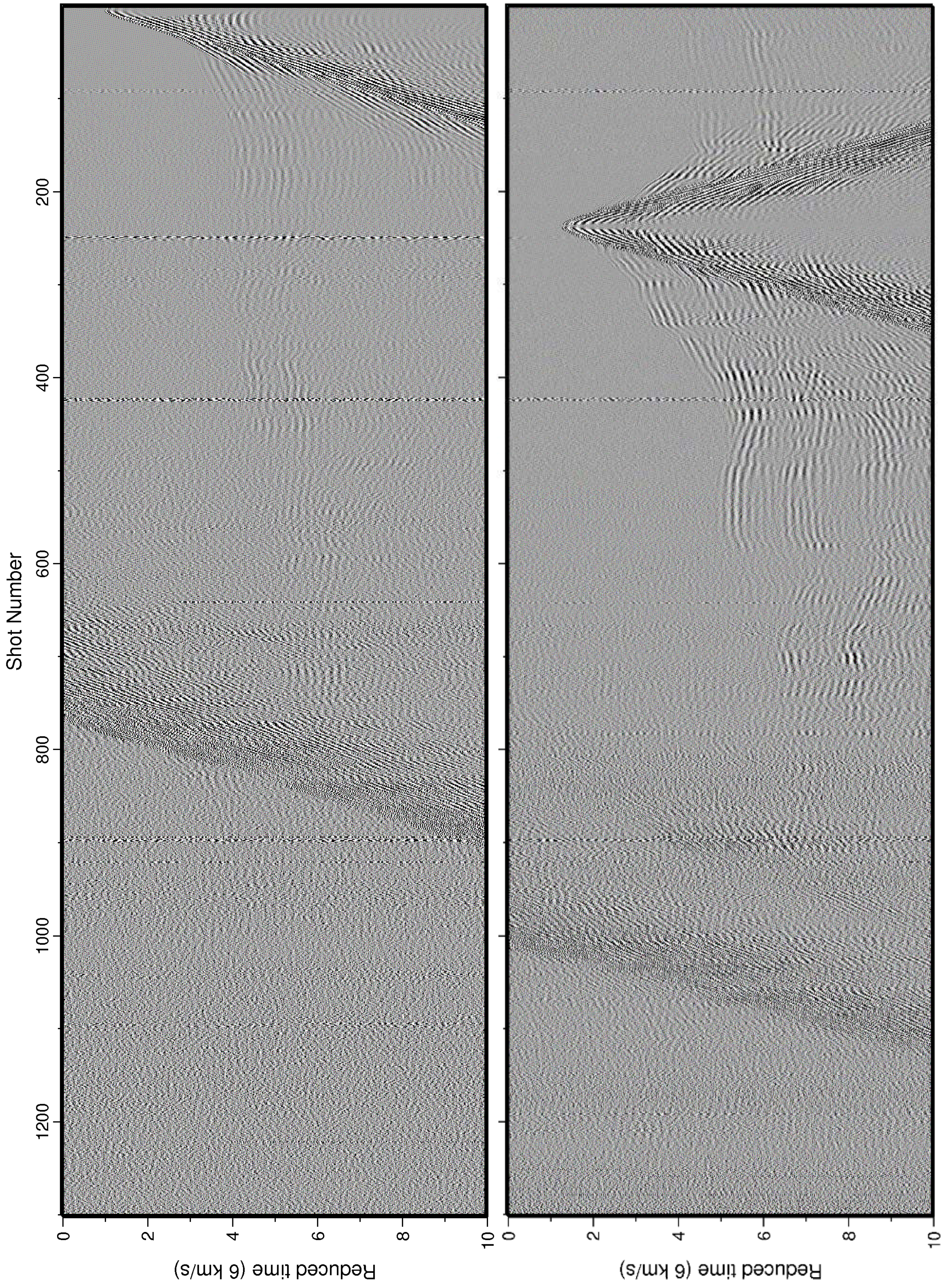

Figure 54: Hydrophone data from OBS instruments at Sites A01 (upper panel) and A02 (lower panel) for all the shots along SUMA (197 km). Data are shown with reduced time (6 km/s), zero-phase band-pass filtered (3-5-25-30 Hz), and gain proportional to offset.

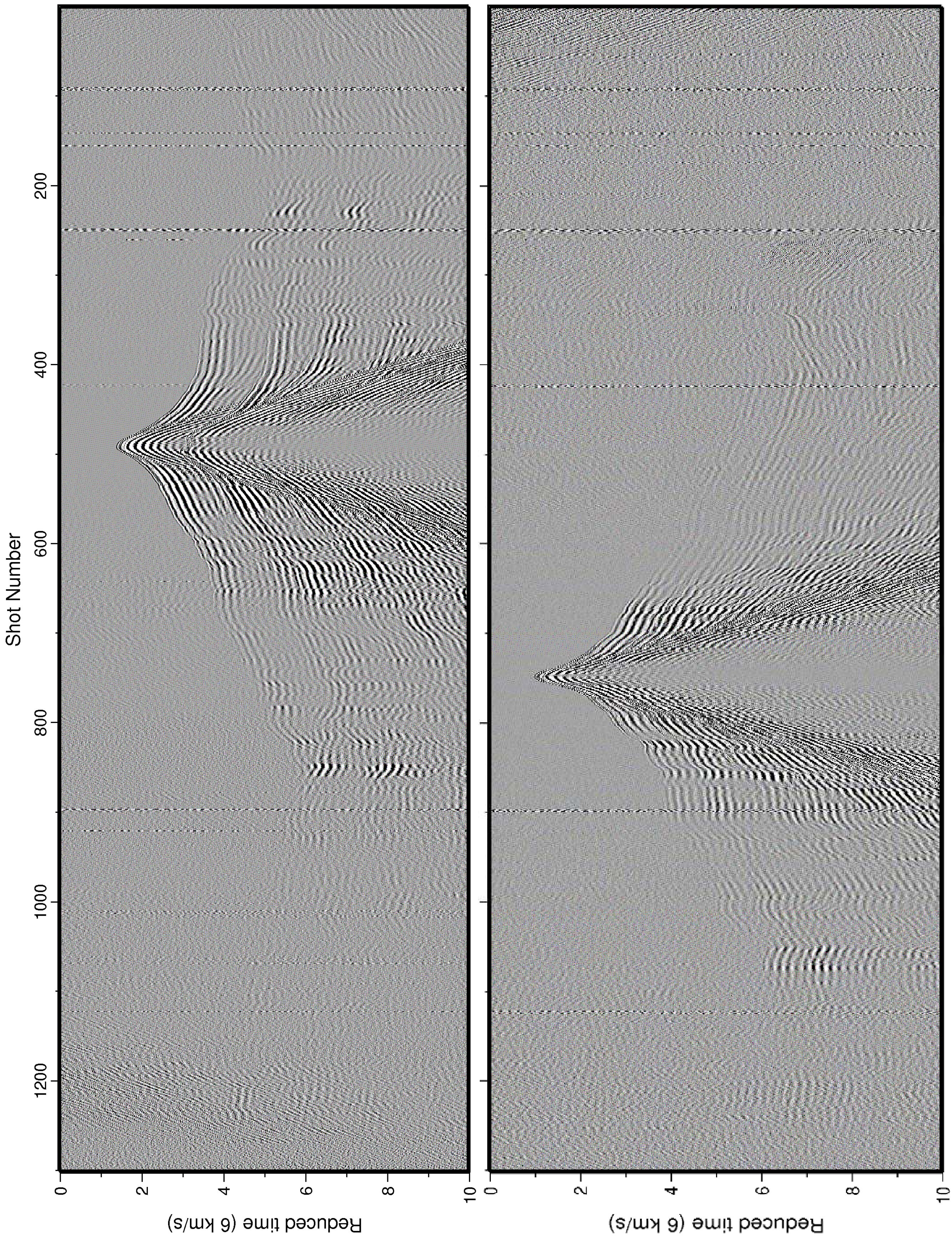

Figure 55: Hydrophone data from OBS instruments at Sites A03 (upper panel) and A04 (lower panel) for all the shots along SUMA (197 km). Data are shown with reduced time (6 km/s), zero-phase band-pass filtered (3-5-25-30 Hz), and gain proportional to offset.

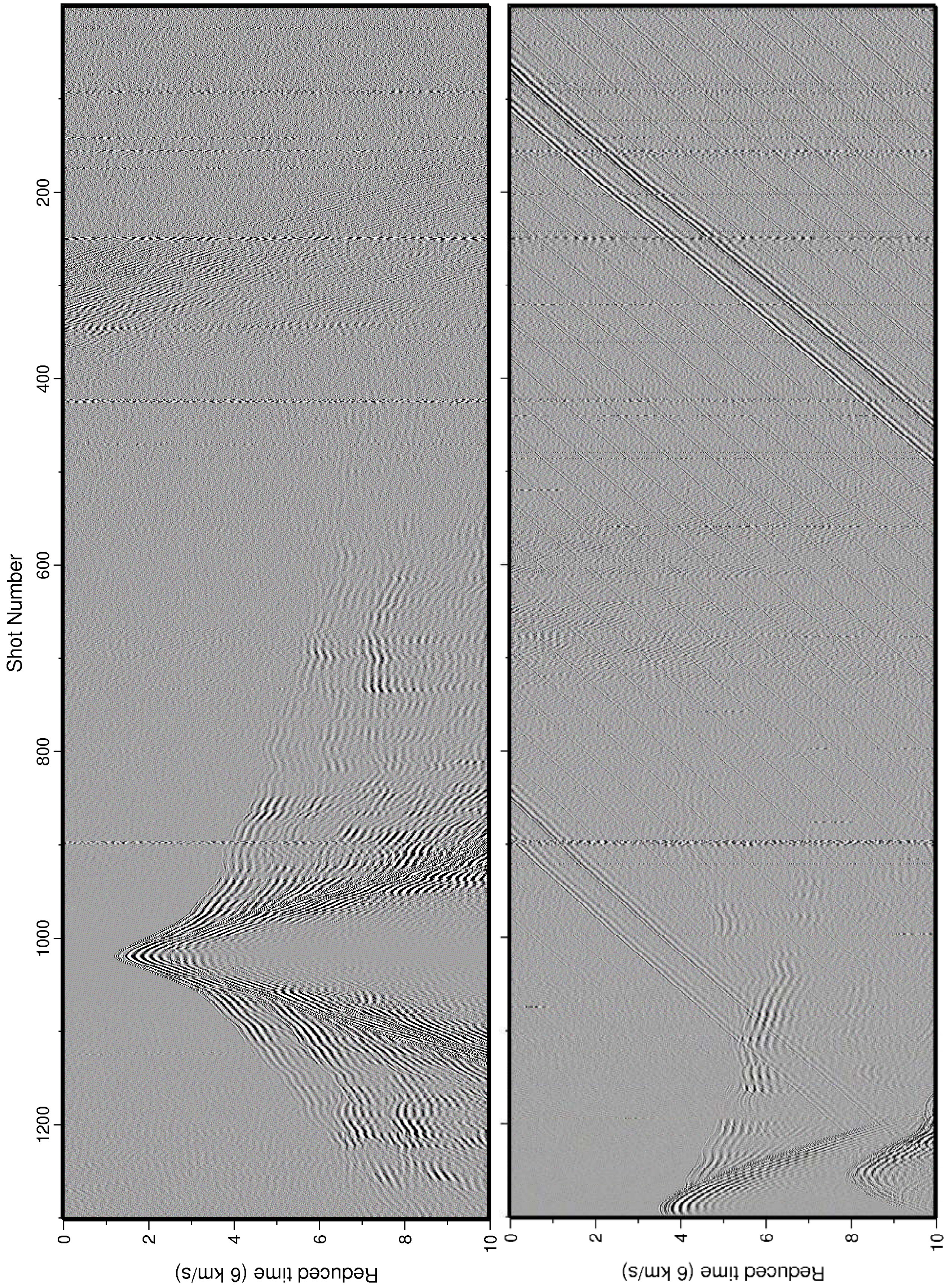

Figure 56: Hydrophone data from OBS instruments at Sites A05 (upper panel) and A06 (lower panel) for all the shots along SUMA (197 km). Data are shown with reduced time (6 km/s), zero-phase band-pass filtered (3-5-25-30 Hz), and gain proportional to offset.

SVP and CTD data

The CTD and SVP were deployed at 2º42.7N, 94º45.7E in ~1930 m water depth. The CTD provides a variety of water properties (Figure 57). Only the acoustic velocity profile is required. The acoustic velocity structure is required to calibrate the swath bathymetric system and the results from both the CTD and SVP are very similar (Figure 58).

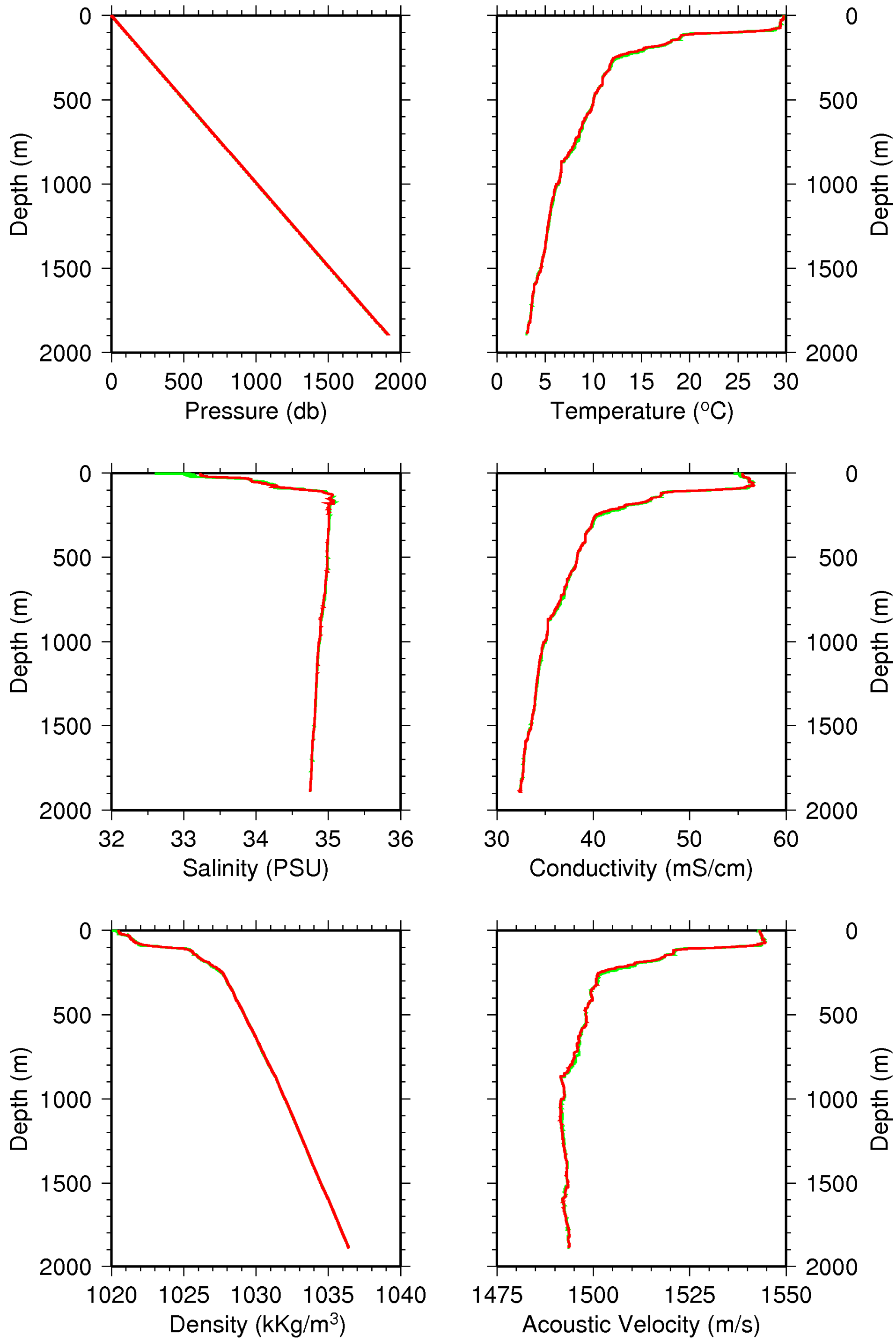

Figure 57: The result of the CTD drop prior to acquiring swath bathymetry in Survey Box 1; red lines identify data acquired as the probe went down, green lines identify data acquired as the probe came back up.

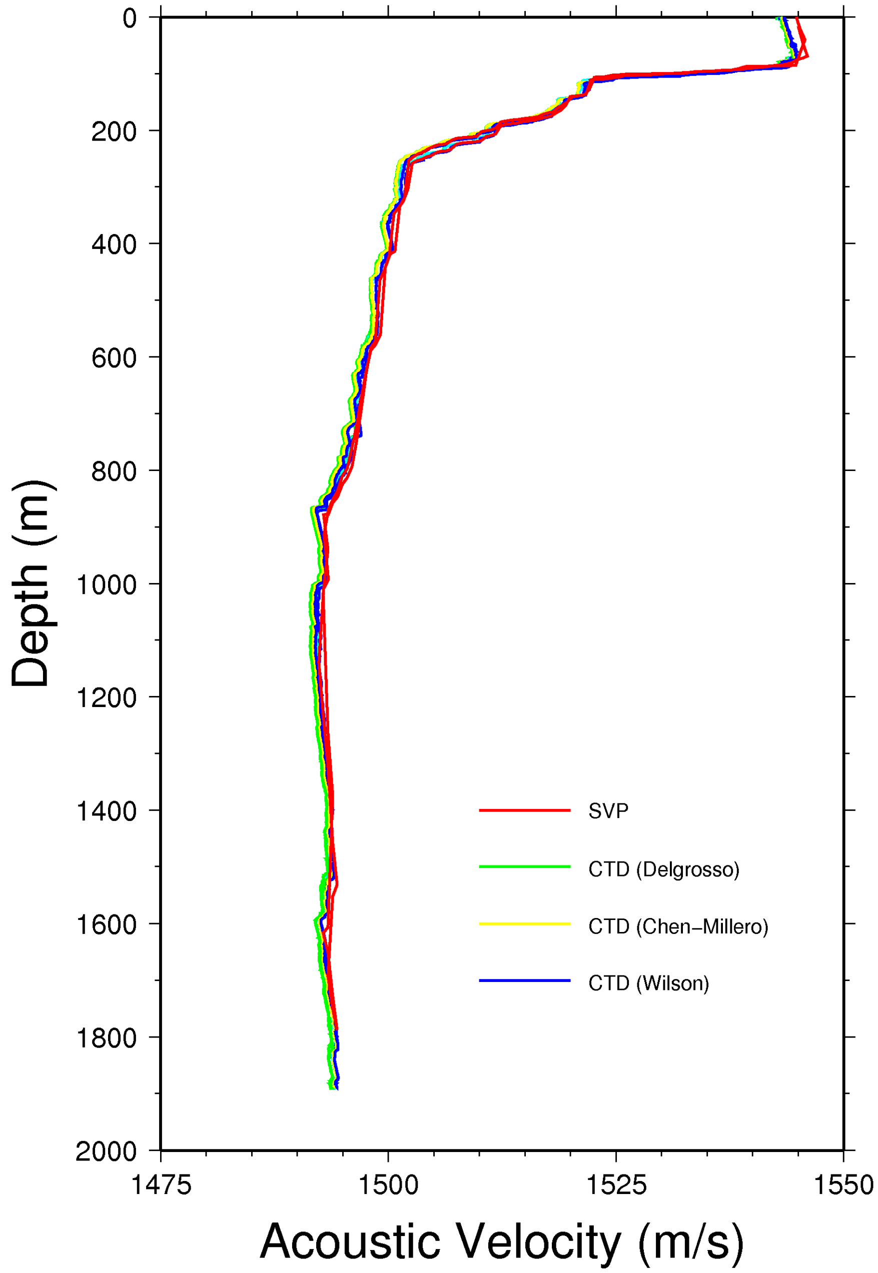

Figure 58: Acoustic velocity measured by the SVP probe (red) and calculated from the CTD data using the method of Delgrosso (green), Chen-Millero (yellow) and Wilson (blue).

Expendable Bathythermograph data

A total of 51 XBT probes were deployed in Survey Box 1 (Table 15). XBT probes were launched after each OBS deployment to provide an even sample distribution (Figure 59). There is relatively little spread in the acoustic velocity structure derived from all the probes, and the XBT results are also very close to those obtained from the SVP and the CTD (Figure 60). A graphical representation of the spatial variations in the acoustic velocity structure obtained by the XBTs is shown in Figure 61.

Sequence (deployment) number	Probe type	Latitude	Longitude	Site No.	Approximate water depth (m)
1	T-5	2.71531	94.76330	A05	1930
2	T-7	2.70821	94.76920	A05	1930
3	T-5	2.45396	94.73570	A06	4550
4	T-7	2.50252	95.01800	A07	1979
5	T-7	2.80942	95.24990	A08	460
6	T-7	2.80871	95.45620	A16	290
7	T-7	2.69261	95.37510	A17	1012
8	T-7	2.54418	95.27460	A18	1203
9	T-5	2.39498	95.17260	A19	2032
10	T-5	2.24695	95.07460	A20	4837
11	T-5	2.07743	95.33240	A21	4880
12	T-5	2.22178	95.43250	A22	2704
13	T-7	2.37182	95.53410	A23	1597
14	T-7	2.57630	95.67610	A24	387
15	T-7	2.47005	95.97930	A33	484
16	T-7	2.33903	95.88940	A34	1353
17	T-5	2.11576	95.73660	A35	2905
18	T-5	1.89200	95.59180	A36	4966
19	T-5	1.71877	95.84580	A37	5023
20	T-5	1.54751	96.10130	A50	5018
21	T-5	1.84219	96.29880	A49	2773
22	T-5	1.94666	95.99800	A38	3576
23	T-7	2.16753	96.14890	A39	679
24	T-7	2.29678	96.24230	A40	618
25	T-7	2.14095	96.50860	A48	797
26	T-7	2.43597	96.71060	A47	760
27	T-7	2.73229	96.91450	A46	1100
28	T-7	2.98322	97.08350	A45	820
29	T-7	3.05372	96.75720	A44	1092
30	T-7	2.90301	96.65440	A43	1106
31	T-7	2.75699	96.55350	A42	1101
32	T-7	2.61922	96.44550	A41	422
33	T-7	2.78893	96.19720	A32	533
34	T-7	2.93895	96.29970	A31	884
35	T-7	3.08614	96.40100	A30	1080
36	T-7	3.38094	96.59600	A29	955
37	T-7	3.40341	96.24110	A28	954
38	T-7	3.25720	96.14050	A27	1026
39	T-7	3.10848	96.03840	A26	932
40	T-7	2.96288	95.93470	A25	364
41	T-7	3.06874	95.63170	A15	431
42	T-7	3.28892	95.78260	A14	1067
43	T-7	3.43884	95.88650	A13	1149
44	T-7	3.68153	96.05140	A12	479
45	T-7	3.70948	95.78880	A11	988
46	T-7	3.40464	95.59200	A10	864
47	T-7	3.10073	95.38850	A09	1033
48	T-7	3.08598	95.12160	A04	654
49	T-7	3.39035	95.31320	A03	1290
50	T-7	3.68430	95.50300	A02	1109
51	T-7	3.95550	95.67350	A01	653

Table 15: XBT launch details for Survey Box 1.

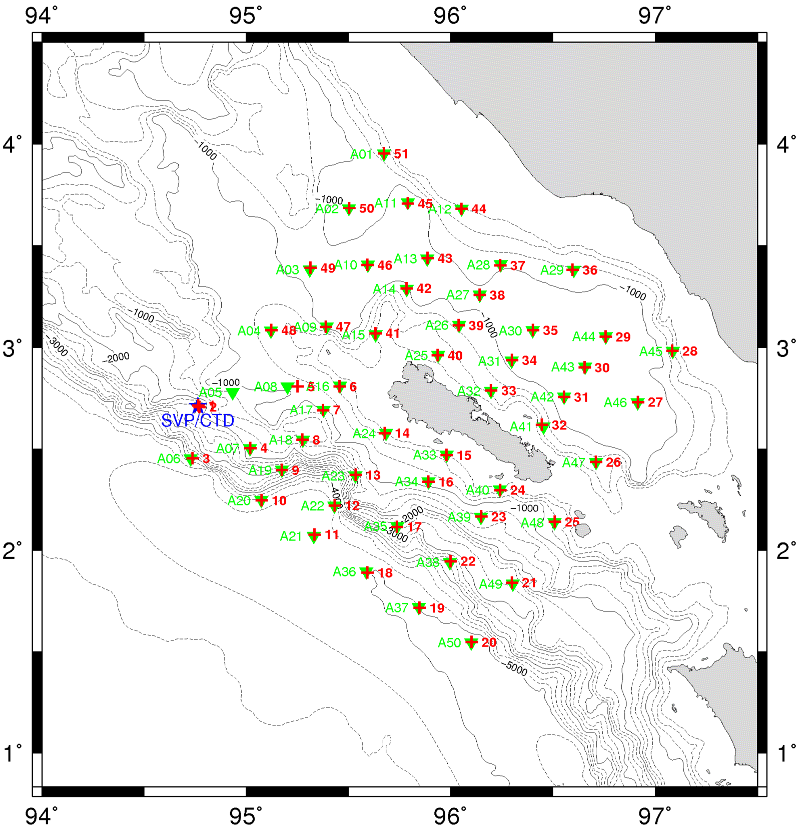

Figure 59: Location of all the XBTs deployed in Survey Box 1 and their Sequence number (red crosses); SVP/CTD deployment (blue star); and OBS locations (green triangles).

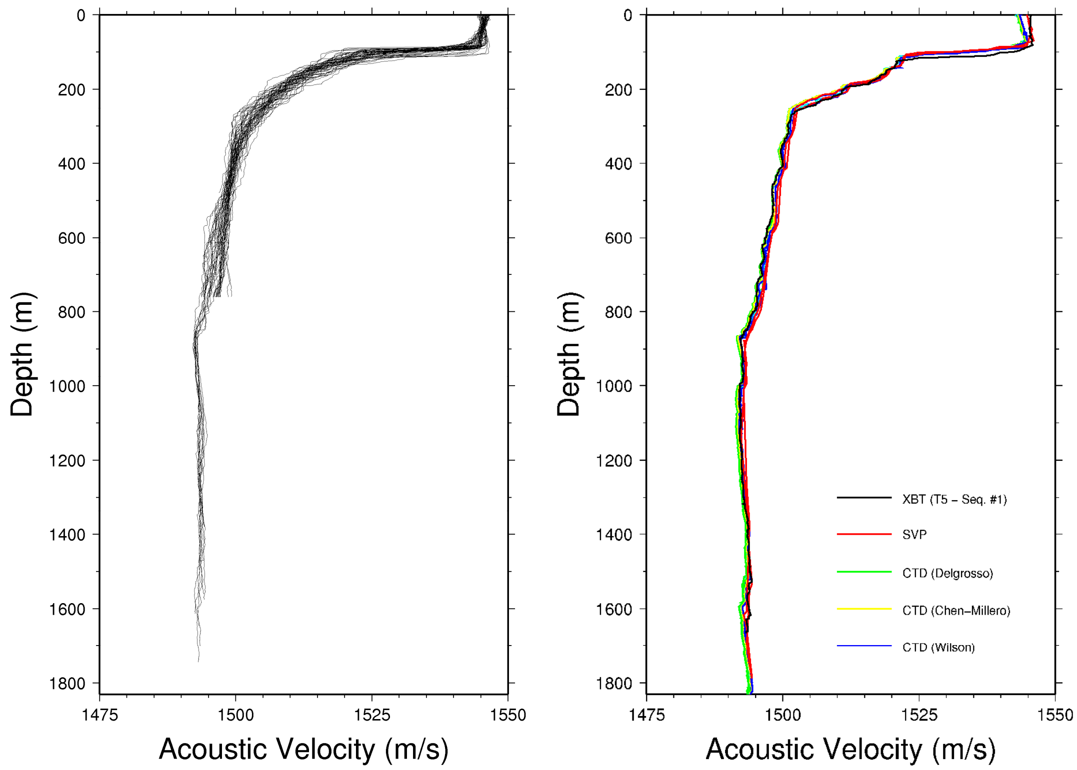

Figure 60: Acoustic velocity versus depth profiles obtained from all XBT probes launched in Survey Box 1 (left). The velocity values obtained by the SVP and CTD probes are very similar to those from the nearest XBT probe (right).

Figure 61: Acoustic velocity versus depth profiles plotted spatially within Survey Box 1. Velocity range (horizontal axes) for each panel is 1485–1555 m/s; depth range is 0–760 m for T-7 probes or 0–1860 m for T-5 probes (red), and expended vertically x3 to show the shallow structure (pink).

Swath bathymetry

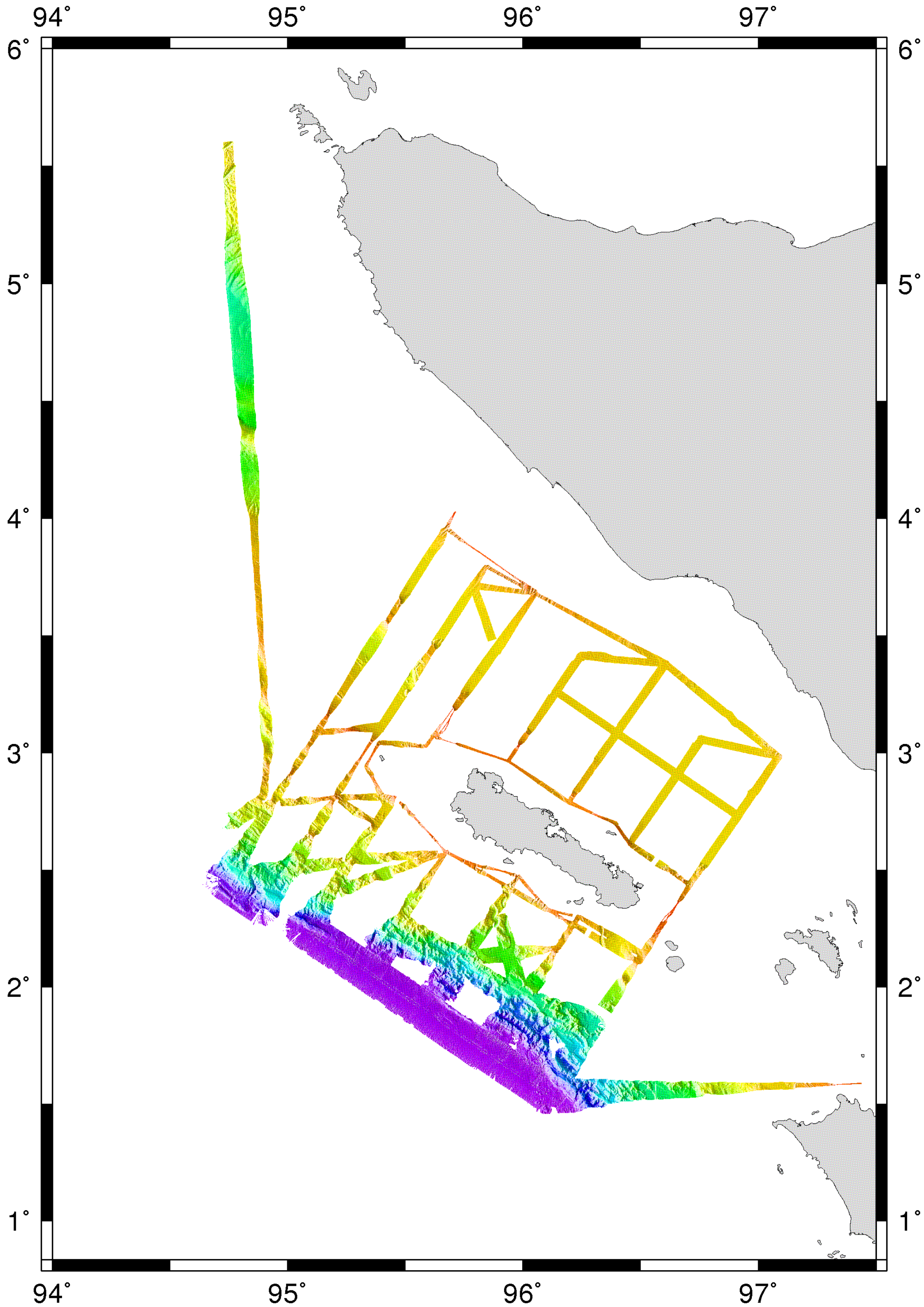

Figure 62: Swath bathymetric data acquired in SB1, including the transit from Singapore. The data were processed using Caris software. Illumination is from the south-west.

Parasound data

The *Parasound* system was used at all times in Survey Box 1 except during deployment and recovery of the OBS instruments, in order to avoid acoustic interference during communications with the instrument release systems (Figure 63). The data quality was generally very good, especially in the basin regions, for example between Simeulue and Sumatra. The maximum penetration of the system was estimated to be ~50 m, with a vertical resolution of 0.5-1.0 m, enough to identify faulting and on-lap structures in the shallow sediments (Figure 64 and Figure 65). As expected, in regions where the seabed varied steeply, such as over the sediment prism, the *Parasound* was unable to provide a usable image.

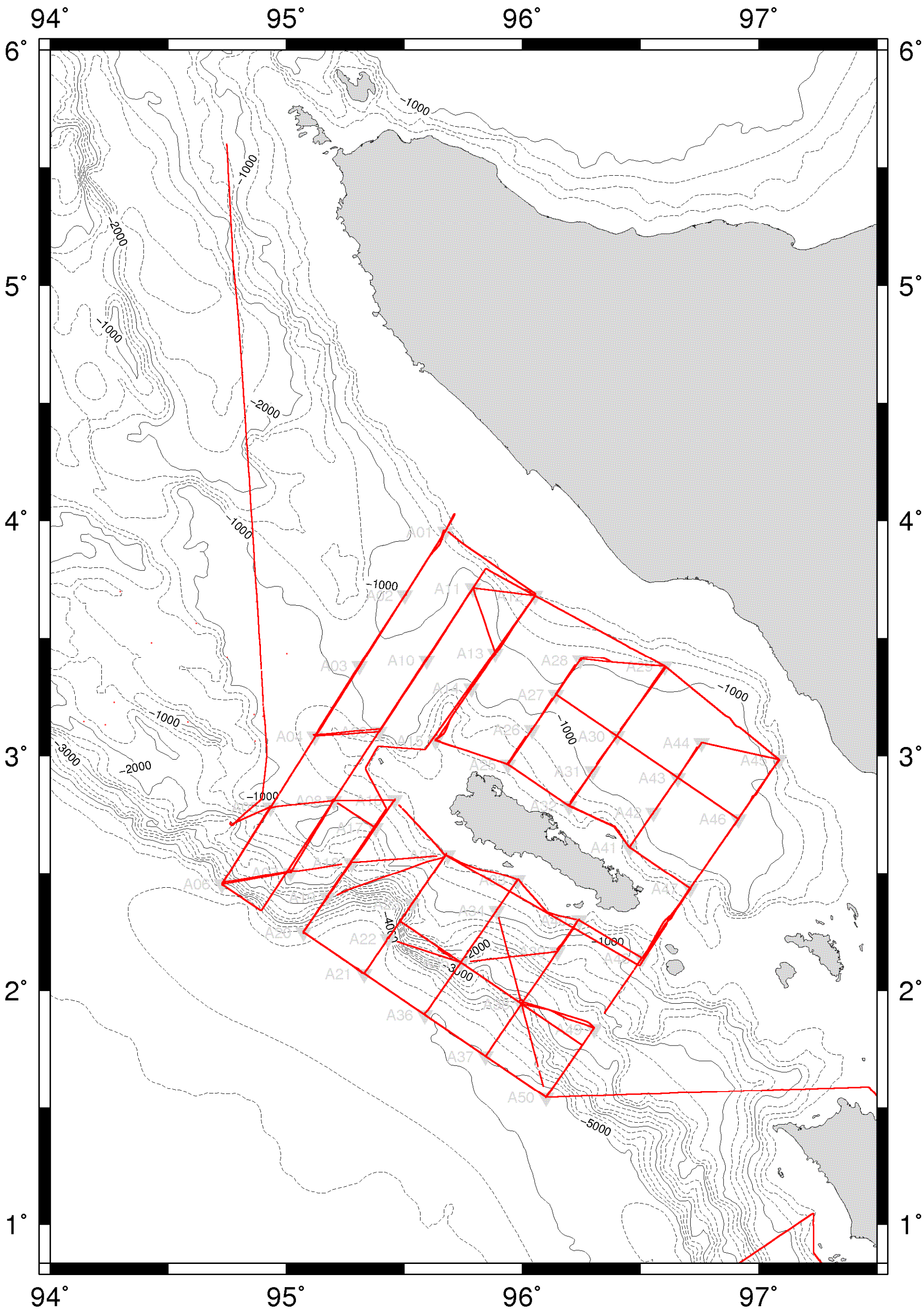

Figure 63: Location of the *Parasound* sub-bottom profiler data on transit to, and in Survey Box 1.

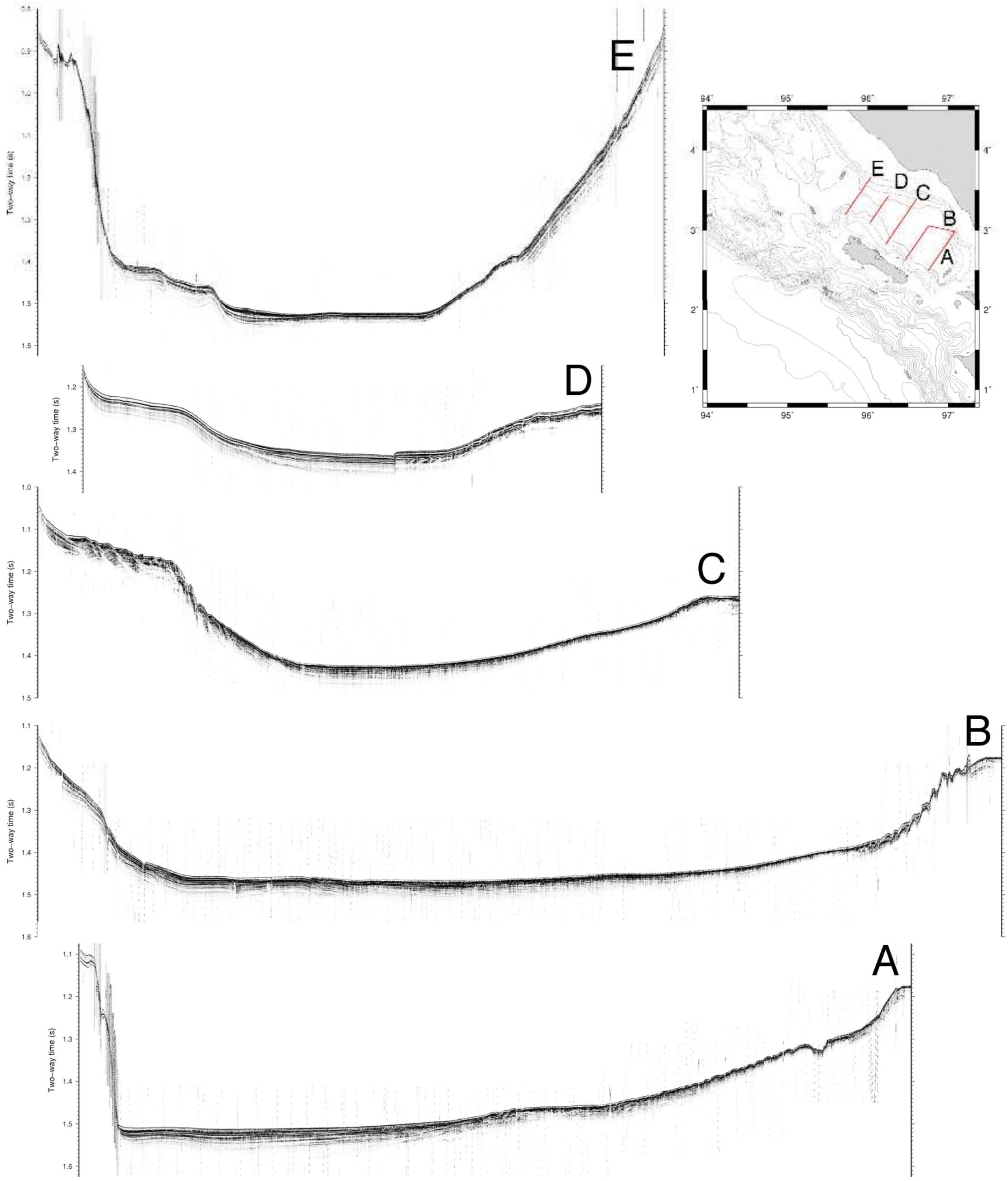

Figure 64: ***Parasound*** **data along profiles across the sediment filled basin that lies between Simeulue and Sumatra.**

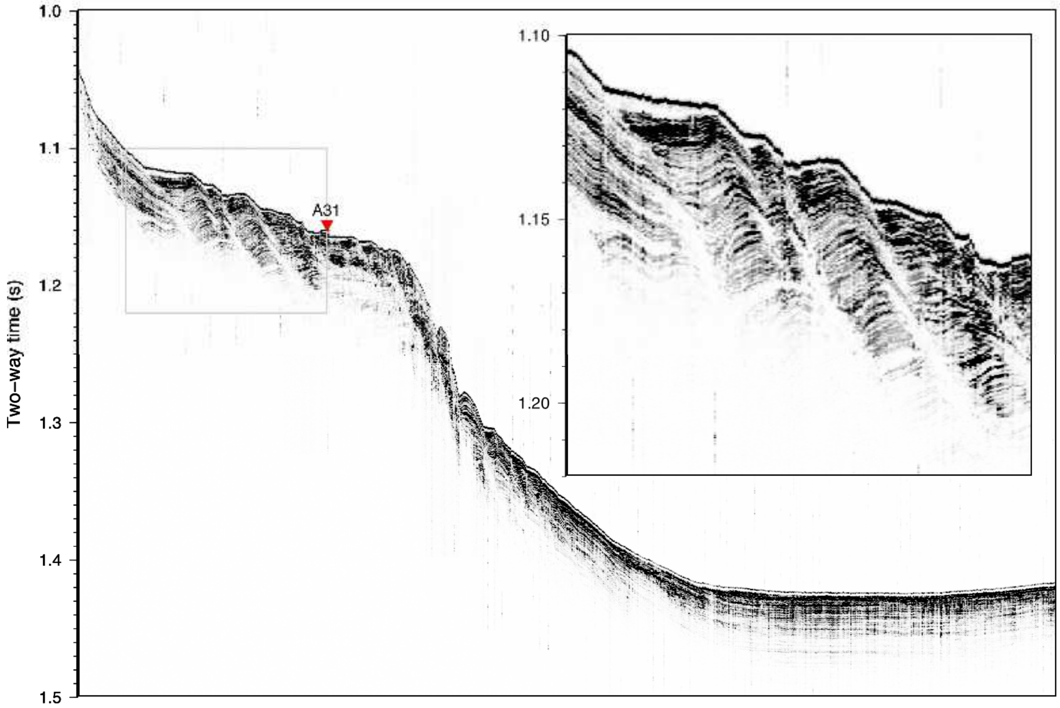

Figure 65: An example *Parasound* record, oriented SSW-NNE, acquired during the deployment of the OBS instruments in SB1; the deployment location of instrument A31 is identified by the red triangle. The data were converted to SEG-Y format and processed as described in the text. The inset shows an enlarged region identified in the main figure by the grey box. Note that the horizontal scale is dependent on the speed of the vessel and is not constant in this figure.

Gravity data

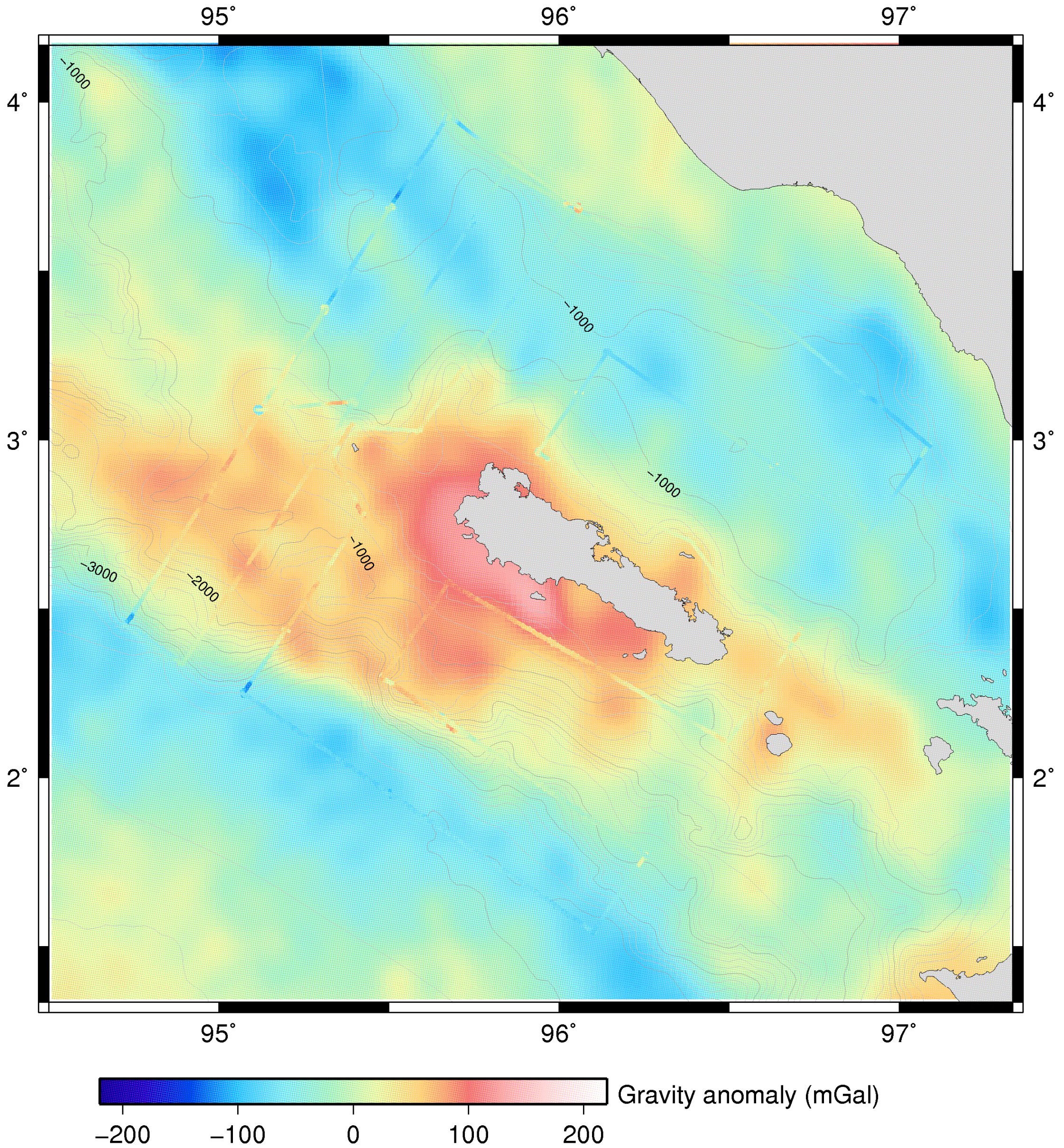

Figure 66: 2-minute gravity measurements in Survey Box 1, adjusted for instrument clock drift and basic Eötvos correction. The main misfits arise from error in ship velocity and heading, as can be observed in the data near turns. The background grid is from Sandwell and Smith (1997).

Magnetic data

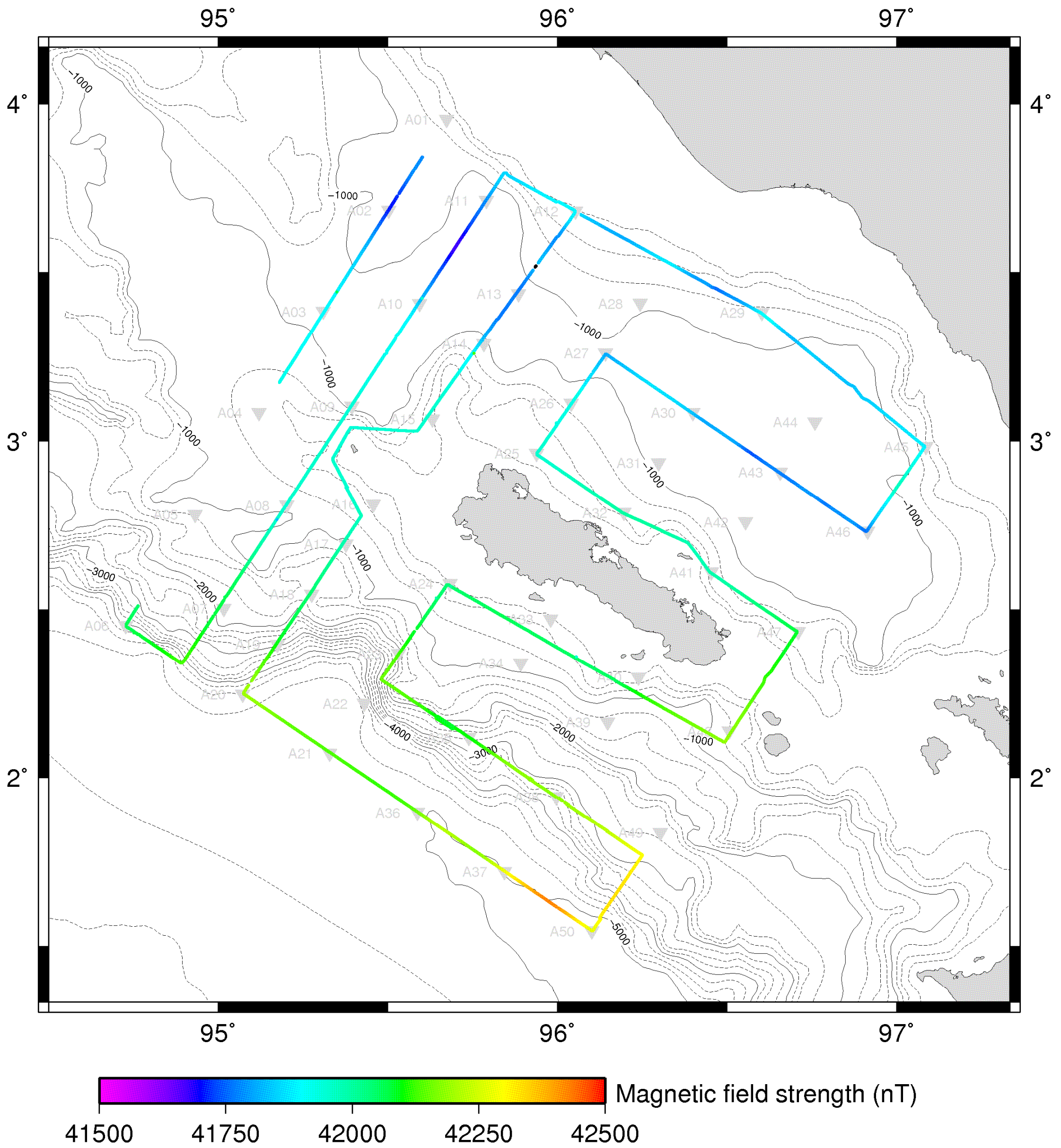

Figure 67: Magnetic field strength in nT measured along the airgun profiles in Survey Box 1. There is a clear trend from high values in the south, over the trench, to lower values to the north, over the basin.

Results: Survey Box 2

The basic scientific operations in Survey Box 2 were as follows:

1. Deploy 47 OBS instruments, with an XBT drop at each site.
2. Survey with airguns throughout the Survey Box.
3. Recover the OBS instruments.
4. Deploy 10 long-term OBS instruments for an 8-month passive seismic experiment.
5. An SVP and CTD drop.

Where possible, the following systems were also operated during this period:

- Swath bathymetry
- Sub-bottom profiler
- Gravity meter
- Magnetometer

Survey narrative

Julian Day 146, Sunday 25th May

On passage to Survey Box 2, arriving off Gunnungsitoli, Nias, at 14:00. Security Officer organised a boat to collect some notices advertising the lost OBSs, and the boat brought some durian fruit. Began OBS deployment in Survey Box 2 (see Table 17), starting behind Nias island.

Julian Day 147, Monday 26th May

Continued OBS deployment in Survey Box 2. One instrument will have to be left out of second deployment due to a cable connector being damaged, so we will deploy 47 in all. Taking care to deploy all OBS in >100m water. Tested a long deployment instrument on 800 m of rope – first that it sank, and then that it refloated at a reasonable velocity after the bottom weight was released. This was successful, and everyone enjoyed helping to haul it back in.

Julian Day 148, Tuesday 27th May

Continued OBS deployment in Survey Box 2.

Julian Day 149, Wednesday 28th May

Continued OBS deployment in Survey Box 2. Discussions with System Manager about logging shots on a PC for next shooting period – he is testing a system. Finished last OBS deployment at 20:30 and began deploying airguns. Began airgun shooting at around 22:00 (see Table 16) with a ramp-up, and then spent about an hour tuning the guns in. Deployed the magnetometer at 23:00. Spectacular lightning storm.

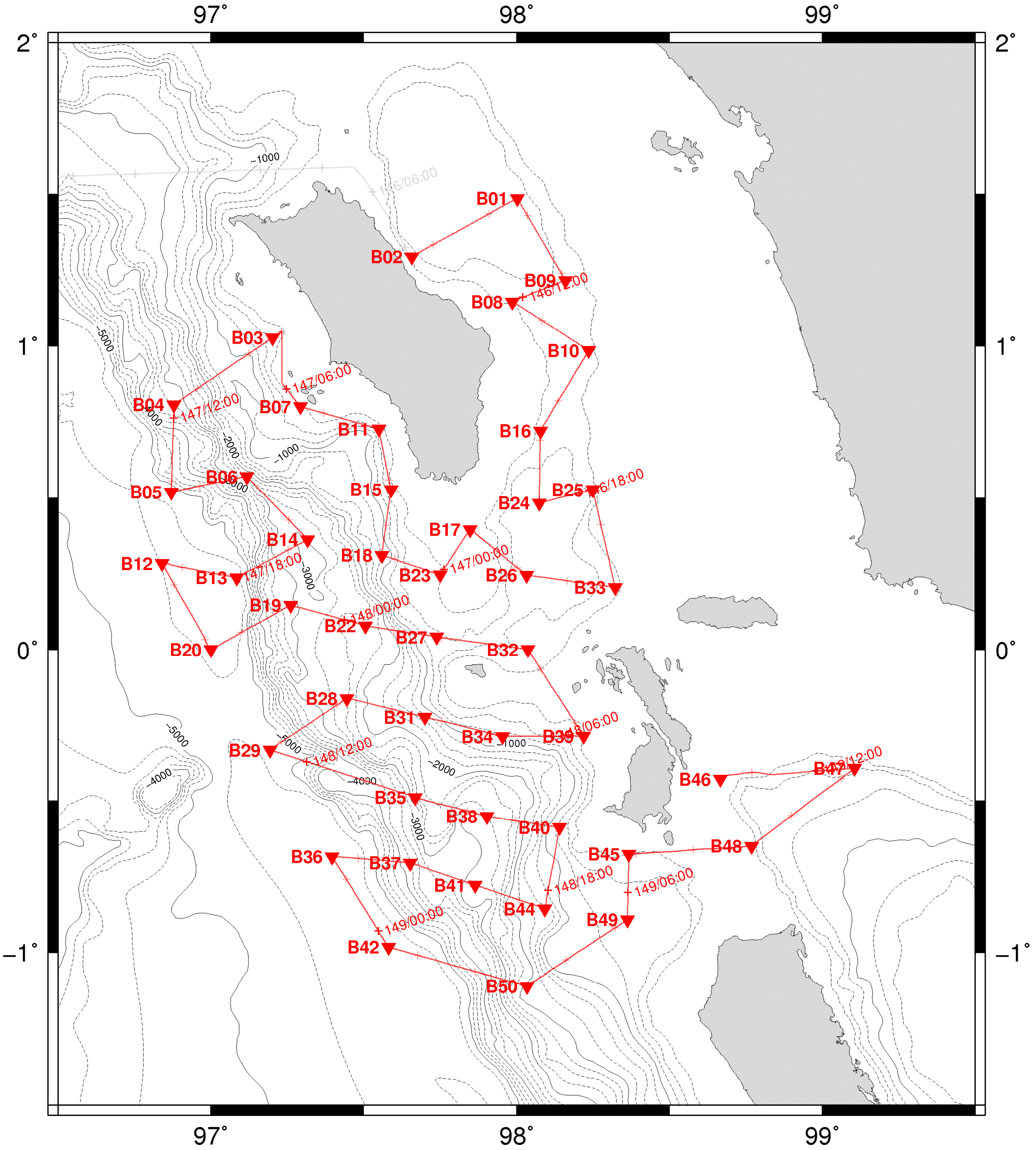

Figure 68: Deployment location for the OBS instruments in Survey Box 2 (triangles) labelled with the Site Number. The red line shows the route taken; crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 150, Thursday 29th May

Started shooting in Survey Box 2. Guns well aligned and pressure good. Extensive preparations for barbeque and party in the evening. Food, music and dancing enjoyed by all.

Julian Day 151, Friday 30th May

Continued shooting in Survey Box 2.

Julian Day 152, Saturday 31st May

Continued shooting in Survey Box 2. Interrupted shooting for about 40 minutes to swap compressors in the hold.

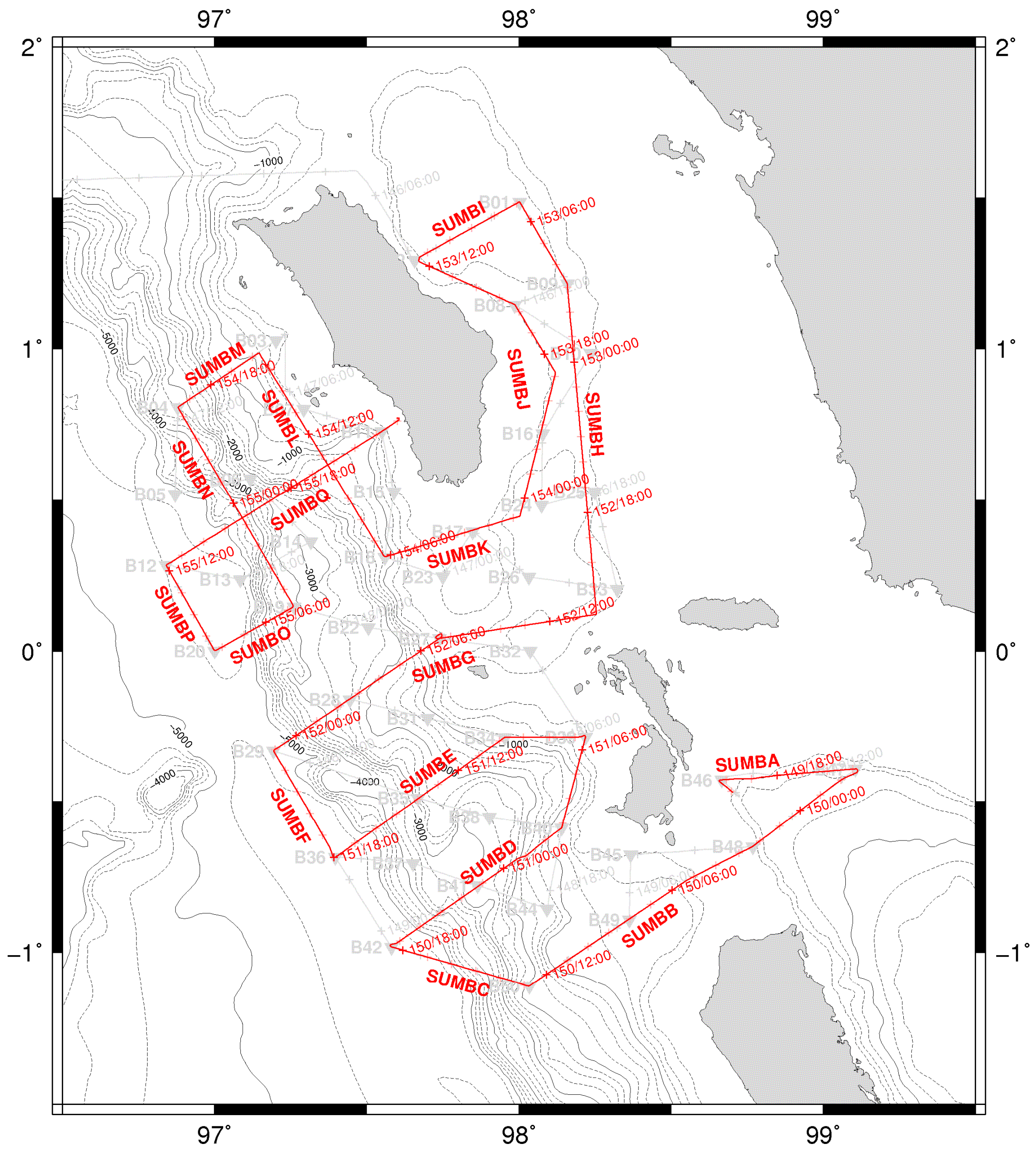

Figure 69: Shooting profiles SUMBA to SUMBQ in Survey Box 2. Crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 153, Sunday 1st June

Continued shooting in Survey Box 2. Guns all well aligned. Began to replay LC4x4 data using a decoder written by Tim Henstock. Unfortunately most hydrophone channels are blank as they were incorrectly pre-set for a Differential Pressure Gauge (DPG).

Julian Day 154, Monday 2nd June

Continued shooting in Survey Box 2. OBS team tried and failed to get LC4x4 data into SEG-Y format using software just received from Scripps; however, a detailed look at a number of instruments with the Henstock decoder suggested they are mostly functioning well.

Julian Day 155, Tuesday 3rd June

Continued shooting in Survey Box 2. Lost 2 guns today (escaping air): gun 1 on the starboard side in the morning, and gun 7 on the port side in the afternoon. Began final (extra) line SUMBQ in the evening, to end by Nias Island at first light.

Julian Day 156, Wednesday 4th June

Finished shooting close to Nias at dawn (06:15). Brought in the magnetometer and gun arrays by 07:15 and set off for the first OBS recovery. Continued OBS recovery, noting large amounts of floating debris around site B03.

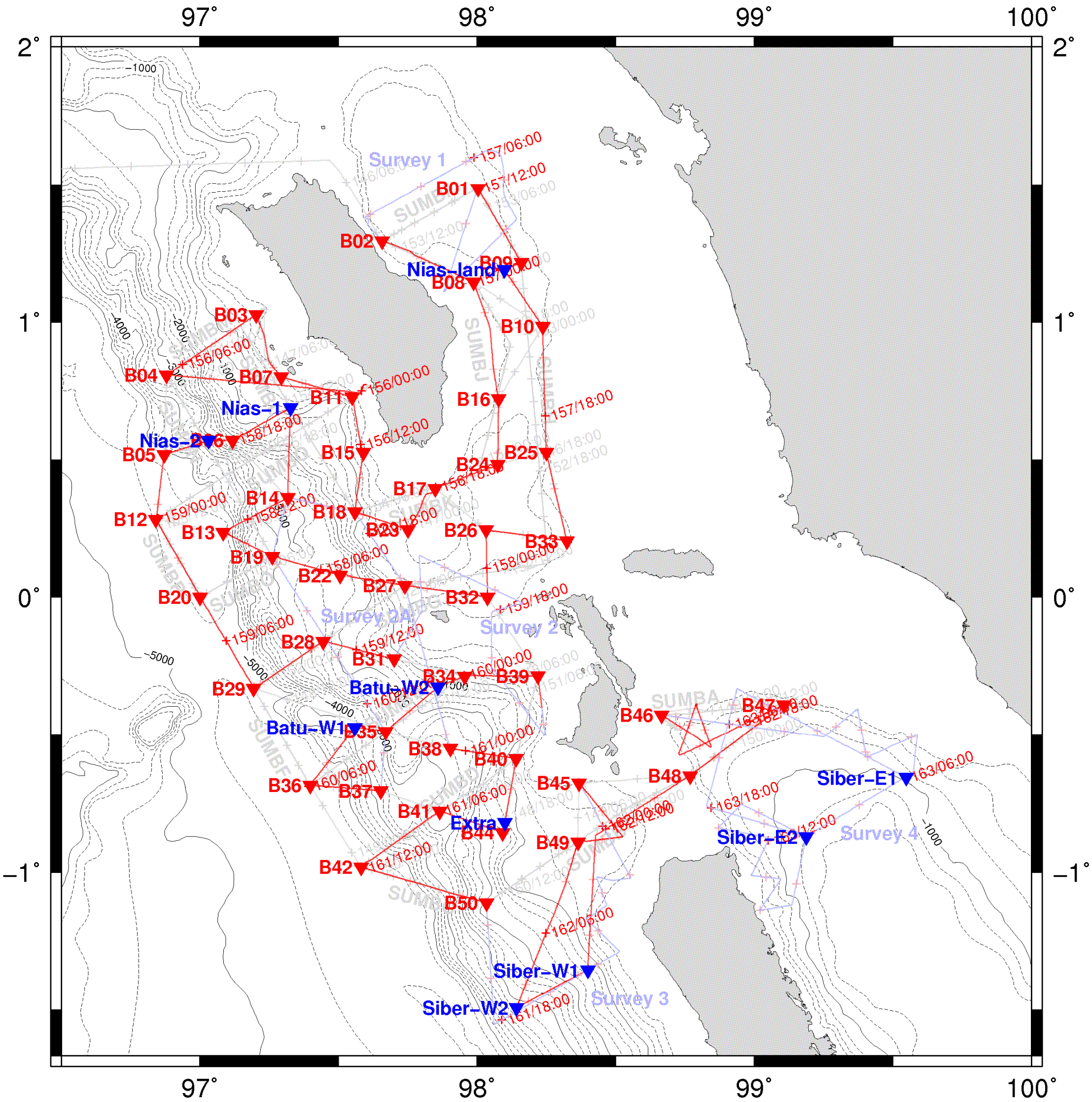

Figure 70: The recovery route for OBS instruments in Survey Box 2; crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. Red triangles identify OBS deployment locations, labelled with the Site Number. Blue triangles identify log term OBS deployments; blue lines are swath/*Parasound* surveys 1-4. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 157, Thursday 5th June

Continued OBS recovery in Survey Box 2. Carried out a small swath/*Parasound* survey (Survey 1; Figure 70), and stopped in deep water for pinger test and to test the DPG for the long deployment by immersion. Also tested by poking with fingers (1 minute), and this was found to be effective. The French broadband instrument was found not to have released its seismometer package until almost the end of shooting in Survey Box 2. Deployed the first long-term OBS at station Nias-Land (see Table 18).

Julian Day 158, Friday 6th June

Continued OBS recovery in Survey Box 2. Deployed long-term OBS at Nias-1 and Nias-2.

Julian Day 159, Saturday 7th June

Continued OBS recovery in Survey Box 2. Weather became quite unpleasantly ‘North Atlantic’ in character for a few hours. Carried out second small swath/*Parasound* survey (Survey 2; Figure 70).

Julian Day 160, Sunday 8th June

Continued OBS recovery in Survey Box 2. Deployed long-term OBS instruments at Batu-W2 and Batu-W1. Carried out the third small swath/*Parasound* survey (Survey 2A; Figure 70) to fill some gaps in coverage.

Julian Day 161, Monday 9th June

Continued OBS recovery in Survey Box 2, picking up the four OBS without lights or radios in the morning. Deployed the long-term OBS station ‘Extra’. CTD and SVP drop to 2000 m.

Julian Day 162, Tuesday 10th June

Continued OBS recovery in Survey Box 2 and deployed long-term OBS instruments at Siber-W2 and Siber-W1, after a swath/*Parasound* survey of this area (Survey 3; Figure 70), which is outside Survey Box 2. Crossed the shallow ‘pass’ north of Siberut for the last time.

Julian Day 163, Wednesday 11th June

Last OBS recovery from Survey Box 2 recovered at dawn. Spent the day doing swath/*Parasound* survey east of Siberut (Survey 4; Figure 70). In late evening wire-tested and then deployed long-term OBS at Siber-E2. OBS teams began packing.

Julian Day 164, Thursday 12th June

Deployed last long-term OBS at Siber-E1 at 07:00 local time and left for Merak. Turned off swath and *Parasound* recording as we approached the edge of the cruise working area at 14:40. On passage to Merak. More packing and data transcription. Party in the evening – weather became wet and windy.

Julian Day 165, Friday 13th June

On passage to Merak. Torrential rain in the night, and poor weather during the day. Packing and data transcription. Short science meeting.

Julian Day 166, Saturday 14th June

Arrive Merak 08:30. Interminable waiting for clearance, freight to be removed etc. Indonesian participants, GT, NF and PT departed. The empty container for the OBS did not appear. Remaining party went ashore for a drink in the evening.

Julian Day 167, Sunday 15th June

In port Merak. Still awaiting OBS container (finally arrived Friday 20th June). Tim Henstock and Lisa McNeill arrive in the morning for a handover meeting with PB and SD. New SO198-2 technical staff arrives. Remaining SO198-1 scientists disembark for travel or hotel in Anyer.

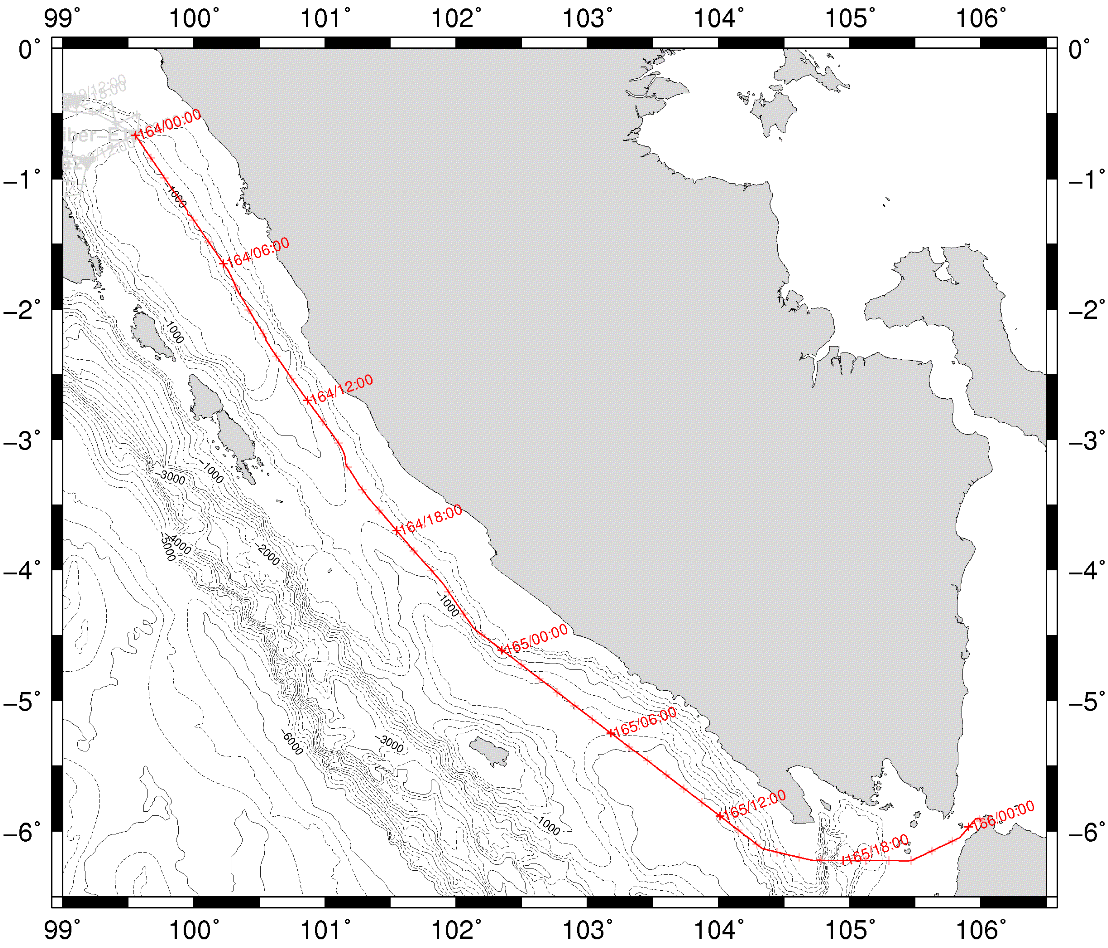

Figure 71: Map of the transit route taken from Survey Box 2 to Merak. Crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. GEBCO 1-minute bathymetry is contoured every 250 m.

Seismic source

Start					End					Line
Julian day	UTC time	Shot No.	Lat.	Long.	Julian day	UTC time	Shot No.	Lat.	Long.	
149	14:52:30.56	20000	-0.469	98.701	149	15:14:30.56	20022	-0.455	98.685	Ramp up
149	15:15:30.56	20023	-0.454	98.684	149	15:39:30.56	20047	-0.434	98.659	SUMB0
149	15:40:30.56	20048	-0.433	98.658	149	15:48:30.56	20056	-0.428	98.664	Turn

149	15:49:30.56	20057	-0.428	98.665	149	21:05:30.56	20373	-0.392	99.104	SUMBA
149	21:06:30.56	20374	-0.392	99.105	149	21:19:30.56	20387	-0.404	99.109	Turn
149	21:20:30.56	20388	-0.405	99.108	150	02:20:30.56	20688	-0.648	98.769	SUMBB-1
150	02:21:30.56	20689	-0.649	98.768	150	02:21:30.56	20689	-0.649	98.768	Turn
150	02:22:30.56	20690	-0.650	98.767	150	05:16:30.56	20864	-0.760	98.554	SUMBB-2
150	05:17:30.56	20865	-0.760	98.553	150	05:17:30.56	20865	-0.760	98.553	Turn
150	05:18:30.56	20866	-0.761	98.552	150	12:47:30.56	21315	-1.111	98.034	SUMBB-3
150	12:48:30.56	21316	-1.111	98.033	150	12:57:30.56	21325	-1.109	98.021	Turn
150	12:58:30.56	21326	-1.109	98.020	150	18:28:30.56	21656	-0.982	97.580	SUMBC
150	18:29:30.56	21657	-0.981	97.579	150	18:53:30.56	21681	-0.967	97.600	Turn
150	18:54:30.56	21682	-0.967	97.601	151	02:46:30.56	22154	-0.589	98.139	SUMBD-1
151	02:47:30.56	22155	-0.588	98.139	151	02:52:30.56	22160	-0.582	98.141	Turn
151	02:53:30.56	22161	-0.580	98.142	151	06:31:30.56	22379	-0.287	98.218	SUMBD-2
151	06:32:30.56	22380	-0.286	98.218	151	06:46:30.56	22394	-0.285	98.202	Turn
151	06:47:30.56	22395	-0.285	98.201	151	09:39:30.56	22567	-0.286	97.960	SUMBE-1
151	09:40:30.56	22568	-0.286	97.959	151	09:50:30.56	22578	-0.292	97.947	Turn
151	09:51:30.56	22579	-0.292	97.945	151	17:55:30.56	23063	-0.684	97.398	SUMBE-2
151	17:56:30.56	23064	-0.685	97.396	151	18:02:30.56	23070	-0.684	97.389	Turn
151	18:03:30.56	23071	-0.683	97.389	151	22:53:30.56	23361	-0.333	97.194	SUMBF
151	22:54:30.56	23362	-0.332	97.194	151	22:59:30.56	23367	-0.328	97.197	Turn
151	23:00:30.56	23368	-0.327	97.198	152	06:53:30.56	23841	0.043	97.739	SUMBG-1
152	06:54:30.56		0.043	97.741	152	07:06:30.56		0.057	97.743	Compressors swapped
152	07:07:30.56	23843	0.057	97.741	152	07:29:30.56	23865	0.041	97.733	ramp up
152	07:30:30.56	23866	0.041	97.734	152	07:32:30.56	23868	0.041	97.737	loop
152	07:33:30.56	23869	0.042	97.738	152	13:50:30.56	24246	0.121	98.251	SUMBG-2
152	13:51:30.56	24247	0.121	98.252	152	13:55:30.56	24251	0.126	98.255	Turn
152	13:56:30.56	24252	0.127	98.254	153	03:06:30.56	25042	1.213	98.159	SUMBH-1
153	03:07:30.56	25043	1.215	98.159	153	03:08:30.56	25044	1.216	98.158	Turn
153	03:09:30.56	25045	1.217	98.158	153	06:49:30.56	25265	1.483	98.004	SUMBH-2
153	06:50:30.56	25266	1.484	98.003	153	06:54:30.56	25270	1.486	97.998	Turn
153	06:55:30.56	25271	1.485	97.997	153	11:20:30.56	25536	1.305	97.675	SUMBI
153	11:21:30.56	25537	1.304	97.674	153	11:36:30.56	25552	1.287	97.676	Turn
153	11:37:30.56	25553	1.286	97.677	153	15:38:30.56	25794	1.148	97.983	SUMBJ-1
153	15:39:30.56	25795	1.147	97.985	153	15:42:30.56	25798	1.145	97.987	Turn
153	15:43:30.56	25799	1.144	97.988	153	18:49:30.56	25985	0.923	98.119	SUMBJ-2
153	18:50:30.56	25986	0.921	98.119	153	18:52:30.56	25988	0.919	98.120	Turn
153	18:53:30.56	25989	0.918	98.120	154	00:41:30.56	26337	0.449	98.004	SUMBJ-3
154	00:42:30.56	26338	0.447	98.003	154	00:49:30.56	26345	0.443	97.995	Turn
154	00:50:30.56	26346	0.443	97.994	154	06:11:30.56	26667	0.312	97.563	SUMBK
154	06:12:30.56	26668	0.312	97.562	154	06:18:30.56	26674	0.315	97.555	Turn
154	06:19:30.56	26675	0.316	97.554	154	15:40:30.56	27236	0.982	97.148	SUMBL
154	15:41:30.56	27237	0.983	97.147	154	15:48:30.56	27244	0.982	97.138	Turn
154	15:49:30.56	27245	0.981	97.137	154	19:31:30.56	27467	0.809	96.882	SUMBM
154	19:32:30.56	27468	0.809	96.881	154	19:39:30.56	27475	0.800	96.882	Turn
154	19:40:30.56	27476	0.799	96.883	155	04:43:30.56	28019	0.150	97.257	SUMBN
155	02:37:30.56	27893	0.302	97.170						Airgun 7 turned off
155	04:44:30.56	28020	0.149	97.258	155	04:47:30.56	28023	0.145	97.256	Turn
155	04:48:30.56	28024	0.144	97.254	155	08:17:30.56	28233	0.002	97.003	SUMBO
155	08:18:30.56	28234	0.002	97.001	155	08:25:30.56	28241	0.008	96.995	Turn
155	08:26:30.56	28242	0.009	96.995	155	12:13:30.56	28469	0.281	96.842	SUMBP
155	10:11:30.56	28347	0.135	96.924						Airgun 1 turned off
155	12:14:30.56	28470	0.282	96.841	155	12:17:30.56	28473	0.285	96.842	Turn
155	12:18:30.56	28474	0.286	96.843	155	23:04:30.56	29120	0.764	97.605	SUMBQ
155	23:05:30.56	29121	0.765	97.606	155	23:17:30.56	29133	0.771	97.598	Turn

Table 16: The start and end time for each shooting profile in Survey Box 2, versus shot number. Airguns 1 and 7, turned off on Julian Day 155, were not turned back on for the remainder of the shooting. Navigation locations are for the vessel, not the source.

OBS data

A total of 47 OBS instruments were deployed in Survey Box 2 (Table 17, Figure 68).

Site No.	OBS No.	OBS type	Julian Day	UTC Time	Lat.	Long.	Depth (m)
B01	UK52	LC4x4	146	09:37	1.48605	98.00182	580
B02	UK16	LC2000/2	146	07:27	1.29458	97.65653	422
B03	FR09	LC2000/2	147	07:23	1.02738	97.20147	130
B04	UK45	LC4x4	147	09:33	0.80668	96.87847	3285
B05	FR11	LC2000/2	147	13:19	0.51863	96.86973	5174
B06	FR12	LC2000/2	147	14:55	0.56978	97.11642	2177
B07	UK44	LC4x4	147	05:30	0.80007	97.29185	394
B08	UK47	LC4x4	146	12:21	1.14538	97.98558	377
B09	UK14	LC2000/2	146	11:11	1.21605	98.15852	463
B10	FR07	LC2000/2	146	13:56	0.98487	98.23502	404
B11	UK15	LC2000/2	147	03:58	0.72682	97.54862	422
B12	UK19	LASSI	147	19:28	0.28330	96.83982	5306
B13	UK27	LASSI	147	18:01	0.23638	97.08337	5262
B14	UK22	LASSI	147	16:33	0.36178	97.31557	3059
B15	UK46	LC4x4	147	02:45	0.52693	97.58837	273
B16	FR05	LC2000/4	146	15:43	0.71992	98.07692	402
B17	UK11	LC2000/2	146	23:11	0.39480	97.84695	105
B18	UK13	LC2000/2	147	01:23	0.31053	97.55785	1197
B19	UK17	LC2000/2	147	23:01	0.14598	97.26017	3304
B20	UK43	LC4x4	147	21:19	-0.00047	96.99930	5303
B21	UNOCCUPIED						
B22	UK02	LC2000/4	148	00:26	0.07797	97.50478	2385
B23	UK05	LC2000/4	147	00:09	0.24587	97.74952	213
B24	FR23	LC2000/BB	146	17:12	0.48302	98.07368	704
B25	UK06	LC2000/4	146	18:19	0.52663	98.24823	237
B26	UK04	LC2000/4	146	21:42	0.24543	98.03148	699
B27	FR14	LC2000/2	148	01:50	0.04138	97.73792	554
B28	US49	LC4x4	148	09:46	-0.16200	97.44358	2363
B29	UK21	LASSI	148	11:17	-0.33210	97.19280	5286
B30	UNOCCUPIED						
B31	FR16	LC2000/2	148	08:22	-0.22393	97.69882	1264
B32	FR13	LC2000/2	148	03:32	-0.00030	98.03658	433
B33	FR08	LC2000/2	146	20:04	0.20475	98.32232	241
B34	FR15	LC2000/2	148	06:55	-0.28775	97.95332	870
B35	UK20	LASSI	148	13:56	-0.48860	97.66823	1812
B36	FR17	LC2000/2	148	22:27	-0.68485	97.39610	5436
B37	UK24	LASSI	148	21:04	-0.70510	97.65053	2850
B38	UK23	LASSI	148	15:26	-0.55118	97.90205	2868
B39	UK09	LC2000/4	148	05:23	-0.28670	98.21813	280
B40	UK12	LC2000/2	148	16:51	-0.58825	98.13973	721
B41	UK48	LC4x4	148	19:50	-0.77845	97.86307	2849
B42	FR06	LC2000/4	149	00:24	-0.98160	97.58018	5484
B43	UNOCCUPIED						
B44	UK10	LC2000/4	148	18:25	-0.85610	98.09143	1172
B45	FR19	LC2000/2	149	06:46	-0.67673	98.36669	258
B46	UK08	LC2000/4	149	13:39	-0.42823	98.66493	182
B47	UK03	LC2000/4	149	11:22	-0.39210	99.10473	373
B48	FR20	LC2000/2	149	09:07	-0.65013	98.76748	127
B49	FR18	LC2000/2	149	05:24	-0.89160	98.36240	722
B50	UK28	LASSI	149	03:05	-1.11133	98.03285	1965

Table 17: OBS deployment details for Survey Box 2.

Site No.	OBS No.	Julian Day	UTC Time	Lat.	Long.	Depth (m)	Data Quality			
							1	2	3	4
B01	UK52	157	11:59	1.487	98.003	565	2a	2b	1	4
B02	UK16	157	02:09	1.295	97.657	431				
B03	FR09	156	07:52	1.028	97.202	125				
B04	UK45	156	05:31	0.805	96.877	3282	2a	2a	1	4
B05	FR11	158	21:59	0.519	96.873	5168				
B06	FR12	158	18:07	0.572	97.118	2176				
B07	UK44	156	09:28	0.800	97.293	397	2a	2b	1	4
B08	UK47	156	23:54	1.144	97.986	374	2a	2b	2a	4
B09	UK14	157	13:59	1.215	98.161	469				
B10	FR07	157	16:18	0.984	98.237	406				
B11	UK15	156	11:04	0.727	97.549	420				
B12	UK19	159	01:02	0.284	96.844	5305				
B13	UK27	158	11:26	0.237	97.087	5246				
B14	UK22	158	13:58	0.363	97.319	3057				
B15	UK46	156	12:28	0.526	97.589	269	2b	2b	3	4
B16	FR05	156	21:21	0.719	98.077	401				
B17	UK11	156	17:50	0.396	97.846	110				
B18	UK13	156	14:40	0.309	97.551	1246				
B19	UK17	158	08:18	0.145	97.262	3301				
B20	UK43	159	04:58	0.001	97.004	5307	2b	2b	2a	?
B22	UK02	158	05:28	0.077	97.506	2386				
B23	UK05	156	16:18	0.245	97.746	222				
B24	FR23	156	19:38	0.482	98.072	706				
B25	UK06	157	19:14	0.525	98.249	228				
B26	UK04	157	23:10	0.245	98.033	701				
B27	FR14	158	02:52	0.042	97.738	549	4	4	-	-
B28	US49	159	11:19	-0.160	97.446	2455	2b	2b	2a	4
B29	UK21	159	08:40	-0.331	97.195	5387				
B31	FR16	159	13:16	-0.224	97.701	1228				
B32	FR13	158	00:49	-0.001	98.038	434				
B33	FR08	157	21:12	0.206	98.324	241				
B34	FR15	160	00:27	-0.288	97.954	877				
B35	UK20	160	03:20	-0.491	97.669	1768				
B36	FR17	160	07:51	-0.685	97.396	5430				
B37	UK24	160	10:09	-0.707	97.652	2803				
B38	UK23	160	23:37	-0.552	97.903	2869				
B39	UK09	159	22:17	-0.287	98.218	281				
B40	UK12	161	01:22	-0.591	98.140	732				
B41	UK48	161	06:04	-0.779	97.863	2842	2b	2b	2a	4
B42	FR06	161	10:08	-0.983	97.580	5489				
B44	UK10	161	03:40	-0.858	98.091	1173				
B45	FR19	162	01:10	-0.677	98.367	260				
B46	UK08	162	22:39	-0.428	98.664	172				
B47	UK03	162	17:07	-0.391	99.105	370				
B48	FR20	162	14:17	-0.648	98.766	75				
B49	FR18	162	03:56	-0.891	98.363	708				
B50	UK28	161	15:21	-1.114	98.031	1934				

Figure 72: OBS recovery times and locations in Survey Box 2. The quality of the data recorded on each channel (1-2 or 1-4 depending on instrument sensor configuration) is indicated in the left four columns: 1 - excellent data quality; 2a - fair data quality, can be picked; 2b - poor data quality, some data can be picked; 3 - data recorded, cannot be picked; 4 - nothing recorded.

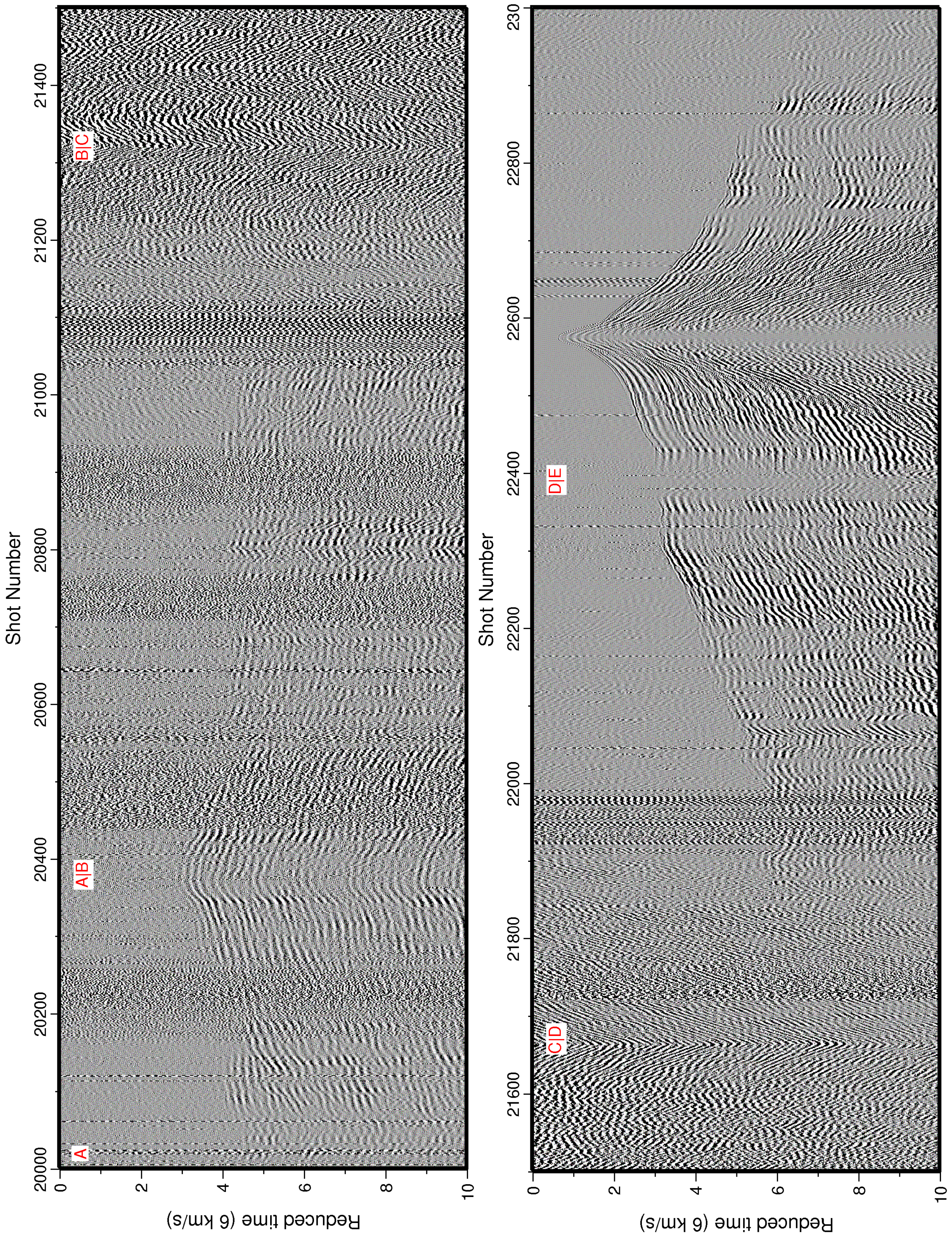

Figure 73: Vertical geophone data from Site B34. Data are shown with reduced time (6 km/s), zero-phase band-pass filtered (3-5-25-30 Hz), and gain proportional to offset. Line segments SUMBA to SUMBE are labelled in red.

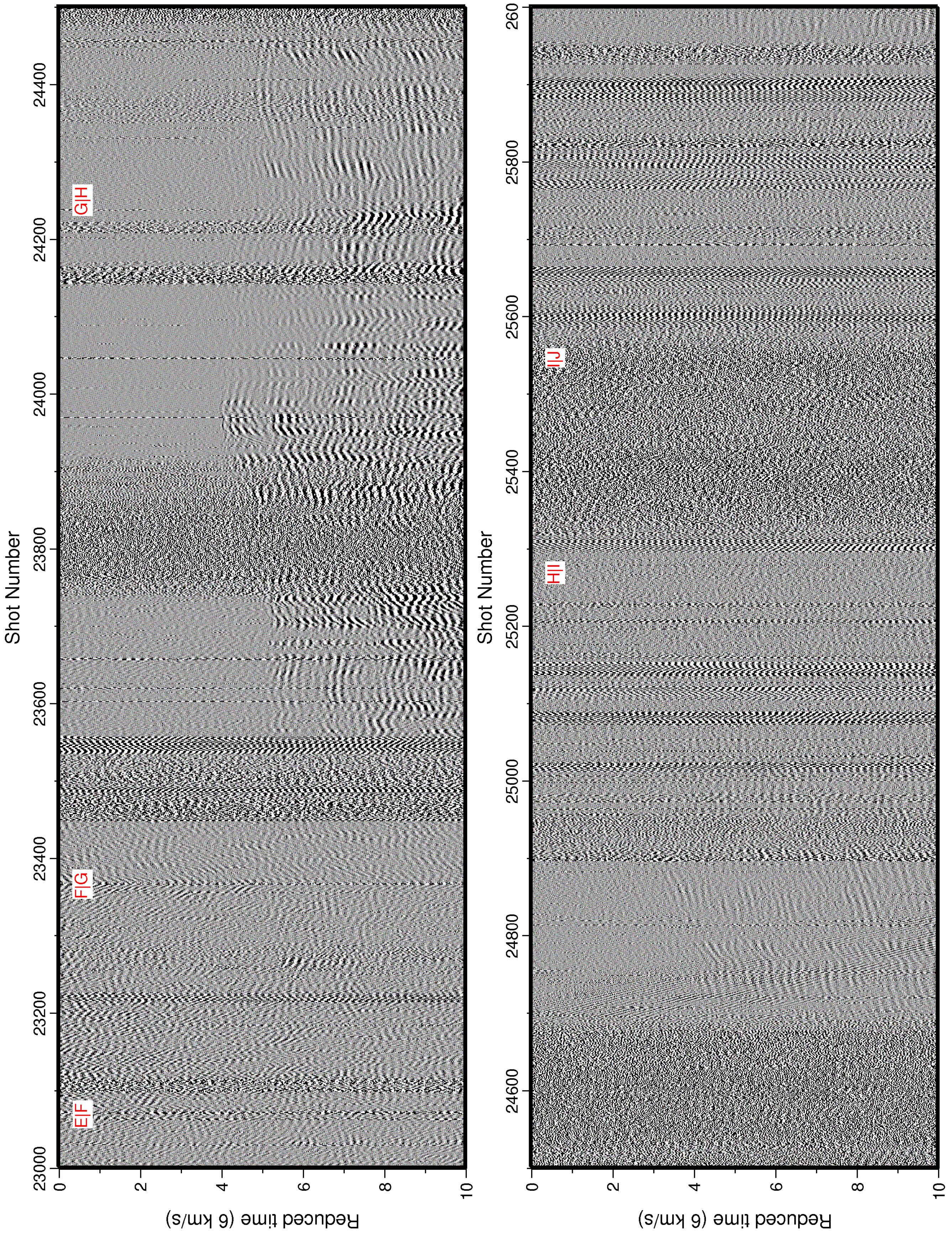

Figure 74: Vertical geophone data from Site B34. Data are shown with reduced time (6 km/s), zero-phase band-pass filtered (3-5-25-30 Hz), and gain proportional to offset. Line segments SUMBE to SUMBJ are labelled in red.

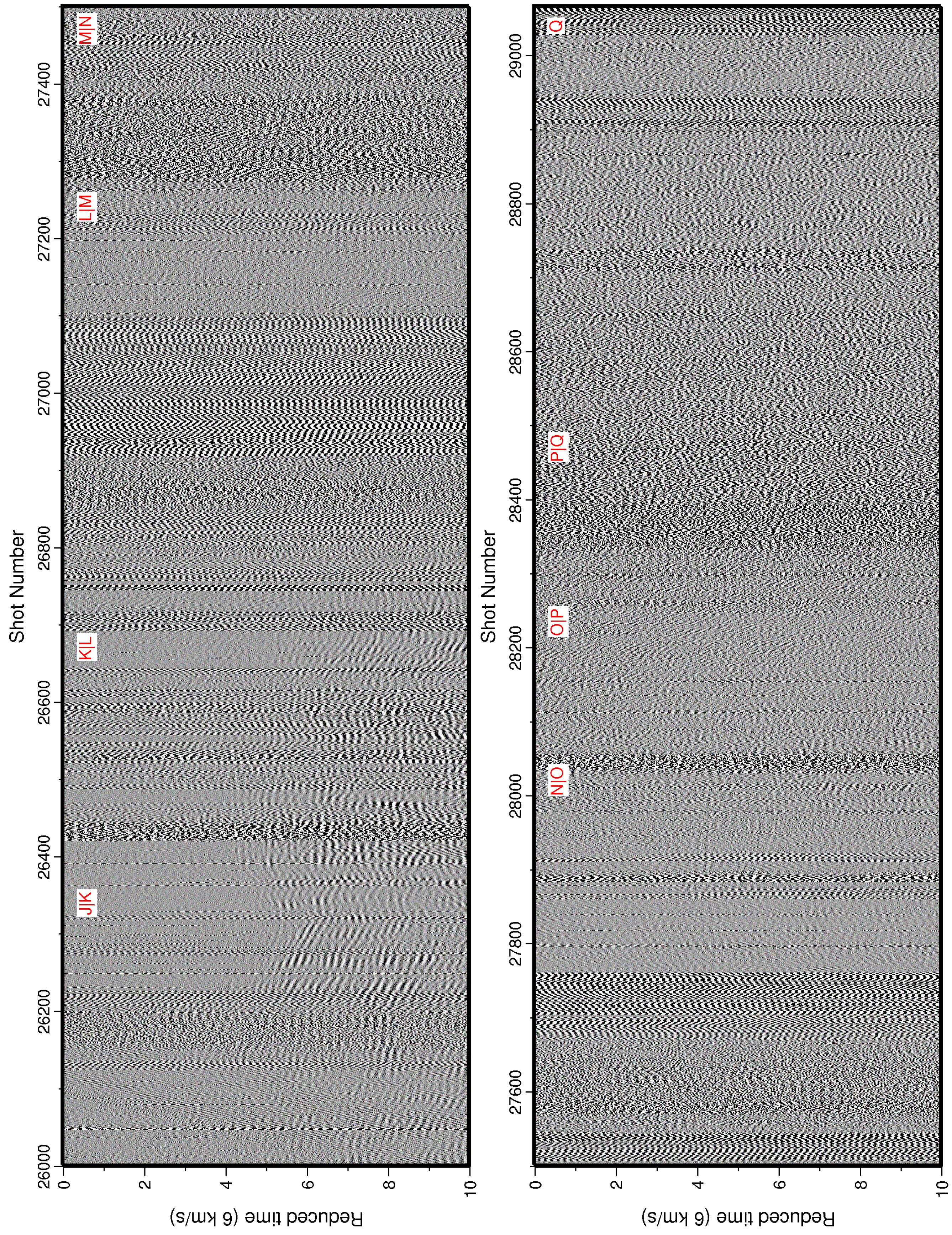

Figure 75: Vertical geophone data from Site B34. Data are shown with reduced time (6 km/s), zero-phase band-pass filtered (3-5-25-30 Hz), and gain proportional to offset. Line segments SUMBJ to SUMBQ are labelled in red.

OBS No.	Site Name	Julian Day	UTC Time	Lat.	Long.	Depth (m)
UK40	Nias-land	157	14:37	1.19108	98.09657	506
UK44	Nias-1	158	15:45	0.68755	97.32537	1018
UK41	Nias-2	158	18:53	0.56928	97.03023	3681
UK45	Batu-W2	160	01:13	-0.32732	97.85667	1257
UK42	Batu-W1	160	04:05	-0.47378	97.55805	3231
UK43	Extra	161	02:41	-0.82018	98.09968	1166
UK47	Siber-W2	162	07:37	-1.49177	98.14150	3762
UK52	Siber-W1	162	09:16	-1.35630	98.39767	1539
UK49	Siber-E2	163	15:59	-0.87097	99.18647	1368
UK48	Siber-E1	163	23:51	-0.65622	99.54715	815

Table 18: Long-term OBS deployment details in Survey Box 2.

SVP and CTD data

The CTD and SVP were deployed at 0º59.026S 97º34.840E in ~5480 m water depth.

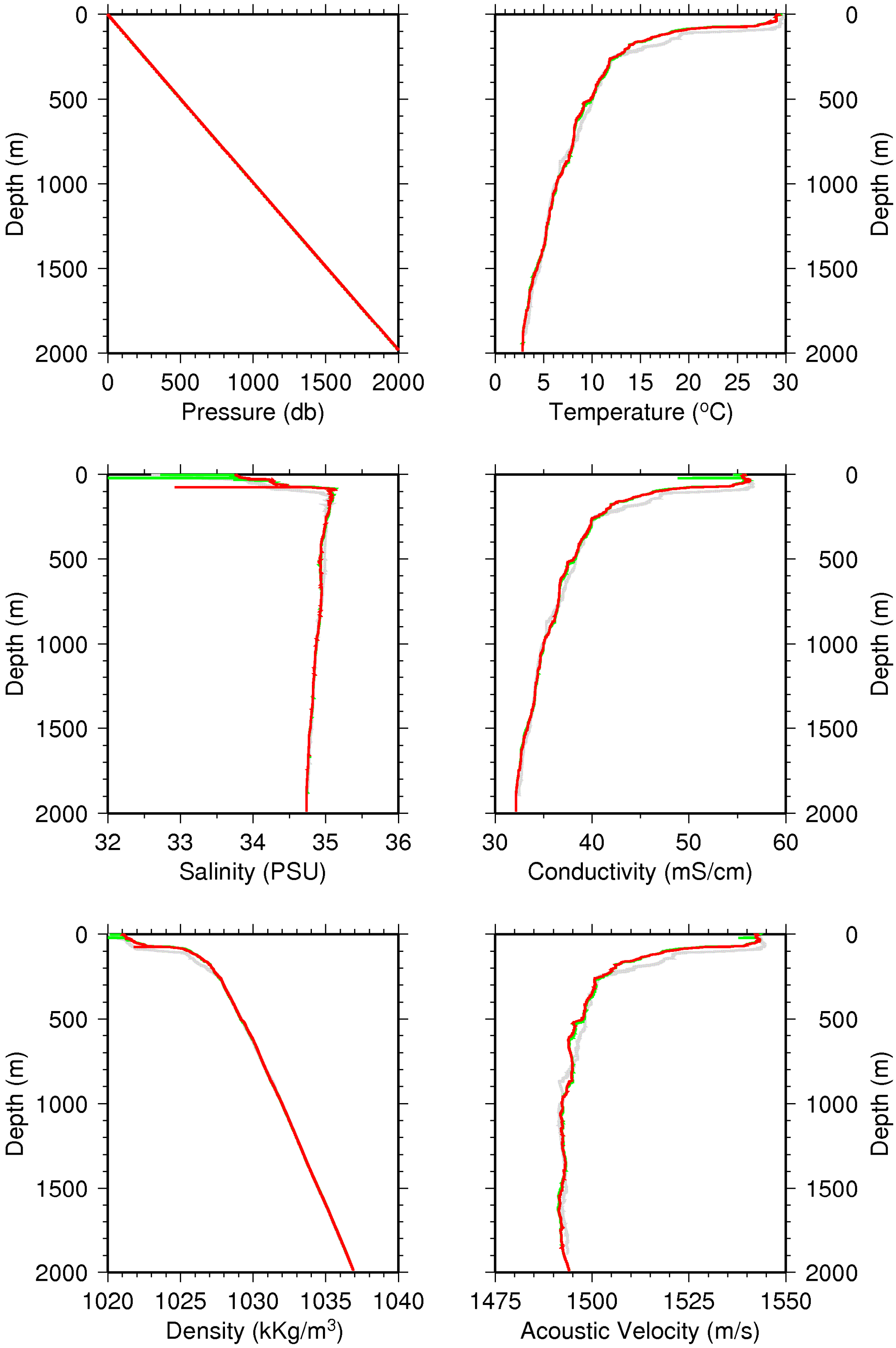

Figure 76: The result of the CTD drop acquiring during OBS recovery in Survey Box 2; red lines identify data acquired as the probe went down, green lines identify data acquired as the probe came back up, grey lines show the result of the CTD drop in Survey Box 1 (Figure 57) for comparison.

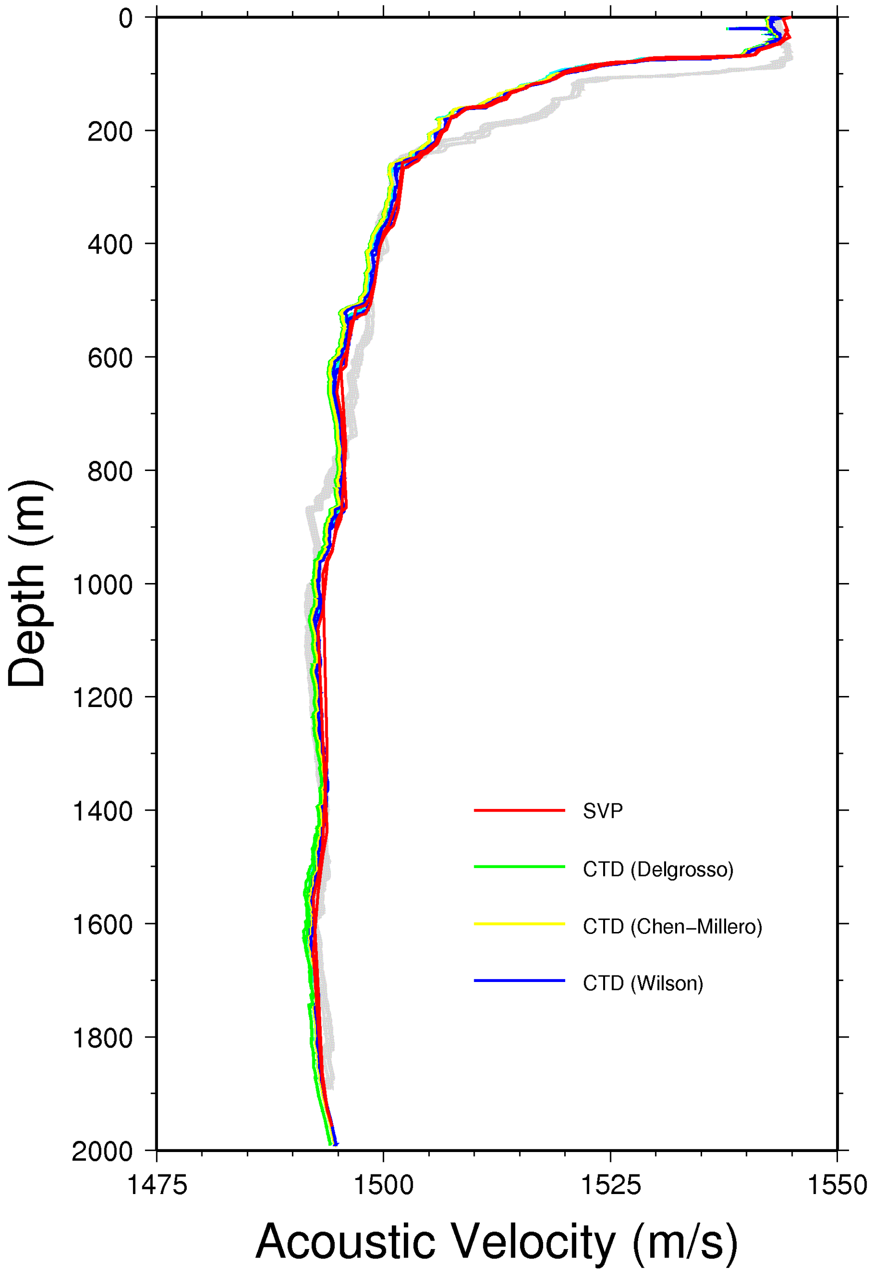

Figure 77: Acoustic velocity measured by the SVP probe in Survey Box 2 (red) and calculated from the CTD data at the same location using the method of Delgrosso (green), Chen-Millero (yellow) and Wilson (blue); the grey lines show the data from Survey Box 1 (Figure 58).

Expendable Bathythermograph data

A total of 50 XBT probes were deployed in Survey Box 2, 47 of which provided useful data (Table 19). As in Survey Box 1, XBT probes were launched after each OBS deployment to provide an even sample distribution (Figure 78). The results in Survey Box 2 show a relatively small spread in velocity (Figure 79), but with a number of subtle differences compared to the structure measured further north, in particular more defined steps in velocity are observed at depths greater than 500 m.

Sequence (deployment) number	Probe type	Latitude	Longitude	Site No.	Approximate water depth (m)
52	T-7	1.29681	97.6574	B02	422
53	T-7	1.48301	98.0039	B01	580
54	T-7	1.21488	98.1575	B09	463
55	T-7	1.14576	97.9873	B08	377
56	T-7	0.982459	98.2354	B10	404
57	T-7	0.718271	98.0769	B16	402
58	LOST				
59	LOST				
60	T-7	0.203926	98.3214	B33	241
61	T-7	0.247176	98.0297	B26	699
62	T-7	0.393121	97.8453	B17	105
63	T-7	0.24593	97.7477	B23	213
64	T-7	0.311718	97.558	B18	1197
65	FAILED				
66	T-7	0.549259	97.5837	B15	273
67	T-7	0.728151	97.5466	B11	422
68	T-7	0.802374	97.2899	B07	394
69	T-7	1.02714	97.201	B03	130
70	T-5	0.806105	96.8825	B04	3285
71	T-5	0.519327	96.8715	B05	5174
72	T-5	0.563811	97.1223	B06	2177
73	T-5	0.358988	97.3108	B14	3059
74	T-5	0.236798	97.0805	B13	5262
75	T-5	0.281008	96.8409	B12	5306
76	T-5	0.00051	97.0022	B20	5303
77	T-5	0.144383	97.2638	B19	3304
78	T-5	0.076943	97.5063	B22	2385
79	T-7	0.040989	97.7393	B27	554
80	T-7	-0.0023495	98.0378	B32	433
81	T-7	-0.288786	98.2175	B39	280
82	T-7	-0.287887	97.9516	B34	870
83	T-5	-0.223933	97.6968	B31	1264
84	T-5	-0.16414	97.4407	B28	2363
85	T-5	-0.335171	97.2006	B29	5386
86	T-5	-0.489021	97.6699	B35	1812
87	T-5	-0.552235	97.9035	B38	2868
88	T-7	-0.591339	98.1397	B40	721
89	T-7	-0.85564	98.0901	B44	1172
90	T-5	-0.777995	97.8611	B41	2849
91	T-5	-0.703862	97.6461	B37	2850
92	T-5	-0.686502	97.3958	B36	5436
93	T-5	-0.982684	97.5826	B42	5484
94	T-5	-1.11009	98.035	B50	1965
95	T-7	-0.890846	98.363	B49	722
96	T-7	-0.676238	98.3702	B45	258
97	T-7	-0.649548	98.7686	B48	127
98	T-7	-0.392011	99.1029	B47	373
99	T-7	-0.429453	98.6661	B46	182
100	T-7	0.48598	98.07	B24	704
101	T-7	0.518969	98.2502	B25	237

Table 19: XBT launch details for Survey Box 2. Due to an error, data from probes 58 and 59 were lost and probes 100 and 101 resampled these sites during the recovery of the OBS.

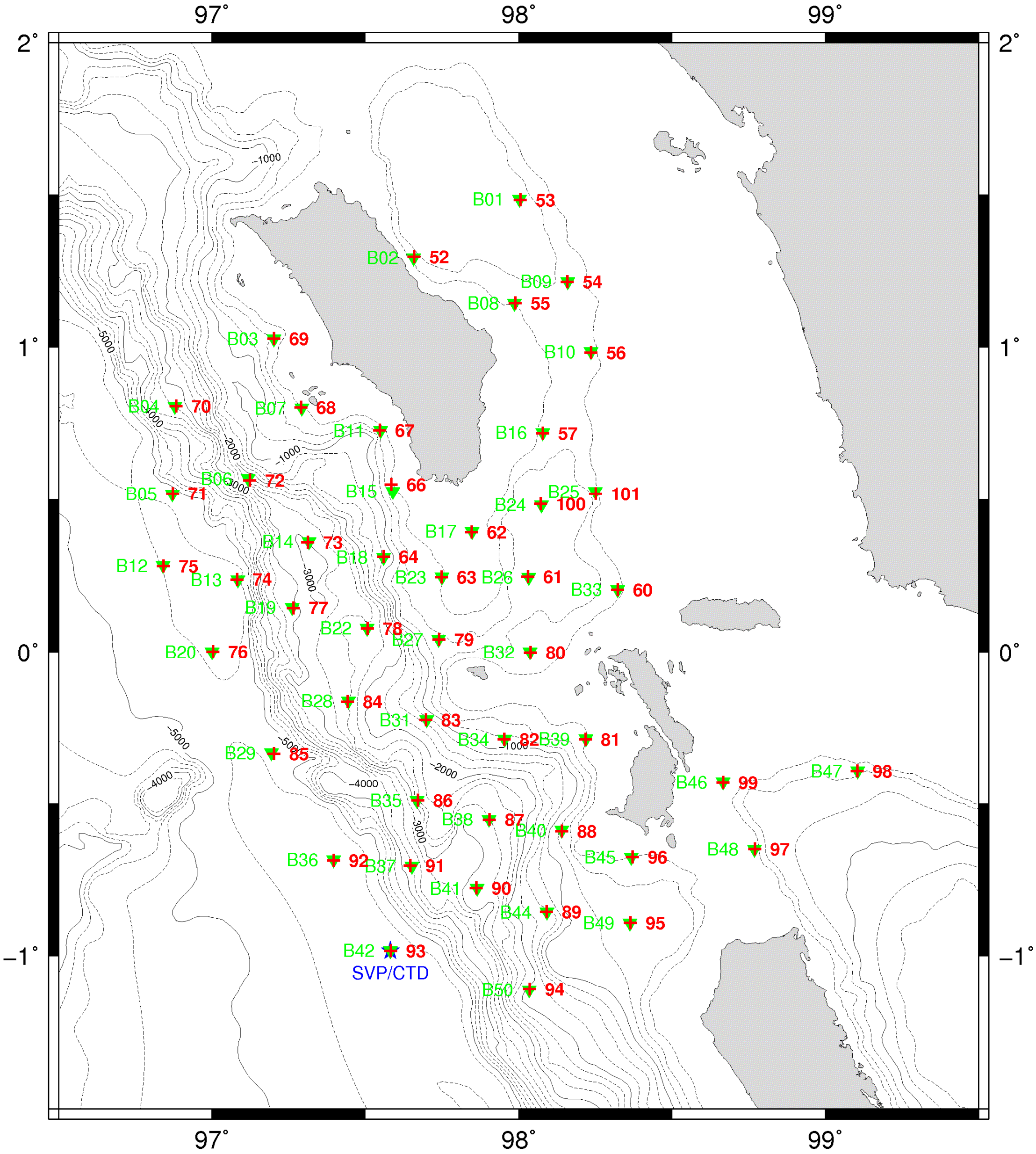

Figure 78: Location of all the XBTs deployed in Survey Box 2 and their Sequence number (red crosses); SVP/CTD deployment (blue star); and OBS locations (green triangles).

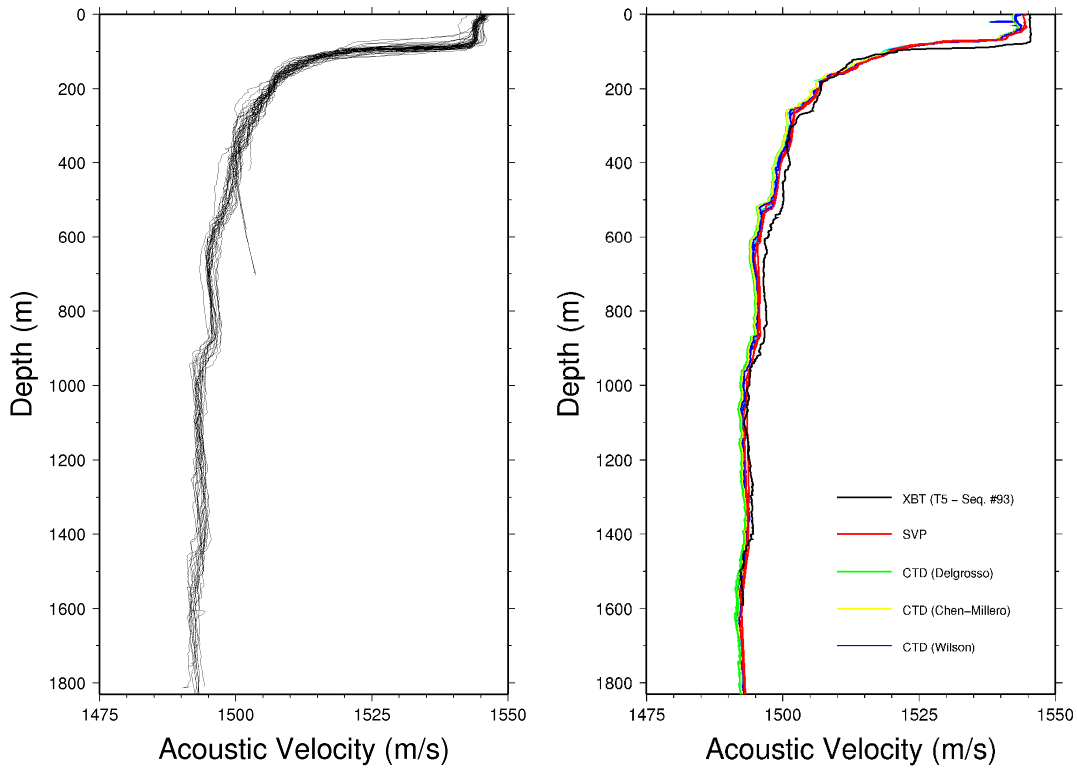

Figure 79: Acoustic velocity versus depth profiles obtained from all XBT probes launched in Survey Box 2 (left). The velocity values obtained by the SVP and CTD probes are close to those from the nearest XBT probe (right), but do not match as well as the results from Survey Box 1 (Figure 60).

Swath bathymetry

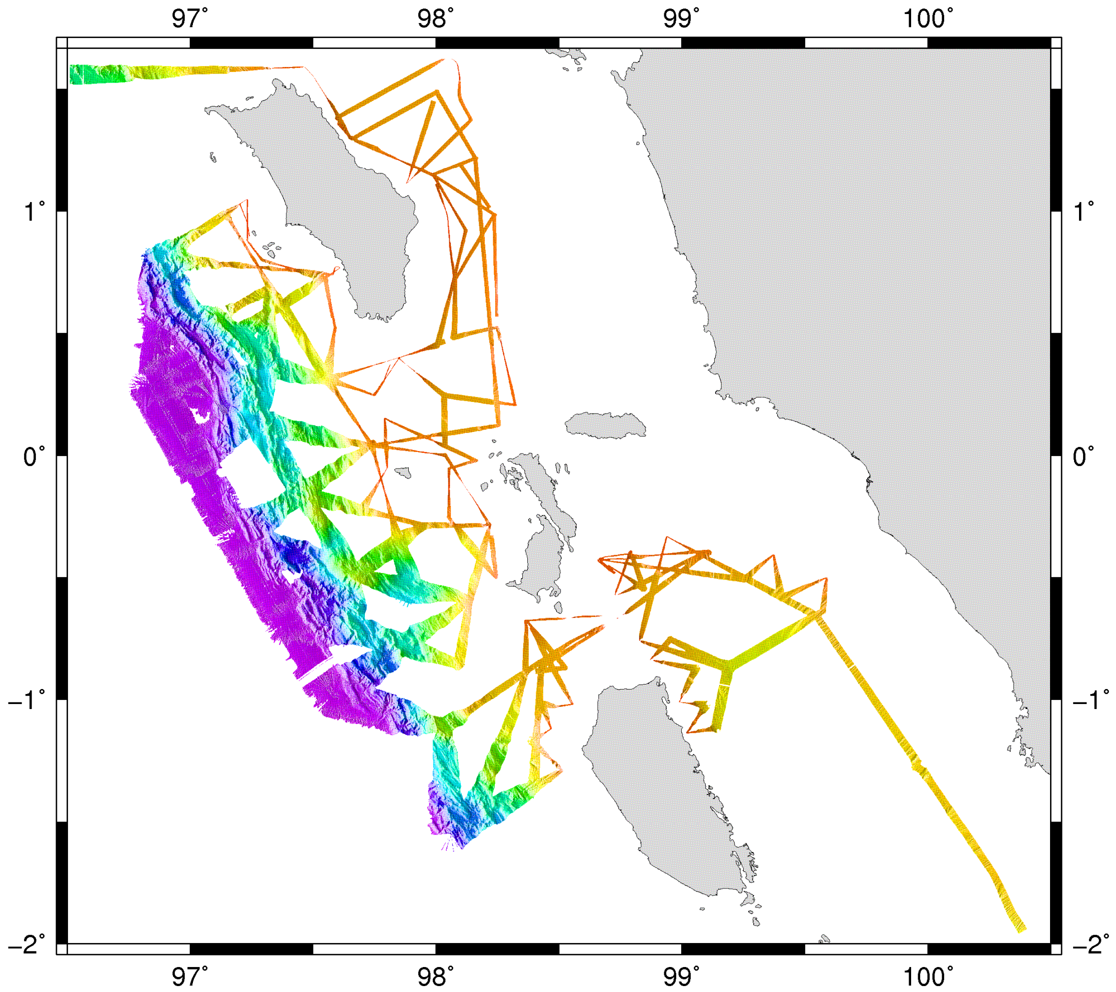

Figure 80: Swath bathymetric data acquired in Survey Box 2, including the start of the transit to Merak. The data were processed using Caris software. Illumination is from the south-west.

Parasound data

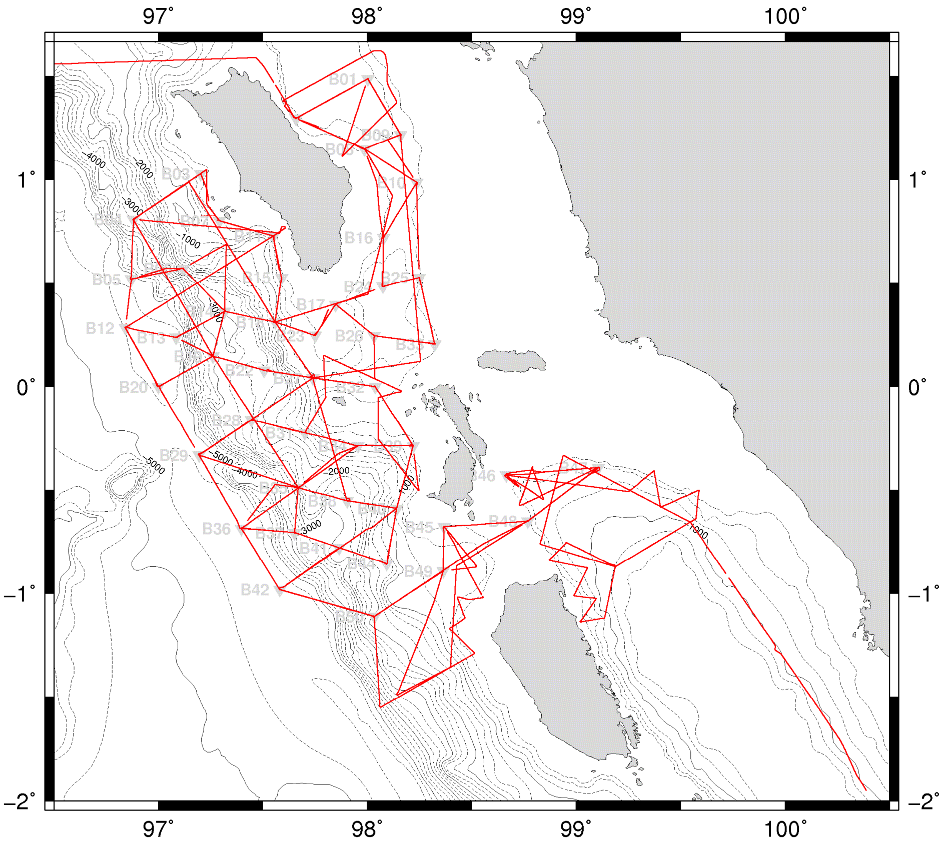

Figure 81: Location of the *Parasound* sub-bottom profiler data in Survey Box 2.

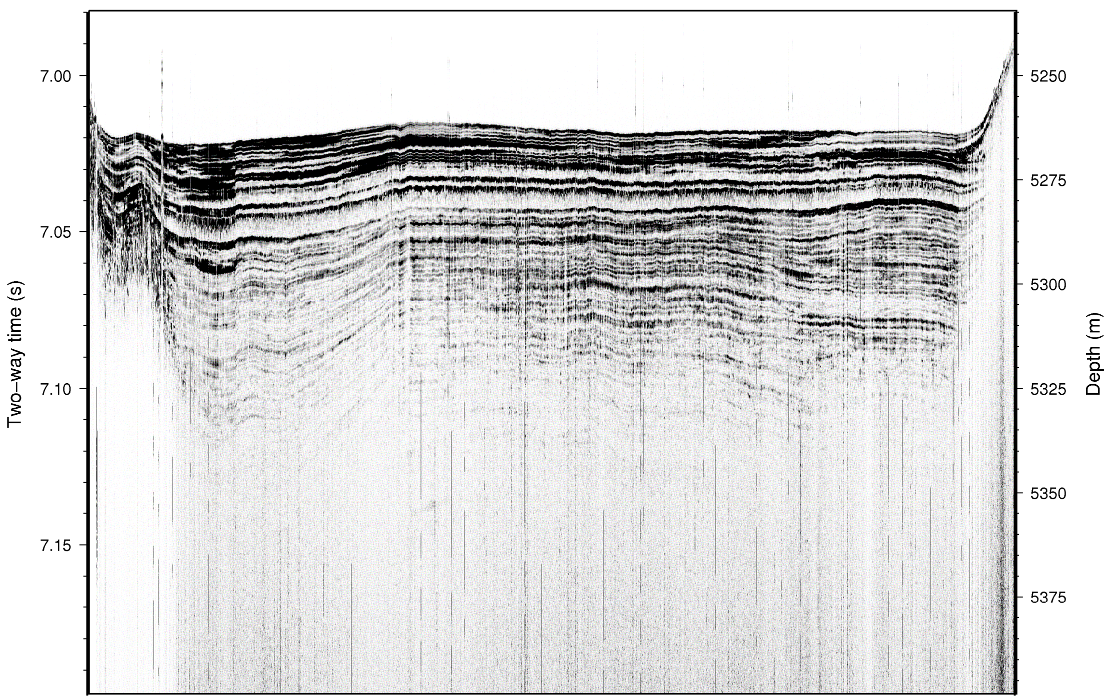

Figure 82: An example *Parasound* section along profile SUMBP in Survey Box 2, showing reflection horizons up to 75 m below the seabed. The data have had time[3] amplitude recovery applied, and an automatic trace static correction to increase coherency.

Gravity data

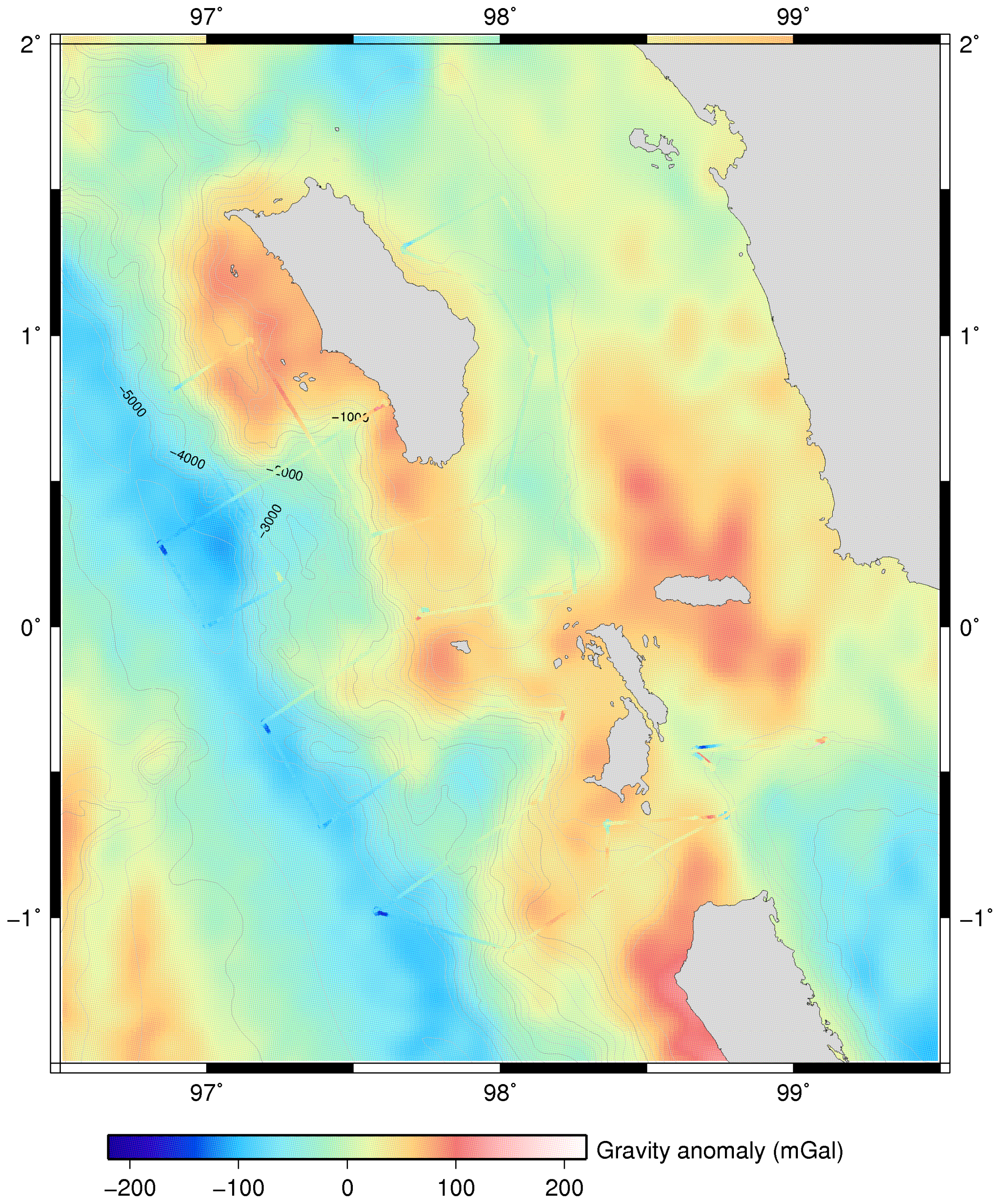

Figure 83: 2-minute gravity measurements in Survey Box 2, adjusted for instrument clock drift and basic Eötvos correction. The main misfits arise from error in ship velocity and heading, as can be observed in the data near turns. The background grid is from Sandwell and Smith (1997).

Magnetic data

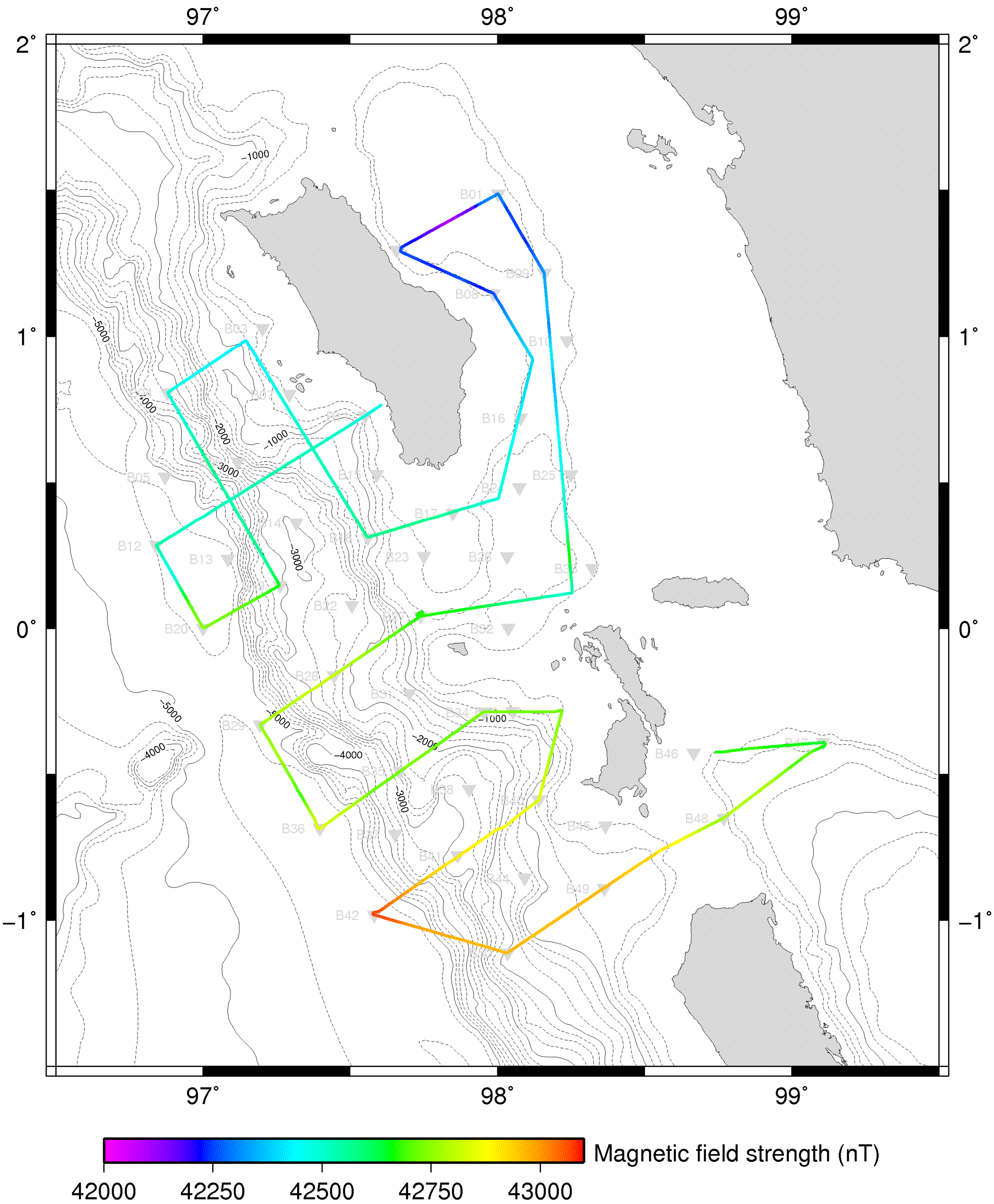

Figure 84: Magnetic field strength in nT measured along the airgun profiles in Survey Box 2.

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Taner, M. T., F. Koehler and R. E. Sheriff, Complex seismic trace analysis, *Geophysics*, *44*, 1041-1063, 1979.

Zyfer Inc., GPStarplus Model 565 User's Manual, Document 565-8006 Revision C, Anaheim, 8th November 2001.

Appendix A: Cruise data

./SO198-1-EM120 — Swath Bathymetry
- EM120 manual
- EM120 configuration file
- Caris vessel file
- Raw data (by day)

./SO198-1-CTD — Current-Temperature-Density Probe
- /ASCII text format
- /RAW SBE format

./SO198-1-SVP — Sound-Velocity Probe
- Text format

./SO198-1-Paradigma — Parasound Sub-bottom Profiler
- Raw data (by day)

./SO198-1-LongShot — LongShot Gun Controller Log
- Text format

./SO198-1-Documents — Cruise Documents (scans)
- Geophysical log books 1-4
- XBT log book
- Gravity meter log book
- OBS deployment log 1, 2 & long-deployment
- OBS recovery log 1 & 2
- Bridge log

./SO198-1-Gravity — Gravity
- /logged by laptop (2-minute data) ASCII format
- /RAW meter data

./SO198-1-Magnetics — Magnetics
- .mag Raw data
- .XYZ ASCII data

./SO198-1-XBT — Expendable Bathythermographs
- /T5 Raw T5 probe data
- /T7 Raw T7 probe data

./SO198-1-OBS — Ocean Bottom Seismographs
- /Surveybox1
  - /raw Raw data
  - /segy_qc SEG-Y converted data along instrument crossing track lines
  - /segy_final SEG-Y converted data for all shots
  - /earthquakes SEG-Y converted data for local earthquakes
- /Surveybox2
  - /raw Raw data
  - /segy_qc SEG-Y converted data along instrument

		crossing track lines - /segy_final SEG-Y converted data for all shots - /Gun_logger Raw data
./SO198-1-Database-Export	Vessel Logs	- /NAV ASCII format navigation etc. - /MRU ASCII format relative motion unit (heave/pitch/roll) - /AirWater ASCII format air/water environment

Appendix B: Julian Day Calendar

May	Julian Day
1	122
2	123
3	124
4	125
5	126
6	127
7	128
8	129
9	130
10	131
11	132
12	133
13	134
14	135
15	136
16	137
17	138
18	139
19	140
20	141
21	142
22	143
23	144
24	145
25	146
26	147
27	148
28	149
29	150
30	151
31	152

June	Julian Day
1	153
2	154
3	155
4	156
5	157
6	158
7	159
8	160
9	161
10	162
11	163
12	164
13	165
14	166
15	167
16	168
17	169
18	170
19	171
20	172
21	173
22	174
23	175
24	176
25	177
26	178
27	179
28	180
29	181
30	182

Table 20: Julian Day dates for the months of May and June 2008.

Appendix C: RV Sonne

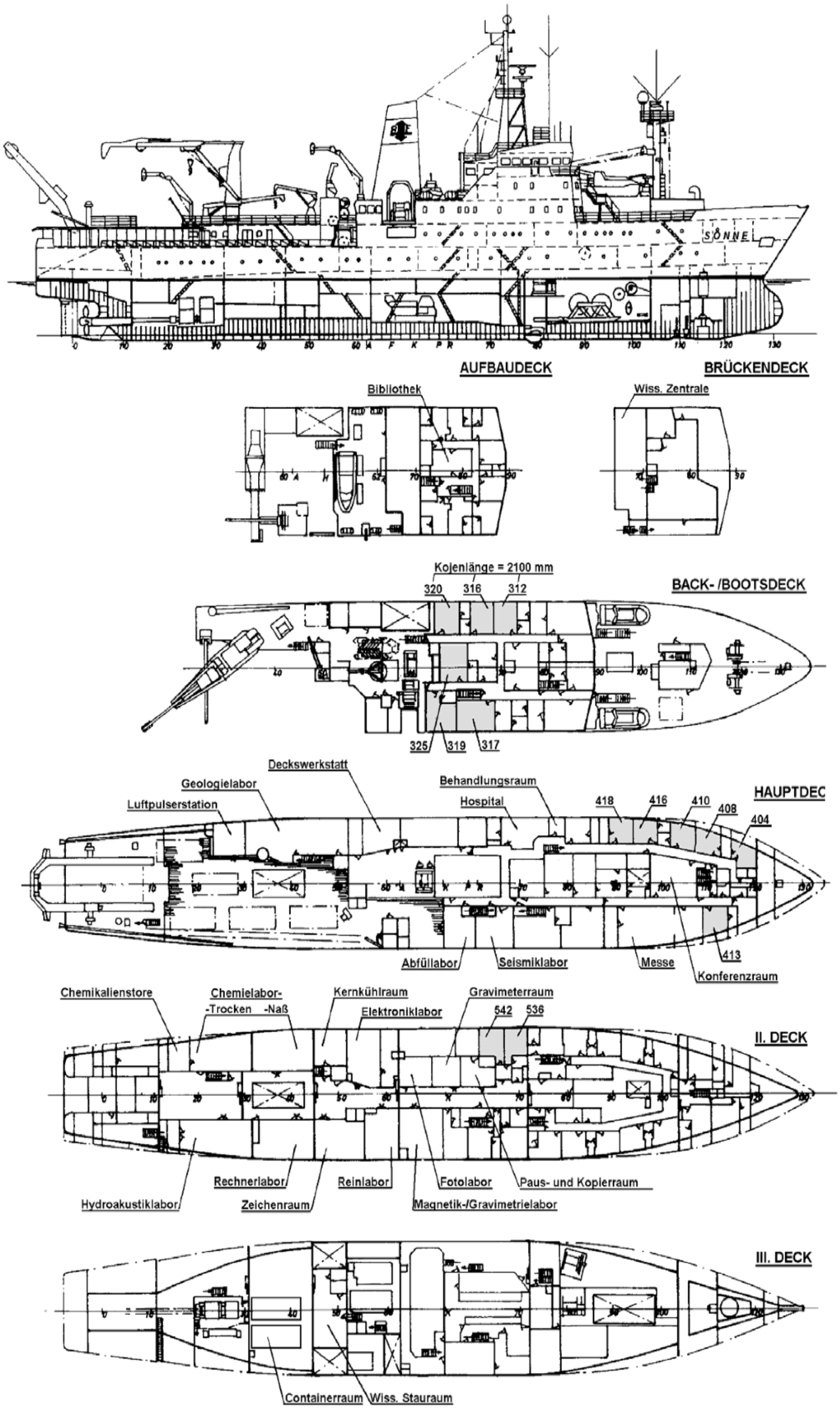

Figure 85: General deck plan for the RV Sonne.