National Oceanography Centre, Southampton

Cruise Report No. 43

RV *Sonne* Cruise 200

22 JAN-11 MAR 2009

Jakarta – Jakarta

Principal Scientists

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2009

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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.

The December 26th 2004 MW 9.3 earthquake and the March 28th 2005 MW 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.

The Sumatran Segmentation Project, funded by the Natural Environment Research Council (NERC), aims to characterise the boundaries between these great earthquakes (in terms of both subduction zone structure at scales of 101-104 m and rock physical properties), record seismic activity, improve and link earthquake slip distribution to the structure of the subduction zone and to determine the sedimentological record of great earthquakes (both recent and historic) along this part of the margin. The Project is focussed on the areas around two earthquake segment boundaries: Segment Boundary 1 (SB1) between the 2004 and 2005 ruptures at Simeulue Island, and SB2 between the 2005 and smaller 1935 ruptures between Nias and the Batu Islands.

Cruise SO200 is the third of three cruises which will provide a combined geophysical and geological dataset in the source regions of the 2004 and 2005 subduction zone earthquakes. SO200 was divided into two Legs. Leg 1 (SO200-1), Jakarta to Jakarta between January 22nd and February 22nd, was composed of three main operations: longterm deployment OBS retrieval, TOBI sidescan sonar survey and coring. Leg 2 (SO200-2), Jakarta to Jakarta between February 23rd and March 11th, was composed of two main operations: Multichannel seismic reflection (MCS) profiles and heatflow probe transects.

KEYWORDS

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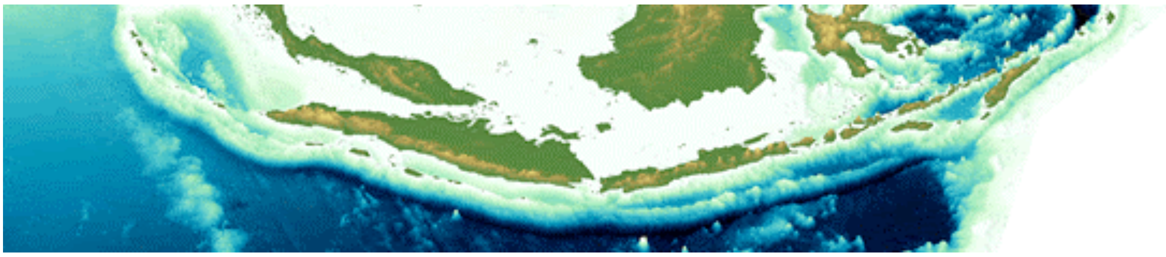
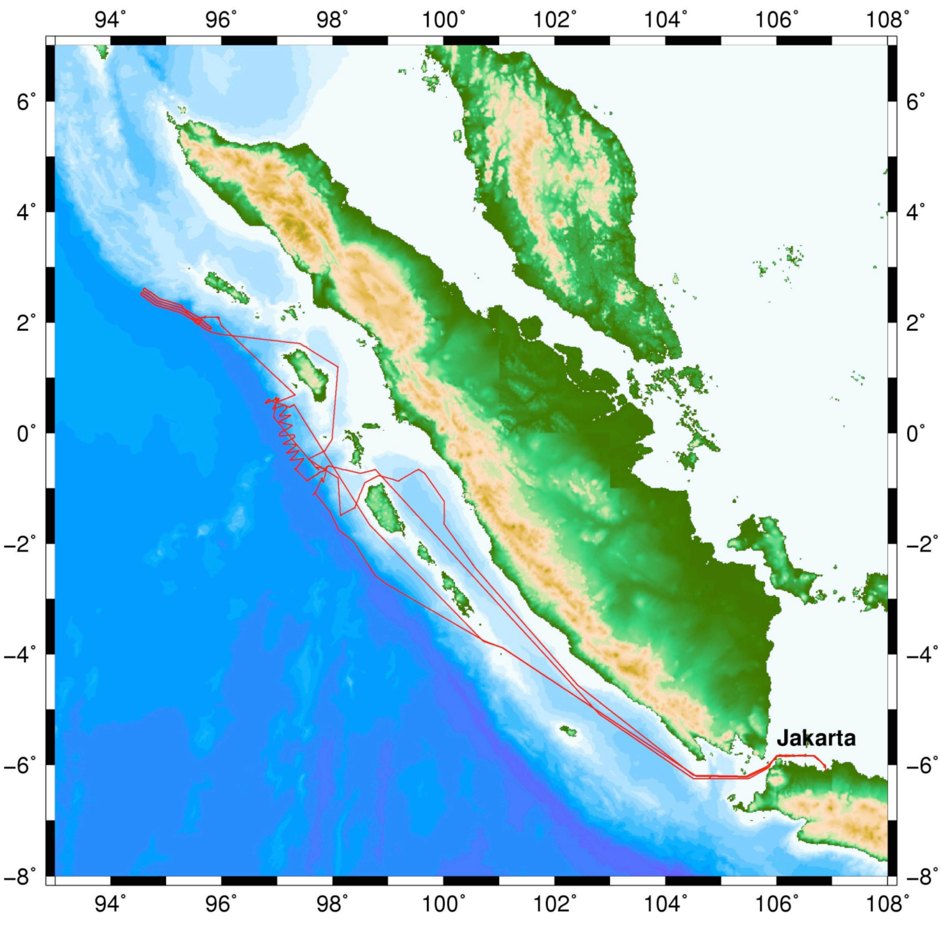


Cruise Report: SO200

22nd January to 11th March 2009

Jakarta to Jakarta



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Participants (22nd January – 22nd February)

Science Party

Name		Institute/affiliation	Position
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RV Sonne

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H.-Ulrich	BÜCHELE	2nd Officer
Anke	WALTHER	Doctor
Andreas	REX	Chief Engineer
Klaus Dieter	KLINDER	2nd Engineer
Thomas	VOSS	2nd Engineer
Evgenij	NEVROTOV	2nd Engineer
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Matthias	GROSSMANN	Electrical Engineer
Andreas	EHMER	System Manager
Wolfgang	BORCHERT	System Manager
Uwe	RIEPER	Electrician
Rainer	ROSEMEYER	Fitter
Volker	BLOHM	Fitter
Robert	NOACK	Motorman
Björn	GRÄFE	Motorman
Wilhelm	WIEDEN	Chief Cook
Frank	TIEMANN	1st Cook
Andreas	POHL	Chief Steward
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Andreas	PONESKY	A.B.
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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.

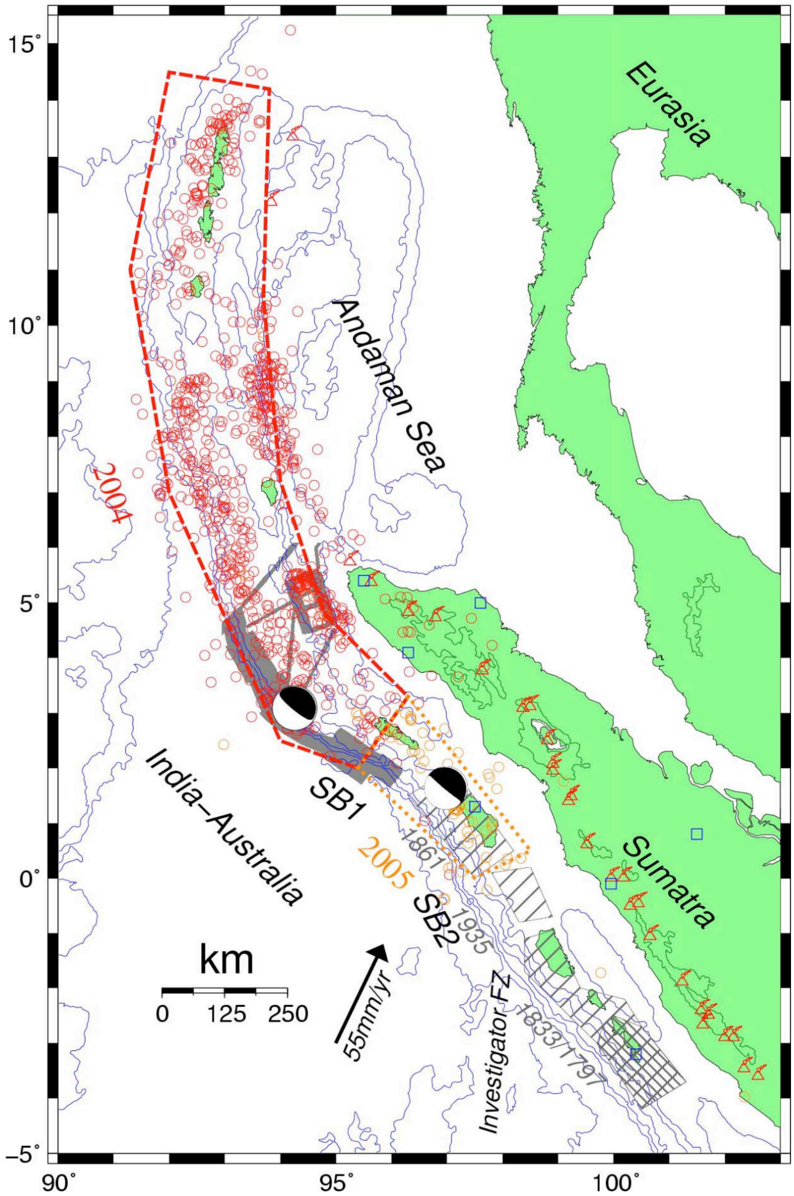

Figure 1: Regional setting of the Sumatra subduction zone. Approximate mainshock rupture extents and the first ten days of aftershocks with M>5 are shown in red (26th December, 2004) and orange (28th March, 2005) respectively, with Harvard CMT solutions. Hatching – estimated extent of major previous 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.

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Cruise SO200-1 Objectives

- To retrieve 10 OBS around SB2 deployed in June 2008 at the end of SO198-1. The OBS are part of a long-term deployment, which also includes seismometers on the forearc islands and Sumatra, recording shots from the active seismic experiment of SO198-2 and passively recording local seismic activity and teleseismic arrivals between June 2008 and February, 2009. The data will be used to help constrain large-scale velocity structure and distribution of seismicity. Well-constrained local earthquake locations during this deployment will also allow relocation of aftershocks from the 2004 and 2005 great earthquakes.
- To image the seafloor geomorphology of detailed fault structure and sediment transport features at the active prism toe using a 30 kHz deep-towed sidescan sonar system (TOBI). The seafloor structure and

its variation along the margin (including across at least one segment boundary) will be correlated with existing and future MCS profiles to provide:
  - Information on how prism thrust faults propagate from the plate boundary at depth towards the seafloor.
  - Whether fault segmentation at the surface is comparable with segmentation at depth.
  - Evidence for rupture of active faults to the seafloor.
  - Evidence for how fault-related deformation affects sedimentary processes.
- To obtain sediment cores at strategic locations along the margin to:
  - Determine the sedimentological record of recent great earthquakes at several locations across the prism and in the trench and at different locations along the margin.
  - Attempt to correlate sediment layers between cores across the margin which may result from earthquake shaking.
  - If possible, use the sediment record to assess historic earthquake frequency at different locations along the margin.

Rationale for Site Selection

Sidescan Sonar: TOBI

A survey was selected where along-strike fault segmentation and variations in fault structure (e.g., dominant dip direction) are observed in multibeam bathymetric data and existing MCS profiles, and where possible small fault scarps have been identified in multibeam data (Henstock et al., 2006). The aim was also to identify a suitable core site within the survey area in order to ground truth the backscatter data. Due to time constraints, one survey area was selected (SB1, SW of Simeulue Island, Fig.) to enable multiple swaths across the prism (3-4), providing both along- and across-strike structural information. The survey area selected also offered opportunities to examine the interactions between structural and sedimentary processes.

Core Sites

The coring during SO200-1 had the following general aims:

- To look for evidence of recent (2004, 2005) large earthquakes in the sedimentary record.
- To attempt to extract the earthquake record on this margin from the sedimentary record.
- To analyse the general sedimentary processes that operate on this margin and how this varies between different seismic segments of the subduction zone.

Cores were collected at three transects across the margin, including trench and slope basin sites. These transects were chosen to be on segments of the plate boundary that are expected to exhibit different types of behaviour (seismological and therefore potentially sedimentological). The first transect was located in the northern part of the study area on the slope south-west of

Simeulue Island. This transect is roughly on the boundary between the segments responsible for the large earthquakes in 2004 and 2005 (Segment Boundary 1). The second transect was located west of Nias Island within the 2005 earthquake segment (Segment Boundary 2). The third transect was located in the southern part of the study area west of the Batu islands (Segment Boundary 2). The Batu Island segment of the subduction zone appears to have different seismogenic behaviour to those to the north and south, generating smaller magnitude and more frequent earthquakes (most recently 1935). The potential terrestrial inputs into the three coring areas are also different. The northern area has large canyons feeding into it from Simeulue Island, whereas there are no major canyons connecting Nias and the Batu Islands and the slope basins sampled west of these islands in our southern two transects.

Previous studies (RR0705 cruise report) have found that the carbonate compensation depth (CCD) in this area is at a water depth of ~3500 - 4100 m. Thus cores taken in prism slope basins should contain suitable amounts of carbonate material to allow radiocarbon dating, whereas cores taken in the trench will contain little if any carbonate material. Ash layers have previously been found in both trench and slope cores taken to the south of Simeulue Island. Whilst the origin and mechanism by which these ash layers were transported is unclear, they may provide suitably distinct or datable layers to aid correlation between different core locations.

A combination of piston-coring and multi/mega-coring was used at each core site (station). The piston core can penetrate many metres into the seafloor sediments; however, the youngest sediments are frequently missing from the top of the core. The mega-core samples the top 60 cm of the seafloor and retains the sediment-water interface. The combination of mega-core, piston-core and where necessary trigger-core allow us to know with certainty that we have sampled the most recent part of the sedimentary record. This is particularly important for determining the sedimentological record from recent major earthquakes. It is evident from existing cores that correlation of individual beds is non-trivial along this margin. The method used during SO200-1 of combining coring techniques should provide the best opportunity of correlating between individual cores.

Core locations were chosen using a combination of multibeam bathymetric data (EM120 and SASSIV) and sub-bottom profiles obtained using the Parasound system. Sedimentary logs and photographs of cores taken during a previous cruise (RR0705) were also used in planning suitable coring sites.

Cruise SO200-2 Objectives

- To collect heat flow measurements (thermal gradient and thermal conductivity) along transects across the subduction zone forearc to provide local estimates of heat loss at the Earth's surface. These data can be used to understand the thermal structure at depth within the forearc, including the plate boundary, the role of fluid circulation, the relationship between thermal properties of the forearc at depth and the seismogenic region of the forearc and potentially the state of stress.

- To collect densely spaced high resolution multichannel seismic reflection profiles across the active toe of the accretionary prism and deformation front at across the major segment boundaries and variations in margin morphology. These data will be combined with existing deep penetration MCS data and other datasets to investigate:
    - Three-dimensional detailed structure, including along-strike segmentation and changing fault structure from the plate boundary to the seafloor, of the youngest active prism faults.
    - The relationship between individual prism faults and the nature of their linkage to the plate boundary fault.
    - The relationship between small scale fault segmentation and structure and large scale margin segmentation and subducting plate topography.

Delays related to customs and immigration in Jakarta port at the beginning of SO200-1 and between SO200-1 and SO200-2 resulted in changes to the timing of the two parts of the cruise (Legs 1 and 2) and reduction of data collected. Further delays were encountered at the end of SO200-2 which resulted in the ship leaving the survey area early. However, the majority of the objectives outlined above were still met, although with restricted opportunities for comparing different locations along the margin. Due to limited time, most operations were focussed at one segment boundary rather than both SB1 and SB2.

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 SO200.

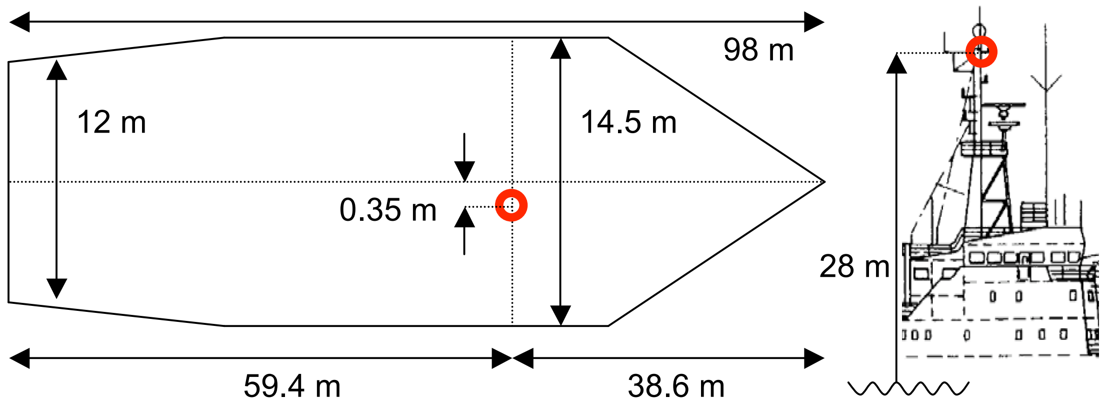

Figure 2: The location of the GPS antenna (red circle) on the mast above the bridge of the RV Sonne, 28 m from the water line.

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 SO200 the Ashtech GG24 Glonass GPS receiver was selected to be the *System GPS*. Differential corrections were available for the Ashtech from 036/11:15 until the end of the cruise.

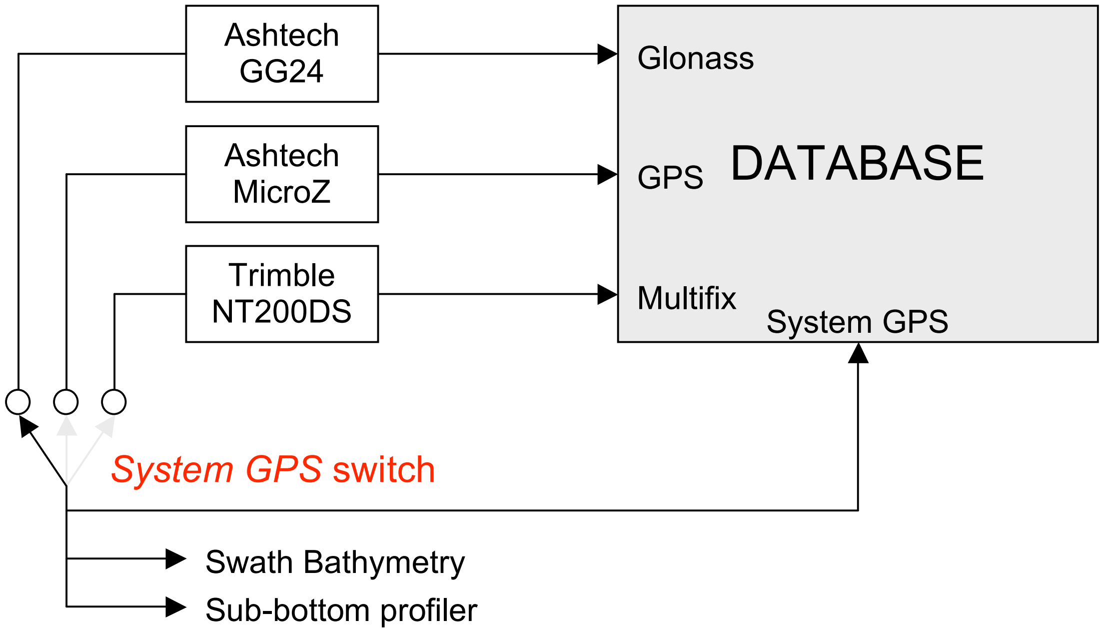

Figure 3: The relationship between the Ashtech GG24, MicroZ and Trimble GPS receivers, System GPS, and the data logged in the ship's database.

Ocean Bottom Seismometer

Ten long-deployment Ocean Bottom Seismometers (OBS) were provided by the Ocean Bottom Instrument Consortium (OBIC, UK), and deployed during SO198-1. The LC4x4 loggers represent the latest development of the LC-OBS family. The physical design of the instrument uses two pressure tubes, one containing the logger electronics and one the release electronics, plus a sensor package all attached to a plastic frame. The long-deployment versions of the LC4x4 instruments are physically modified from their normal configuration by the addition of an extra set of flotation spheres to compensate for the weight of the batteries required to extend the recording period. Data storage is on solid-state Compact Flash (CF) memory cards.

The OBS were configured to record data sampled at 50 Hz (20 ms sample rate) from two sensor packages: a three-component geophone (vertical- and two orthogonal horizontal-components) and a differential pressure gauge (DPG). With the three 8 GB CF cards fitted for this experiment, these instruments are capable recording for nearly 350 days. The frequency response of the geophone is given in Figure 4, the response of the DPG is not known.

Recoding channels:

Differential pressure gauge:	Channel 1
Vertical geophone:	Channel 2
Horizontal geophone 1:	Channel 3
Horizontal geophone 2:	Channel 4

Data logger specifications for the LC4x4:

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

Mechanical specifications for the long-deployment LC4x4:

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:

Mark Products L-28LB geophone
Differential Pressure Gauge

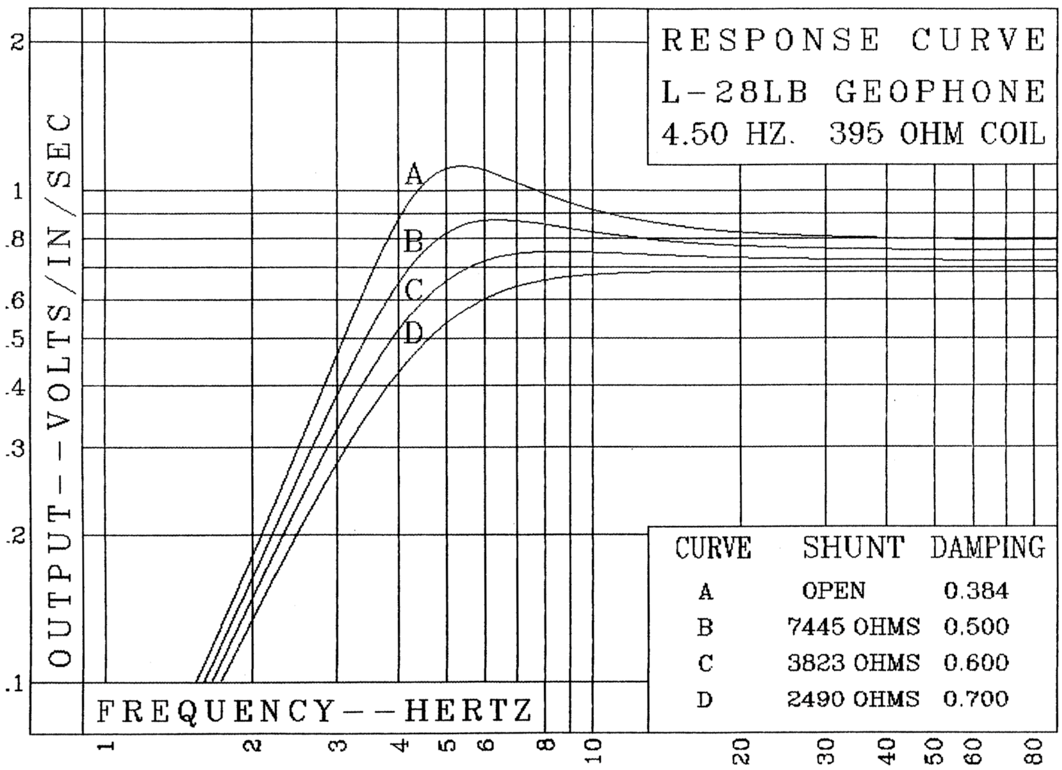

Figure 4: Frequency response for the Mark Products (Sercel) L-28LB geophone (curve A) used in the LC4x4 instruments.

Operational issues with the *OBS*

One instrument, located at station Nias-2, failed to record for the full deployment period. The problem appears to be power related, a fault either in the main batteries or the instrument itself drawing more power than usual. Unfortunately the backup battery on the clock is sufficient for ~3 months only, and had also failed by the time the instrument was recovered. It is recommended that in future the OBS are fitted with backup clock batteries sufficient for the entire deployment period; in this example, the controlled source portion of the experiment was recorded in entirety, but since the clock failed the instrument drift will have to be estimated.

All the instruments suffered from corrosion to some degree, although it was particularly acute in those deployed in shallow water depths of 500-1000 m. Most of the stainless steels parts were affected, including the pins holding the float and layer sections together, nuts, bolts and washers, and even the large structural sections (Figure 5). Damage was greatest where different pieces of metal came in contact, e.g. nuts and washers on bolts.

Figure 5: Stainless steel OBS pins in varying stages of decomposition.

TOBI 30 kHz Deep-Towed Sidescan Sonar

TOBI - Towed Ocean Bottom Instrument - is the National Oceanography Centre, Southampton's deep towed vehicle. It is capable of operating in 6000 m of water. The maximum water depth encountered during the TOBI surveys during SO200 was around 5000 m.

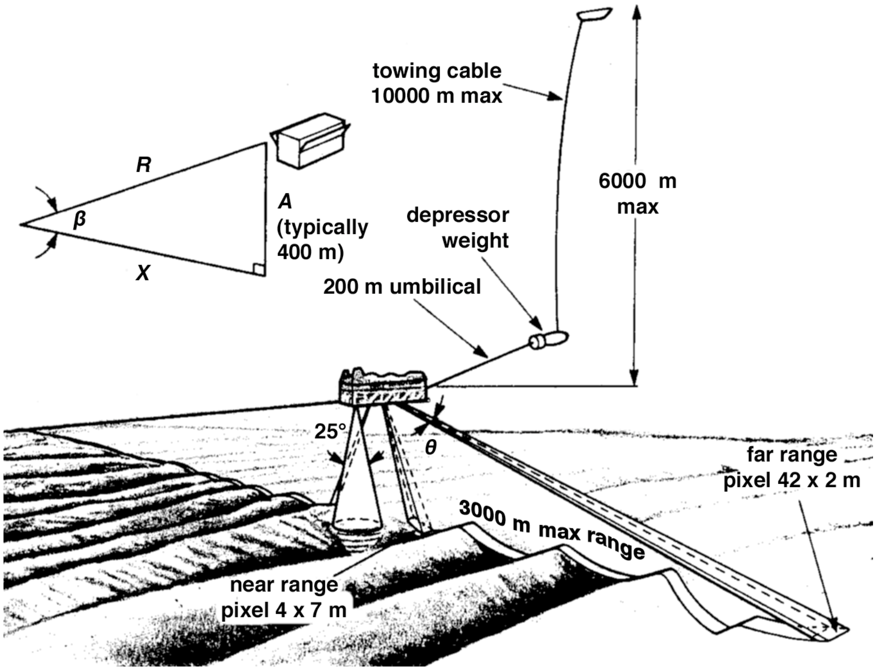

Figure 6: Schematic representation of TOBI's towing configuration and acoustic systems. Modified from Flewellen et al. (1993).

Although TOBI is primarily a sidescan sonar vehicle a number of other instruments are fitted to make use of the stable platform TOBI provides. For SO200 the instrument complement was:

1. 30 kHz sidescan sonar with swath bathymetry capability (Built by IOSDL)
2. 8 kHz chirp profiler sonar (Built by IOSDL/SOC)
3. Three-axis fluxgate magnetometer. (Ultra Electronics Magnetics Division MB5L)
4. CTD (Falmouth Scientific Instruments Micro-CTD)
5. Pitch & Roll sensor (G + G Technics ag SSY0091)
6. Gyrocompass (S.G.Brown SGB 1000U)
7. Light backscattering sensor (Seapoint Turbidity Meter)

The TOBI system uses a two-bodied tow system to provide a highly stable platform for the on-board sonar. The vehicle weighs 2.5 tonnes in air but is made neutrally buoyant in water by using syntactic foam blocks. A neutrally buoyant umbilical connects the vehicle to the 600 kg depressor weight. This, in turn, is connected the main armoured coaxial tow cable. All signals and power pass through this single conductor.

Technical specification

Mechanical

Towing method:	Two bodied tow system using neutrally buoyant vehicle and 600 kg depressor weight
Size:	4.5 m x 1.5 m x 1.1 m (lxhxw)
Weight:	2500 kg in air
Tow cable:	Up to 10 km armoured coax
Umbilical:	200 m long x 50 mm diameter, slightly buoyant
Tow speed:	1.5 to 3 knots (dependent on tow length)

Sonar Systems

Sidescan Sonar Freq.:	30.37 kHz (starboard) 32.15kHz (port)
Pulse Length:	2.8ms
Output Power:	600W each side
Range:	3000 m each side
Beam Pattern:	0.8 x 45° fan

Bathymetry Sonar

Transmitter:	Uses sidescan sonar
Receiver:	6 hydrophone arrays in 2 housings for each side
Detection:	Single and multi-phase
Range:	Up to 3000 m each side

Profiler Sonar Frequency:	6-10 kHz Chirp
Pulse Length:	26 ms
Output Power:	1000W
Range:	>50 ms penetration over soft sediment
Resolution:	0.25 ms
Beam Pattern:	25° cone

Standard Instrumentation

Magnetometer	Ultra Electronics Magnetics Division MB5L
Range:	+/- 100,000 nT on each axis
Resolution:	0.2 nT
Noise:	+/- 0.4 nT
CTD	Falmouth Scientific Instruments, Micro CTD
Conductivity	
Range:	0 to 65 mmho/cm
Resolution:	0.0002 mmho/cm
Accuracy:	+/- 0.005 mmho/cm
Temperature	
Range:	-2 to 32°C
Resolution:	0.0001°C
Accuracy:	+/- 0.005°C
Depth	
Range:	0 to 7000 dbar
Resolution:	0.02 dbar
Accuracy:	+/-0.12% F.S.
Extra Depth Sensor	AML Pressure Smart Sensor
Range:	0 to 6000 dbar

Resolution:	0.1 dbar
Accuracy:	+/-0.05% F.S.
Heading	S.G. Brown SGB 1000U gyrocompass
Resolution:	0.1°
Accuracy:	Better than 1°, latitude < 70°
Pitch/Roll:	Dual Axis Electrolytic Inclinometer
Range:	+/- 20°
Resolution:	0.2°
Altitude	Taken from profiler sonar
Range:	1000 m
Resolution:	1 m

Additional Instrumentation

Light scattering sensor	Seapoint turbidity meter
Source:	2 x 880nm LEDs
Detector:	Visible light blocked silicon light detector
Range:	0-25 FTU
Sensitivity:	200 mV/FTU
RMS Noise:	<1 mV

Mobilisation

The deployment and umbilical winches were mounted on a bedplate designed for previous cruises on the RV Sonne. The bedplate was assembled on the deck and bolted into position. The launch and umbilical winches and the power pack were bolted to the bedplate. The power pack was connected to a 3-phase 63A supply in the air gun shack aft of the geophysics laboratory.

Figure 7: TOBI's deck electronics rack set up in the *Geologielabor*.

The deck electronics systems were set up in the geophysics laboratory on the port side of the main deck. Four 8' by 4' x 18mm thick plywood sheets were used to extend the centre bench space available. The electronics racks were mounted on these at the forward end giving a large chart plotting area at the aft. The replay system was mounted on the bench along the port side of the laboratory.

The GPS receiving aerial was mounted on a pole on the port side of the deck above the air gun shack to give navigation and time inputs to the logging system.

Launch procedure

The TOBI vehicle is launched in a fore-aft position rather than the more preferred athwart ships position on the Sonne due to the narrow 'A' frame. The vehicle is lifted off the deck with the A-frame winch while being steadied by two lines to the fore of the vehicle. The 'A' frame is then extended over the stern of the ship and the launch winch paid out until the vehicle is in the water. The steadying lines are then let go, pulled back aboard and the quick release pulled to let go the vehicle. As the umbilical is being paid out the depressor weight is brought round under the 'A' frame and the main tow cable fed through the main block. The cable is mechanically connected to the depressor. At the end of the umbilical a loop enables it to be tied off so that the free end can be mechanically connected to the depressor weight and electrically to the main cable. If no loop then a Chinese finger stopper is applied. The vehicle is then powered up to check correct operation. If all is OK then the depressor is lifted into the water and survey commenced.

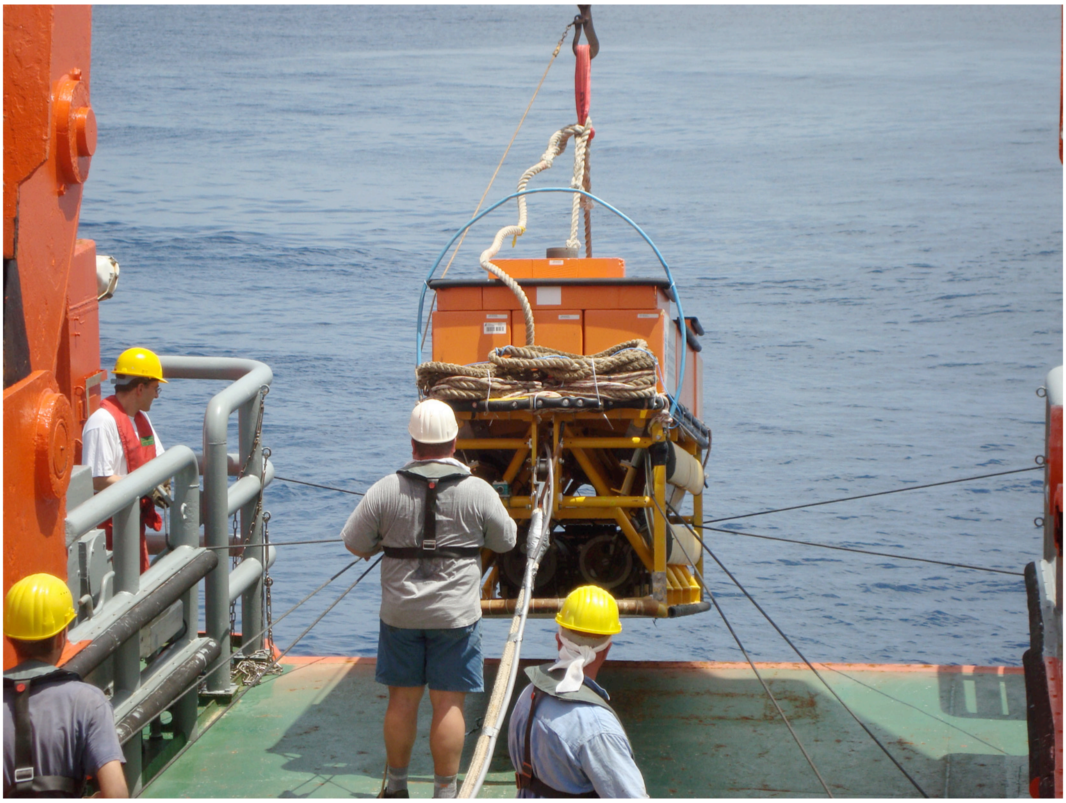

Figure 8: TOBI being deployed through the Sonne's 'A' frame.

Recovery procedure

Recovery of the TOBI system commences with the recovery of the depressor weight. Making sure that the power to the vehicle is switched off; the depressor is swung aboard and landed in its cradle. The loop in the umbilical is grabbed and made fast to a cleat or eye with a rope. The umbilical is then disconnected from the depressor weight and main cable. The free end is attached to the rope pennant on the umbilical winch and is slowly recovered. During this time the depressor is disconnected from the main cable, the main cable is replaced through the main block with the launch wire. When the vehicle is in boat hook range (~10 m) the recovery hoop is grabbed and the steady and recovery lines brought aboard. These are carefully sorted out with the vehicle just astern of the ship. The recovery line is attached to the launch wire and once the steady lines are in position – two fore inside the 'A' frame, two aft outside the 'A' frame – the vehicle is brought out of the water. Once clear of the stern the 'A' frame is brought in and the vehicle landed on the deck.

TOBI Watchkeeping

TOBI watchkeeping was split into three, four-hour watches repeating every 12 hours. Watchkeepers kept the TOBI vehicle flying at a height of ideally 400-500 m above the seabed by varying wire out and/or ship speed. Ship speed was usually kept at 2.5 knts over the ground with fine adjustments carried out by using the winch. In deeper water - greater than 2500 m – this speed reduced to 2.3 knts. As well as flying the vehicle and monitoring the instruments watchkeepers also kept track of disk changes and course alterations.

The bathymetry charts of the work area were found to be reasonably accurate which helped immensely when flying the vehicle. Both the ship's EM120 multibeam sonar and *Parasound* sonar monitors mounted in the TOBI lab gave the watchkeepers read outs of bathymetry and water depth.

Data Recording and Display

Data from the TOBI vehicle is recorded onto 1.2 Gbyte magneto-optical (M-O) disks. One side of each disk gives approximately 16 hours 9 minutes of recording time. All data from the vehicle is recorded along with the ship position taken from the GPS receiver and wire out from the sheave. Data were recorded using TOBI programme *LOG*.

As well as recording sidescan and digital telemetry data *LOG* displays real-time slant range corrected sidescan and logging system data, and outputs the sidescan to a Raytheon TDU850 thermal recorder. *PROFDISP* displays the chirp profiler signals and outputs them to a Raytheon TDU850. *DIGIO9* displays the real-time telemetry from the vehicle – magnetometer, CTD, pitch and roll, LSS – plus derived data such as sound speed, heading, depth, vertical rate and salinity.

LOG, *PROFDISP* and *DIGIO9* are all run on separate computers, each having its own dedicated interface systems.

Data recorded on the M-O disks were copied onto CD-ROMs for archive and for importation into the on board image processing system.

The gyro in the vehicle had been removed for repair prior to this cruise. In remounting the unit the offset in the reading was changed from -10.1° to +10.1°. This was corrected easily in *DIGIO9* – the data display programme – and was also corrected on the CD-ROMs by running programme *DAYFIX* – which added 20.2° to the raw reading - prior to copying onto CD-ROM.

Processing

The ship's navigation was recorded online. The data were transferred on a daily basis and then tested for time-continuity and abnormal speed values. No gaps in the navigation data file occurred. Good navigation data is essential for processing, because the vehicle position and hence the sidescan image position is calculated from it.

The winch data (wireout) were recorded analogue and stored in a separate file. The TOBI imagery was downloaded from the CD-ROMs using a subsample and average factor of 4. This gave a pixel resolution of 3 metres and an almost 2-fold improvement of the signal-to-noise ratio.

The survey consisted of three runs. These were split into 11 blocks (processed at 0 degrees standard latitude) to facilitate processing. The approximate size of the blocks was approximately 0.25 by 0.25 degrees for most areas. After each survey run was completed, the imagery was processed using the PRISM (v4.0) and ERDAS Imagine (v9.1) software suites to produce geographically registered imagery which could then be composed onto a series of map sheets. The digital version of the imagery was also made available for the onboard Geographical Information System (GIS) of the area.

The processing of TOBI imagery has two main phases: Pre-processing and Mosaicing. The pre-processing stage involves correcting of the side-scan sonar characteristics, removal of sonar specific-artefacts and geographical registration of each individual ping. This processing stage is solely composed of PRISM programs and runs from a graphical user interface. The PRISM software uses a modular approach to 'correct' the imagery, which is predefined by the user in a 'commands.cfg' file. For this dataset it was defined as:

```
suppress_tobi -i %1 -o %0
tobtvg -i %1 -o %0 -a
mrgnav_inertia -i %1 -o %0 -u 182 -n navfile.veh_nav
tobtvg -i %1 -o %0 –h -l 100 # use track heading
tobslr -i %1 -o %0 -r 3.0 , res
edge16 -i %1 -o %0 -m
drpout -i %1 -o %0 -u -f -p -k 201
drpout -i %1 -o %0 -u -f -p -k 51
shade_tobi -i %1 -o %0 -t1,4095
increm –i %1 –o %0
```

To explain this in sonar terms (in order):

- Removal of any surface reflection (i.e. from vehicle to the sea surface and back) – generally only a problem in shallower water depths, where a bright stripe or line is seen semi-parallel to the ship's track. Removal is only done when the imagery is unambiguous, whether the line is true artefact and not an actual seafloor feature. The result can sometimes be seen on the final imagery as a faint dark line.
- Smoothing of the altitude of the vehicle above the seafloor. The altimeter sometimes cannot locate the seafloor, possibly due to very soft sediment thus reducing the return profiler signal. Smoothing is done by a median filter of the given values, comparing this with the first return seen on the port and starboard sides, and applying a maximum threshold for altitude change if first return and altitude value differ. Generally first return values are used, as these values will be used in the slant-range correction too.
- Merging of ship navigation and cable data with the imagery and calculation of the TOBI position using an inertial navigation algorithm. The 'navfile.veh_nav' file contains ship position and cable values and an umbilical length of 120metres plus an additional 62 metres for the distance between the GPS receiver and the approximate point where the cable enters the water. The cable values from the shipboard winch system were used in the TOBI cable file. Various assumptions are applied: the cable is assumed to be straight, the cable value is

assumed to be correct, and zero cable is set when the depressor enters the water.

- Uses the TOBI compass heading. A smoothing filter of 100 pings is applied. The heading values are used in the geographic registration process to angle each ping relative to the TOBI position.
- Slant-range correction assuming a flat bottom. This is a simple Pythagoras calculation assuming that the seafloor is horizontal across-track and sound velocity is 1500ms^{-1}. Each pixel is 8ms and generally equates to 6 metre resolution; any pixel gaps on the output file are filled by pixel replication.
- A median filter to remove any high or bright speckle noise. A threshold is defined for the maximum deviation for adjoining pixels over a small area above which the pixel is replaced by a median value.
- Dropout removal for large imagery dropouts. When the vehicle yaws excessively, it is possible for the 'transmit' and 'receive' phase of each ping to be angled apart. If this exceeds the beam sensitivity value (0.8º) little or no signal is received, creating a dark line on the imagery. The program detects the dropout lines and interpolates new pixel values. If more than 7 dropouts are present concurrently (28 seconds) no interpolation is done.
- More dropout removal but for smaller, partial line dropouts. If more than 7 partial dropouts are present concurrently (28 seconds) no interpolation is done.
- Across-track equalisation of illumination on an equal range basis. This assumes that the backscatter from a particular range should average a given amount for each piece of data. The near-range pixels and far-range pixels are generally darker than mid-range pixels. This is due to the transducer’s beam pattern and differences in seafloor backscatter response in terms of angle of incidence. The result of this is to amplify the near and far-range pixels by about 1.5 and reduce the mid-range pixels by 0.8.
- Adds a pixel value of 1 to each pixels to avoid zero pixel values that would appear white on a transparent or white background, e.g. when printing maps.

Once these calculations have been applied to a piece of data the individual pings are placed on a geographic map. To emulate beamspreading the pixels are smeared over a small angle (0.8º) if no other data is present in those pixels. As survey tracks are designed to overlap the imagery at far-range, any overlapping data pieces are placed on separate layers of the same map. This allows user intervention to define the join where one piece touches the other. If small pixel gaps are visible between the geographically mosaiced pings, these are filled with an interpolated value plus a random amount of noise (but having the same variance as the surrounding data pixels).

The second phase (of mosaicing) allows the user to view all the ‘layers’ of data for an area. The software used is a commercial package named ERDAS Imagine (v9.1). Within this software the different layers can be displayed in different colours to distinguish the layers with data that will overlap data from another layer. In order to merge the different layers and their data together, polygons (Areas of Interest –or AOI) are drawn by the user to define the join lines between layers and then applied to create a single layer final image map. This procedure can also be used to remove shadow zones and areas of no data. The program that merges all data within selected AOIs into the final single layer image is called ‘addstencil’. Several of these final images can then be mosaiced together into a big image from which maps can be created in different projections and spheroids, including scales, co-ordinates and text. Also annotation such as ship's track, vehicle track and dates and times can be added to the map. The map can then be plotted on the A0 plotter and/or converted into other format e.g. TIFF, JPEG, generic postscript etc. to be used for further analysis on PC, Macintosh or UNIX workstations.

Note: All onboard TOBI sidescan processing is only preliminary due to the short amount of time available. Special care should be taken when trying to identify positions of seabed features as some inaccuracies remain. The data will be processed more thorough back at NOCS, including true slant-range correction based on the bathymetry dataset available compared to a flat-bottom assumption used aboard. Another, more special correction is the altitude correction within asymmetrical canyons, and a more specialised cable algorithm compared to a straight cable path assumption.

Piston Corer

A piston corer was used to obtain long cores (1–5 m), complementing shallow (surface) cores from the mega corer (see below). Conventional gravity coring is limited in the overall length of the sample that can be recovered. It also compresses the sample inside the liner due to friction with the liner walls. The addition of an internal piston allows the soft sediment to be captured without significant compression or disturbance producing a better-preserved sediment sample.

The piston corer consists of a 1.5 tonne head-weight that is attached to one or more 6 m long, 110 mm diameter steel tubes (up to a maximum of 24 m). Plastic liner is inserted inside the steel tube and a piston is placed at the bottom end, just above a sediment cutting device and a sediment catcher. The head weight is attached to a trigger arm that is in turn attached to the ship's winch wire. A small gravity corer hangs from the trigger arm on a rope set to a length that is longer than the overall length of the main corer. The entire assembly is lowered over the side of the ship to the seafloor using a specialized deployment system.

When the small gravity corer makes contact with the seabed, it releases the trigger arm allowing the main corer to free-fall. As the corer penetrates the seabed, the piston inside stops at the sediment surface creating a pressure differential at the top of the sediment column. This allows the sediment to enter the core liner with minimal compression or disruption. The corer is then pulled from the seabed with the ship's wire and hauled back to the ship. The plastic liner is then removed and first cut into 1.5 m lengths and then split longitudinally to reveal the sediment sample inside.

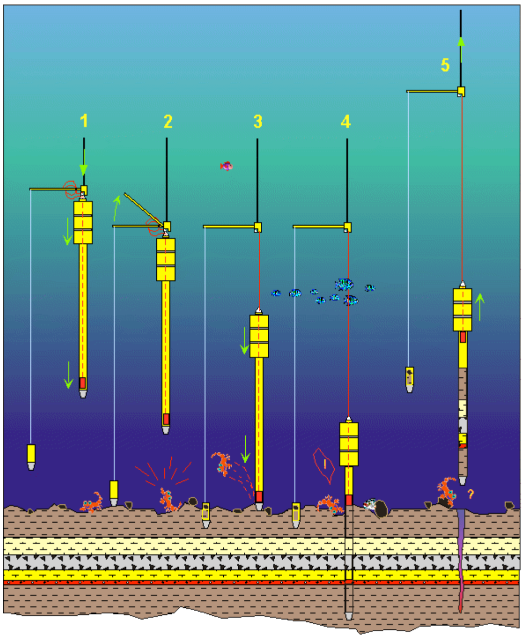

Figure 9: The piston corer: (1) being lowered to the seabed; (2) trigger core contacts the seabed, trigger arm is raised; (3) trigger releases, head-weight drives piston corer to the seabed; (4) corer penetrates the seabed, piston remains just above the seabed; (5) piston corer is retrieved.

Mega Corer

The mega corer allows the sediment-water interface and uppermost 50 cm of sediment to be sampled intact and can be combined with piston or gravity cores to produce the most complete possible record of young sediments.

The mega corer comprises an outer bell-shaped metal frame, and an inner central weight and hydraulic damper system with up to 12 sample tubes. The corer is lowered to the seafloor. When the frame reaches the seafloor the hydraulic damper slowly pushes the tubes into the sediment. As the tubes are raised again, a gate is triggered and closes the base of the tube.

Once the corer is on deck, the tubes are removed from the frame. Excess seawater is removed from above the sediment and then the cores are sub-sampled using a 6 cm diameter Perspex tube and piston device.

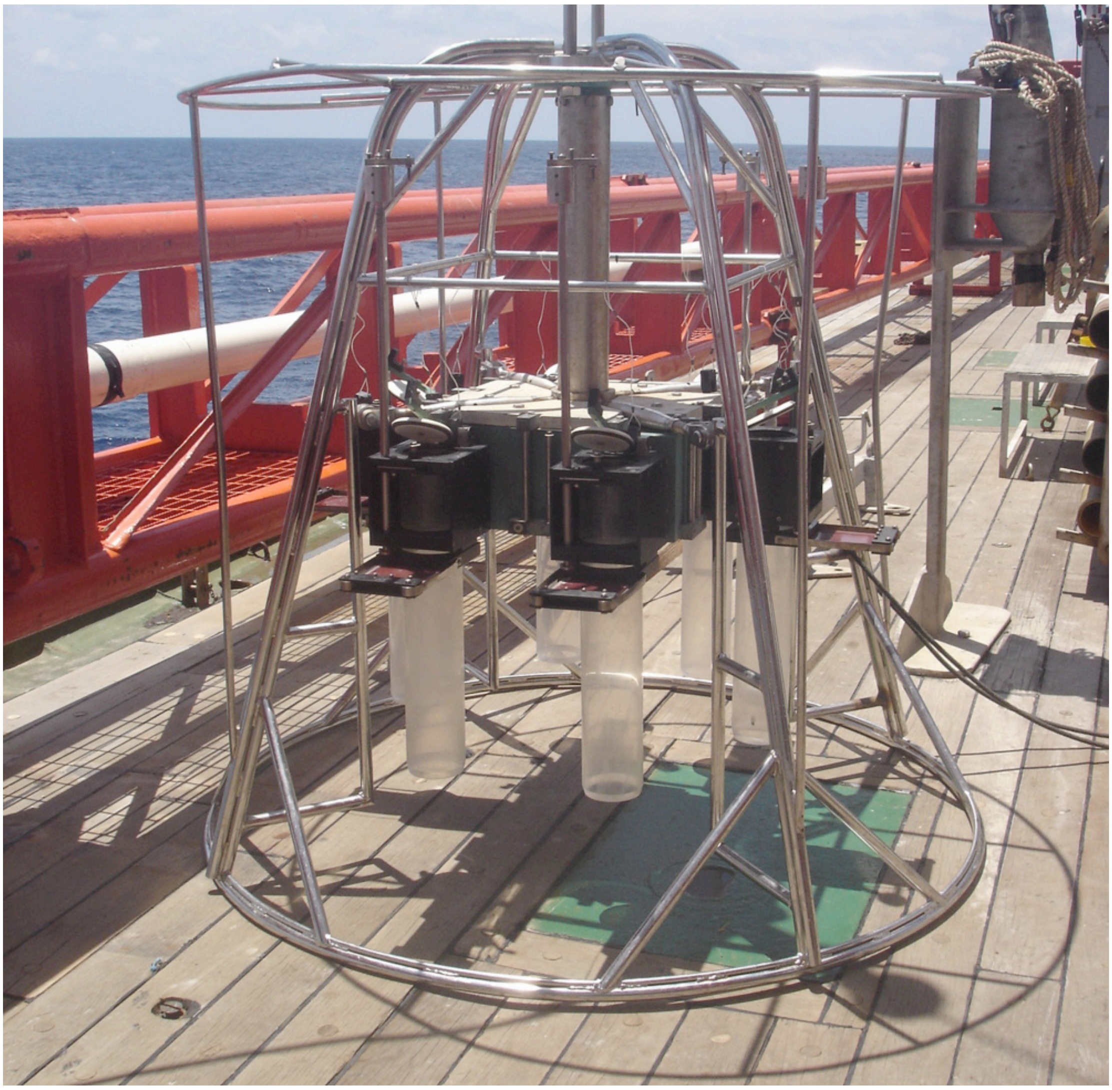

Figure 10: The mega corer ready for deployment. Note the (red) piston corer frame in the background.

Heat Flow

Heat-Flow from the Earth surface is usually determined as the product of measured temperature gradient and measured thermal conductivity of rocks. In marine domains, it can be obtained with instruments a few meters long, because temperature of the ocean bottom is more stable with time than that of the surface of continents.

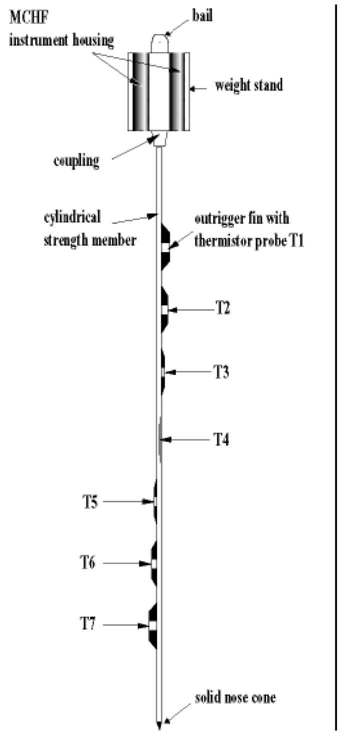

Figure 11 The IPGP heat flow instrument

Figure 12 Launching the IPGP heat flow instrument during SO200-2

The IPGP heat-flow (Figure 11, Figure 12) instrument can determine both temperature gradient and in-situ thermal conductivity. It is composed of several outrigger thermal probes (up to 10) mounted on an 8.9-cm-diameter cylindrical probe barrel (up to 7 m long). Each probe 3.18 mm in diameter contains a thermistor sensor and a heater wire. The control and recording instrumentation, and power supplies (batteries), are contained within 2 cylindrical pressure cases located within the weight-stand at the top of the probe barrel. The data are recorded in the instrument and also transmitted in a digital format to the surface by an acoustic transducer. A surface transducer and a deck receiver (Figure 13) allow the remote control and processing of data.

Figure 13 a) Surface transducer on board, b) deck receiver

A typical measuring sequence is composed of the following steps (Figure 14):

- Lowering through the sea water
- Penetration into the bottom sediments and frictional heating.
- Subsequent cooling period. 5-6 minutes of undisturbed cooling after penetration are used to obtain a good estimate of the equilibrium sediment temperatures.
- In-situ thermal conductivity period characterized by heating (10 sec) followed by cooling (5 min) in the pulse-heating mode or heating (10 min) in the continuous-heating mode. The choice of heating mode is made by a program in the instrument.
- Pull-out from the bottom and a period of recording near-bottom sea water temperature while the instrument is being towed to another location by the ship.

During each sampling sequence (1 record), all thermistor probe temperatures are measured, as well as the hydrostatic pressure, the tilt angle, and two reference resistors (data calibration). For example, with 8 thermistors (including the water temperature on the top of the instrument) and a sampling rate of 1 second, each variable is measured every 14 seconds. After the instrumentation is pulled out of the seafloor, the ship moves to the next

location at slow speed (1-2 knots), with the instrument suspended at least 100 meters above the bottom: this is the POGO method. When the batteries are depleted which occurs up to 72 hours after the instrument starts recording, the probe is pulled up on deck and the memory is dumped to a binary file using a portable micro-computer. A station includes the time spent by the instrument in the water, and could comprise up to 25 penetrations.
After collection, the binary data are converted to temperatures. This can be also performed on the real-time data collected on the ship. The data recorded in the MCHF instrument are generally of better quality and more complete than the acoustically transmitted data. These temperatures are processed to obtain final heat flow values using the Hfanalysis software (Bonneville, et al., 1993].

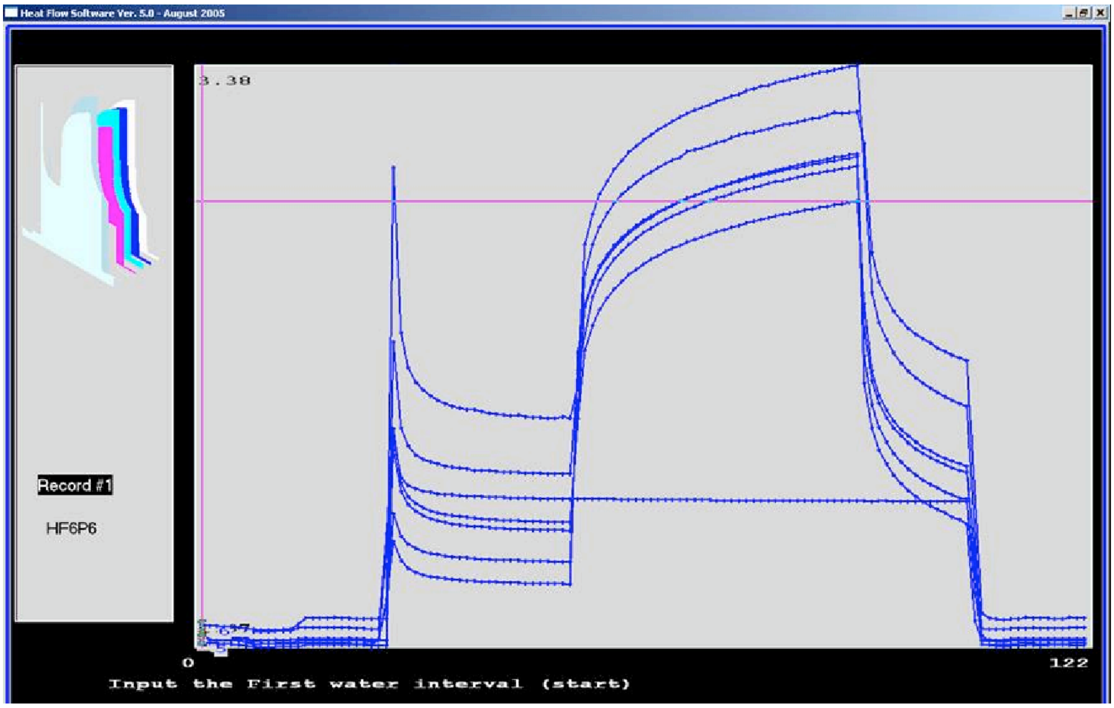

Figure 14 Typical temperature record during a heat-flow measurement: vertical axis represents temperature and horizontal axis represents time (in records number, 1 record number = 14s). Seven sensors are used, which record first the water temperature above the sea bottom, then a friction peak during penetration and next a temperature decrease and finally a progressive increase during heating for thermal conductivity determination.

Multichannel Seismic Reflection Profiling

The objective of multichannel seismic profiling during SO200-2 was to collect a dense grid of lines at the front of the accretionary prism. This is the region where material from the incoming plate is first incorporated into the prism, and on the Sumatra margin tends to have the least eroded geomorphology. Thrust-controlled folds can be easily identified in swath bathymetry data which defines a scale of segmentation typically 10s of km in length, i.e., significantly smaller than the ruptures of major earthquakes. The large-scale seismic data from SO198-2 and other recent studies of the margin shows that the majority of these initial folds are related to faults that dip seaward, i.e., in the opposite direction from the main plate boundary; however the presence of small scarps on the seaward side of these folds suggests that they may be affected by the major earthquakes on the plate boundary (Henstock et al., 2006). Our aim was to determine to what extent the surface morphology may be diagnostic of variations in the deeper plate boundary by tracing the key faults from the surface to depth.

A small airgun array was used as the seismic source (Figure 15), with 6 G-guns deployed of which 4 (guns 1, 3, 4, and 5) were used during the survey. The total array volume was 1400cu.in. with a spread of chamber volumes to maximise bubble pulse cancellation and maximise resolution; a short test during SO198-2 suggested that this array was capable of penetrating to the downgoing plate in the trench. The airguns were operated by staff from IFM/GEOMAR. The airguns were controlled by an 8-channel Longshot firing system, although persistent problems were experienced with the firing sensors. The serial port output from the Longshot was logged on a laptop using a program which integrated GPS time and position information with the shot number, although we believe that the file stores the shot number for the *previous* shot against the time for the *current* shot.

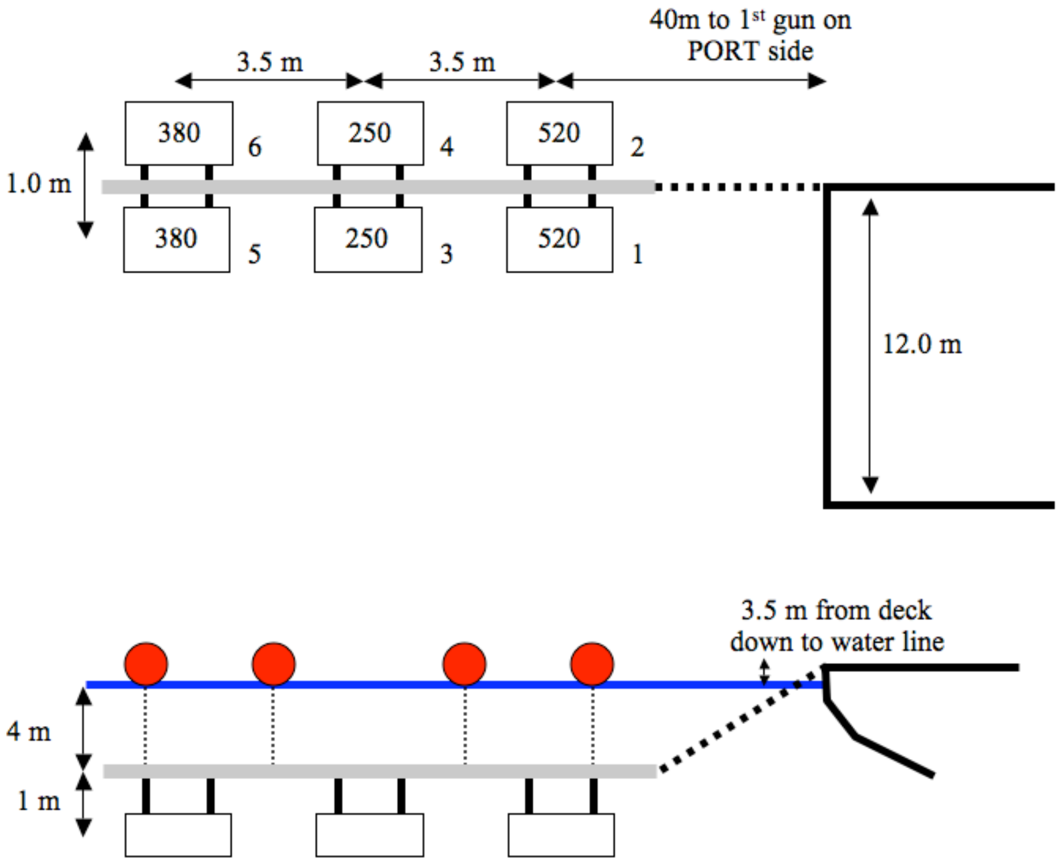

Figure 15 Layout of seismic source; array used was 1x520 cu. in., 1x380 cu. in., 2x250 cu. in. airguns.

The source was recorded on a short (24-channel, 300m aperture) streamer (Figure 16) supplied by Exploration Electronics Limited, and towed from the centre of the stern. A Geometrics Geode NX was used as the recording system with a sample interval of 2ms throughout. Record lengths and shot intervals varied between 8-10s and 10-15s respectively depending on the water depths to minimise effects of multiple energy from the previous shot (Table 1). Data were recorded in SEGD format onto hard disk. The shot times are logged on this system against the internal PC clock, which was synchronised to UTC at the beginning of the experiment. The system ran continuously from 63/1536 until 65/1503; logical line breaks were determined by the start of turns but logging continued throughout. File number and shot number were logged manually approximately every 50 shots by the observer (generally Stefan Paterson from EEL or Tim Henstock from NOCS).

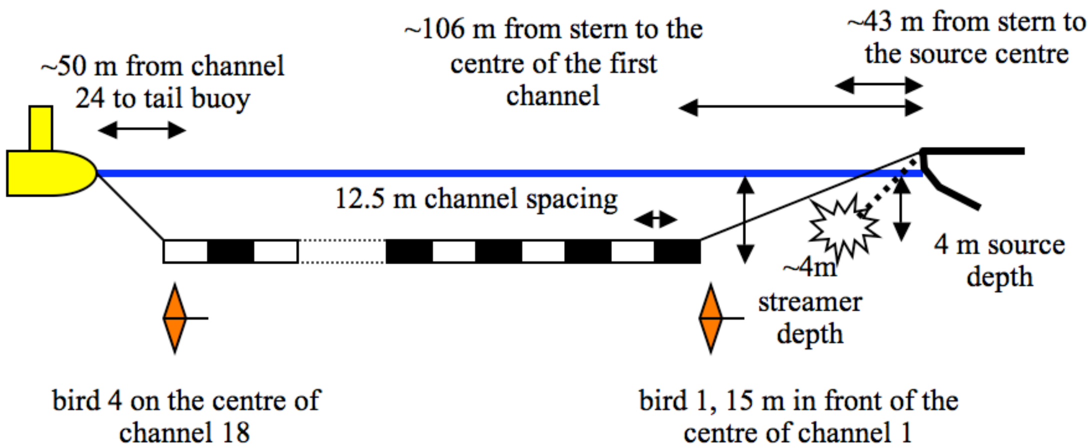

Figure 16 Layout of the hydrophone behind the ship.

Seabed two-way time	Record length/shot interval
<4s	8s/10s
4-6.5s	9s/11s
>6.5s	10s/15s

Table 1 Record lengths and shot intervals used during the survey.

17 lines were recorded with an average speed of 5.1 knots being enabled by good sea surface conditions, giving a total line length of approximately 240nm or 450km.

Expendable Bathythermographs (XBTs) and Expendable Sound Velocity probes (XSVs)

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. Expendable sound velocity probes appear physically similar to an XBT but provide a direct measurement of the acoustic velocity of water using a piezoelectric transducer. 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.

XBT/XSV probes consist of a weighted 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. Probe depth is calculated from the time elapsed since the probe entered the water. XSV probes are battery powered and measure the velocity of water passing through a slit in the front of the probe; measurements are transmitted back to the data acquisition system along a single-conductor insulated wire as a frequency modulated signal. XBT probes sample temperature using an integrated thermistor and send the measurements to the data acquisition system along a two-conductor insulated wire. 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 SO198-1 CTD drop, which provided comparable velocity values to the XSV probes.

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

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/XSV launcher and data acquisition system

The XBT/XSV system comprised of a hand-held launcher (Figure 17) and Lockheed Martin Sippican, Inc. MK21 I/O module (serial number 00157, running June 14th 2007 firmware) connected via USB to a laptop PC.

Figure 17: The XBT/XSV hand-held launcher ready with a T-7 probe in its launch tube (bottom), and an unused T-5 probe (top). XSV probes appear identical to an XBT except the canister is green.

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 laptop was connected to the vessel's NMEA GPS feed to provide the location of each launch.

The hand-held launcher was connected to a deck connection box located on the main deck directly behind the *luftpulserstation* (Figure 18). The probes were deployed over the port rail adjacent to the deck connection box.

The launch of each probe creates two files on the laptop, 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 data values logged by the system in text format; in the case of the XBT data, both the original temperature measurements and the calculated velocity measurements (for the assumed salinity value, set to 35 ppt) are included.

Two types of XBT probe were deployed during SO200: 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 17). 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. Two types of XSV probe were deployed during SO200: XSV-01 probes with a maximum depth of 850 m; and XSV-02 probes with maximum depth of 2000 m. Both types of XSV probe could be deployed at up to 15 knots.

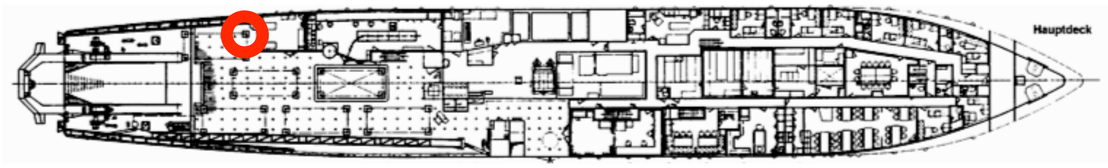

Figure 18: The launch location for XBT/XSV probes, on the main deck directly behind the *luftpulserstation*.

Figure 19: An XSV probe being deployed using the hand-held launcher.

Operational issues with the XBT/XSV system

1. None of the XSV-01 probes deployed during SO200 provided any data, although the XSV-02 probes mostly worked; this is thought likely due to the age of the probes, with a use-by date in the 1990s, having failed batteries.
2. 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.
3. The deck connection box is not rain/waterproof.

4. 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 20).

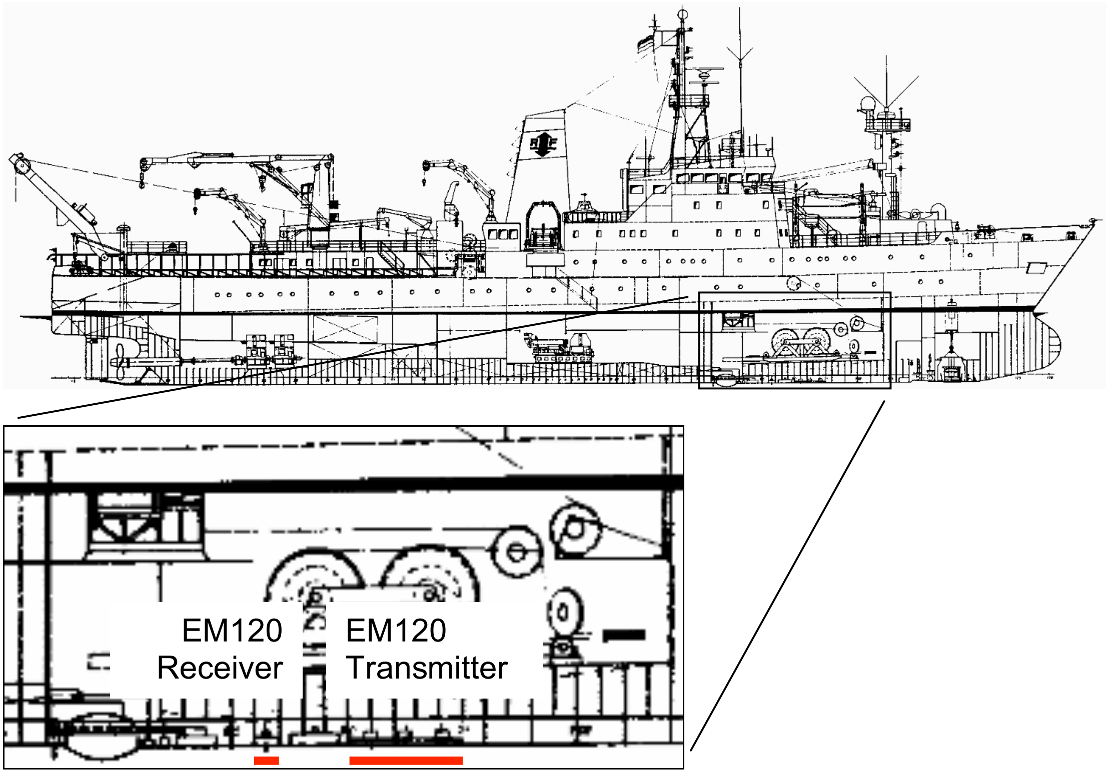

Figure 20: Location of the EM120 transmitter and receiver transducers in the Sonne's hull.

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 21). The system provides a 1° beam width 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 velocity profile acquired during SO198-1 from XBT sequence number 1, extended in

depth to account for the deep velocity structure, depending on location relative to the trench (Figure 22, Table 2 and Table 3)

3. A zero-tide correction was applied
4. A swath/sweep filter rejects soundings with a beam-to-beam slope of >25° and swaths were edited by hand
5. Data were gridded at 50 m and interpolated using a 5x5 grid where at least 10 grid nodes are populated

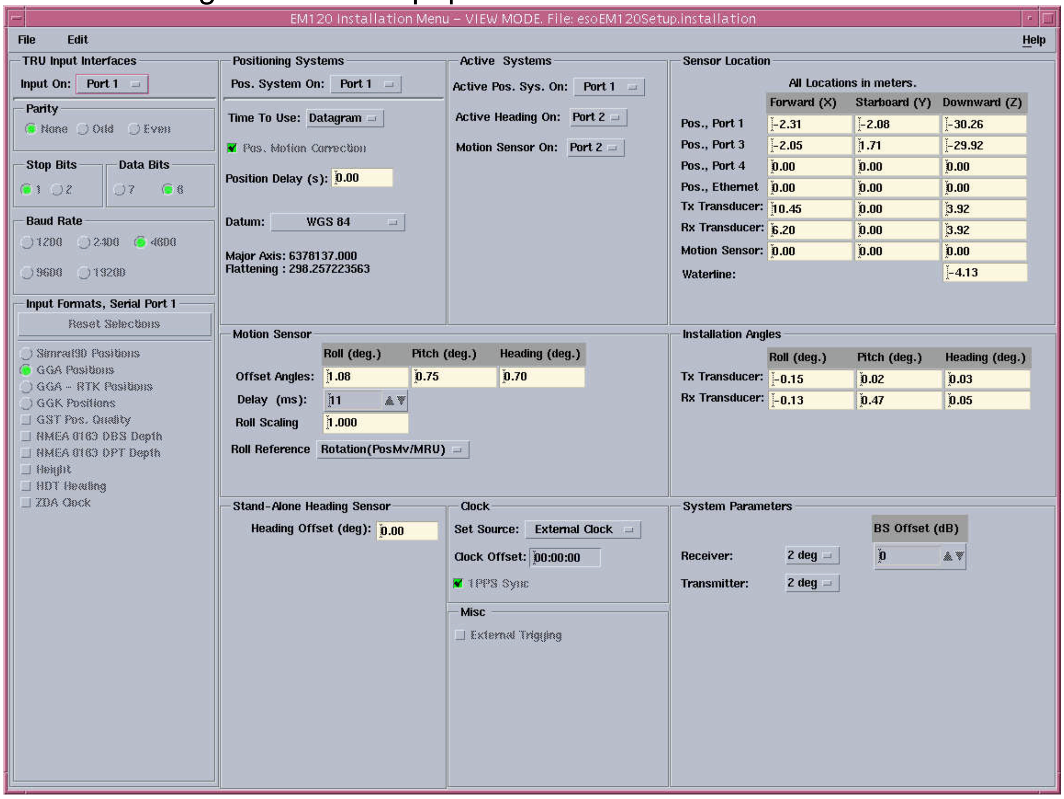

Figure 21: The EM120 Installation Menu, showing the settings used during data acquisition on SO200.

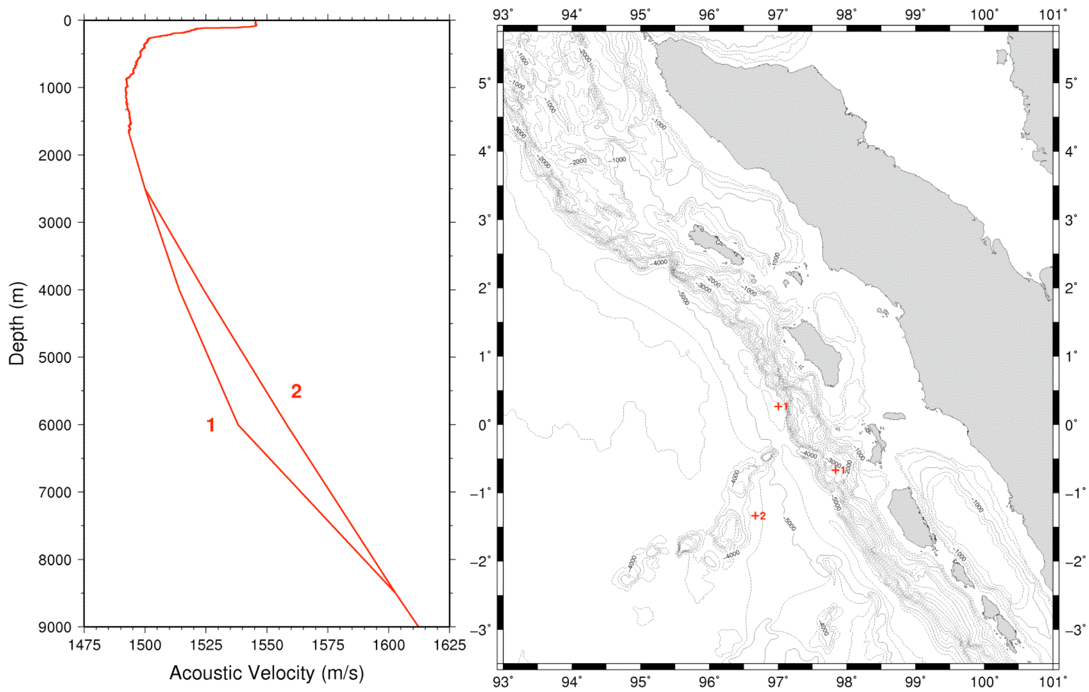

Figure 22: Sound-velocity profiles 1 and 2 (left panel) used to perform the slant-range correction for the swath bathymetric data, and their locations (right panel), as entered into the Caris software, where they were applied to the nearest data.

Depth (m)	Profile 1 velocity (m/s)	Profile 2 velocity (m/s)
2500	1500	1500
4000	1514	1524
6000	1538	1558
8500	1602	1602
12000	1669	1669

Table 2: Velocity profiles 1 and 2, used to extend SO198-1 XBT sequence number 1 for the slant-range correction of the swath bathymetric data. The two profiles were applied spacially to correct the nearest data; locations are given in Table 3.

Profile	Latitude	Longitude
1	0.26667	97.0
1	-0.66667	97.83333
2	-1.33333	96.66667

Table 3: Locations for velocity profiles 1 and 2 (Table 2) used to slant-range correct the swath bathymetric data.

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 23), a heave sensor, and an electronic control, data processing and logging system. Since SO198 the hull transducers and the control/logging system have been replaced, although the fundamentals of the system are unchanged. The control console is now a single PC workstation running *Atlas Hydromap* software (version 2.1.3) to control the main system settings, and *Parastore* software (version 3.2.5) to store and display the data.

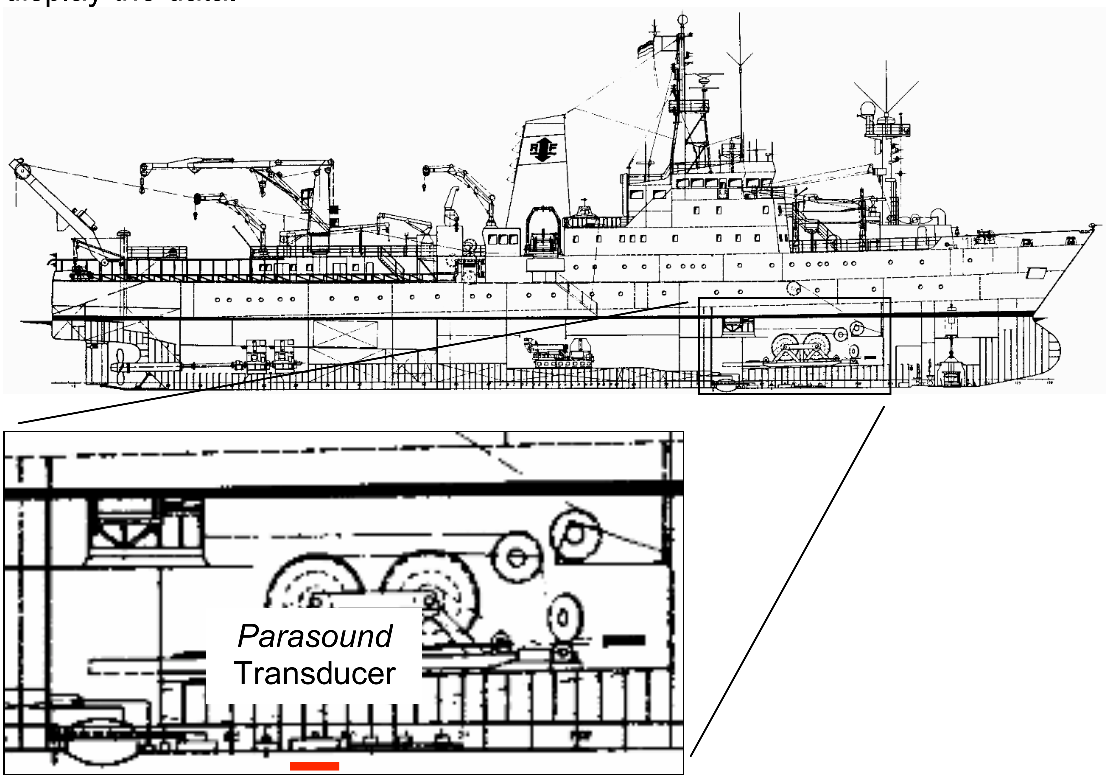

Figure 23: Location of the *Parasound* transducer in the Sonne's hull.

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. 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 SO200 the second signal was set to result 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.

A data sample rate of 50 kHz (20µs 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 400 m long (26667 samples assuming 1.5 km/s) and the start of the window is set in depth *Hydromap* software. The data is output in SEG-Y format.

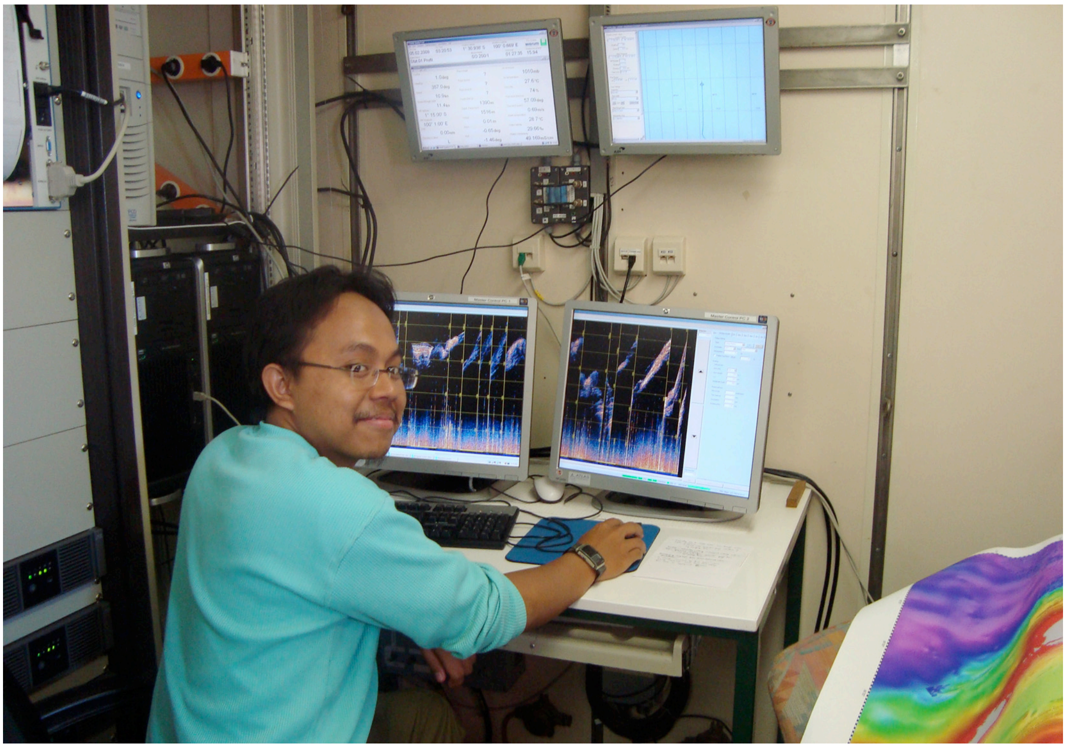

Figure 24: The *Parasound* control console, located in the *Hydroakustiklabor*.

Operational issues with the *Parasound* system

1. The recording window does not automatically track the seafloor reflection and must be adjusted manually by the operator as the water depth changes.
2. The search window for the water depth output was recommended to be set to ~1000 m for best results. Once the seafloor is outside this search window the *Parasound* depth is invalid. The window must be monitored and updated manually by the operator.
3. The software to control the *Parasound* is not available on a workstation in the *Geologielabor*, so the operator must be in the *Hydroakustiklabor*. A repeat of the control screen is displayed in the *Geologielabor*.
4. The new system proved rather less reliable than the old *Parasound*, requiring frequent restarts, up to two times per day, with data lost each time it stopped working.

Gravity meter

Gravity was recorded continuously during SO200 on a LaCoste and Romberg marine gravity meter (S40). The meter was installed in the *Gravimeterraum* on deck II of the Sonne (Figure 25). 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 1-second using software provided by the Sonne on a laptop PC connected to the serial output of the console.

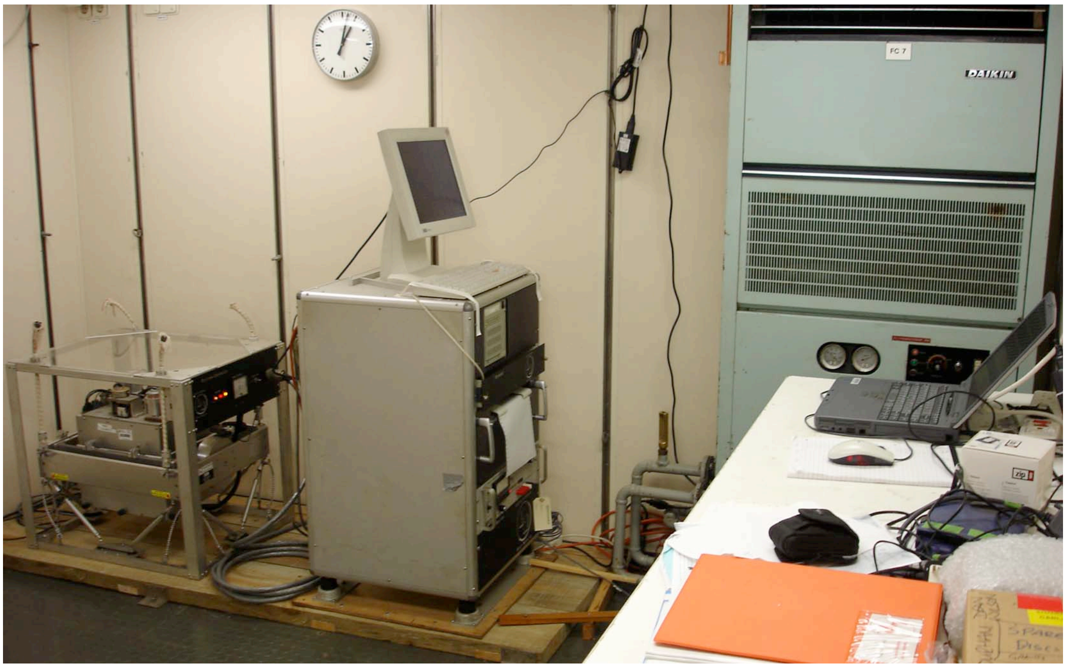

Figure 25: The gravity meter S40 (left) installed in the *Gravimeterraum* on deck II of the Sonne with the control and logging console (centre) and the laptop PC used to capture 1-second gravity data via an RS-232 serial connection (right; on the bench).

Jakarta base station tie

During the port call at Tanjung Priok Port, Jakarta, between SO200-1 and SO200-2 a base station tie was made at TJ Priok 1 base station. The base station and measurement point (adjacent to the base station which could not be directly accessed) locations and base station absolute gravity values are shown in Table 4.

Location	Latitude	Longitude	Absolute gravity value (mGal)
Tanjung Priok 1 Base Station (TP1)	6.10463 S	106.88675 E	978146.4
Measurement location (adjacent to TP1)	6.1068 S	106.8869 E	

Table 4 Details of Jakarta port gravity base station and measurement location.

From the above measurement:
Absolute gravity value at ship meter = 978146.77 mGal.

Gravity meter clock drift

The clock on the S40 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 manually approximately every hour during SO200 either using the exported laptop display or directly fromm the meter. The gravity meter's clock tended to gain time relative to UTC. The time offset is shown in Figure 26.

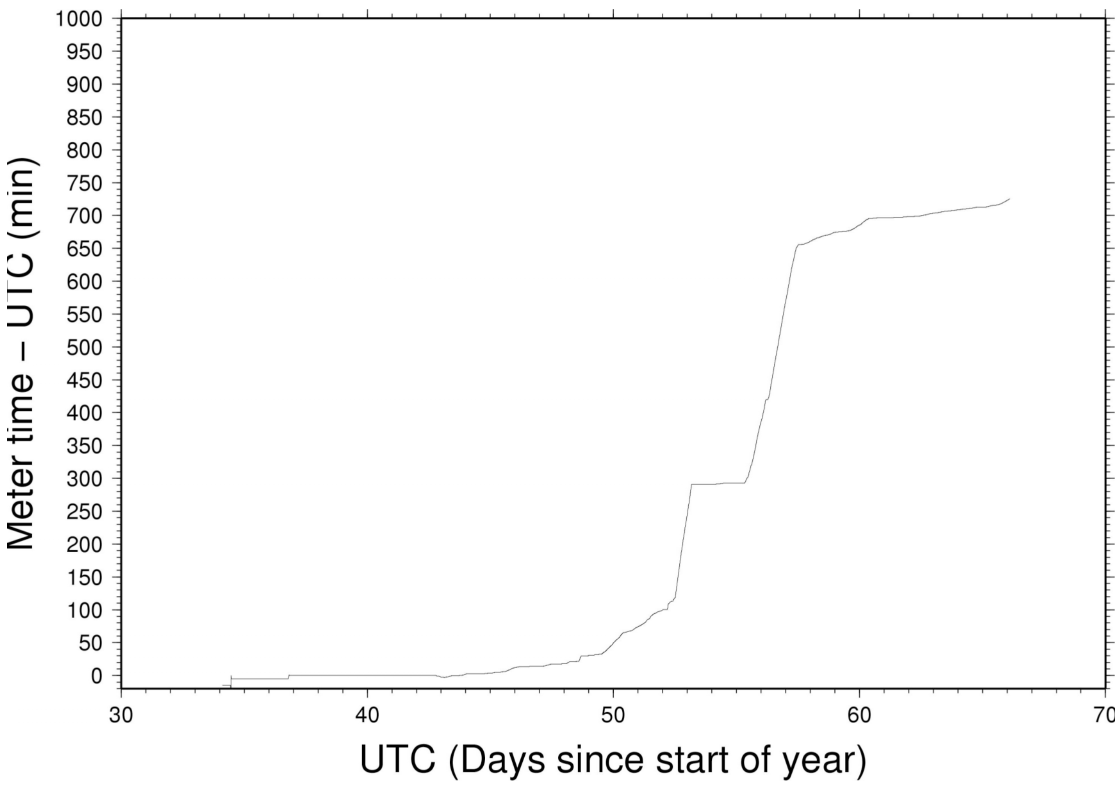

Figure 26 Drift of the gravity meter clock relative to UTC time derived from GPS clocks on board R/V Sonne.

Gravity data reduction

The 1-second gravity data 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 27).

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.

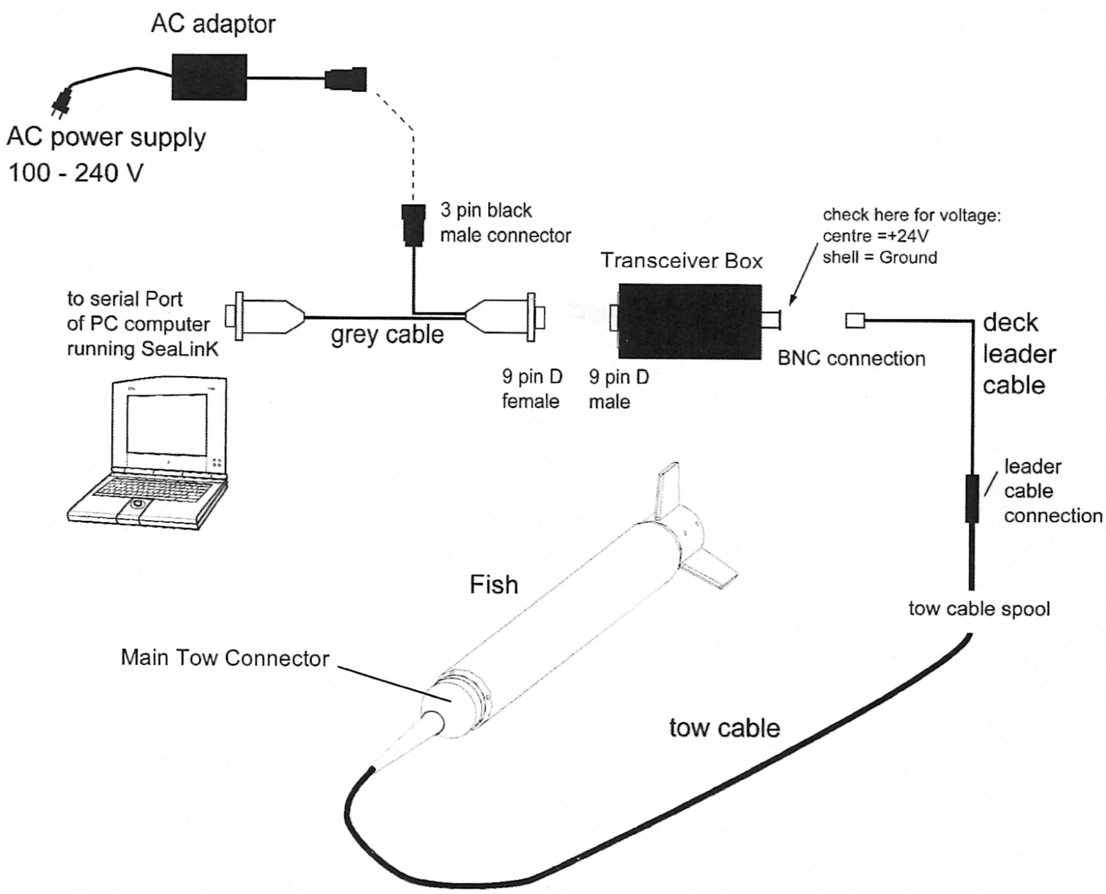

Figure 27: The *SeaSPY* total field magnetometer system (after Marine Magnetics Corporation, 2008).

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 28). The location of the winch drum and the end of the boom that formed the towing point were measured using a tape (Figure 29 and Figure 30).

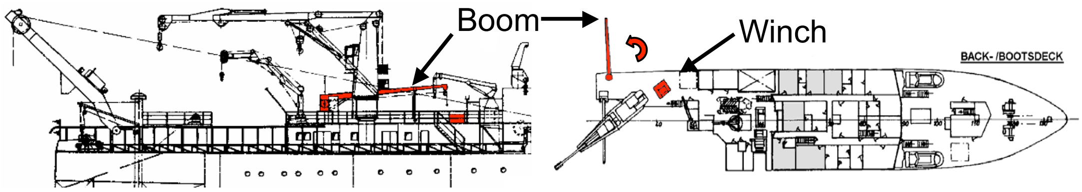

Figure 28: Location of the magnetometer winch and deployment boom on the port side of the back-boat deck, one deck above the main deck.

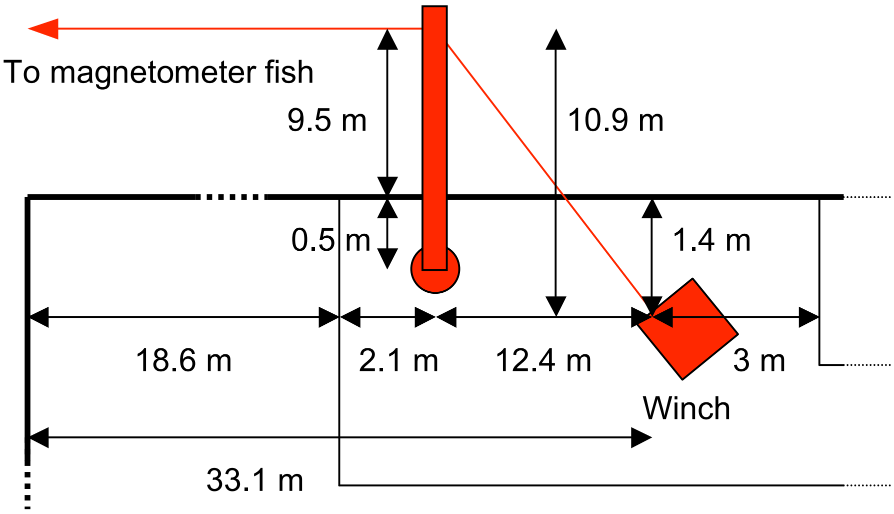

Figure 29: The location of the magnetometer winch and the towing point at the end of the rotating boom on the port side of the back-boat deck. Distances are given in metres relative to the tow point at the end of the extended boom, the point at which the cable leaves the winch drum, and the stern and port rail of the Sonne.

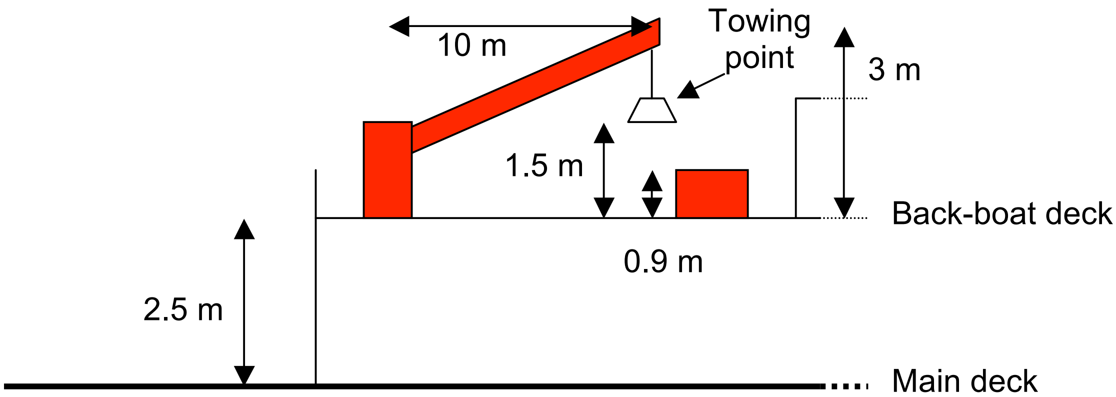

Figure 30: The height of the magnetometer winch, cable on the winch drum, and the towing point on the boom (not extended in this diagram) above the main deck of the Sonne. The water line is a further 3.5 m below the main deck.

Of the 300 m of tow cable, 20 m remained on the winch drum (the cable had been measured out at NOC and marked with blue tape at 280 m) and 16.5 m lies between the winch and the towing point on the end of the boom, leaving 263.5 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 31); assuming the same rate of increase in tow depth with cable length at 3 kt (Figure 32) and extrapolating to 263.5 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

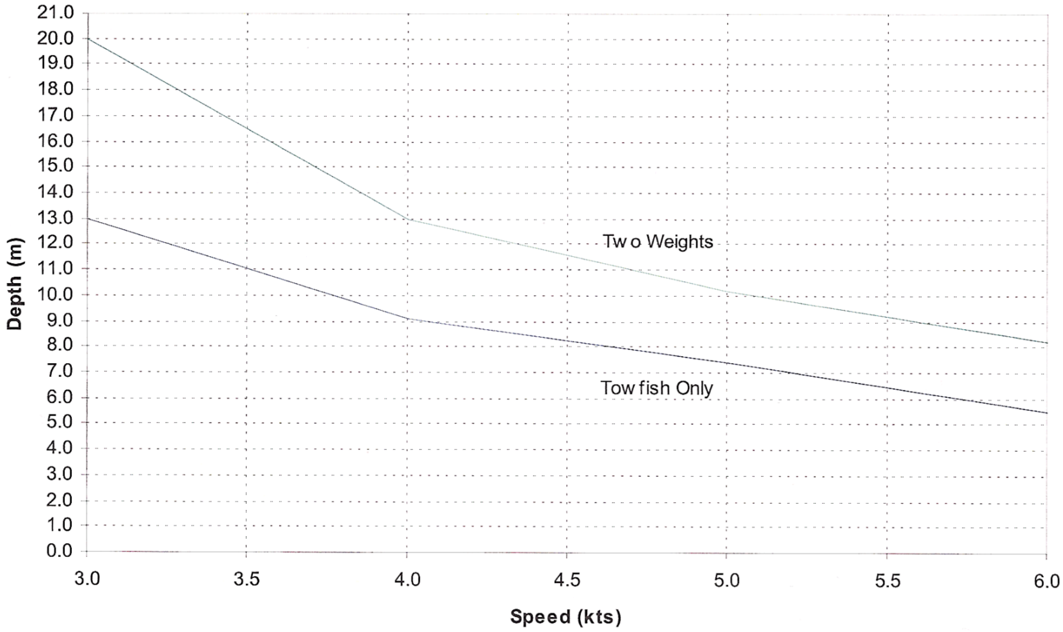

Figure 31: Towing depth of the *SeaSPY* tow fish versus towing speed with a 120 m tow cable. The un-weighted tow fish (bottom curve) represents the sensor used during SO200 (after Marine Magnetics Corporation, 2008).

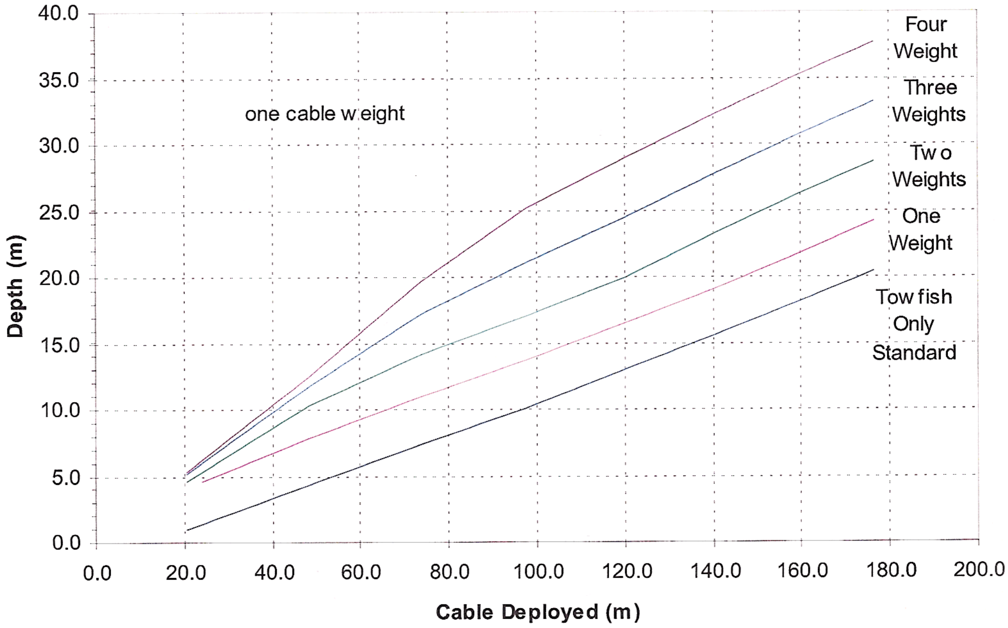

Figure 32: Towing depth of the *SeaSPY* tow fish at 3 kt towing speed. The un-weighted (standard) tow fish (bottom curve) represents the sensor used during SO200 (after Marine Magnetics Corporation, 2008).

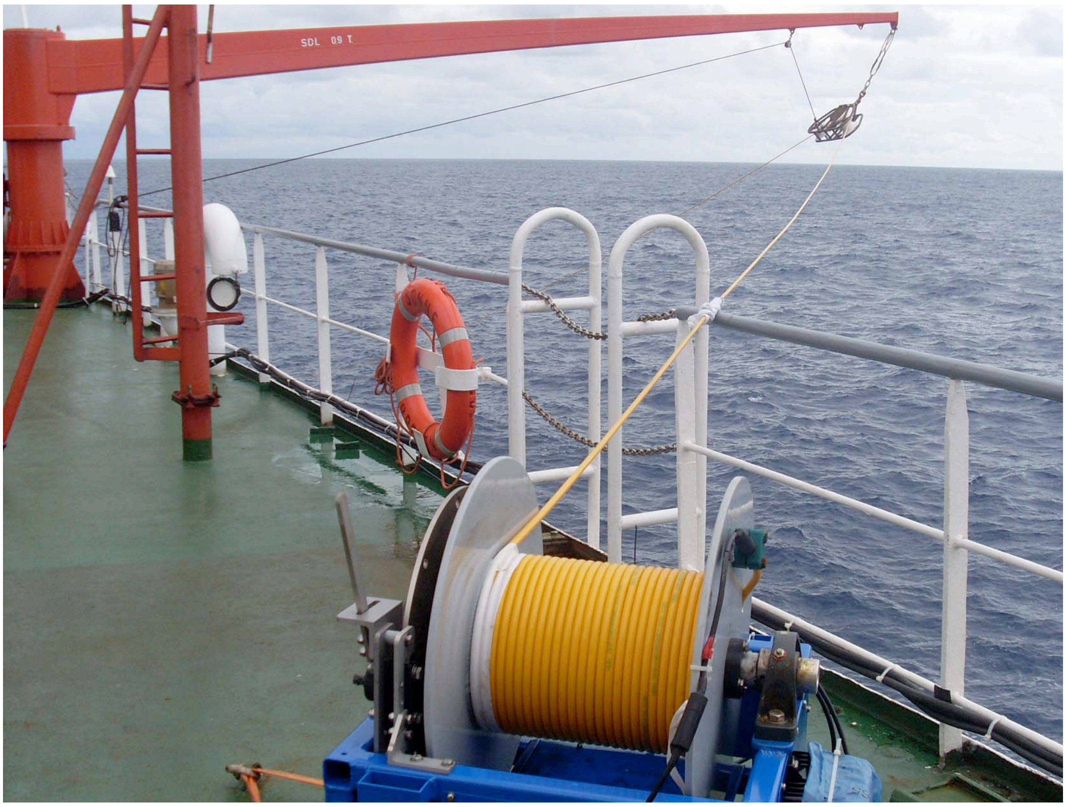

Figure 33: Magnetometer winch and deployment boom.

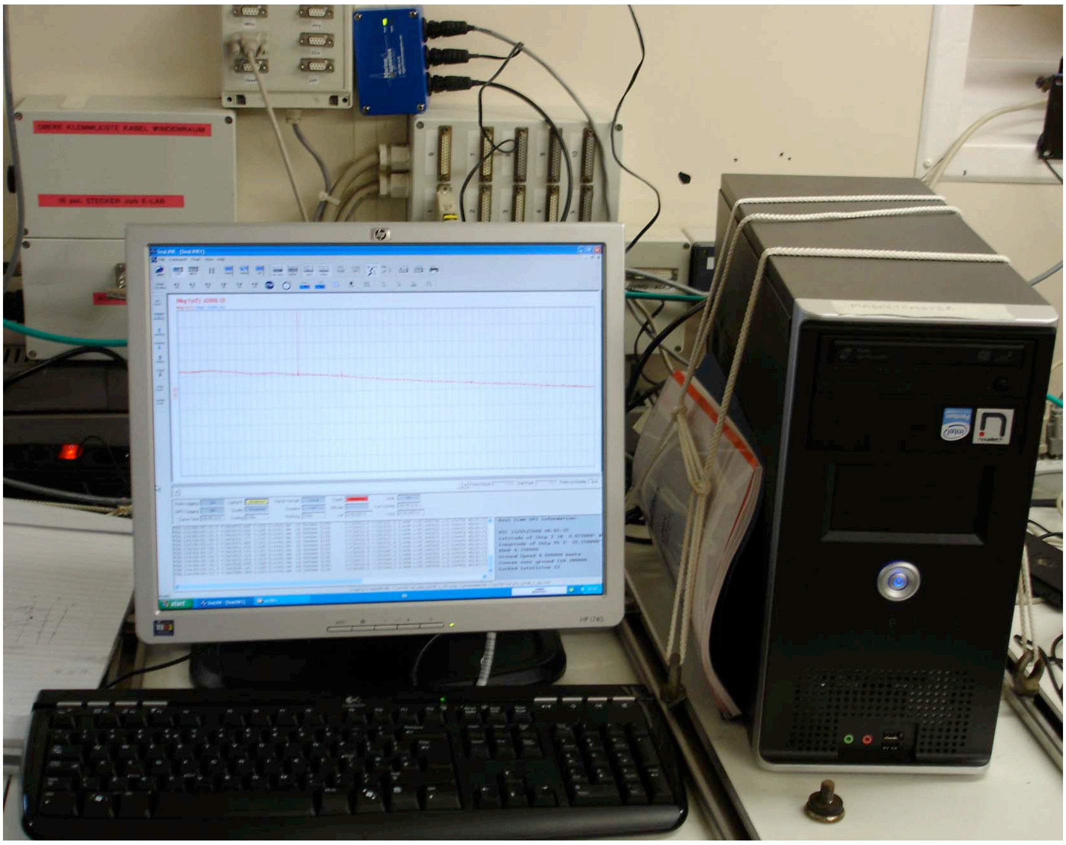

Figure 34: The magnetometer logging PC running *SeaLINK* software. The *Smart Transceiver* interface module is visible behind the monitor (blue box, centre top).

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 SO200.

The .mag file contains all the possible data fields available, including any commands issued to the fish (Figure 35). 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 35: 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 36: 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 SO200, using a value of 300 m. Both antenna and layback-corrected positions are recorded in the .mag files.

Operational issues with the *SeaSPY* system

During the previous cruises SO198-1/2, a number of issues were identified with the *SeaSPY* system, mainly with the *SeaLINK* software, that seriously affected its functionality. In particular, it proved impossible to sync the fish/transceiver clock with either GPS or the PC clock; this was thought to be related to a fault with the Julian Day date calculation (the magnetometer software does not understand leap years). During SO200, the time synchronisation feature appears to not be working.

The addition of slip rings to the magnetometer winch did allow the depth sensor on the fish to work, but requires some coordination between the lab and deck to ensure it is zeroed properly during deployment.

When the magnetometer was dismantled, it was discovered that one of the O rings had failed.

SO200-1: OBS Retrieval SB2 (22nd January – 7th February)

Basic objectives, after transit from Jakarta and entry to the permitted survey area, were as follows:

1. Retrieve the majority of the long-term deployment ocean bottom seismometers OBS around Siberut, Batu and Nias islands. During this period, 8 OBS were recovered.
2. Test the status of the recovered OBS (clock drift, battery life, data recording, backup clock function) to determine timing of collection of all of the OBS within SO200-1.

During this period, the multibeam, *Parasound* (sub-bottom profiler) were operated continuously within the permitted survey area, except for short periods during OBS retrieval. The gravity meter was operated continuously except for periods when it was not functioning. The magnetometer was deployed during longer transits, away from shoals and where data did not exist from previous cruises. XBT probes and some XSV (sound velocity probes) were launched within the survey areas.

Survey narrative

Times given in the text are local (UTC+7 hours).

Julian Day 20, Tuesday 20th January

Jakarta. Lisa McNeill, Simon Dean, Alan Burchell, and Pete Talling discuss permissions, immigration issues and customs clearance at the BPPT office. Documents were copied and forms completed for majority of SO200 science party to complete research permission (individual permits). Containers are still clearing in Jakarta port. The remaining science party members (scientists and technicians) plus Colin Day and Jason Scott (NMF-SS) arrive in Jakarta in the evening.

Julian Day 21, Wednesday 21st January

Jakarta. RV Sonne berths at Tanjung Priok port in AM. Documents and forms were completed for the entire SO200 science party and handed to BPPT. Research permission and security clearance documents were given to LM by BPPT, including individual Ristek research permits for the scientists (not technicians). We expected to install the gravity meter today, but the containers are still clearing so this is not possible. Further documents are provided to the customs office by BPPT to assist customs clearance. Attempting to get data on Tanjung Priok port gravity base station for the tie to the onboard gravity meter. AB trying to obtain an empty container via the Sonne's agent to have onboard for the retrieved OBS.

Julian Day 22, Thursday 22nd January

Jakarta – Tanjung Priok port. Science party (excluding Indonesian participants), CD and JS transfer to RV Sonne in Tanjung Priok port at 09:00, arrive at ship 10:00. Discussion of customs clearance of containers between Roger Lapian (Sonne's agent) and office, Master, Yusuf Djajadihardja, CD, JS and LM took place throughout the day, but containers (5 total: 4 for SO200-1 and EEL streamer winch for second leg) still not cleared by end of day. BPPT having to provide documents to Customs concerning import and export of all goods. Established that IPGP heat flow containers (1) for second leg has recently arrived in Jakarta but not begun clearing yet. Attempting to get data on Tanjung Priok port gravity base station for tie to onboard gravity meter. A final decision is made to use one of emptied NMF-SS containers for OBS, as hired container cannot sail with the ship. Brief meeting for partial science party about shipboard issues and introduction to science.

Julian Day 23, Friday 23rd January

Jakarta – Tanjung Priok port. Indonesian participants (with YD) arrive at 10:30. Roger Lapian arrives shortly after with discussion between YD, RL, Master, LM and various Indonesian scientists about customs clearance situation. Further documentation for immigration now required (to be prepared by BPPT). Mobilisation procedures discussed by technicians and ship's crew to establish minimum work required before sailing. Ship's safety briefing and tour given to science party. At 17:00, documentation is received from the Customs head office by RL allowing further progress of clearance. It may now be possible to complete the procedure at the Port Customs office on morning of 24th January and containers may be available in the afternoon/evening of 24th.

Julian Day 24, Saturday 24th January

Jakarta – Tanjung Priok port. Technical meeting at 09:00 to discuss deployment and operation of all equipment during SO200-1 between ship's crew and science party technicians. Roger Lapian arrives at 13:00 with news that problems have been encountered at Customs (computer crashed) and the containers are unlikely to clear, with confirmation from RL's assistant at 13:45 that they have not cleared. The next opportunity for finalising the paperwork will be Tuesday, with an earliest departure of Tuesday evening (27/01/09) or Wednesday morning (28/01/09). There are also ongoing problems with Immigration for the ship's crew (related to the Dahsuskim). SD and AB search for the 2 gravity base stations in the port but are unable to access them.

Julian Day 25, Sunday 25th January

Jakarta – Tanjung Priok port. At 10:00, part of the science group leave the port for a visit to Jakarta. At 18:30 a meeting is held for the science party to give final introductions, update on situation and possible changes to the cruise schedule and further science discussion.

Julian Day 26, Monday 26th January

Jakarta – Tanjung Priok port. Chinese New Year – holiday in Indonesia. A science meeting was held at 10:00 where alternative plans and priority for data collection (considering 6 day delay) were discussed. RL visits the ship at

11:00 but has no news on customs or immigration issues (holiday today). At 16:00 the ship moves to a different berth within the port.

Julian Day 27, Tuesday 27th January

Jakarta – Tanjung Priok port. RL's assistant has visited Customs Head Office in the morning where computer problems persist delaying processing. At 14:30, a science meeting is held to discuss potential TOBI and coring sites based on delays and available time. At 15:30/16:00, RL and YD visit the ship to discuss progress with customs and immigration issues. The containers have completed the computer check and may be able to undergo the physical check this evening, with containers potentially available tomorrow AM. Immigration still progressing and crew passports likely to be processed and returned by lunchtime tomorrow. We conclude that it should be possible to sail tomorrow, however, nobody is happy with the complexity of the customs and immigration procedure. At 16:45, we learn from RL that the Customs office signatory has gone home, so clearance cannot be completed tonight.

Julian Day 28, Wednesday 28th January

Jakarta – Tanjung Priok port. No news is received in the morning. At lunchtime, there is some indication that the physical check has begun. At 12:00, LM spoke with US Embassy representatives who offered assistance during SO198-2 to gain advice about getting British or German Embassy representatives involved. AT 14:00, RL arrives at the ship and delivers bad news: a letter from the Dept of Trade, Indonesia which waives import tax payment is missing and preventing customs clearance. This letter may take several days to obtain so will generate major delays. LM spent the afternoon talking to the British Embassy (Julia Nolan, Dean Barrett), the American Embassy (Molly Mahar, Beth Spelsberg) and CD and TH back in UK to gain external assistance and discuss options. Alan Burchell investigated potential for releasing the OBSs with shipboard equipment. We establish that this is possible but will take more than 1 week to accomplish and therefore it may be preferable to stay in port. The ship needs to leave the berth at 00:00. At 18:00, a decision is made to not pick up the OBS but go to anchorage, however we learn that the Sonne can now remain along side until 09:00 tomorrow.

Julian Day 29, Thursday 29th January

Jakarta – Tanjung Priok port. At 00:15, the crew's passports are returned fully processed so the immigration procedure is complete. The berth is now available until 16:00 today. At 09:30, LM, DT and the Master discuss a strategy for pushing forward customs clearance and agree that it is important to stay alongside to avoid further delay when the containers are ready. RL arrives at 11:30 and a decision is given for the ship to stay at the same berth until 16:00 tomorrow. Ristek are now preparing a supporting letter to try to move along the customs clearance. The Minister at the Department of Trade is in meetings today, but RL's office and BPPT will try to get his signature later today or tomorrow. LM requested and received a supporting letter from the British Embassy to be taken to the Department of Trade and the Customs Office.

Julian Day 30, Friday 30th January

Jakarta – Tanjung Priok port. In the morning, Roger's staff are at the Department of Trade waiting for the signed letter to waive import tax. Later in the morning, Dody (BPPT) is also sent to the Department. YD, Sumirah and agent's staff go to the Port Customs Office to negotiate and await the letter. Thomas Mueller has contacted the German Embassy and Foreign Office, but it is unclear what action is being taken. Unfortunately, the letter is signed at 15:30 and faxed at 16:30, so there is little time for further customs processing before the office closes. The process has to begin again on Saturday morning. The berth allocation is extended again until 16:00 Saturday. Discussions with Dian Andrianto (Security Officer) about possible discrepancy between actual crew list and that attached to the Security Clearance. He will work on this at the BPPT office to try to resolve.

Julian Day 31, Saturday 31st January

Jakarta – Tanjung Priok port. Customs processing continues at the Port Customs Office in the morning (with DY and RL's staff at various locations in Customs), but queues and further computer problems slow the process down. Members of the science/technical group finally proceed to the containers for the physical check around 12:00. At 14:00 the partial check is complete, but no further processing can proceed as the office is now closed, reopening on Monday. But it was good to finally see the containers and their contents. We later find out that there is a problem with the goods being used whereas the paperwork states or expects new goods, however a workaround is found which may prevent further complications on Monday (potentially involving another letter from the Department of Trade). During the day, DA and others work at BPPT office on resolving the security clearance issue (crew list). The berth allocation is extended again until 16:00 Monday. LM discussed possible scenarios for schedule of Leg 1 and 2 with TH to determine changed date for the next port call.

Julian Day 32, Sunday 1st February

Jakarta – Tanjung Priok port. All offices closed today, so no progress can be made on customs clearance. At 10:00, part of the science party depart for a touristic trip to the old city of Batavia along the coast (Kota) for a change of scene. At 14:30, YD, RL visit the ship to discuss various issues with LM and Master. It becomes clear that the discrepancy with the crew list on the Security Clearance is a serious issue. However after considerable discussion, YD says that he can provide a report that will be acceptable to the Ministry of Defense and that we can proceed. Discussions also held about changes to the port call date, sharing of samples, container clearance on Monday, etc. RL hopes that we can get a final signature to clear the containers on Monday morning and be able to sail. At 23:00, LM discusses with TH different options for moving the port call date and impact on science plans throughout SO200.

Julian Day 33, Monday 2nd February

Jakarta – Tanjung Priok port. LM discusses Security Clearance issue with DA. He believes that the crew list issue is resolved and that making a change to the port call date is a more minor problem. It appears we are able to sail when the containers arrive. LM, ES and others start making plans for sidescan and coring data collection based on different scenarios. In considering the different scenarios for a changed port call date, the science party is homing in on the 22nd February, as there is less reliance on OBS collection variables. Obtain final signature from Customs Office at 15:00. At 17:15 the containers arrive to everyone's relief and crane is on site by 17:45. Rapid loading and securing of large items begins, finishing at 21:00. The gravity meter is quickly setup by SD and AB, however there is insufficient time before departure to do a base tie. At ~22:00, we discover that the Indonesian scientists need documents checking but luckily a quick solution is found and we are able to sail.

Julian Day 34, Tuesday 3rd February

Transit from Jakarta to Survey Area. The pilot joins the ship and we finally sail at 00:50 - at last. During this time, the power supply on the gravity meter failed, the meter became unstable and the spare power supply was installed. The clock drift was minimal for some time. The meter failed again several times later in the day with intermittent good data being logged. In the morning we passed Krakatoa with very clear views. Weather picked up as we exited the Sunda Strait. Work throughout the day on setting up coring and TOBI equipment and labs. A science meeting was held at 12:00 and safety drill at 15:30. With wind and current against us, our speed dropped to ~9 kn.

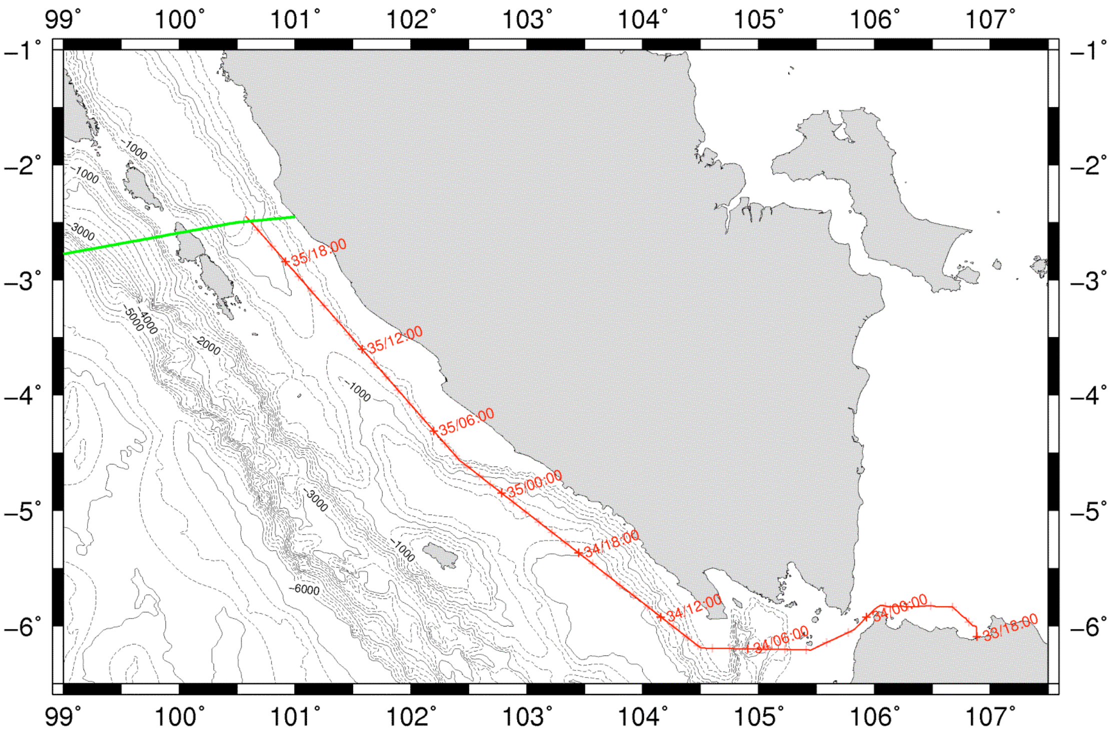

Figure 37: Transit map from Jakarta into the survey area (green line).

Julian Day 35, Wednesday 4th February

Transit from Jakarta to Survey Area. Further preparation of equipment on deck (TOBI plus winch, piston core, magnetometer) and in labs (OBS, coring, TOBI). The port call for the end of this Leg is finalised at 22/02/09. The weather begins to improve through the day as we head north and our speed increases somewhat. The science party gets training in operating the new *Parasound* sub-bottom profile system. The gravity meter has further problems in the morning, but is stable for the rest of the day. Gravity data now being directly exported and will be logged on a PC against UTC time and downloaded daily to the network.

Julian Day 36, Thursday 5th February

Transit within Survey Area and OBS recovery. We arrive within the survey area at 04:00 and begin watches, recording Multibeam, *Parasound* and gravity and deployed the magnetometer. The new *Parasound* system has some initial teething problems with settings and needs to be restarted several times. Successfully retrieved the two OBS located east of Siberut Island (Siber-E1 at 16:30, Siber-E2 at 19:30). Rise times are as expected and the OBS are retrieved efficiently. The clocks have small drift, battery voltage is close to optimum and data quantity is as expected.

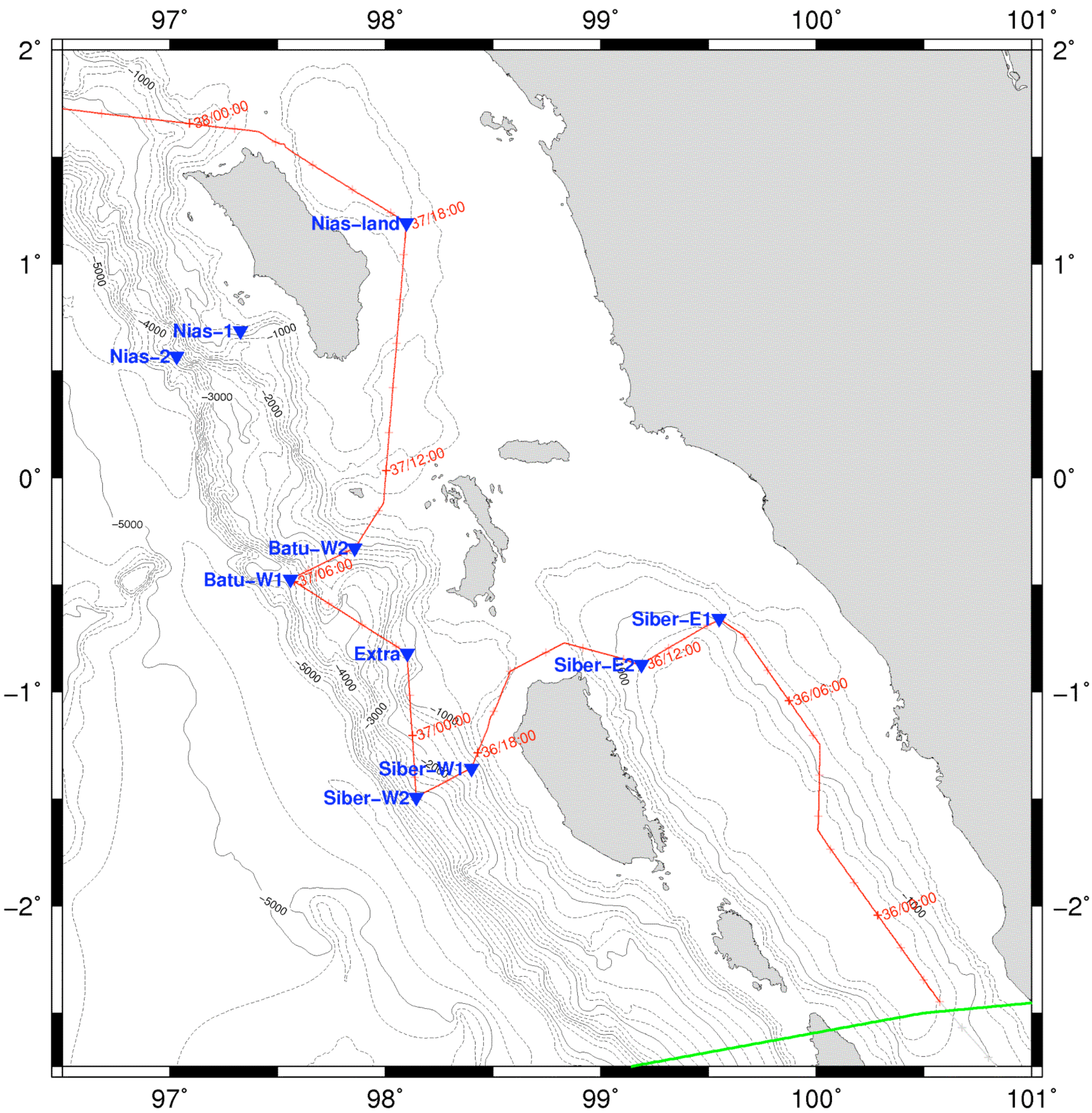

Figure 38: Recovery of the long-deployment OBS from SO198-2. Crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. Blue triangles show OBS locations. *Parasound* and swath bathymetry were acquired during transits. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 37, Friday 6th February

OBS retrieval, west of Siberut, Batu, and Nias Islands. Continuing to improve *Parasound* data and learn different settings in different environments (plus somewhat temperamental – needs restarting occasionally). Successfully retrieved five of the OBS (Siber-W1, Siber-W2, Extra, Batu-W1, Batu-W2) with all OBS releasing on first burn wire (based on rise time). Again, the clocks are showing small drift (<3 s) and expected data volumes. Transit times between the OBS are good so we are gradually gaining time lost during slower transit into the survey area. A decision is made to change the order of operations and to retrieve the OBS located east of Nias next rather than the two remaining west of Nias: this will allow more flexibility for coring sites post-TOBI and give AB a chance for some rest between OBS recoveries. This results in leaving two OBS rather than one until later in the cruise, but checks on battery life and on the backup GPS clocks gives confidence.

Julian Day 38, Saturday 7th February

OBS retrieval east of Nias Island. OBS Nias-Land was recovered in the early hours of the morning. Transit to the TOBI sidescan survey area SW of Simeulue Island. At ~03:00, the gravity meter fails again. SD and KS spend some time in the night trying to swap out parts and fix but to no avail. Decide to look at again during the day. Arrive at the deployment location for TOBI at ~12:00.

SO200-1: TOBI Survey SB1 (7th February – 14th February)

The basic objective was as follows:

- Collect a block of sidescan sonar data along the toe of the accretionary prism and trench SW of Simeulue Island, around the 2004-2005 earthquake segment boundary (SB1).

Multibeam, *Parasound*, and the gravity meter were operated and recorded continuously. The magnetometer was not deployed due to low towing speeds. XBTs were launched at the ends of the survey area.

Survey narrative

Times given in the text are local (UTC+7 hours).

Julian Day 38, Saturday 7th February

TOBI survey SW of Simeulue Island. Arrive at the deployment location for TOBI at ~12:00. Deploy TOBI and start producing usable data at ~15:00 with vehicle ~500 m off seafloor. With a current from the SE and trying to maintain a course to the NW at ~1.5 kn, it is challenging to maintain course, a low and consistent speed and to keep TOBI at ~500 m above the seafloor with only 7000 m of cable. The ship ends up crabbing with TOBI towing off to port side (therefore deployment of the magnetometer is abandoned for fear of tangling cables).

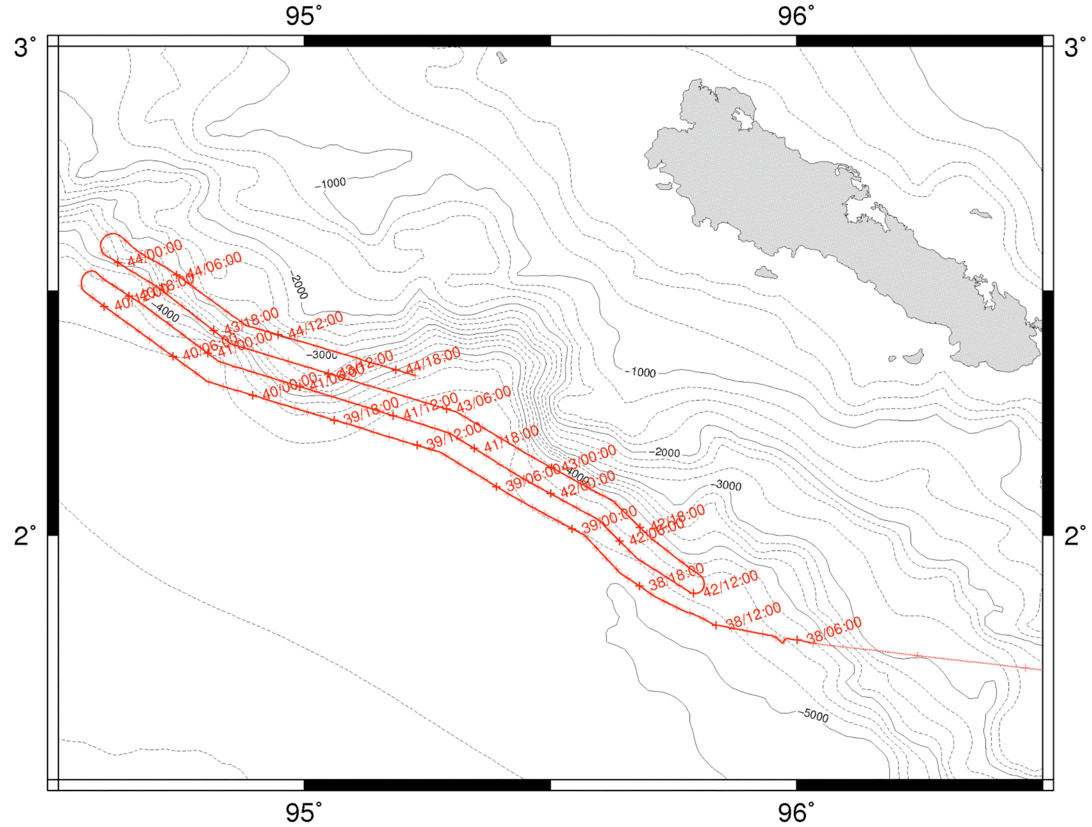

Figure 39: TOBI survey tracks southwest of Simeulue Island: Line 1 (southern-most) to Line 4 (northern-most). Crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. *Parasound* and swath bathymetry were acquired continuously. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 39, Sunday 8th February

TOBI survey, SW Simeulue Island. Gradually getting a balance between ship speed and TOBI elevation giving an average speed for the first line of ~1.8 kn. TOBI elevation varies between 300-650 m, but later maintaining 450-500 m. TOBI data are excellent with good across track resolution (almost the full 6 km) and excellent structural and sedimentological features, including linear sharp fault scarps, channel-gully systems and bedforms. An attempt was made to launch the magnetometer but its weight and the slow speed make it drift, so abandoned for fear of cables tangling. Line 2 (to SE) should present less problems maintaining speed as we will be driving into the current and may allow magnetometer deployment. IR spends some time with the gravity meter and by fixing the original power supply, gets it operational again around 16:00. Excellent weather conditions.

Julian Day 40, Monday 9th February

TOBI survey, SW Simeulue Island. Good weather continues. An overview of progress along Line 1 suggests that the complete survey could be conducted in ~7 days – good news. The gravity meter still seems happy with small clock drift so far. A safety drill and lifeboat overview is given at 10:20. Started turn from Line 1 to 2 at 20:30 after TOBI passes through end of line.

Julian Day 41, Tuesday 10th February

TOBI survey, SW Simeulue Island. Ship passes through WP25 at beginning of Line 2 at 00:10. At 08:00 a second attempt to deploy the magnetometer fails again with the fish not streaming. Excellent data of a meandering channel between 2 thrust ridges and good overlap with Line 1.

Julian Day 42, Wednesday 11th February

TOBI survey, SW Simeulue Island. End of TOBI Line 2 reached at 19:00 and ship passes through start of Line 3 at 22:00. Gravimeter deteriorates with lots of interrupt errors and inaccurate data.

Julian Day 43, Thursday 12th February

TOBI survey, SW Simeulue Island. Continuing TOBI survey along Line 3. At 04:00-05:00, a rather close call with the seafloor for TOBI (15 m) with an unexpected bathymetric high. After this incident, the watchkeepers start tracking very carefully the expected depth for the vehicle as we go. End of Line 3 at 07:49 and ship passes through start of Line 4 at 10:46. Later in the day, LM spends time trying to arrange visas for the arriving German airgun technicians.

Julian Day 44, Friday 13th February

TOBI survey, SW Simeulue Island. LM and DY spend much of morning making calls to shore to ensure the German technicians' visas are faxed to Germany, with success finally at the end of the day. TOBI continues to generate excellent data including possible signs of seep-related carbonate on the flanks of some of the shallower ridges. A science meeting is held at 15:30 to discuss latest TOBI results and to plan core sites and watchkeeping tasks during core processing. The gravity meter failed during the day but later back online.

Julian Day 45, Saturday 14th February

TOBI survey, SW Simeulue Island. End TOBI survey at 02:00, ending Line 4 with the vehicle and depressor on deck at 04:25. The ship then transits to the first core site in the trench off Simeulue Island (within the TOBI survey area) via a short *Parasound* line across fault scarps imaged in the sidescan data.

SO200-1: Coring & OBS Retrieval SB1&2 (14th February – 22nd February)

Basic objectives were as follows:

1. Collect sediment cores (piston core and mega core) at several sites from the mid slope accretionary prism to the trench, and at multiple locations along the margin.
2. To initially collect mega cores to test surface substrate, and follow with a piston core where possible.
3. To retrieve the remaining OBS (2) west of Nias island.

Multibeam, *Parasound*, and the gravity meter were operated and recorded continuously. The magnetometer was deployed during the transit between the main coring sites and OBS retrieval area. XBTs were launched during transit, distributed around the survey areas.

Survey narrative

Times given in the text are local (UTC+7 hours).

Julian Day 45, Saturday 14th February

Coring, SW of Simeulue Island. A *Parasound* survey is carried out and the first core site chosen (WD = 4895 m). The piston corer is deployed in daylight for its first operation for the first core (SO200/1PC) and recovered at 13:45, but the piston failed and no sample is obtained. This is followed by a mega core at the same site, recovered successfully at 19:20 (SO200/2MC). A second attempt is made to obtain a piston core at this site and the corer is deployed at 20:34 (SO200/3PC).

Julian Day 46, Sunday 15th February

Coring, SW of Simeulue Island. The piston corer is recovered at 00:58 with only a short core (<1.5 m), but multiple visible turbidite layers. KS and RP discuss changing parameters on the coring system during the day, including amount of free fall for the piston. The ship transits to the second coring site in a lower slope basin. The mega corer is deployed and recovered at 08:30 (S200/4MC) with excellent cores containing turbiditic layers and datable material (forams). A decision is made not to take a piston core at this site. The ship transits to the third coring site in an upper slope basin fed by two canyons off the west coast of Simueulue. The mega corer is recovered successfully at 14:00 (SO200/5MC) again with good cores. The piston corer was deployed at the same site and recovered at 16:45 (SO200/6PC). This time the core is much more successful with ~3.5 m of core including multiple thin turbiditic layers. At 15:00, a problem with the ship's engine generators occurs with potential for significantly reduced transit speed, so the decision is made to move on from this coring site. En route we pass over an OBS not retrieved during SO198-1 but are unable to get a response. The crew spend some time working on the engine problem and we eventually move off back to full transit speed around 19:00, but with unknown cause of the electrical problem. The ship transits to south the final two long-term OBS sites west of Nias Island.

Julian Day 47, Monday 16th February

OBS retrieval and coring, west of Nias Island. OBS Nias-1 successfully retrieved at 05:20 with battery, clock and data good. Transit to the last long term OBS (Nias-2), which was also successfully retrieved at 09:00. However, the battery had died and the instrument was found to have only recorded ~70 days of data. This is disappointing for the last OBS, but will still provide useful data from recorded shots during MCS data collection of SO198-2 plus all 10 instruments have been safely recovered. Transit a short distance north to the first coring site off Nias in a lower slope basin. The megacorer is deployed and recovered at 15:08 (SO200/7MC), at a water depth of 3875 m. This is followed by a piston core (SO200/8PC) recovered at 19:10 with ~3 m of core. Scientists for SO200-2 start to arrive in Jakarta and discussions re: status of customs clearance of containers and immigration clearance for new science group continue between the ship, Roger Lapian, BPPT and Tim Henstock now in Jakarta.

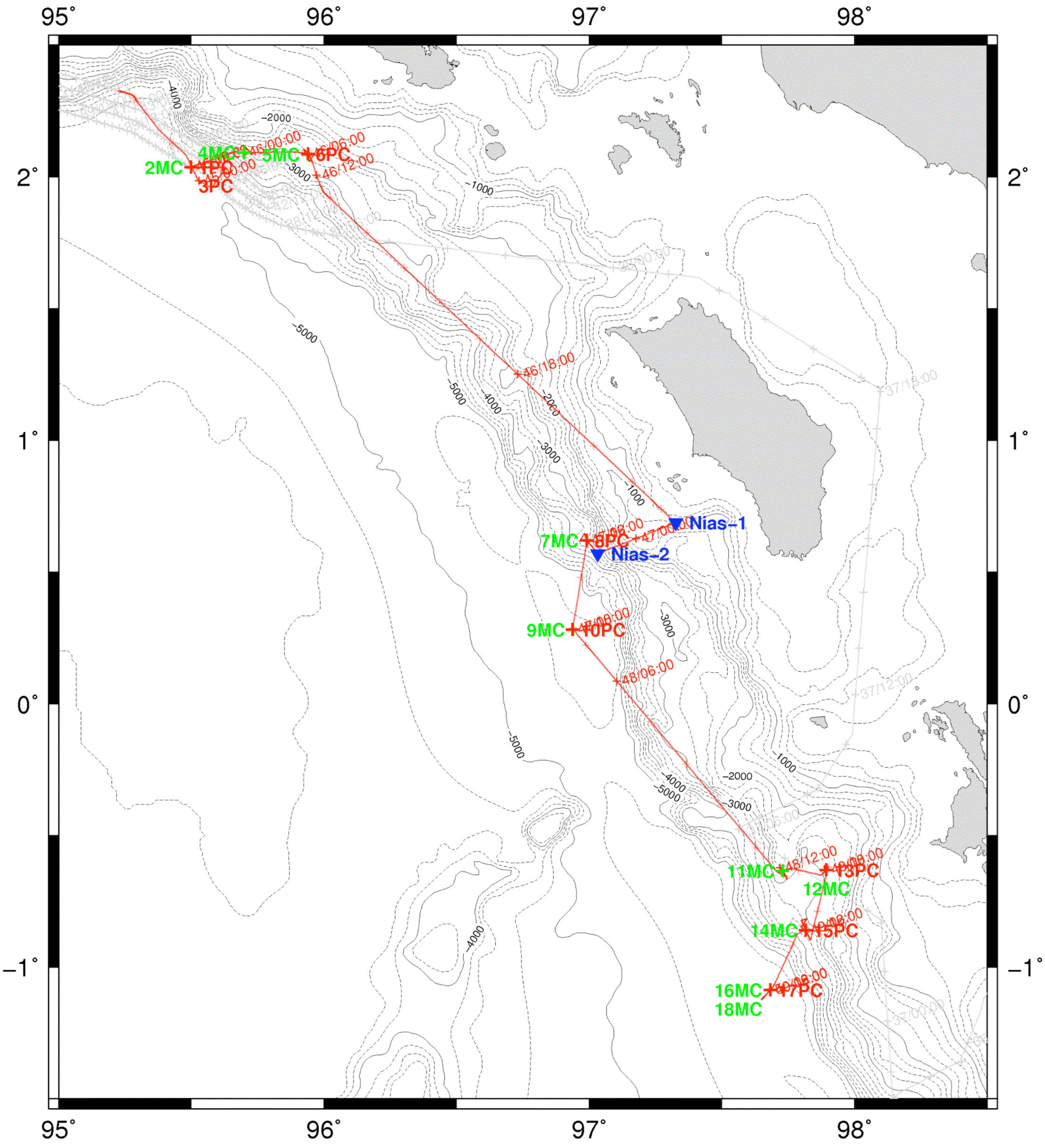

Figure 40: Mega core (MC) and piston core (PC) sites, and the recovery of the remaining long-deployment OBS from SO198-2. Crosses indicate the position each hour and every 6 hours is labelled with Julian Day and UTC time. *Parasound* and swath bathymetry were acquired continuously, except during OBS retrieval. GEBCO 1-minute bathymetry is contoured every 250 m.

Julian Day 48, Tuesday 17th February

Coring, west of Nias Island and Batu Islands. Transit to trench site off Nias Island and a mega core recovered at 04:20 (SO200/9MC). A lifeboat test was conducted at 08:30. The piston corer was deployed and recovered at 11:00 with a 5.4 m core (SO200/10PC) using a 9 m core barrel. Still not satisfied with the piston performance – should be getting much longer cores in these, on average, fine grained sediments. Following the piston core, the ship transits south to the next coring site west of the Batu Islands. At the first site, a small lower slope basin, the mega corer was deployed and recovered at 22:41 (SO200/11MC). No piston core was taken at this site.

Julian Day 49, Wednesday 18th February

Coring, west of the Batu Islands. The ship transits to a second slope basin site (mid slope, WD=3209 m) and the mega corer deployed. Mega corer was recovered at 04:30 (SO200/12MC). The piston corer was deployed with a 6 m core barrel and recovered at 08:45 (SO200/13PC). The 3.8 m core includes thin carbonate sand layers and several pink-brown layers interpreted as ash. Transit to a third coring site west of the Batus, in a different lower slope basin. The mega corer was deployed and recovered at 16:56 (SO200/14MC), WD = 3839 m. This was followed by the piston corer (6 m barrel), which was recovered at 21:24, with a short 1.4 m core only. Transit to the fourth Batu core site in the trench. The mega corer was deployed at 23:54, WD = 5450 m. Ongoing discussions with shore based group about customs and immigration progress (containers for SO200-2 still not cleared).

Julian Day 50, Thursday 19th February

Coring west of the Batu Islands, and transit back to Jakarta. The mega corer was recovered at 06:20 (SO200/15MC) but the wire had got caught in the frame and it returned to the surface on its side with damage to one of the tube frames and only two short disturbed samples. Decided to go ahead with deployment of the piston corer (07:00, 6 m core barrel) and maybe re-try the mega corer as the last core. The pullout for this core does not look promising, and the piston corer is recovered with no core (one sample bag in core catcher), concluding that it fell over at the seabed. Decide to deploy the mega corer again as the final core. Mega corer deployed and recovered at 18:47 (SO200/18MC). TOBI winch is dismantled and start to stuff containers during the day. Coring operations cease at 19:00 and the ship begins its transit back to Jakarta. Recording multibeam, Parasound, gravity and deploy magnetometer until southern boundary of permissions box.

Julian Day 51, Friday 20th February

Transit back to Jakarta. Reach the southern boundary of the permissions box at 05:00, stop recording and bring in magnetometer. An end of cruise BBQ is held to celebrate excellent data collection (considering the reduced time available) and to thank everyone for their hard work. Receive news in the evening that both of the remaining containers have now completed their physical check. Back in Jakarta, TH, Jez Evans, Colin Day and Stefan Paterson visit the EEL streamer container in the agent's storage yard. Immigration paperwork was completed for the arriving SO200-2 science party.

Julian Day 52, Saturday, 21st February

Transit back to Jakarta. Transit continues. Discover that a problem with 2 of the containers for SO200-1 has been raised by customs following the physical check and BPPT prepare a letter to try to bypass this issue.

Julian Day 53, Sunday, 22nd February

Transit back to Jakarta, port call Jakarta. Pilot on board and alongside at 08:00. Demobilisation of SO200-1 containers and equipment and mobilisation of the MCS streamer for SO200-2 take place after clearance and operations are completed by 15:00 with the assistance of Jez Evans from NMFSS. Still awaiting clearance of 2 containers for SO200-2 (Leg 2). Members of the science party of SO200-1 leave the ship having obtained their processed passports for departure.

SO200-2: Heat Flow measurements and Multichannel Seismic Reflection Survey, SB2 (23rd January – 7th February)

Basic objectives, after transit from Jakarta and entry to the permitted survey area, were as follows:

1. Collect heat flow measurements along two transects across the accretionary prism within Segment Boundary 2 area. The northern transect was located west of central Nias Island and the southern transect was located west of the Batu Islands.
2. Collect a grid of closely spaced MCS profiles across the outer accretionary prism in Segment Boundary 2 area between ~ 0.5° S and 0.5° N, between the Batu and Nias Islands.

During this period, the multibeam, *Parasound* (sub-bottom profiler) and gravity meter were operated continuously within the permitted survey area. The magnetometer was deployed during longer transits and away from shoals. XBT and XSV (sound velocity probes) probes were regularly launched within the survey area.

Survey narrative

Times given in the text are local (UTC+7 hours).

Julian Day 54, Monday, 23rd February

Tanjung Priok Port, Jakarta. The new science party arrives at the ship. Discussion in the morning between the IPGP heat flow group and the ship about technical issues related to operations of the heat flow probe. The new security officer (Captain Iwan Laut) raises a problem with the security clearance (based on the crew change raised during SO200-1). We establish later in the day that the security clearance is no longer valid and there are discussions between the Security Officer and BPPT colleagues to find a resolution. The containers are still in customs and we discover that the BPPT letter is not sufficient and a further letter from the Dept. of Trade will be needed. A science meeting is held between members of the science party to discuss potential survey options with reduced available time.

Julian Day 55, Tuesday, 24th February

Tanjung Priok Port, Jakarta. Documents are sent to BPPT to prepare an amended Security Clearance. Container clearance is still progressing at Department of Trade and appears that several more days of delay are likely. At 12:30 a meeting is held for the scientists to explain the situation. At 17:30, RL visits the ship to discuss the customs issue and confirms that the procedure may take a further 4 working days. Changing the final port call to Singapore is discussed, however complications with both customs and immigration rule this out as a viable alternative to Jakarta at this time. Discussion within science group about options of leaving without containers when little working time remains.

Julian Day 56, Wednesday, 25th February

Tanjung Priok Port, Jakarta. All documents for the amended Security Clearance are now at the Department of Defense. To move the customs situation forward, efforts are made to make a personal visit to the Departments of Industry and Trade. In the afternoon, YD, LM, Jamie Austin and Alain Bonneville visit the Dept of Industry with agent representatives but are relatively unsuccessful. This is followed by a visit to the Dept of Trade where, after much persuasion, documents for the two containers are prepared but must be signed by two directors the next day.

Julian Day 57, Thursday, 26th February

Tanjung Priok Port, Jakarta. LM, JA, AB return to the Dept of Trade to wait for the signed documents. One signature is obtained in the morning, but the second signature has to be obtained by a representative travelling to Bogor and back. The documents are signed by 14:00 before rapid transfer to Customs Port office before end of office hours, with other members of the science group and agent representatives. Discussions at Customs are held with various parties, including the Director, where it emerges that the paperwork is incorrect, with complications concerning used goods and import status. The Director agrees to try and find a solution rather than starting again with the paperwork.

Julian Day 58, Friday, 27th February

Tanjung Priok Port, Jakarta. LM and AB, along with YD, RL and others meet representatives and the Director of the Customs Port office at 07:00. They try to find a procedure and allow the containers to clear as a special case. At 08:00 the Director agrees to release the containers today after preparation of letters by BPPT and himself. The containers arrive at the ship in the late afternoon and, after further delays, the ship finally leaves the dock at 22:00.

Julian Day 59, Saturday, 28th February

Transit to working area. A good view of Krakatoa just before breakfast with clear skies. A science meeting is held at 09:00 to discuss data collection options with the time available and a technical meeting is held at 10:20 for heat flow and MCS operations. The weather deteriorates in the Sunda Straits slowing the ship to ~6-7 kn and slow progress is made to the work area.

Julian Day 60, Sunday, 1st March

Transit to working area. Weather gradually improving and transit speed increasing, but the weather has caused an additional delay of ~12 hours. Heat flow probe, air guns and streamer being prepared. A problem with the streamer bird coils emerges (only one functioning properly). A science meeting is held at 12:30 to discuss watch keeping tasks and *Parasound* training at 15:30.

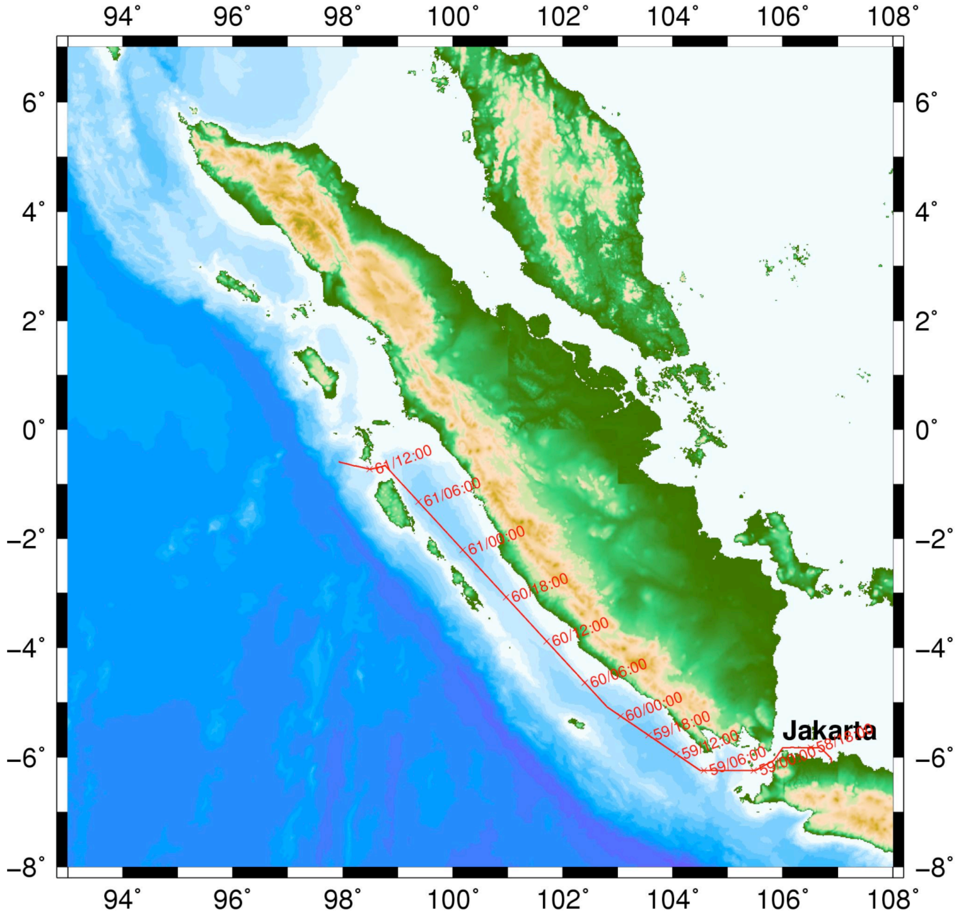

Figure 41 Trackline plot of transit from Jakarta to the survey area.

Julian Day 61, Monday, 2nd March

Survey within permissions area. At 05:00 we enter the permissions area and start recording data and deploy the magnetometer. Weather is much improved. At 22:00, arrive at the first heat flow station of Heat Flow Transect 1 (offshore Batu Islands) but the probe is not functioning properly. Several hours are spent working on the probe and it eventually starts working.

Julian Day 62, Tuesday, 3rd March

Heat flow transect 1, offshore Batu Islands. The heat flow probe is finally deployed at 00:50. During deployment only intermittent communications from the probe are received via the transducer but continue to deploy to the seafloor. Penetration at the first station occurs at 02:20, but without proper communication to the probe the heaters cannot be activated for measuring thermal conductivity. The probe penetrates the seafloor at a further five stations (1-6) making successful thermal gradient measurements only. During this time the modem setup is tested on board and a solution is found after station 6. Penetration of the sediments is achieved at a further 3 stations with conductivity measurements at each.

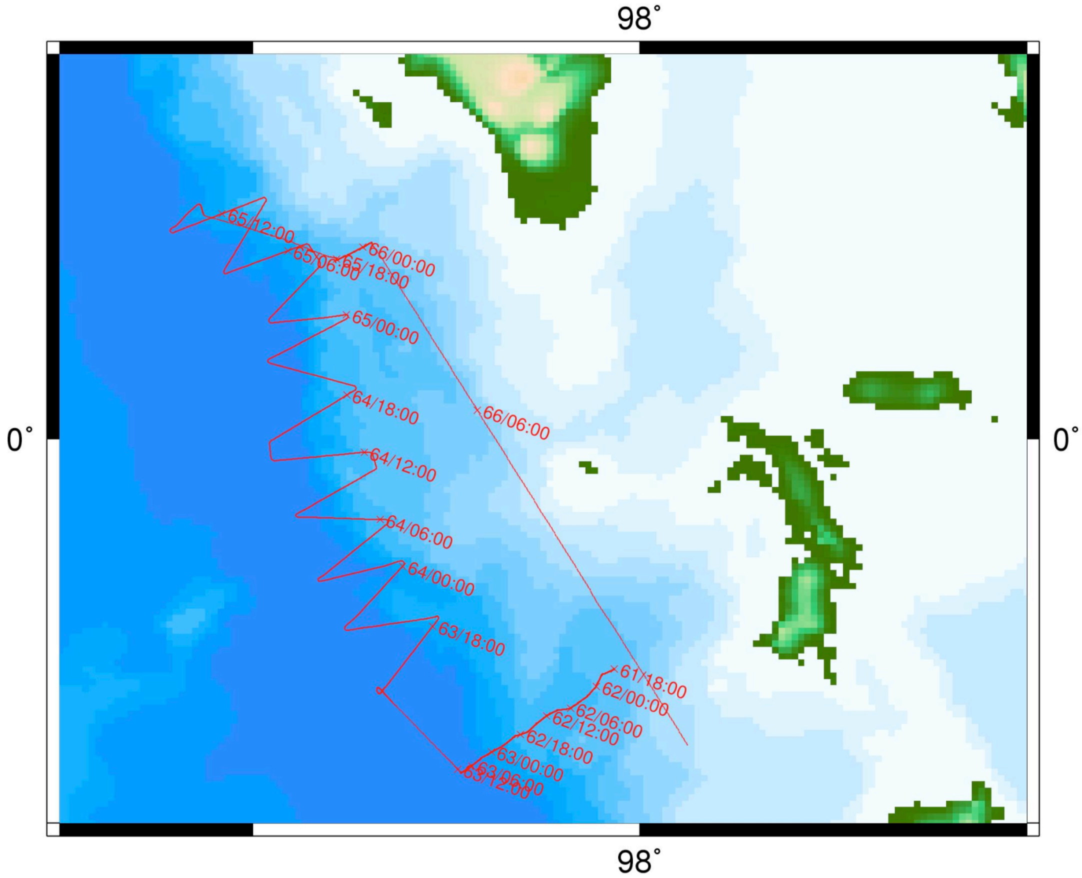

Figure 42 Trackline plot of heat flow transects 1 and 2 and MCS survey over the accretionary prism west of the Batu and Nias Islands.

Julian Day 63, Wednesday, 4th March

Heat flow transect 1, offshore Batu Islands and MCS survey of Nias-Batu accretionary prism toe. A further 6 stations are attempted but the probe fails to penetrate the sediments. 2 thermistors are also no longer functioning. In retrospect, these failures are due to a bent probe. The probe is recovered and on deck at 18:50. The probe has been bent by 30-40° and two thermistors and fins have been lost. The ship transits a short distance to the start of the MCS survey of a section of the accretionary prism toe and deformation front offshore Batu and Nias Islands affected by subducting plate topography. The streamer is deployed at 20:45 but 3 of the 4 bird coils are not functioning. The streamer is brought in again and the 3 birds with non-functioning coils are set flat and batteries removed. The functioning bird coil is fortunately closest to the ship. The streamer is redeployed at 22:05 and air guns deployed at 22:30. Start shooting along first line of survey, SUMF1.

Julian Day 64, Thursday, 5th March

MCS survey of Nias-Batu accretionary prism toe. Continuing the MCS survey and making good progress at ~ 5kn. The overnight winds and swell diminish allowing speed to be increased slightly. Data appear good with minimal noise.

Julian Day 65, Friday, 6th March

MCS survey of Nias-Batu accretionary prism toe. The MCS survey continues until 22:00 off central Nias and the airguns and streamer are on deck by 22:45. The ship transits towards the start of the second heat flow transect on the accretionary prism west of Nias Island. Some problems emerge in the evening related to the ship's return to Jakarta port at the end of SO200-2, therefore the transect is shortened.

Julian Day 66, Saturday, 7 March

Heat flow transect 2, offshore Nias Island. The heat flow probe is prepared and deployed at 01:00. Five successful heat flow stations within the transect are completed when the probe has to be brought on board for transit at 10:20. The ship transits rapidly to the south towards Merak and a potential changed port call in Singapore. Multibeam, Parasound and gravity data continue to be recorded and XBT/XSVs are deployed.

Julian Day 67, Sunday, 8 March

Survey within permissions area and transit towards Sunda Strait-Merak. The ship continues transiting south and exits the permission area at 04:30. Discussions between the ship and organisations in Germany and the UK continue about the final port call of the ship. A party is held in the evening to celebrate two crew members' birthdays.

Julian Day 68, Monday, 9 March

Transit towards Sunda Strait and Merak. The ship continues its transit south and stops in the western Sunda Strait at ~11:00.

Julian Day 69, Tuesday, 10 March

Offshore Merak and transit to Jakarta. Ship transits towards Merak arriving ~08:00. Ship proceeds slowly to Jakarta at ~14:00. Alongside Tanjung Priok port, Jakarta ~20:00. Indonesian scientists and security officer leave the ship at ~21:00.

Julian Day 70, Wednesday,11 March

Jakarta – Tanjung Priok Port. Empty containers arrive for demobilisation at 11:30 and are loaded by 13:30. Passports for departing scientists and crew are delivered at 15:30 and entire science party leaves the ship for Jakarta city and the airport. RV Sonne sails for Singapore at 19:45.

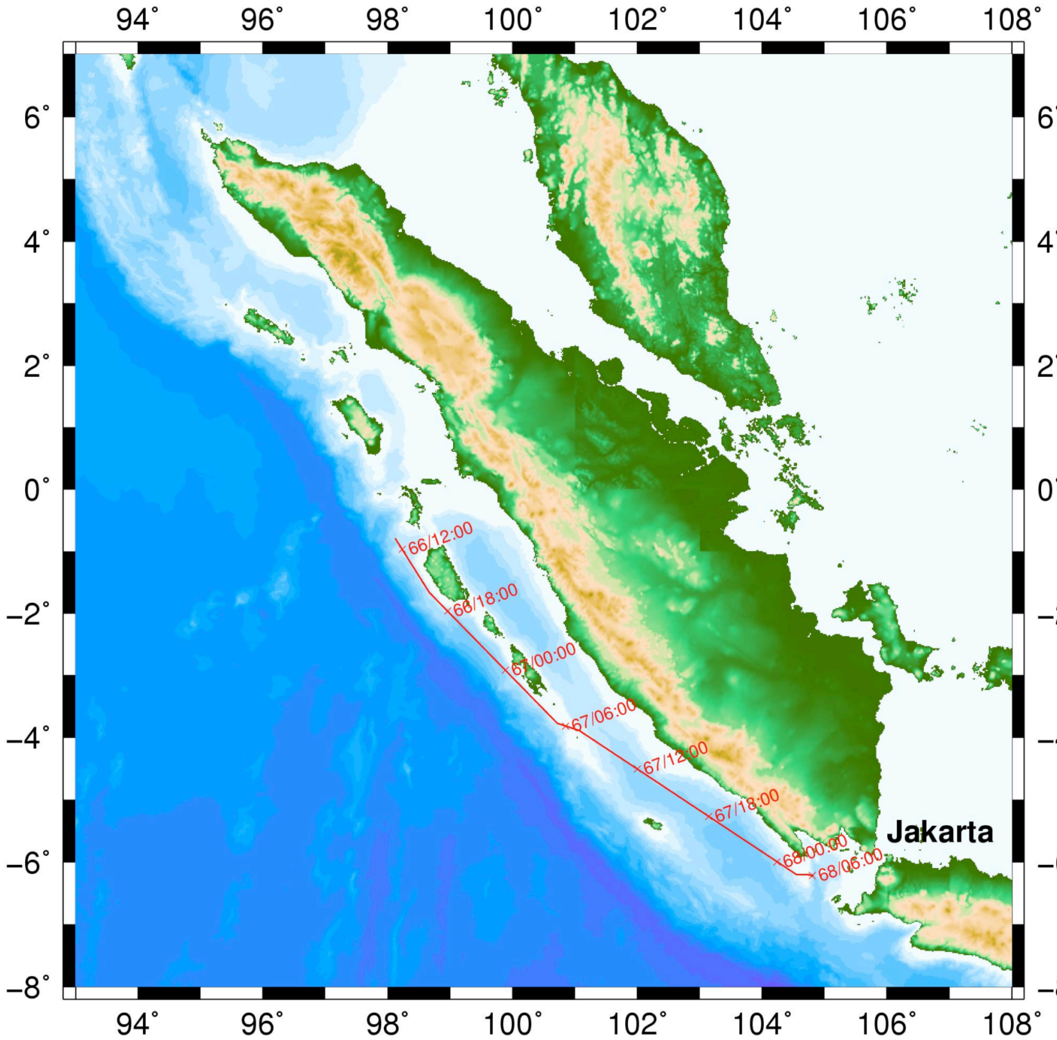

Figure 43 Trackline plot of transit from survey area towards Merak and Jakarta.

Results: Long-deployment OBS

All ten long-deployment OBS instruments, deployed during SO198-1, were recovered successfully during SO200. All instrument release units responded well and rise times were close to those predicted, usually reaching the surface up to 5 minutes earlier than predicted. All radio and light beacons were functioning on recovery. The ship retrieved all instruments quickly and efficiently.

All instruments except that at site Nias-2 were found to have recorded a full dataset, with all channels functioning (see Table 5). The instrument at Nias-2 had stopped recording at 09:35 on Julian Day 228 (2008); the main instrument battery was found to have dropped below 2.5v; the backup clock battery, only sufficient for ~4 months operation, had also run out so no timing drift rate is recorded for this instrument.

In summary: all instruments therefore recorded the controlled source portion of SO198-2 (Figure 44 and Figure 45), all but Nias-2 recorded earthquake data for ~240 days, while Nias-2 recorded earthquake data for 68 days.

Site	Latitude	Longitude	Depth (m)	Recording window		Comments
				Start Time	End time	
Nias-land	1.191	98.0963	507	2008:158:00:00:00	2009:037:18:53	Full recording
Nias-2	0.5693	97.3257	3682	2008:160:00:00:00	2008:228:09:35	Partial recording
Batu-W1	-0.4738	97.558	3232	2008:161:00:00:00	2009:037:07:53	Full recording
Extra	-0.8203	98.0996	1164	2008:162:00:00:00	2009:037:03:13	Full recording
Nias-1	0.6878	97.3257	1021	2008:159:00:00:00	2009:046:23:40	Full recording
Batu-W2	-0.3274	97.8566	1257	2008:161:00:00:00	2009:037:10:13	Full recording
Siber-W2	-1.4918	98.1415	3753	2008:163:00:00:00	2009:036:22:44	Full recording
Siber-E1	-0.6563	99.5472	815	2008:164:00:00:00	2009:036:10:00	Full recording
Siber-E2	-0.871	99.1865	1361	2008:164:00:00:00	2009:036:12:47	Full recording
Siber-W1	-1.3563	98.3977	1541	2008:163:00:00:00	2009:036:19:35	Full recording

Table 5: Long-deployment OBS location and recording details. The end time for the recording window is the time at which the instrument was reset upon recovery, the end of useful data will be ~2 hours earlier.

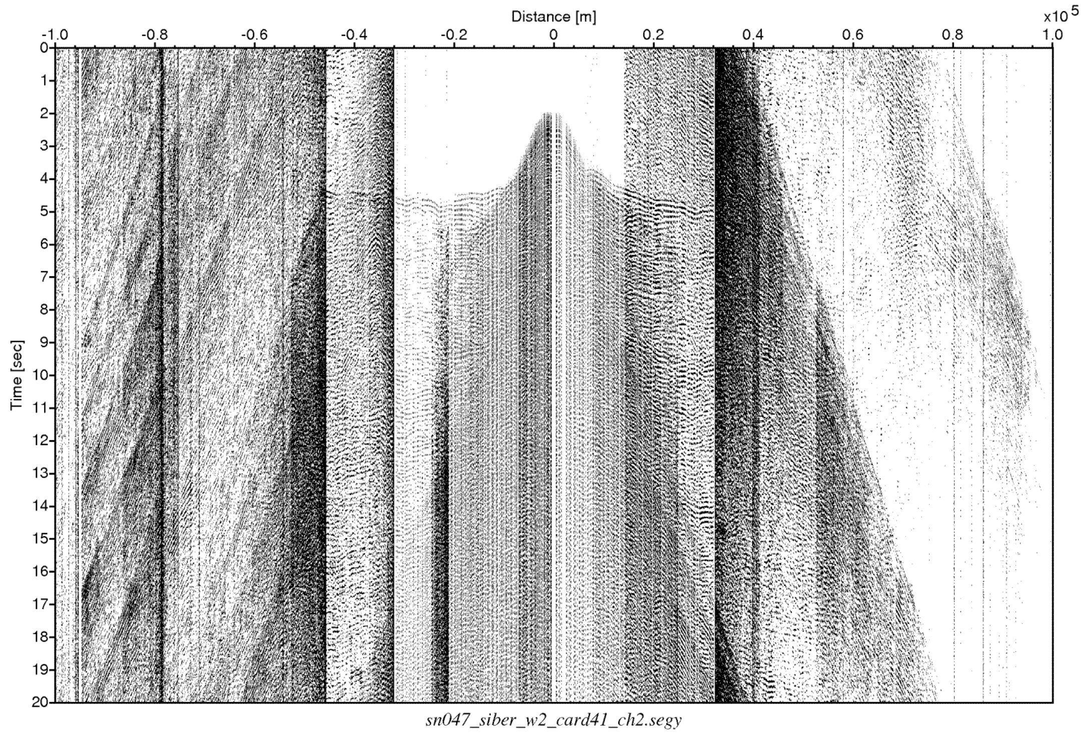

Figure 44: Vertical geophone data recorded during the controlled source portion of SO198-2 for the long-deployment OBS at Site Siber-W2. Time axis is reduced at 6 km/s.

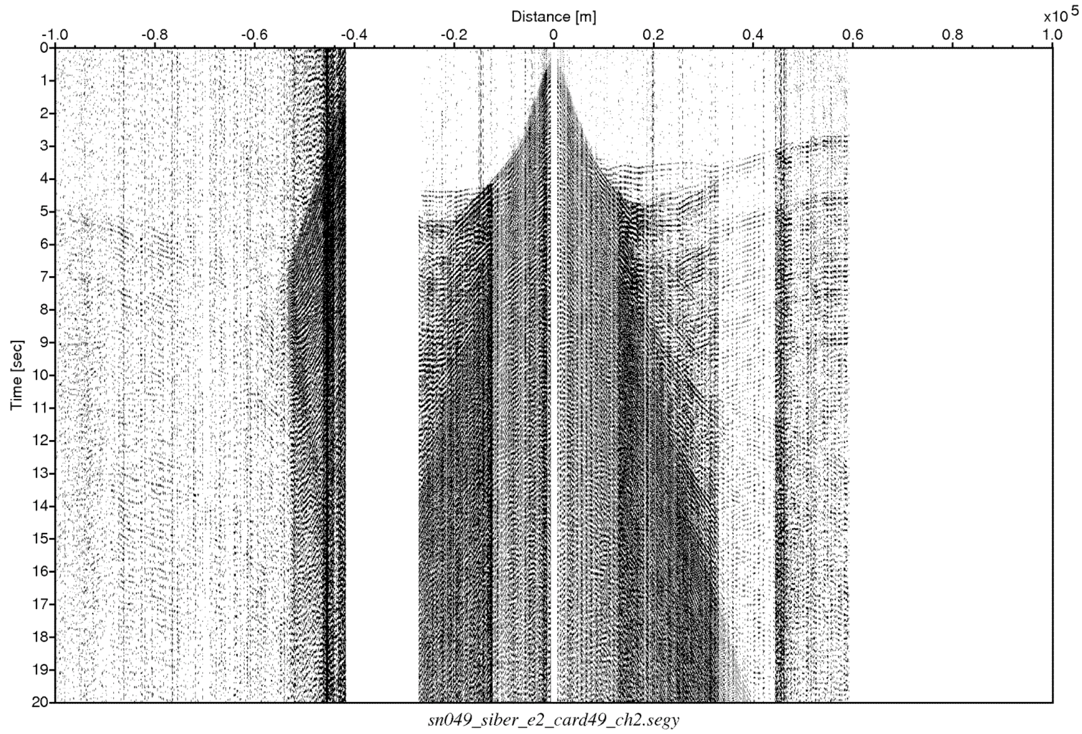

Figure 45: Vertical geophone data recorded during the controlled source portion of SO198-2 for the long-deployment OBS at Site Siber-E2. Time axis is reduced at 6 km/s.

Results: TOBI Sidescan Sonar

Instrument Performance

Vehicle

The vehicle performed well throughout the survey. The trim could be a little better to give a more level attitude when in neutral flight.

Sidescan

Performed excellently throughout the cruise. The data was clean and free from noise artefacts.

Profiler

Initially the profiler only gave good returns off strong reflectors. The previous cruise had been over extremely hard ground so the receiver levels in the vehicle had been reduced by 16dB. It was thought that this reduction had been too much for this terrain but a subsequent increase in the top-end receiver gain of approximately 20dB compensated for this and restored the sonar's performance. Before the gain increase, the logging system's bottom tracking had been having trouble keeping lock due to the low signal. After the gain increase, the profiler gave good tracking to altitudes of 1000 m and more.

This was the first cruise to use the Coda Octopus 360 system to log and display the profiler data. In general this worked well although a couple of small problems were found – the annotation update rate was too high and cluttered the screen to such an extent you couldn't see the signal. An external event signal could be used to trigger this in future. Also the bottom tracking of the unit was not fast enough to keep up with the terrain over which we were flying. A more careful setup may be required. The data were stored on the unit's hard drive in SEG-Y format for easy further processing.

Magnetometer

The unit worked well throughout the cruise. An incorrect reading of the x value was observed in the logged data every 12 seconds, which may be explained by the asynchronous nature of the A/D converter for the unit leading to readings during a sonar transmission. A calibration circle was performed at the start of the cruise over a 'quiet' magnetic region so that variations in field due to the vehicle can be factored out in the processing of the data.

Gyro

Gave very stable, reliable data throughout. The unit's fast spin up time of less than 30 minutes was due to the equatorial location of the cruise.

CTD

Worked well for the whole cruise. No crashes in the whole survey.

Pitch/Roll
This unit performed admirably for the whole cruise although on deck anomalous readings were observed. This could be down to a screen being disconnected. The data looked fine.

Light scattering sensor (LSS)
The light scattering sensor was used throughout the cruise. Some signals were observed although from first glance it cannot be ascertained whether this was due to biology or sediment.

Swath bathymetry
The swath system provided phase data for most of the survey. The starboard side gave around 1.5-2 km of range. The port side was very low with at best 1 km of range over high backscatter ground.

Deck Unit
The system proved very reliable in operation throughout the cruise. A voltage of 350V was used to power the vehicle with a current of approximately 700-800mA. The GPS aerial cable had to be repaired twice to overcome dampness in a joint. Once these repairs were carried out the system remained solid for the remained of the cruise.

Scientific Results

One sidescan sonar survey was carried out during SO200-1, SW of Simeulue Island (NW Sumatra) over the deformation front and lower slope of the accretionary prism. The survey was designed to image fault-related features and sedimentary features across the steep prism toe and onto the abyssal plain of the trench. The total survey area was ~70-160 km in length and up to 20-25 km across the prism encompassing the youngest 2-3 thrust ridges. The fish was flown between 200 and 600 m above the seafloor, with variation in altitude a function of the limited cable length (therefore fish altitude was controlled by ship speed in deep water) and by the complex topographic terrain. In spite of these complexities, the data quality was excellent, with usable data almost to the edge of the 6 km swath (usable 5.5-6 km).

Figure 46 shows the TOBI sidescan survey mosaic (without final processing) SW of Simeulue Island.

Structural features:
At several locations along the deformation front, sharp linear scarps were imaged often corresponding to features already identified in bathymetric data and to faults within existing seismic reflection data. In some cases the faults are controlling the position and path of sedimentary features, e.g., submarine channels. The structural morphology of individual thrust ridges will be well resolved when the sidescan data are overlain on swath data. Gravitational extensional faults were also imaged where slopes are failing.

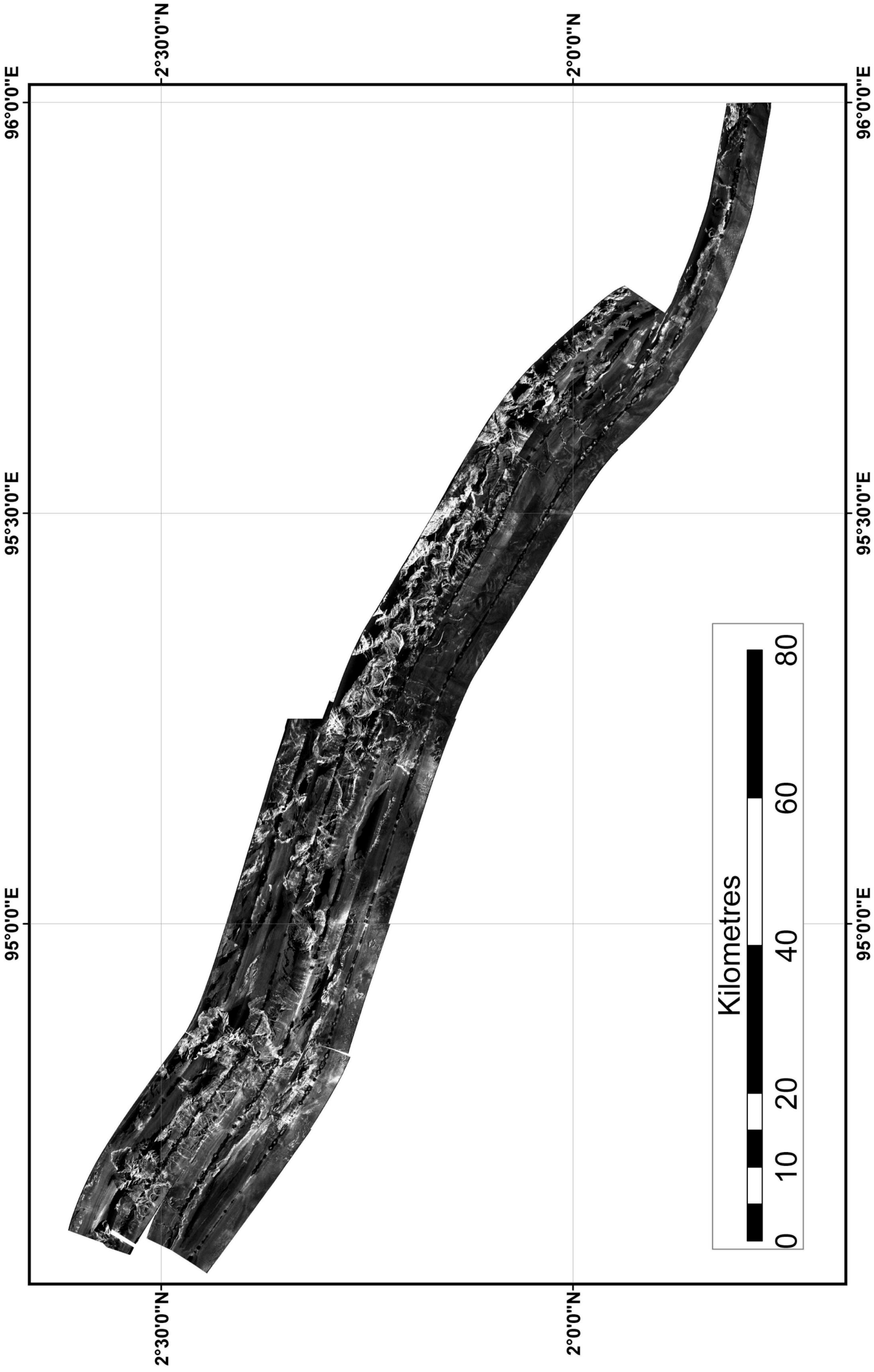
2°30'0"N
2°0'0"N
96°0'0"E
95°30'0"E
95°0'0"E
Kilometres
0 10 20 40 60 80

Figure 46 TOBI 30 kHz deep-towed sidescan sonar mosaic of the accretionary prism toe and deformation front SW of Simeulue Island.

Sedimentary features:
Sedimented areas away from major topographic features or large blocks were typically low backscatter with rare examples of high backscatter. This suggests predominantly fine grained sediments in the trench, a hypothesis supported by later coring. Sedimentary features include submarine channel and canyon systems, bedforms and complex landslide and slump scars.

Results: Coring

18 core sites were sampled during SO200 (Table 6; Figure 49). The results, with core site numbers, are as follows:

Trench and slope cores generally contained material of consistent composition; fine to medium grained quartz-rich sands and muds with variable amounts of mica and lithics. There was an exception to this in a single shallow basin (13PC) in which there were ash- and carbonate-rich beds in addition to quartz-mica sands. In general the background sediment contained quartz and mica, as well as forams and shell fragments, in water depths shallower than about 4000 m. Trench cores (3PC, 10PC, 17PC) showed frequent small turbidites in fine to medium grained quartz-rich sand; grain size generally decreased slightly towards the southern end of the trench. Turbidites were usually non-erosive and structureless although occasionally contained planar and cross laminae suggesting relatively dilute events. Trench cores commonly contained an uncompacted event towards the top of the core (2MC, 9MC, 18MC). Slope basin cores also showed frequent turbidite and occasionally debrite events (6PC, 8PC, 13PC, 15PC). Slope basin sediments generally contained oxidised hemipelagic material towards the top of the core (4MC, 5MC, 7MC, 12MC, 14MC), above the youngest event.

Core	Core type	Location description	Latitude	Longitude	Date/Time recovered (UTC)	Water depth (m)	Core Length (m)
SO200/1PC	Piston	Simeulue trench	2°2.280N	95°29.820	14/2/09 06:45	4895	0
SO200/2MC	Mega	Simeulue trench	2°2.279N	95°29.821	14/2/09 12:20	4894	0.3
SO200/3PC	Piston	Simeulue trench	2°2.269N	95°29.810	14/2/09 17:58	4886	1.5
SO200/4MC	Mega	Simeulue lower slope basin	2°5.538N	95°41.796	15/2/09 01:32	3512	0.4
SO200/5MC	Mega	Simeulue upper slope basin	2°5.19N	95°56.284	15/2/09 07:00	2150	0.3
SO200/6PC	Piston	Simeulue upper slope basin	2°5.282N	95°56.284	15/2/09 09:45	2198	3.4
SO200/7MC	Mega	Nias lower slope basin	0°37.216N	96°59.336	16/2/09 08:08	3875	0.4

SO200/8PC	Piston	Nias lower slope basin	0°37.216N	96°59.344	16/2/09 12:10	3874	3.3
SO200/9MC	Mega	Nias trench	0°16.946N	96°56.178	16/2/09 21:19	5299	0.5
SO200/10PC	Piston	Nias trench	0°16.943N	96°56.172	17/2/09 03:42	5301	5.4
SO200/11MC	Mega	Batu lower slope basin 1	0°38.026S	97°43.657	17/2/09 15:41	3456	0.3
SO200/12MC	Mega	Batu mid slope basin	0°37.826S	97°53.531	17/2/09 21:29	3209	0.2
SO200/13PC	Piston	Batu mid slope basin	0°37.825S	97°53.535	18/2/09 01:45	3214	3.8
SO200/14MC	Mega	Batu lower slope basin 2	0°51.557S	97°48.899	18/2/09 09:56	3839	0.3
SO200/15PC	Piston	Batu lower slope basin 2	0°51.562S	97°48.896	18/2/09 14:24	3840	1.4
SO200/16MC	Mega	Batu trench	1°5.238S	97°40.836	18/2/09 23:20	5450	0.2
SO200/17PC	Piston	Batu trench	1°5.226S	97°40.844	19/2/09 05:00	5449	0
SO200/18MC	Mega	Batu trench	1°5.239S	97°40.846	19/2/09 11:47	5449	0.3

Table 6: Core acquisition summary.

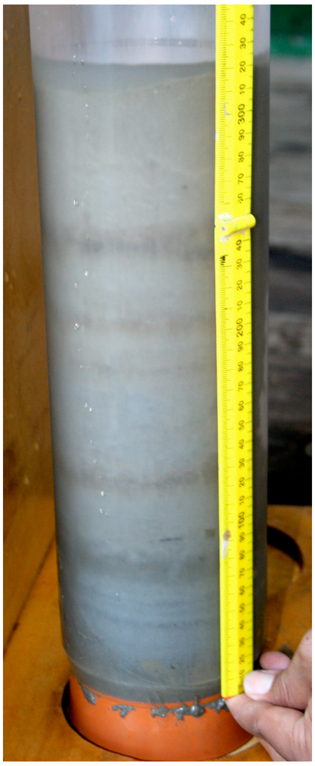

Figure 47: Mega core prior to sampling from site 14 MC.

Figure 48: Section 3 of core 6PC showing frequent small turbidite events.

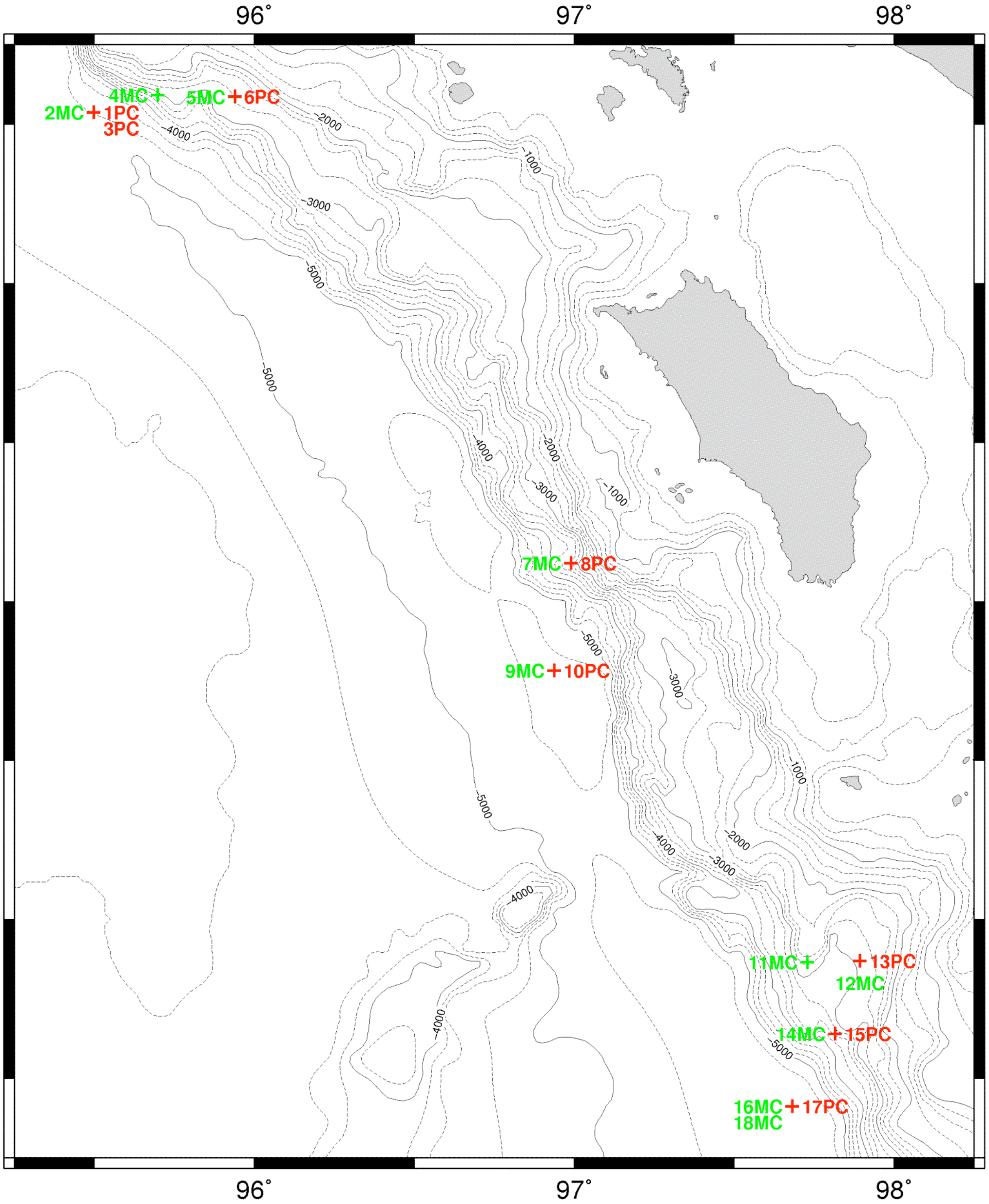

Figure 49: Core location map. Mega core sites are in green; piston core sites are in red. GEBCO 1-minute bathymetry is contoured every 250 m.

Results: Heat Flow

During the SO200-2 survey, heat-flow measurements were performed along 2 profiles where seismic reflection and Parasound data have been already collected during SO198-2 (Table 7).

15 measurements were planned on Profile 1. On the first 5 penetrations, we obtained a thermal gradient measurement, on 1 penetration, both thermal gradient and thermal conductivity, and on 2 penetrations, thermal conductivity only. We were not able to penetrate the seafloor at the remaining 7 sites due to the hard bottom on slope of the accretionary prism which bent the lance.

On the 15 measurements planned for Profile 2, only 5 were achieved due to the departure of the ship for Jakarta earlier than expected. However, these 5 measurements were all successful with both thermal gradient and thermal conductivity measured at each site.

In summary, 11 new heat-flow data points have been obtained during the SO200-2 cruise in a region of the accretionary prism where no previous heat flow values existed. Even though they are much less numerous than expected (2 days of heat flow measurements compared to the initially planned 11 days), these data will bring important constraints to the interpretation of the thermal regime of these segments of the Sumatra subduction zone. The dataset have not been processed nor corrected for sedimentation, refraction of heat or topographic effects and this will be done before the end of 2009.

P	Latitude	Longitude	Water Depth(m)	Penetration depth (m)	Number of working thermistors	Type of data collected
Profile 1						
1	0°35.98 S	97°56.00 E	3040	3.2	6	thermal gradient
2	0°36.89 S	97°54.11 E	3207	4.9	6	thermal gradient
3	0°38.65 S	97°53.19 E	3201	4.5	6	thermal gradient
4	0°40.20 S	97°51.89 E	3138	4.9	7	thermal gradient
5	0°41.30 S	97°50.38 E	3033	3.2	5	thermal gradient
7	0°42.40 S	97°47.19 E	2780	0	0	thermal conductivity
8	0°42.40 S	97°47.19 E	2797	4.3	5	thermal gradient+thermal conductivity
10	0°46.49 S	97°43.99 E	3394	0	0	thermal conductivity
Profile 2						
1	0°27.94 N	97°13.00 E	2584	2.6	4	thermal gradient+thermal conductivity
2	0°28.50 N	97°14.30 E	2784	4.9	4	thermal gradient+thermal conductivity
3	0°29.21 N	97°15.72 E	2742	2.9	4	thermal gradient+thermal conductivity
4	0°29.90 N	97°16.98 E	2520	3.8	5	thermal gradient+thermal conductivity
5	0°30.59 N	97°18.40 E	2586	4	4	thermal gradient+thermal conductivity

Table 7 Heat flow measurements during SO200-2.

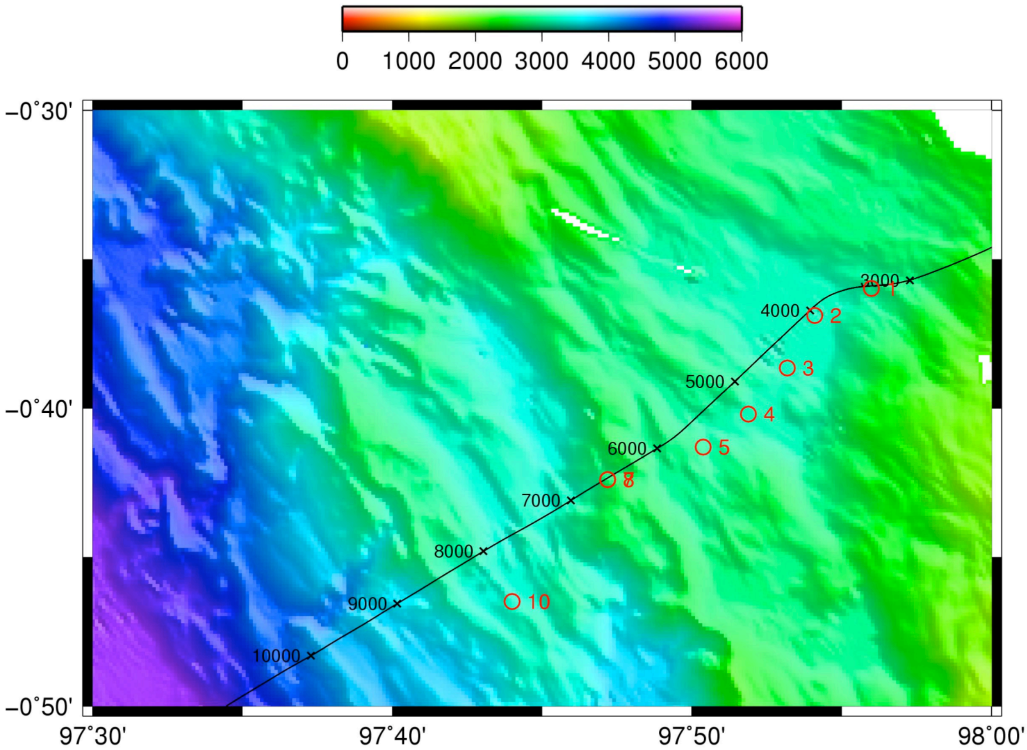

Figure 50 Location of heat flow transect 1 overlain on gridded swath bathymetry collected during SO198 and SO200 (depth in m). Station locations and numbers in red. Black line is location of MCS profile collected during SO198-2 (CDP numbers labelled).

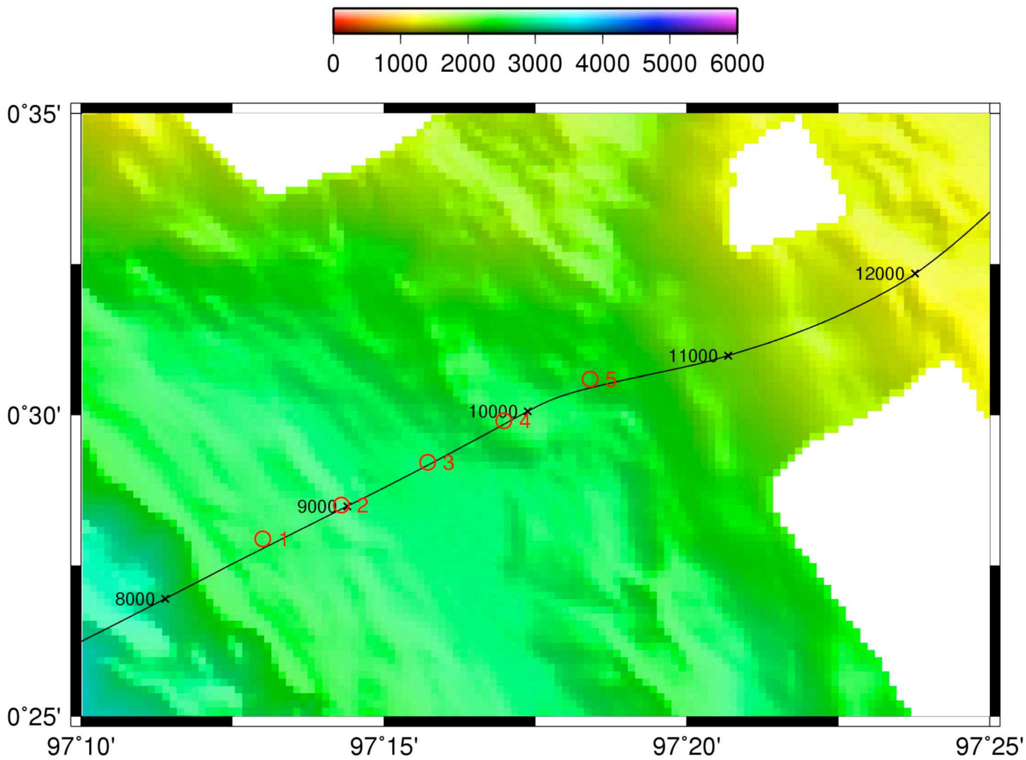

Figure 51 Location of heat flow transect 2 overlain on gridded swath bathymetry collected during SO198 and SO200 (depth in m). Station locations and numbers in red. Black line is location of MCS profile collected during SO198-2 (CDP numbers labelled).

Results: Multichannel Seismic Reflection Profiling

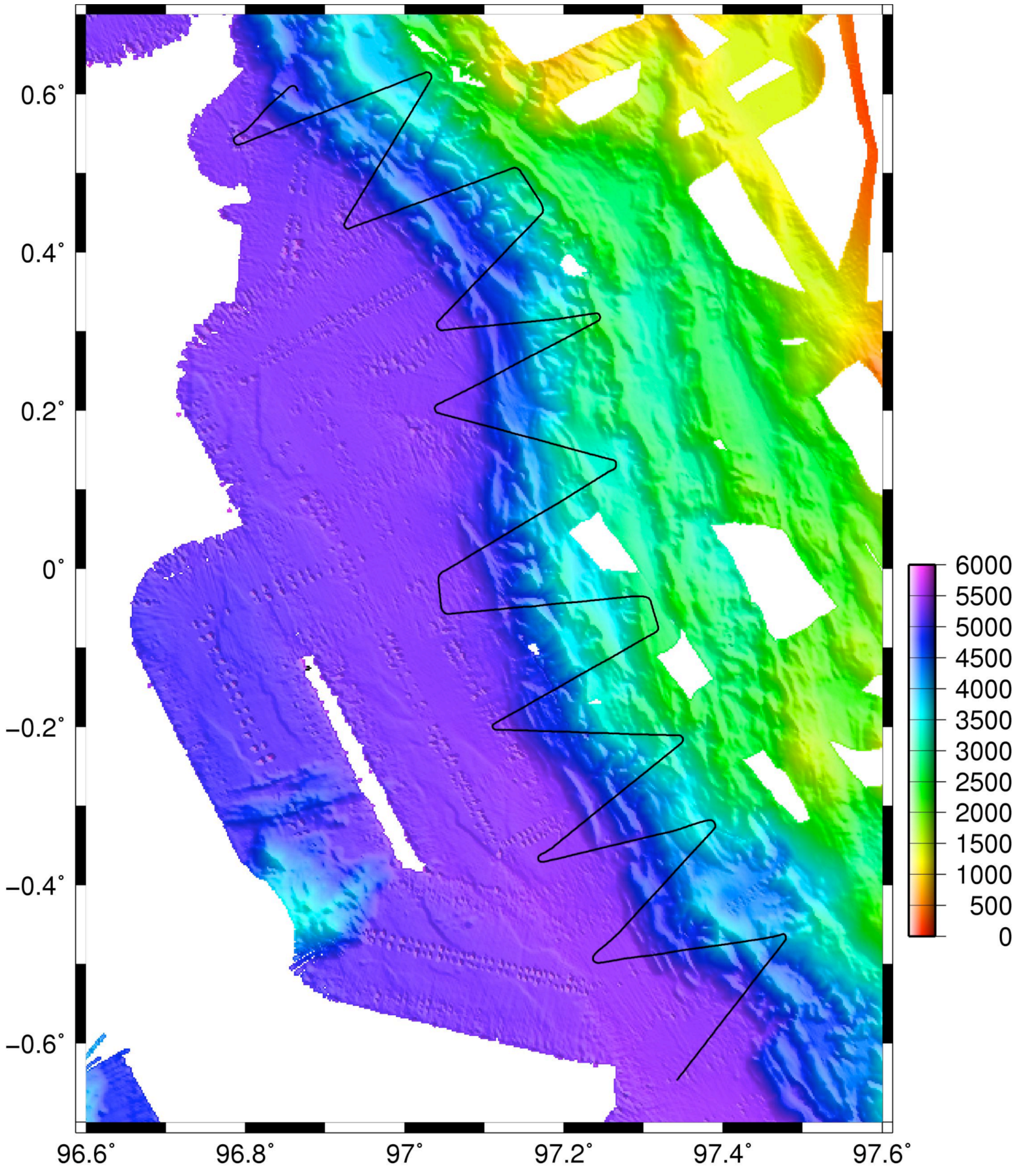

Figure 52 MCS profile tracklines across the toe of the accretionary prism west of the Batu and Nias Islands. Tracks overlain on gridded swath bathymetry data collected during SO198 and SO200. Scale bar is seafloor depth in m.

Results: XBT/XSV

Sequence (deployment) number	Probe type	Latitude	Longitude	Approximate water depth (m)
1	Not deployed			
2	T7	-2.36155	100.509	1468
3	T7	-0.679351	99.5169	1094
4	T7	-0.867021	99.156	1263
5	S2	-0.856546	99.1277	1114
6	T5	-1.3592	98.4029	1472
7	T5	-1.48731	98.1422	3755
8	S2	-1.44983	98.1394	3570
9	T5	-0.790241	98.0533	1469
10	T5	-0.474618	97.5608	2223
11	S2	-0.466299	97.5744	2223
12	T5	-0.305049	97.8725	1204
13	T7	1.19358	98.0977	508
14	S2	1.19728	98.0907	513
15	T7	1.63205	97.2848	552
16	T5	1.76339	96.1689	3053
17	T5	2.26843	95.1035	4398
18	S2	2.26604	95.1117	4430
19	T5	2.04136	95.5077	4888
20	Not deployed			
21	T5	0.638991	96.9841	3833
22	S2	0.641276	96.9775	3833
23	T5	0.0875917	97.1005	4823
24	S2	0.0543633	97.1282	4634
25	T5	-1.25053	97.8096	5427
26	S2	-1.27485	97.8288	5429
27	T7	-2.33394	100.29124	1600
28	T7	-1.32316	99.36938	1690
29	S2	-1.27827	99.32896	1630
30	T5	-0.62281	98.03049	1260
31	Failed			
32	T5	-0.82335	97.493	5450
33	S2	-0.80083	97.47033	5450
34	T5	-0.31939	97.22635	5098
35	S2	-0.31382	97.23312	5017
36	T5	-0.20768	97.23615	4700
37	S2	-0.20703	97.21775	4700
38	T5	0.30545	97.08747	4009
39	S2	0.30447	97.07565	5250
40	T5	0.43932	96.95498	5240
41	S2	0.43598	96.9459	5260
42	T5	-0.12850	97.70600	776
43	S2	-0.15133	97.72050	602
44	S2	-0.47865	97.92430	2704
45	T5	-0.50652	97.94232	2600
46	T5	-1.25333	98.40897	1115

Table 8: Launch details for XBT/XSVs deployed between 22nd January and 11th March.

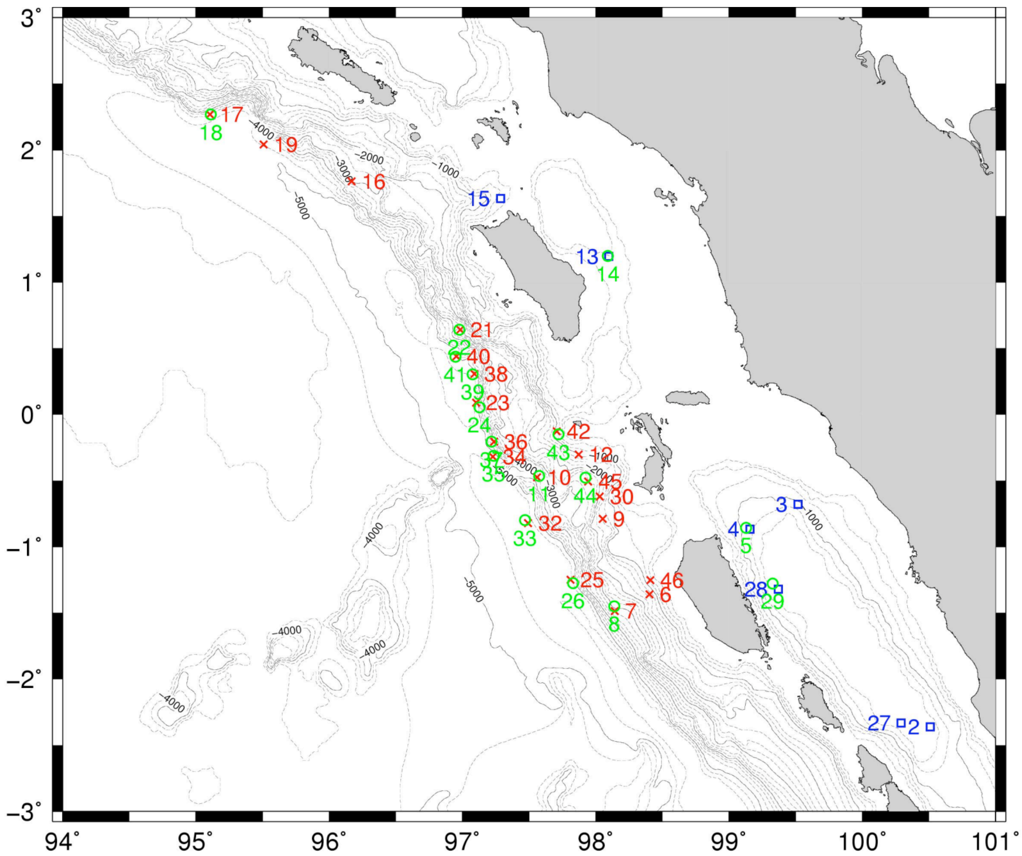

Figure 53: Location of underway hydrographic measurements made during SO200. Red crosses show the location of T5 XBTs, blue squares T7 XBTs, and green circles S2 XSVs. GEBCO 1-minute bathymetry is contoured every 250 m.

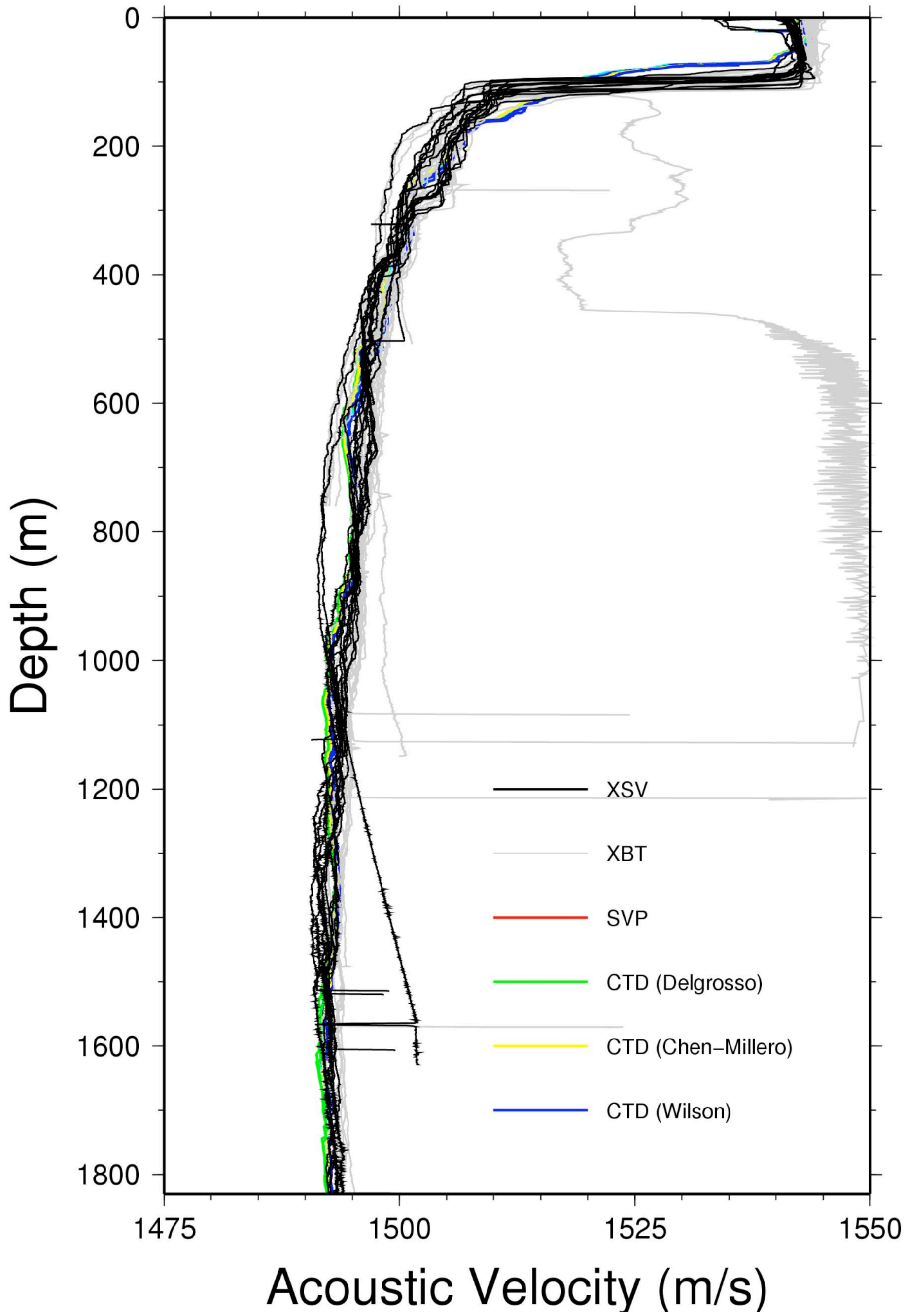

Figure 54: Acoustic velocity versus depth profiles obtained from XSV (black) and XBT (grey) probes during SO200. Also shown are the velocity values obtained during SO198-1 by SVP (red) and CTD (green, yellow and blue).

Results: Swath Bathymetry

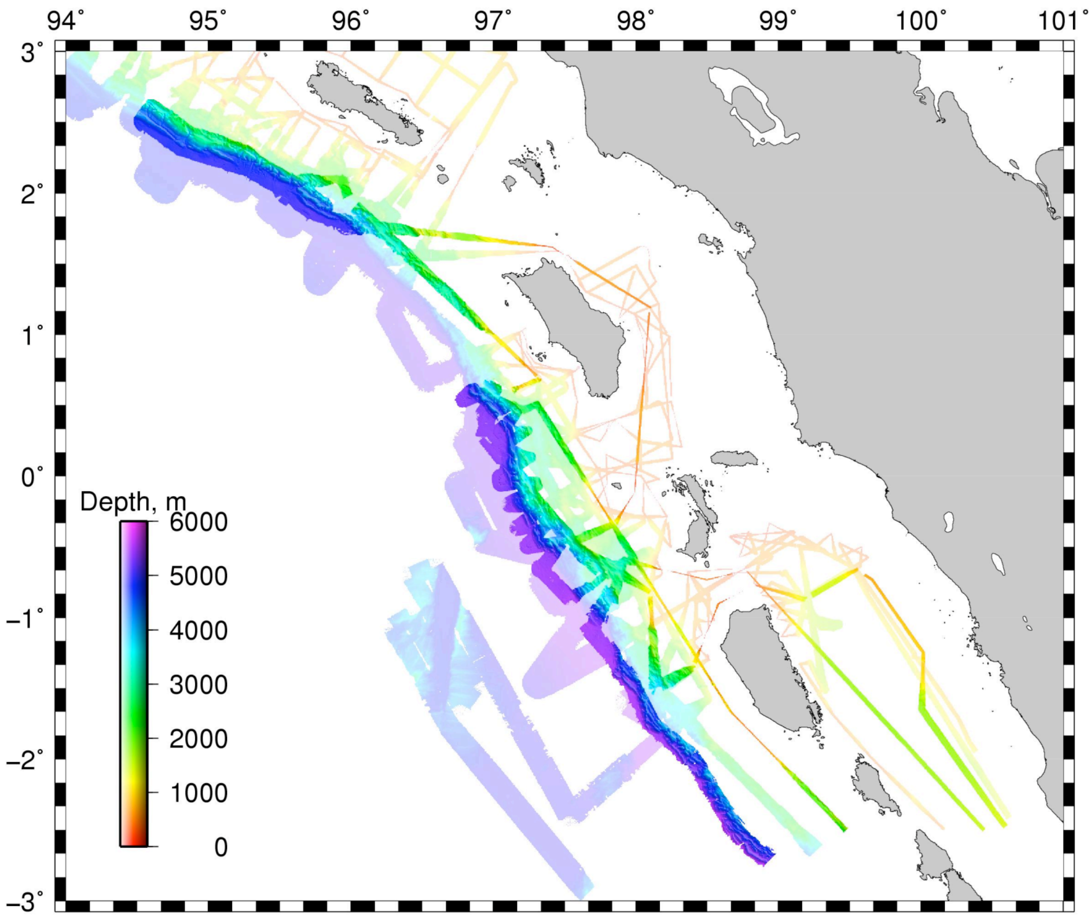

Figure 55: EM120 swath bathymetry data collected during SO200 superimposed on swath bathymetry data collected during SO198 (faded). The data have been filtered and undergone initial editing in Caris/HIPS software. Illumination is from the northeast.

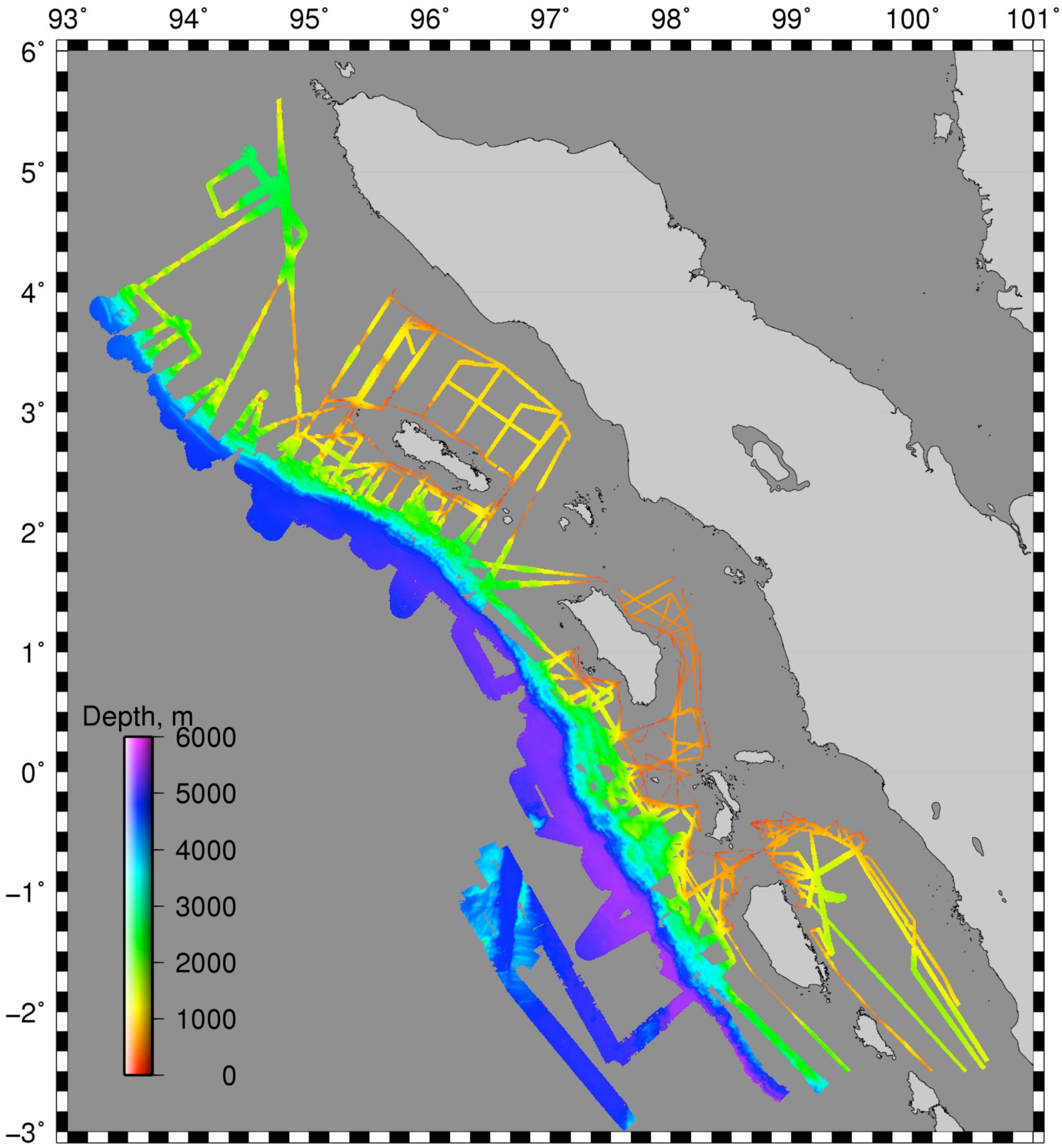

Figure 56 Combined swath bathymetry collected during SO198 (May-August, 2008) and SO200 (January-March, 2009). The data have been initially cleaned and processed using Caris/HIPS software.

Results: Gravity

The gravity meter did not operate reliably throughout large parts of SO200-1. Initially the meter did not function at all. After several days of switching parts a configuration was achieved that worked, mostly, from 09:51 on Julian Day 39 to the end of the cruise. Periods of data from earlier in the cruise may be usable with caution. A summary history of the issues with the meter follows:

1. 033/16:50 the meter is first turned on, the platform is unstable, the meter inoperable.
2. 033/18:00 phase “A” on the 200 Hz power supply has failed, the power supply is replaced and the meter restarted. Logging commences.

3. 034/09:17-034/13:50 the platform repeatedly dumps and is restarted. At 035/11:05 it is noticed that the instrument clock was set to 2008 during one of the earlier restarts, and is now corrected to 2009. The meter is logging throughout this period.
4. 037/19:20 the platform dumps and the meter shuts down. The platform repeatedly dumps on start-up. The computer board is replaced but does not fix the problem. The meter is inoperable.
5. 039/08:51 the meter is started with the original computer board and the original 200 Hz power supply, with phase "A" fixed. Data logging starts.
6. 044/03:44 the meter stops cycling and is restarted. Logging continues.
7. 044/13:00 the error "Interrupt routine re-entered" first noted on the console and the instrument clock starts drifting.

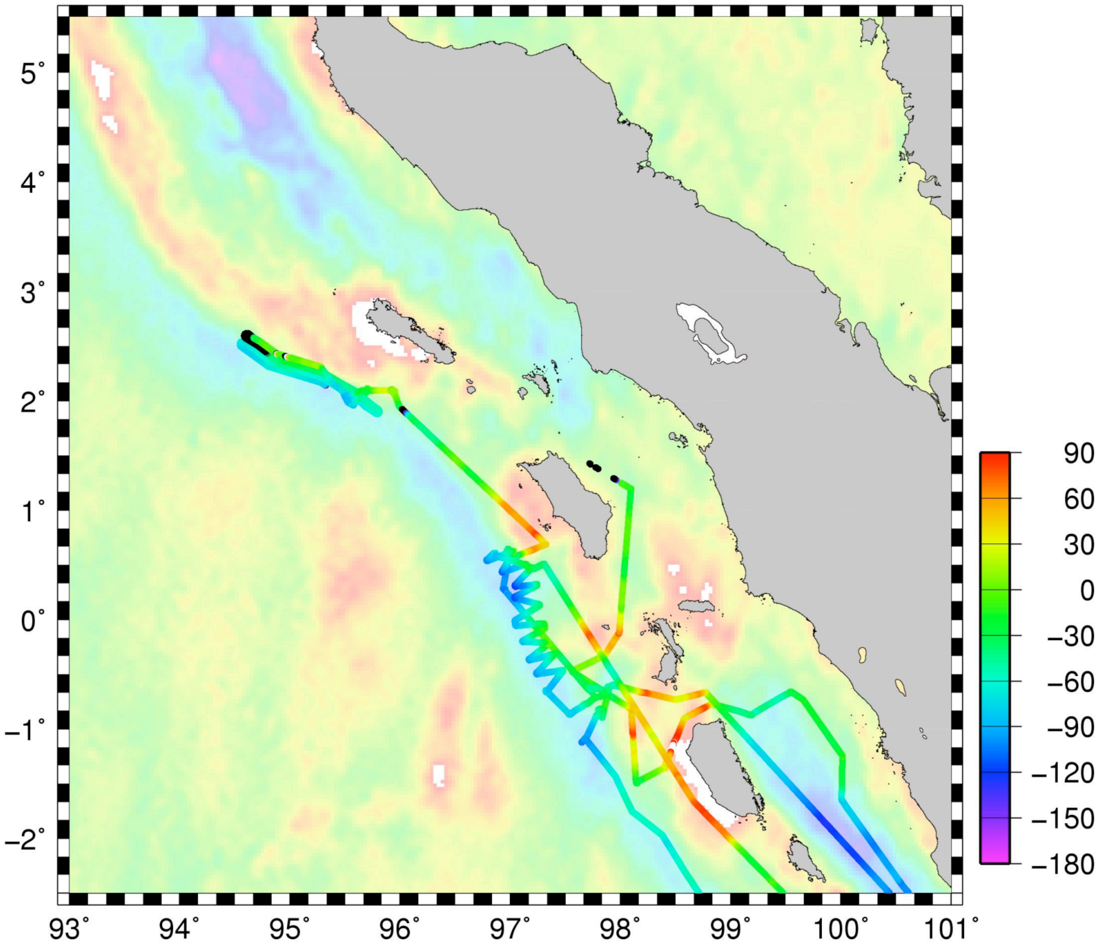

Figure 57 Initial free air gravity anomaly calculated from data collected during SO200. Clock drift has been corrected, and the data are reduced using a single base tie in Tanjung Priok port during the intermediate port call in Jakarta. At times the meter has dumped, causing the zones of bad data apparent in the figure, and extensive further QC will be required. Unfortunately, no second base tie to constrain instrument drift is possible. Background image shows the good general agreement with the Sandwell and Smith (1997) global dataset.

Gravity Base Station Ties

At the beginning of SO200-1, rapid departure from Jakarta port shortly after the gravity meter had been switched on prevented a base tie being made.

During the port call between SO200-1 and SO200-2, a base tie was made at the Tanjung Priok port base station 1 (see Explanatory Notes). At the end of SO200-2, uncertainty in the location of the final port call and the possibility of the science party leaving the vessel prior to the instrument led to the gravity meter being shut down before a final base tie could be made.

Results: Magnetometer

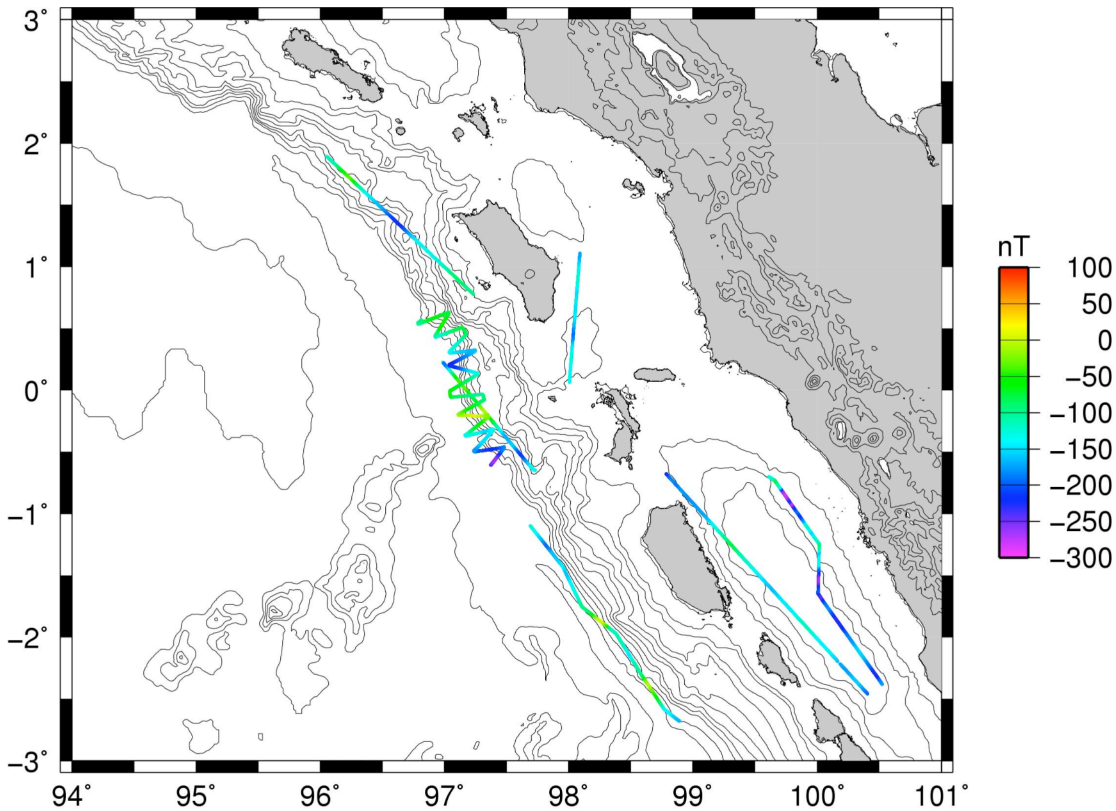

Figure 58: Magnetic anomaly data from SO200, reduced using the IGRF10 predicted coefficients at the location of each reading.

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Appendix A: Cruise data

./SO200-EM120	Swath Bathymetry - EM120 manual - Caris vessel file - Caris project - Raw data (by day)
./SO200-Parasound	Parasound Sub-bottom Profiler - Atlas manuals - SEG-Y data (by day)
./SO200-Documents	Cruise Documents (scans) - Scientific log books - XBT log book - Gravity meter log book - Bridge log - TOBI log book - Heat flow and MCS log book - Core site logs - Core photos
./SO200-Gravity	Gravity - /logged by Sonne - /RAW meter data
./SO200-Magnetics	Magnetics - .mag Raw data - .XYZ ASCII data
./SO200-XBT	Expendable Bathythermographs - Raw T5, T7 & S2 probe data
./SO200-Database-Export	Vessel Logs - /NAV ASCII format navigation etc. - /MRU ASCII format relative motion unit (heave/pitch/roll) - /AirWater ASCII format air/water environment - /Winch ASCII format
./SO200-TOBI	TOBI Sidescan system data - Raw TOBI data by folder - Data format description - Preliminary mosaic PDF
./SO200-Long_Deployment_OBS	Ocean Bottom Seismographs - Raw 4x4 format data
./SO200-MCS	Multichannel Seismic Reflection - /Geometrics logfiles - /Observer logs - /SEGD files
./SO200-Longshot	Long shot records

		- /Data (shot logs)
./SO200-Heatflow	Heat flow	
		- /MCHF raw data
		- Data format description
		- Station forms
		- Station table

Appendix B: Julian Day Calendar

January	Julian Day
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	10
11	11
12	12
13	13
14	14
15	15
16	16
17	17
18	18
19	19
20	20
21	21
22	22
23	23
24	24
25	25
26	26
27	27
28	28
29	29
30	30
31	31

February	Julian Day
1	32
2	33
3	34
4	35
5	36
6	37
7	38
8	39
9	40
10	41
11	42
12	43
13	44
14	45
15	46
16	47
17	48
18	49
19	50
20	51
21	52
22	53
23	54
24	55
25	56
26	57
27	58
28	59

March	Julian Day
1	60
2	61
3	62
4	63
5	64
6	65
7	66
8	67
9	68
10	69
11	70
12	71
13	72
14	73
15	74
16	75
17	76
18	77
19	78
20	79
21	80
22	81
23	82
24	83
25	84
26	85
27	86
28	87
29	88
30	89
31	90

Table 9: Julian Day dates for the months of January, February and March 2009.

Appendix C: RV Sonne

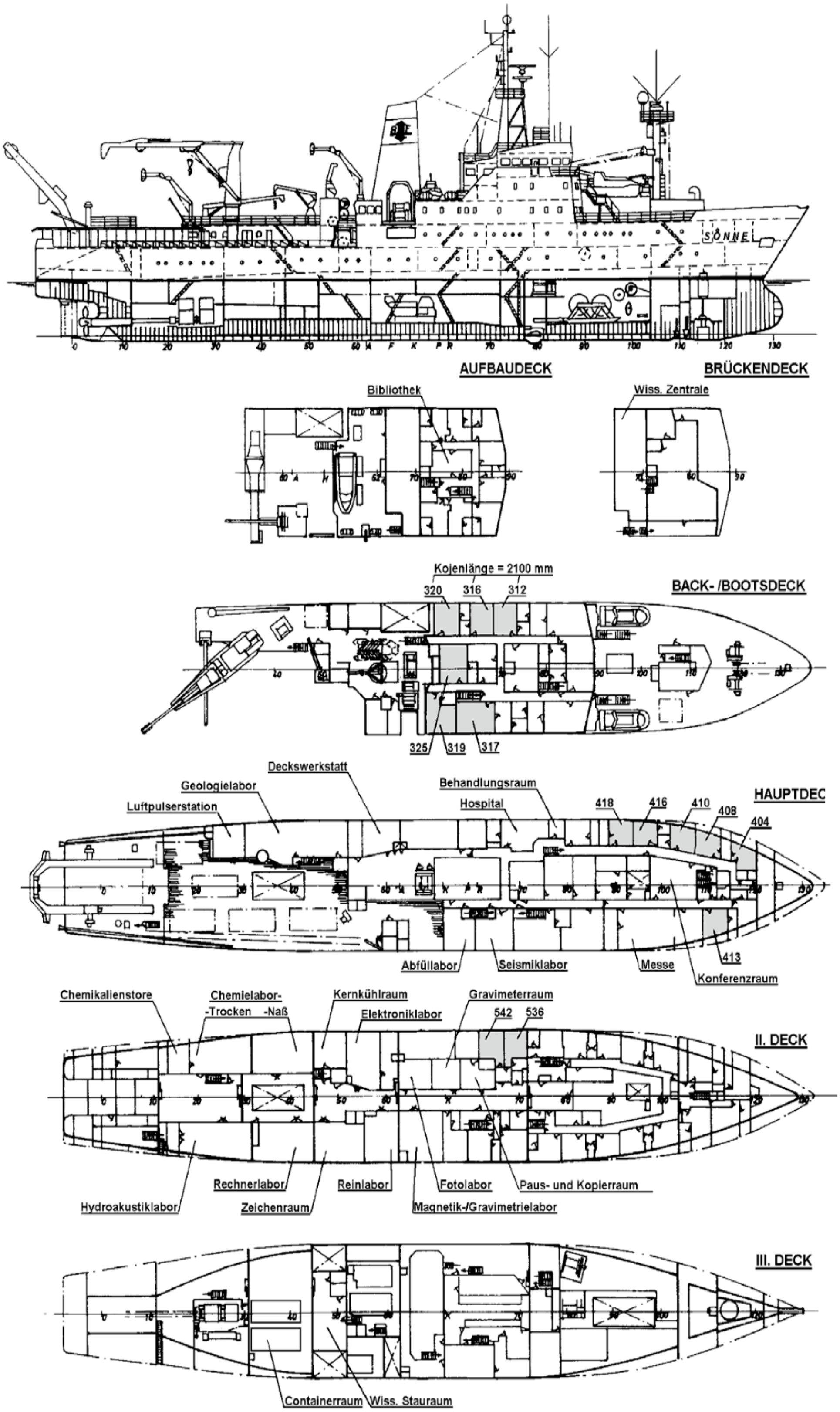

Figure 59: General deck plan for the RV Sonne.