Cruise report - JR63

R.R.S. James Clark Ross

Recife, Brazil - Ponta Delgada, Azores
14th April - 23d May 2001

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Summary

RRS *James Clark Ross* cruise JR63 started in Recife, Brazil, on 14th April 2001 and ended in Ponta Delgada in the Azores on 23rd May 2001. Twenty-eight days were spent in scientific operations in the area around the Fifteen-Twenty fracture zone on the Mid-Atlantic Ridge. Effort was centred on an area around 15°45'N 46°55'W, ~30km the west of the present axis and ~35km north of the fracture zone. This region is well known as a 'magma starved' part of the Mid-Atlantic Ridge system.

Previous swath mapping of this region had revealed four anomalously shallow massifs, rising to ~1540m below sea level, with prominent spreading-parallel corrugations on their upper surfaces on a hundreds-of-metre to kilometre scale. These and other similarly striated massifs found in several places along the Mid-Atlantic Ridge have been interpreted as the surface exposures of sub-horizontal detachment faults.

The principal aim of cruise JR63 was to make a detailed geological investigation of the corrugated massifs at 15°45'N in order to test the detachment fault hypothesis and constrain the mechanisms of their formation and deformation. It was hoped that mapping and sampling of the surfaces would also offer insights into the processes of accretion of the lower crust at slow-spreading mid-ocean ridges.

TOBI deep-towed sidescan sonar imagery was acquired of a 2000km^2 area centred on the corrugated knolls, with a single line crossing the axis out to another corrugated massif ~70km to the east of the axis. Striations are prominent on the TOBI images of the massifs, and a large number of faults that cut them and the surrounding area are visible. Multibeam swath bathymetry was collected throughout the cruise using the ship's Simrad EM120 mapping system.

Detailed sampling of the massifs and surrounding areas (including the neovolcanic zone on the ridge axis) was carried out with the BRIDGE portable wireline rock drill, with which we obtained metre-length geographically orientated cores. 73 sites were drilled over a period of ~12 days, in water depths of up to 4520m and on slopes of up to 44°. Core was retrieved at 63 sites, and material was recovered from the drill frame at two more. Dredging was also carried out in order to sample the steepest slopes. 32 sites were dredged in total, out of which 29 recovered igneous material.

Photographs and samples from the corrugated upper surfaces of the massifs show that striations are present down to the millimetre scale. Drill cores commonly contain highly deformed schistose serpentinite with sub-horizontal fabrics. This suggests that the corrugated surfaces are indeed low angle detachment-type faults and that they are 'lubricated' by serpentinite, which behaved in a very weak manner and was responsible for localising deformation.

A cupola of gabbro underlies the shallowest and most intensively studied of the massifs (the 'SE knoll'). It has a very irregular form. At its sides it intrudes undeformed serpentinised mantle peridotite, and its upper surface passes into a very large swarm of dolerite dykes that intrude into deformed serpentinite. Deformation and magmatism were clearly synchronous: some dykes cut deformed serpentinite; others are deformed and incorporated into a sheared serpentinite mélange. Many dolerites and gabbros are cataclastically deformed. Little or no evidence for high-temperature ductile deformation was observed.

The new observations made during cruise JR63 place the most detailed constraints yet upon models for the formation of detachment faults at slow-spreading ridges. Post-cruise structural and petrological studies should help refine our ideas significantly.

List of Participants

Scientific Party

Chris MacLeod	Cardiff University	*(Chief Scientist)*
Javier Escartín	CNRS/IPG, Univ. Paris VI/VII	*(Co-Chief Scientist)*
Debleena Banerji	University of Houston	
Graham Banks	Cardiff University	
Martina Gleeson	Open University/University College Dublin	
Duncan Irving	Cardiff University/University of Manchester	
Richard Lilly	Cardiff University	
Andrew McCaig	Leeds University	
Yaoling Niu	Cardiff University	

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Lee Fowler	(TOBI) Southampton Oceanography Centre
Duncan Matthew	(TOBI) Southampton Oceanography Centre
Dave Booth	(Acoustic Navigation) Southampton Oceanography Centre
Colin Brett	(BRIDGE rock drill) British Geological Survey, Edinburgh
John Derrick	(BRIDGE rock drill) British Geological Survey, Edinburgh
Dave Smith	(BRIDGE rock drill) British Geological Survey, Edinburgh
Dave Wallis	(BRIDGE rock drill) British Geological Survey, Edinburgh
Andy Barker	(Information Technology Services) British Antarctic Survey
Pete Lens	(Information Technology Services) British Antarctic Survey
Paul Woodroffe	(Engineering Technology Services) British Antarctic Survey
Jim Fox	(Engineering Technology Services) British Antarctic Survey

Ship's crew

Master: Robert Paterson
Chief Officer: Peter Moxom
2nd Officer: David Gooberman
3rd Officer: Scott Baker
Deck Officer (Science): John Summers
Chief Engineer: David Cutting
2nd Engineer: Bill Kerswell
3rd Engineer: Glynn Collard
4th Engineer: Steve Eadie
Deck Engineer: Simon Wright
Senior Electrical Officer: Norman Thomas
Purser/Catering Officer: Ken Olley
Radio Officer: Charlie Waddicor
Doctor: Pippa Bradbury
Bosun's Mate: Dave Williams
Seaman: James Kennedy
Seaman: Marc Blaby
Seaman: John McGowan
Seaman: Derek Jenkins
Seaman: Jim Baker
Motorman: Mark Robinshaw
Motorman: Charlie Smith
Chief Cook: Tracy MacAskill
2nd Cook: Frank Hardacre
2nd Steward: Cliff Pratley
Steward: Tony Dixon
Steward: Kenneth Weston
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1. Introduction

Preamble

The discovery of peridotites – rocks derived from the Earth's mantle – in some dredge hauls from mid-ocean ridge axes has long intrigued marine geologists. The observation cannot be reconciled with models derived from seismic refraction experiments, which predict that a uniform 6-7km thickness of ocean crust is produced at all but the very slowest spreading ridges. Exposure of peridotite on the seafloor could mean that the full thickness of ocean crust was never formed: one proposition is that the lower crust may not be a continuous layer of gabbro, but a collage of small bodies of gabbro intruded into partially serpentinised mantle peridotite. An alternative, potentially complementary, mechanism for exhuming the deep ocean crust is that the crust has been removed by tectonic means. However, faults documented at spreading centres such as the Mid-Atlantic Ridge are not large enough to explain removal of the entire thickness of the crust.

In 1996 a British sidescan sonar survey of a portion of the Mid-Atlantic Ridge revealed that a number of flat-topped highs adjacent to the axis had spectacular parallel striations on their upper surfaces [Cann *et al.*, 1997]. The favoured interpretation of these structures is that they are the surface expressions of large near-horizontal extensional faults (detachments) that cut through the entire crust, helping to accommodate separation of the plates at the ridge axis when magma supply from the mantle is low. The limited sampling carried out to date has suggested that they are probably responsible for exhuming deep levels of the crust and the shallow mantle on the seafloor.

Rationale and Background to the Cruise

The principal aims of RRS *James Clark Ross* cruise JR63 (Figure 1) were twofold: (1) to determine whether the flat-topped corrugated massifs (often termed 'megamullions' or 'oceanic core complexes') really are detachment faults, and thence to work out how they form and how strain is localised on them; and (2) to map out and sample the exposures of gabbro and peridotite on the the footwalls of the structures in order to gain observational constraint on models for accretion of the lower ocean crust.

We proposed to meet these aims by using the TOBI ("Towed Ocean-Bottom Instrument") deep-towed sidescan sonar together with the ship's swath bathymetry to determine where the corrugated surfaces occur on the seafloor and to map out the surrounding faults. After this we proposed to sample the exposed surfaces using the BRIDGE wireline rock corer. This device is a rotary drill mounted in a tripod frame which is lowered to the seafloor on a cable and drills 1m-long, geographically orientated cores. We envisaged 'pogoing' around with this drill on the corrugated outcrops, getting large numbers of cores of peridotite and gabbro, and building up a geological map and sample suite to study back in the laboratory. We also proposed to sample the surrounding steep slopes using conventional rock dredges.

In our original proposal (written in 1997 by Chris MacLeod, Simon Allerton and Joe Cann) we intended to implement this plan at a large corrugated surface near the inside corner of the southern ridge-transform intersection of the Kane fracture zone at 23°N on the Mid-Atlantic Ridge (MAR). However, since that time submersible dives on similar structures at Atlantis and at 26°N [*e.g.* Tucholke *et al.*, 1998] on the MAR, and on the SW Indian Ridge [Tamaki *et al.*, 1998] had showed that all these corrugated surfaces are covered by pelagic sediment, gravel and (mostly basaltic) rubble, with very few of the predicted outcrops of gabbro or peridotite. Given that the structure at Kane is old (~30 km away from the axis), we reasoned that its surface was

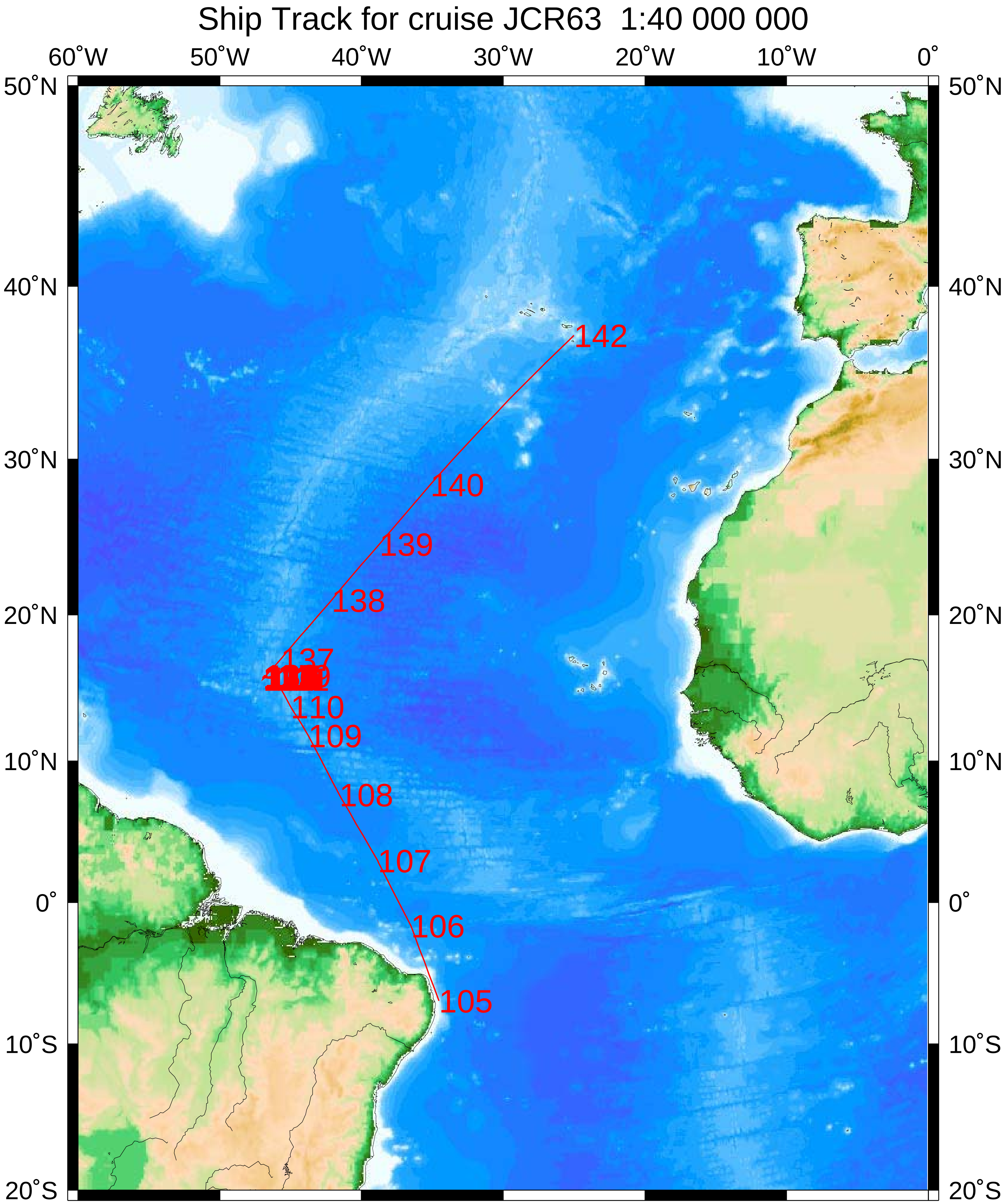


Figure 1: Shiptrack for JR63 over ETOPO5 bathymetry. Numbers correspond to Julian days.

likely to be no different. We had tried and failed to obtain funding to bring along an ROV or seafloor camera system, and so had no means of searching for outcrops that might be drillable except using the relatively broad-scale TOBI sonographs.

In 1998 a joint Japanese–American submersible cruise was run in the Fifteen-Twenty Fracture Zone region of the Mid-Atlantic Ridge [Matsumoto *et al.*, 1998]. One dive (*Shinkai* dive #422) was devoted to a region west of the axis near 15°45'N where corrugations had been recognised on swath bathymetry maps [Escartin & Cannat, 1999] (Figures 2a and 2b). The corrugations occurred on and around four relatively flat-topped knolls that formed a square pattern, the shallowest rising to ~1600m below sea level. Dive #422 made a south to north transect up the southern slope of the southeastern knoll (Figure 2b), across outcrops of both gabbro and serpentinised peridotite [M. Braun, *pers. comm.*, 2001], some of which were striated bare-rock pavements. This was the first place where significant outcrop had been observed on one of the corrugated surfaces.

Recognising that we were more likely to be able to drill basement outcrop and hence address our original scientific objectives by mapping and sampling in the Fifteen-Twenty region rather than Kane, Chris MacLeod and Javier Escartin decided early in 2001 to shift the cruise to the former location, at least in the first instance (Simon Allerton and Joe Cann had by then withdrawn from active participation in the cruise). This was feasible logistically because our cruise on RRS *James Clark Ross* started in Recife (Brazil) and ended in the Azores, so no extra passage was needed.

Early in 2001 Debbie Smith (WHOI) was on a cruise in the region, recovering and redeploying hydrophones for seismic monitoring. She also had on board a prototype towed seabed camera system (built by Dan Fornari, WHOI) which she wanted to test. At our request she conducted this test on the SE corrugated knoll at 15°45'N, close to the end-point of the *Shinkai* dive. A number of regions of striated basement outcrop were identified on the digital seafloor images (Figure 3), giving us several targets to aim for with the BRIDGE rock drill.

General tectonic setting; geological and geophysical observations

The Fifteen-Twenty Fracture Zone (FTFZ) has been the subject of several sampling, hydrothermal, gravity and seismic studies that have provided some constraints on the tectonics, composition and structure of the oceanic lithosphere in the area. The tectonic history of the FTFZ is affected by the migration of the triple junction between the North-American, South American and African plates from the Marathon FZ (10°N) to the 14°-16°N area [Roest & Collette, 1986; Müller & Smith, 1993]; the FTFZ may correspond to the present location of the triple junction [Müller & Smith, 1993]. The overall trend of the ridge-axis north and south of the FTFZ is subperpendicular to the spreading direction (~100°), and the spreading rate is ~26 km/Ma (NUVEL-1 plate motion model [DeMets *et al.*, 1990]). North of the FTFZ the axial valley is linear, bounded by large fault scarps (>1 km in vertical relief), and showing a well-developed axial volcanic ridge north of 15°45'N.

Submersible and dredge sampling on the area during the FARANAUT [*e.g.*, Casey *et al.*, 1992; Cannat & Casey, 1995; Cannat *et al.*, 1997] and MODE'98 [*e.g.*, Kelemen *et al.*, 1998; Matsumoto *et al.*, 1998] cruises have documented extensive outcrops of serpentinized peridotites, gabbro, and, to a lesser degree, diabase, with extrusive basalt caps both peridotites and gabbros. Such ultramafic exposures are commonly thought to indicate accretion at a magmatically starved portion of the ridge axis [Cannat, 1993; Tucholke & Lin, 1994]. If this interpretation is correct, geological observations in the 15°N area suggest highly reduced magma supply along a substantial portion of the ridge axis (>100 km) during recent times, that results in a compositionally heterogeneous lithosphere [*e.g.*, Cannat, 1993]. However, high degrees of melting are inferred from the geochemistry of basalts and peridotites [Bonatti *et al.*, 1992; Xia *et al.*, 1992]. These peridotite outcrops are locally associated with hydrothermal activity [Rona *et al.* 1987; Bogdanov *et al.*, 1995].

Detailed bathymetry maps also reveal the presence of corrugated surfaces off axis, both north and south of FTFZ [Escartin & Cannat, 1999; Casey *et al.*, 2000]. These surfaces measure 10 to 15 km across-axis and up to 25 km along axis, are relatively smooth, and present striations sub-parallel to the spreading direction at wavelengths of <3 km. Later higher angle faults with small vertical displacement (<100 m) truncate these structures. Similar structures were first described near the Atlantis Fracture Zone [Cann *et al.*, 1997] and have been discovered since in other areas of the Mid-Atlantic Ridge [Tucholke *et al.*, 1998; Deplus *et al.*, 1988], and at the Central Indian [Mitchell *et al.*, 1998], Antarctic-Australian [Christie *et al.*, 1997], Southwest Indian [Tamaki *et al.*, 1997] and Chile [Martinez *et al.*, 1998] ridges. They are interpreted as the exposed surfaces of long-lived detachment faults that tectonically uplift ultramafic rocks [Cann *et al.*, 1997; Tucholke *et al.*, 1998] which is consistent with the exposure of gabbros and peridotites over the detachment at 15°45'N [Casey *et al.*, 1998]. Unlike oceanic detachments elsewhere, which seem to occur in crust formed at the inside corner of ridge discontinuities [Cann *et al.*, 1997; Tucholke *et al.*, 1998; Deplus *et al.*, 1988], some of the corrugated surfaces in the 15°N (*e.g.*, ~15°45'N, ~46°55'W) occur at the outside corner, away from the FTFZ, and cannot be associated with any non-transform discontinuity [Escartin *et al.*, 1999; Casey *et al.*, 2000].

Gravity data over the area suggest that anomalously thin 'crust' (defined seismically) is associated with the outcrop of peridotites [Escartin & Cannat, 1999; Casey *et al.*, 2000], both at the ridge axis and over the corrugated surface north of FTFZ, at the W flank of the ridge (~15°45'N, ~46°55'W). A recently acquired seismic refraction line [Detrick *et al.*, 1999] along the ridge axis at the same area shows <3 km of seismic crustal thickness (*i.e.*, v_p velocities >7.5 km/s at ~3 km depth). The vertical seismic velocity profile at the ridge axis shows a continuous velocity gradient to mantle velocities, without a clear seismic layer 3, as observed near fracture zones and/or transform discontinuities along the Atlantic [Detrick *et al.*, 1993], where serpentinized peridotites commonly outcrop.

The origin and tectonic evolution of oceanic corrugated surfaces is commonly attributed to low-angle detachments [*e.g.*, Cann *et al.*, 1997; Tucholke *et al.*, 1998; Blackman *et al.*, 1998; Escartin & Cannat, 1999], sharing some similarities in size and morphology with continental core complexes [*e.g.*, Cann *et al.*, 1997; Tucholke *et al.*, 1998]. However, the mode of formation, depth extent of the detachment, downdip geometry, mode of accommodation of deformation, driving mechanisms, and duration of extension along the fault surface are still poorly understood.

Corrugated surfaces (postulated oceanic core complex) north of Fifteen-Twenty

The corrugated surface at ~15°45'N and ~46°55'W is a gently-dipping (<15°) corrugated surface, with striations sub-parallel to the spreading direction [Escartin & Cannat, 1999; Casey *et al.*, 2000]. It is located ~35 km north of the Fifteen-Twenty Fracture Zone, and ~27 km from the present-day axial volcanic ridge, corresponding to ~2.1 My old oceanic crust. The corrugated surface extends for ~30 km in an axis-parallel direction, and ~15 km in an across-axis direction, and existing multibeam bathymetry shows fine-scale corrugations with lateral spacings of ~1-3 km and a vertical relief <200 m. A larger-scale undulation (~15-20 km) defines two ribbons of elevated seafloor. A relative low runs N-S through the middle of the corrugation, possibly as a

Mid-Atlantic Ridge, Fifteen-Twenty Fracture Zone

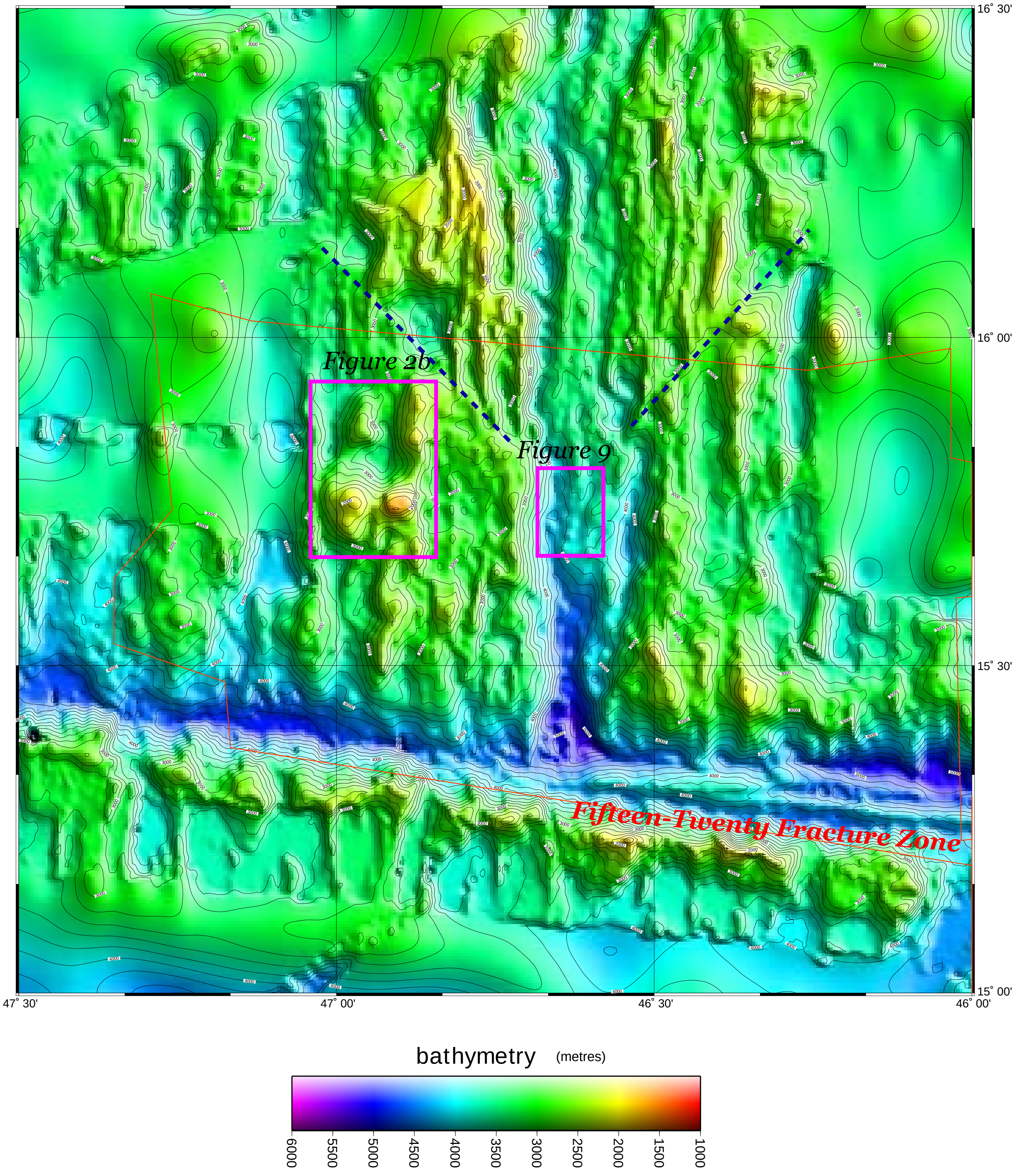


Figure 2a: General bathymetry of the study area. The boxes correspond approximately to the areas shown in Figures 2a and 9. Seabeam multibeam data from an earlier NO Charcot cruise [Escartin and Cannat, 1999] has been complemented with topography predicted from satellite gravity and shipboard bathymetry [Smith and Sandwell, 1997]. The dashed line corresponds to the transition from terrain with linear, axis-parallel ridges, to irregularly faulted seafloor, where peridotites outcrop.

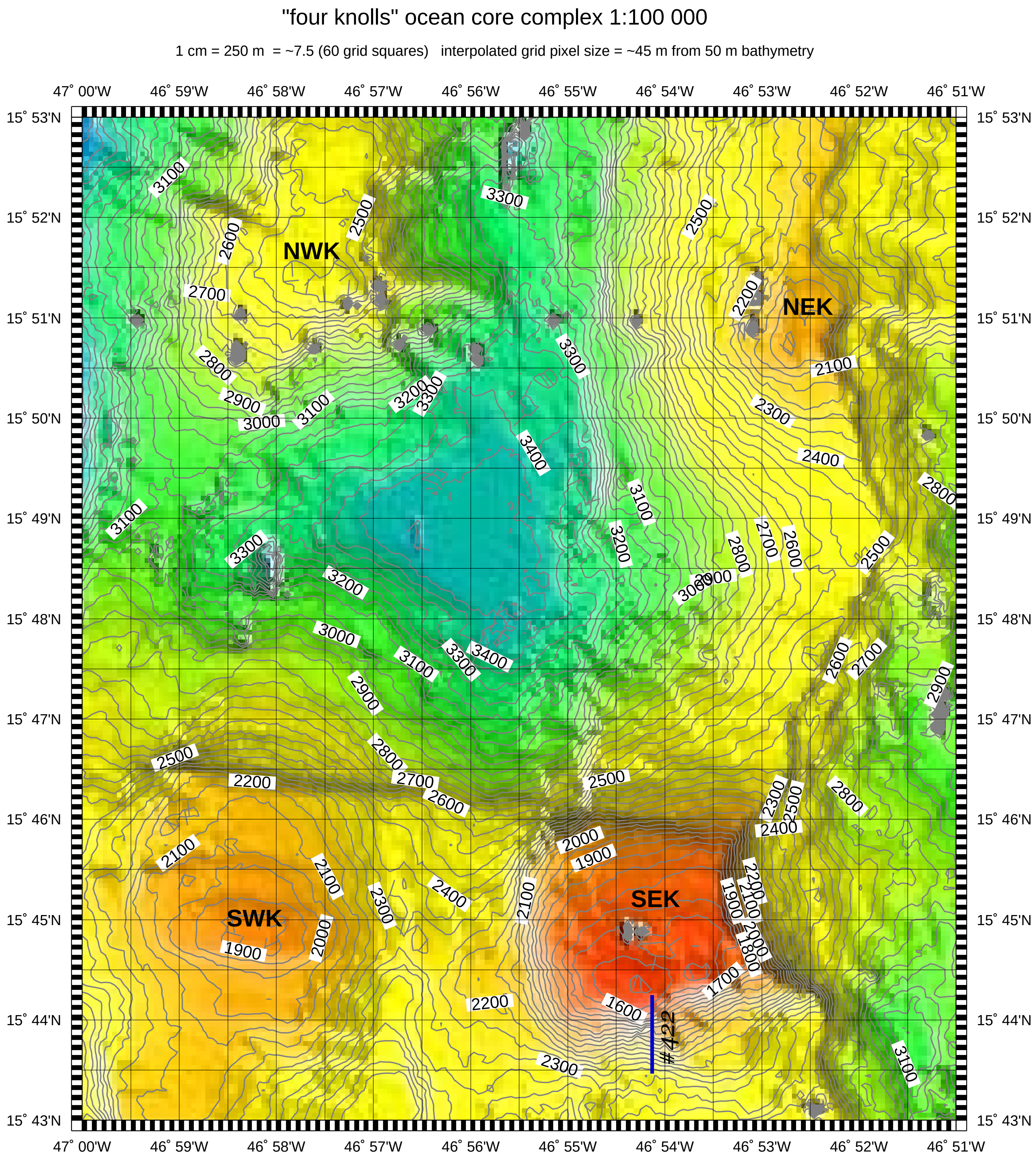


Figure 2b: Multibeam bathymetry (SIMRAD EM120) of the study area, showing the striations running at ~095°. NWK, NEK, SWK and SEK correspond to the North West Knoll, North East Knoll, South West Knoll and South East Knoll, respectively. The blue line corresponds to Shinkai Dive #422 of the MODE'98 cruise (see Matsumoto et al. [1998]).

Figure 3: Photo-mosaic of electronic still camera pics of center of platform at top of the South East Knoll (see Figure 2b). The images were taken along a N-S track over the top of the SE knoll by D. Smith (WHOI) in February-March 2001, onboard R/V Atlantis (USA). Numbers correspond to the time the picture was taken. No altimetry information nor camera attitude are available. The striations on the rock outcrop run E-W approximately, sub-parallel to those observed in the multibean and TOBI data.

consequence of faulting or other type of tectonic deformation. The shallowest parts of the detachment define four knolls ranging between 1500 m and 2000 m water depth at their summit.

The detachment is limited to the west (ridge-ward) by a steep normal fault, probably corresponding to a normal fault scarp, with a vertical relief of 200-1000 m. The cuspate shape of the scarp, particularly at the north-west and south-west knolls, indicates later mass wasting (slumping) of the slope. A linear ridge, possibly corresponding to an inward-facing fault scarp, marks the eastern limit of the detachment. The corrugated terrain shows a rapid transition laterally to ridge-parallel abyssal hill terrain, characteristic of normal slow-spreading crust. The nature of these northern and southern limits (gradual vs. tectonic termination) is not clear.

Both gabbros and peridotites crop out at the SE part of the detachment, with a few gabbros reported as showing mylonitic textures [Matsumoto *et al.*, 1998]. Gabbros tend to outcrop in the lower levels, while peridotite outcropping at the upper part of the dome [M. Braun, *pers. comm.*, 2001].

Both north and south of the FTFZ there is a transition from a 'linear' terrain with long abyssal hills forming spines sub-parallel to the ridge axis, to a 'rugged' terrain with short and oblique fault scarps [Cannat *et al.*, 1997; Lagabrielle *et al.*, 1998]. The 'rugged' terrain is found at either side of the FTFZ, with south-propagating V-shaped transitions to the 'linear' terrain distant from the FTFZ (at ~15°50'N and ~14°30'N, Figure 2a [Escartin and Cannat, 1999]). South of the FTFZ this transition can be identified to the edge of the bathymetry survey. North of the FTFZ the transition can be identified to ~30 km off-axis. At greater off-axis distances the terrain is 'rugged' and the transition disappears (Figure 2a). The change in tectonic pattern is well correlated with along-axis variation in sampled rock types. Extensive outcrops of serpentinized peridotite together with gabbro are found at distances <~60 km from the FTFZ, always within the 'rugged terrain', and on both flanks of the axis. These outcrops are capped by a thin (<500 m) layer of extrusive basalt [Cannat *et al.*, 1997]. There have been no peridotites recovered from the 'linear' terrain at six sample locations (N and S of ~15°50'N and ~14°30'N, respectively. These observations suggest that there is an along-axis variation in lithospheric composition and tectonic pattern in the area, with substantially more peridotite in shallow levels of the crust in the 'rugged' terrain near the FTFZ, and a more magmatic crust away from it in the 'linear' terrain. However, the presence of serpentinized peridotite in the lithosphere of the 'linear' terrain away from the FTFZ cannot be ruled out due to the few existing dredges and dive tracks.

2. Survey Plan

Although originally designed for the corrugated surface at Kane, our survey plan could be applied almost without modification to the 15°45'N region. First of all we planned to map the corrugated knolls and surrounding region using the shipboard EM120 multibeam bathymetry system together with TOBI sidescan sonar to identify fault striations, hangingwall blocks and erosional pits associated with the detachment surface. A long TOBI line across to an equivalent distance on the east of the ridge was planned to give some constraint on volcanic outcrop and faulting patterns in the conjugate crust on the opposite side of the axis, and to detemine the strains associated with normal faults [*cf.* Escartin *et al.*, 1999]. Shipboard surface three-component magnetic measurements plus deep-towed total-field TOBI magnetic data from these profiles should help constrain the timing of magmatic accretion and movement on the detachment fault [*cf.* Allerton *et al.*, 2000].

After imaging the corrugated surfaces with TOBI acoustic sonar, our plan was to sample them using the BRIDGE wireline rock drill to obtain a large number of short orientated cores from across and parallel to the axis. From this we hoped gain insights into deformation mechanisms, provided that we recovered fault rock from the corrugated surfaces, and in the distribution of lithologies on the footwall of the detachment, and hence of the deeper levels of the oceanic lithosphere. Steeper slopes surrounding the flat-topped platforms were to be dredged. We anticipated using the TOBI images to choose drill or dredge sites. To this end acoustic transponder navigation was sought, and full processing and geographical registering of the TOBI and swath bathymetry data was to be carried out on board.

3. Operations: Ship's Navigation and Station-Keeping

Shipboard GPS Receivers

Several different global positioning system (GPS) satellite navigation systems are fitted on *James Clark Ross*. These have different functions and, because they are mounted in different places on the ship, give slightly different positions. For the kind of scientific operations carried out during JR63 these offsets are significant. When positions are reported, therefore, it is important to know which receiver was used and what the offset of each receiver is relative to a fixed reference point on the ship (taken as the 'centre of rotation' or COR, which approximates to the position of the control console on the ship's bridge). The COR lies 12.10m forward of the centre of gravity of the ship, and 32.4m behind the bow of the ship.

For its own navigation the ship uses a Leica MX-400 Professional DGPS Navigator system. This is displayed on the navigation console on the bridge and on repeater monitors in the scientific laboratories, and it is not logged. ***The latitude and longitude recorded by the scientific party in the science logs for station positions (*e.g.** *of drill and dredge sites) in the accompanying report, are those of the Leica system, which are not part of the automated ship logs.*** It is offset by 2.13m to starboard of the ship's COR but is in line with it fore-and-aft. It is 28.86m above the keel line.

The scientific computer system (SCS) logs position from a Trimble receiver, also mounted on the fore-and-aft COR of the ship but offset 4.28m to starboard. Its positions are therefore 2.15m to starboard of the Leica. In addition, data are acquired from a Glosnass GG24 mounted 9.42m behind the COR and 9.28m to starboard of it. The Glosnass system is the Russian version of the (American) GPS system and is independent of it (and theoretically better). This is logged as a separate data stream in the SCS.

Two Ashtec G12 receivers used for differential GPS positioning (see below) are also mounted on the wheelhouse top: one is 0.1m behind the fore-and-aft COR of the ship and 3.17m to port of it; the other is 2.8m behind the COR and offset 6.55m to port.

The stern gantry is 66.6m behind the COR and offset 2.1m to starboard. The midships gantry is 23.1m behind the COR and offset 12.7m to starboard. ***Logged positions given in this report and accompanying data sheets for scientific stations (made from the Leica and/or Trimble GPS) need to corrected back to the position of either the stern or midships gantry, as appropriate.*** To do this the ship's heading also needs to be known. Fortunately, during scientific operations in the 15°N area, the trade winds kept a more or less constant ENE direction (see Cruise Narrative) and, because the ship was kept head to wind whilst on station, her heading was rarely more than 10° away from a heading of 080°.

Dynamic Positioning

RRS *James Clark Ross* is fitted with a Simrad SDP-11 dynamic positioning (DP) system. It calculates the deviation from the measured position of the vessel and the required position, calculates the forces the thrusters must produce in order to make the deviation as small as possible, and then makes the necessary adjustments.

Ship navigation and especially DP station-keeping makes use of differential GPS satellite navigation. DGPS relies upon the assumption that certain types of errors, which can degrade positioning accuracy, are common to all users in a given area. If these errors can be calculated at a known location, a reference station, then their application to the measurements of the user, as a correction, will allow them to be reduced. In other words, DGPS involves the removal of correlated systematic error between a reference receiver and a remote user. DGPS positioning on *James Clark Ross* makes use of a combination of two entirely separate, dedicated positional reference systems: two Ashtech G12 DGPS receivers mounted on the wheelhouse top. Comparison of the positions given by the two systems is made automatically to verify positional accuracy. DGPS positional error is measured as units of standard deviation, and under normal stable conditions shows a straight line along the X-axis on a 'Minutes' versus 'Refsys Standard Deviation' X-Y plot.

The DGPS position of *James Clark Ross* is given as the position of the ship's DGPS antenna, using the reference station in Trinidad. Stations in the Cape Verde Islands and Curacas (Venezuela) were tried at intervals during the cruise but offered no advantage over Trinidad.

DGPS problems encountered on cruise JR63

During cruise JR63 several, mainly short, periods of DGPS instability were experienced. During the most extreme periods it was impossible to hold the ship on dynamic positioning (see below), and in consequence drilling had to be aborted. The ship's position was held manually by joystick with reference to the ship's Leica GPS position until the drill package had been lifted clear of the seabed. This happened on two occasions.

The DGPS instabilities are thought to have been caused by 'scintillation' – the phenomenon of signal loss near the equator due to sunspot activity, which does not affect higher latitudes. This hypothesis is reinforced by the observations that (i) DGPS loss was less of a problem after dark; (ii) here the sun has virtually the same latitude as the ship (~16°N); (iii) sunspots were observed directly by Captain Paterson at sunrise and sunset; (iv) RRS *Ernest Shackleton* observed a similar problem off the coast of Brazil; (v) 2001 is a peak year in the sunspot activity cycle; and (vi) several large solar flares were reported being emitted from the sun in a direction that would impinge upon Earth and hence be expected give rise periodically to magnetic storms. There are no present measures for prevention of scintillation. This phenomenon occurred intermittently throughout the cruise.

4. Operations: Long Baseline Acoustic Navigation

Background

The Oceano long baseline (LBL) acoustic navigation system uses a series of seabed transponders. These transponders operate at two frequencies, one being common to all and the other unique. When triggered by one of its frequencies it will reply at the other. The frequency range used was between 8.5kHz and 16kHz.

To communicate with the seabed transponders a towed fish is deployed. Maximum ship speed with the fish deployed is 5kt. The fish carries the acoustic module (transceiver, preamp & TVG) which is connected to the rangemeter. The rangemeter is a series of receivers / filters & timers each tuned for a single frequency. On transmit the timers are zeroed and start to count after a preset fixed delay (see calibration section below). This compensates for the inherent lag in the transponder receiving a trigger pulse and it responding to it. When a pulse is received at the correct frequency then the count is stopped. The count is in metres using a preset fixed sound velocity. This was set to 1500m/s during JR63. Thumbwheel switches on the front of the rangemeter set these preset values. A PC controls the rangemeter. Prior to issuing a transmit command the PC downloads the count values from each of the timer channels using a GPIB link. Two software programs are available, one for raw range logging only and the other a full long baseline navigation package 'LBL10'.

LBL10 System

The range data is reverted to a time by using the preset values and then calculated into a revised range using a new delay and a sound velocity profile. These values along with all other system variables (*e.g.* transponder positions) are all held in a parameter file and are not obtained directly from the rangemeter (*N.B.* all transponders used had a 15ms delay).

To position a relay transponder (the one attached to the instrument, *viz.* TOBI, the BRIDGE rock drill, a dredge *etc.*) two acoustic cycles are required. The first cycle positions the ship acoustically. To do this the common frequency is sent, following which each seabed transponder in range will then reply at their individual frequency. The second cycle transmits the unique frequency for the relay beacon. This replies at the common frequency thus triggering the seabed beacons. By using the revised ranges from both cycles it is possible to calculate the distance from the seabed beacons to the relay transponder and therefore obtain the acoustic position for the relay.

The LBL10 system received GPS (Trimble) and gyro input data from the ship's navigation systems. However, the LBL10 system itself works with UTM projection only and all output values are in UTM (metres).

Operation

Eight seabed transponders were deployed in the 15°45'N 46°55'W region. They were arranged in two diamond patterns of four (see Figure 8). The range of the individual transponders was not known but was estimated at approximately 8-10km. In an attempt to maximise coverage of the region of the four corrugated knolls (keeping as large an area as possible within range of three or more transponders) the distance between any two adjacent transponders was kept at ~7km where possible. Steep slopes and prime drilling targets were avoided.

Deployment

Each seabed transponder had the same configuration and each was deployed in the same way. The seabed mooring consisted of a concrete bottom weight (160kg in water), 200m of line to the transponder release ring, 15 m of line from the top of the transponder to three 17inch glass spheres held together by a short length of long-link chain. A 10m stray line attaches a 10 inch buoy to the top of the main buoyancy.

The complete mooring was built on deck prior to deployment. When deploying, the ship was initially positioned a few hundred metres upwind and the three glass spheres were lowered into the water using a crane and released. The 10 inch recovery buoy was then dropped into the water forward of the main buoyancy. Once the stray line was clear the transponder was lowered into the water using both lines attached to it. The 200m line was fed out as the ship moved slowly downwind onto the precise drop position requested and the weight lifted over the side using a cut line and the crane. As the ship drifted over the required location the cut line was cut. The position was recorded both in UTM & geographic coordinates. These are summarised in Appendix A01 for the eight transponders.

Calibration

Once the deployment had been completed the transponder net needed calibration, firstly for relative position and then for absolute position of transponders. A series of range data sets were obtained during several runs in different directions through the transponder net. This was carried out at 4 kt on day 112 (22nd April 2001) prior to the initial deployment of TOBI.

Once the data had been collected the data was processed using the LBL10 software. Various settings were tried but none of them gave a converging solution even though the data sets showed consistent ranges. During the previous cruise the rangemeter had been used with zero transponder delay and changed back to 15ms prior to this cruise. It was discovered that by altering the preset delay in the parameter file the data did converge. Several values were tried and it was found that 10 ms gave the best fit. This was then used for the rest of the cruise.

Once the transponder net was calibrated relative to itself – *i.e.* arranged to minimise the acoustic RMS errors of the ranges from the beacons to the ship to give the most self-consistent acoustic geometry – then the absolute positions were computed by moving the now fixed acoustic array to fit the GPS data. To check the calibration a small run was carried out in the southern part of the net during day 116 (26th April 2001), in the period when TOBI was inoperable. This confirmed the relative calibration, but showed a small absolute error (acoustic to GPS ~68m @ 270 degrees). As the ship acoustic position is logged the acoustic relay position can be corrected to the GPS by comparing the offset acoustic ship to GPS ship and applying that offset to the relay acoustic position. This has *not* yet been applied to *any* of the acoustic positioning data included in this report.

TOBI Operations

During the TOBI runs the slant range to a transponder placed above the depressor weight from the acoustic navigation fish was logged. The transponder was mounted 50m above on the first deployment and 35m above on the second. While inside the transponder net the ranges to the seabed beacons was also recorded. This was not successful and only provided a few scattered locations for the TOBI vehicle.

BGS Drill Operations

When inside the net coverage area a transponder was used 50m up the conducting cable. The results after processing were examined and the valid data blocks (if any) were used to form an average value. Where two blocks could be used these were used separately and then compared to form the final result (Appendix A02). The data were chosen to provide a near continuous block of valid data if possible during the drilling but no later than a couple minutes after it was away from the seabed. The error of a data pair compared with the average of the data block allowed noisy data to be removed. Some sites did not produce any valid data. See Appendix A02 for details.

Looking at sites which had good data coverage during both the drilling and recovery stages showed that as soon as the drill was lifted off the bottom it would very quickly swing back to a position directly beneath the ship if the ship had drifted during the drilling.

Dredging

Again when working in the area a transponder was placed 100m up the main dredge cable, *i.e.* 200m above the basket and 50m above the pinger. The data were collected and processed. Appendix A03 gives a graphical presentation of the data: UTM position X (easting) *v* time, UTM position Y (northing) *v* time, and UTM X *v* UTM Y. On all graphs the ship acoustic position is in pink and the acoustic dredge positions in blue. On the X-Y plots invalid dredge positions are shown in Yellow. Where no graphs exist then there are insufficient data to produce them.

Data Processing

Three sets of files were produced for each of the drill & dredge sites. These being a *log* file which contains the raw LBL10 data, a *par* (parameter*)* file which holds the system files and a *cap* (capture) file which logged the positional data. Only the capture files data are directly available for use. The format of capture file is as follows:

YEAR DAY HH:MM:SS CYCLE VALID UTM NORTHING UTM EASTING DEPTH RMS ERROR GPS LAT LONG

For both the drill & dredge the *cap* files were imported into a spreadsheet. For each station / deployment a separate sheet was created. The year, day, valid, rms error, GPS data was deleted. The data was then sorted on cycle. The relay data block was then cut from the spreadsheet (cycle=1) and pasted along side corresponding ship cycle (=0) using time as the match. Once the complete file had been checked for mismatched times the cycle, relay times, and depths for the ship cycle were deleted from the spreadsheet. Note this data can be obtained from the raw cap files if required. The first validation of the data now took place. A temporary valid flag was created which marked the data row as valid if both the ship & relay data pairs contained non-zero values. A sort was then carried out on this flag and the valid data set transferred to the main file (Appendices A02 and A03) The temporary work spreadsheet was then deleted. A valid flag was created such that it was set if the horizontal range was less that 100m.for the drill and 1000m for the dredges

Recovery

The transponders were recovered in two groups. An over-the-side dunking transducer and TT301 telecommand unit were used to release the transponders. All transponders released without any problems. Generally they were released at the previous site (~5km slant range), shortening recovery time, and helped by the excellent weather.

The moorings were grappled and tied onto the crane for recovery. The transponder itself was pulled in by hand. Out of the 8 transponders recovered 5 were tangled, 4 of which were recovered without incident, the remaining one came untangled as it was being lifted and crashed down onto the deck, possibly damaging the spheres.

General Points

The PC running the LBL10 software crashed continuously during relay navigation. No reason could be found for this during the cruise. Problems with other equipment using a very limited acoustic bandwidth need to be addressed as soon as possible, and not on board. This would have saved a large amount of expenditure on preparing equipment that was not used.

5. Operations: Multibeam Echosounding

James Clark Ross is fitted with a hull-mounted Kongsberg Simrad EA120 multibeam swath mapping system, installed in the summer of 2000. The nominal sonar frequency is 12kHz with a ping rate determined by water depth. It has 191 beams, ping width of 1°, and an angular coverage of up to 150°. The angular coverage sector can be varied with depth, thus maximising the number of usable beams. The beam spacing is normally equidistant with the available equiangle. At maximum, this gives a 1° x 1° seabed footprint (~50m at 3000m water depth) and a measurement accuracy typically of the order of 0.2-0.3% of water depth (*i.e.* 6-9m at 3000m). This is one of the highest resolution systems on any non-military survey vessel to date. In practice the data were far better, especially at far range, when the beam width was reduced from its maximum to between 58° and 65° on either side, giving typical swath width of ~10km in 3000m of water.

Bathymetry data were collected as soon as *James Clark Ross* was outside the Brazilian 200nm exclusion zone (00°37.70'N 37°40.76'W, at 1126Z on 16th April 2001 (Julian day 106)), and continued until she entered the exclusion zone of the Azores at at 34°57'N 28°35'W, at 1712Z on 21st May 2001 (141). The system was either switched off or not logged when the ship was on station for drilling or dredging.

Processing of the bathymetry data was carried out on board ship by the scientific party using the shipboard 'Neptune' system. The raw data, recorded in 30 minute blocks, were transferred from the workstation used for logging onto a separate UNIX machine for processing. The scientific party processed the raw data from the transit to the survey area and much of the data from the survey area itself onboard ship. Initially the raw data were gridded at a grid cell size of 100 metres both in the E-W and N-S directions. We used the global rule of removing depths in a grid cell greater than 2 standard deviations from the mean and a noise level of 5%. Manual editing was done in Binstat. Some artifacts remained in the data, espscially along beam edges. These were removed wherever possible by careful and detailed editing . Processed data were saved as ASCII xyz lat/long files. These files were later exported to the GMT program [Wessel & Smith 1991] and regridded to produce bathymetry maps and printed to the onboard HP1055 A0 plotter. In some cases data were merged with the existing French Seabeam data (the Japanese/American multibeam data were not available in digital format). In practice many artifacts were still visible on many of the finished maps, and post-cruise processing using software more sophisticated than the version of Neptune installed on board will be necessary.

Expendable Bathythermograph (XBT)

Echo-sounding is used to calculate the depth of the seabed below the ship, and for bathymetric imaging of the seabed, using the ship's bathymetric EM120 system. However, processing of this data requires prior knowledge of the sound velocity structure of the water column, which varies with varying water temperature, depth, and salinity. The accuracy to which this is constrained directly affects the accuracy to which the sea depth can be calculated and displayed by the EM120 workstation. Expendable Bathythermographs (XBTs) and Sound Velocity Probes (SVP)s are used in conjunction with the Sippicam Ocean Systems software to produce an acoustic velocity profile of the water column below the ship.

Two models of XBT probe were used during the cruise, the Sippican T5 and T7. T5 probes were used during ship transit of less than 6 knots, and the heavier T7 probes when faster than 6 knots. The probes contain a thermistor attached to the logging PC by a conductive copper wire. The wire is spooled to the aft launcher and the probe and released at a known rate; depth is then a simple function of time.

Before bathymetry acquisition commenced a 'one-off' SVP was released from the motionless ship. The SVP is more accurate than the T5 and T7 models whose profiles were then compared to the SVP's profile. The daily XBT and SVP profiles correlated well.

For the duration of bathymetric data acquisition, an XBT probe was released daily into the sea from the moving ship. The exception was when the ship was conducting science in the same area. The released XBT probes sank and relayed the temperature of the water with increasing depth back to the ship via the thin copper wire to a 'terminal depth' (of 1830 metres and 760 metres for the T5 and T7 probes respectively) before their copper wire snapped. Using the salinity at the surface at the point of XBT release, the Win MK12 programme version 1.4.3 on the Sippicam Ocean Systems software created the sound velocity profile measured by the descending XBT, and extrapolated this profile down to 12000 metres deep. The processed XBT data was then uploaded to the EM120 workstation ensuring correct multibeam depths were displayed.

The XBT system worked without problems throughout the cruise. In reality only the upper 200 metres of the water column showed any significant change in sound velocity with location.

6. Operations: TOPAS Sub-Bottom Profiler

The 'TOPAS' (TOpographic PArametric Sonar) system fitted to *James Clark Ross* is a high-resolution narrow-beam sub-bottom profiler. It uses parametric interference of sound waves generated by a hull-mounted transducer array to construct a narrow (≤5°) acoustic beam with high (potentially sub-metre) spatial resolution and high band width. It has a primary frequency of 15kHz and a range of secondary frequencies generated in the water column from 0.5–5kHz in a variety of pulse forms, including chirp mode. TOPAS requires close monitoring of gain, seafloor tracking and front-end high-pass filtering during data acquistion, and further post-processing including digital band pass filtering, application of time-varying gains *etc.*

During JR63 we tried on several occasions to use TOPAS to monitor sediment thicknesses near the ridge axis and on top of the corrugated surfaces. The purpose of surveying the latter was to see whether we could detect sediment drifts and thus aid drill site selection. In practice it was extremely difficult to detect any coherent reflections whatever the input parameters chosen, whether over the rough near-ridge topography or over older sedimented terrains, and it required the almost constant attention of the BAS ITS and ETS personnel. Furthermore, the transmission frequencies of TOPAS interfered with four of the acoustic transponders from the long baseline navigation system (the four deployed in the northern diamond: see Acoustic Navigation section). Accordingly the TOPAS was used infrequently during cruise JR63.

Holding station or sailing at less than 1kt over the surface of the SE corrugated knoll (15°45.45'N 46°53.48'W at 111/2230Z) we were able to detect some high-amplitude returns at the seabed which probably imply bare, hard-rock seafloor. Elsewhere, however, it was difficult in most instances even to pick a seabed reflection, probably in part because of interference from side lobes from the rough topography. Only in a few instances were any sub-bottom reflections seen: notably at 15°46'N 46°54'W, the north-central part of the southeast corrugated knoll (near dredge JR63-DR22), where a number of seabed-parallel reflections of the order of 15m thick were observed. It is possible, therefore, that substantial thicknesses of sediment (gravel?) do blanket some parts of the corrugated surfaces (as is probably the case at other core complex massifs where no basement outcrops have been observed), but a far more thorough survey needs to be undertaken before this can be concluded with any confidence.

7. Shipboard Three-Component Magnetometer

The British Antarctic Survey Shipboard Three-Component Magnetometer (STCM) was installed on *James Clark Ross* in February 1996. Its purpose is to measure the Earth's magnetic field around the vessel. Magnetic field anomalies recorded by the STCM system show variations in the magnetic flux density of the area of seafloor beneath the vessel, which can then be mapped.

A Bartington Triaxial Magnetometer (M3CES) is located on the upper deck of the James Clark Ross and contains three magnetometers that measure static and alternating magnetic fields in three axes. The three component signals are converted from magnetic flux density into a bipolar digitised analogue voltage by three multi-channel digitising 6B12 modules, and the measured values passed down to a PC located in the Underway Instrumentation and Control Room (UIC). The STCM software package, running in Microsoft Windows, interrogates the 6B12 modules, converts the voltage signal to micro Teslas (µT), then displays the x, y, z, and total field components on a magnetic flux density versus time x-y graph. Pitch, roll, heading and GPS can be used later for real-time processing of the data set. The data were not processed during the cruise. There were no operational problems with STCM for the duration of the cruise.

For calibration purposes, 'figure-of-eight' manoeuvres were performed in order to calibrate the compass, and assess and calculate out the effect of the magnetic field of the ship. These were performed on Julian days 108, at 9°43.6'N 43°27.6'W, and 136, at 15°45.5'N 46°45.1'W.

8. Operations: TOBI

System Description

TOBI – Towed Ocean Bottom Instrument – is Southampton Oceanography Centre's deep towed sidescan sonar vehicle. It is capable of operating in 6000m of water. The maximum water depth encountered during the TOBI surveys during this cruise was around 4500m.

Although TOBI is primarily a sidescan sonar vehicle a number of other instruments are fitted to make use of the stable platform TOBI provides. This particular TOBI system ('TOBI2') was built for RVS in 1995 and has a different instrument suite to that of the SOC TOBI. For this cruise the instrument complement was:

1. 30kHz sidescan sonar (Built by IOSDL)

2. 8kHz 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)

A fuller specification of the TOBI instrumentation is given in the following section.

A Maplin GPS receiver provides the TOBI logging system with navigational data.

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

For this cruise the ship's winch system was used for towing with separate deck-mounted launch and umbilical winches. During the TOBI surveys the winch was controlled from a remote station in the UIC laboratory. The deck electronic systems and the logging and monitoring systems were set up along the port side of the UIC laboratory, giving both watchkeepers and scientists a clear view of the incoming data. The data are recorded onto magneto-optical (M-O) disks. The setting up of the TOBI equipment was straight forward as the system had been on the JCR in previous years for cruises JR39B and JR51. The umbilical winch was mounted on the starboard side of the main deck with the launch winch in the middle of the deck just aft of the TOBI container.

TOBI2: Brief Technical Specification

Towing method	Two bodied tow system using neutrally buoyant vehicle and 600kg depressor weight
Size	4.5m x 1.5m x 1.1m (l x h x w)
Weight	1800kg in air
Tow cable	Up to 10km armoured coax
Umbilical	200m long x 50mm diameter, slightly buoyant
Tow speed	1.5 to 3 knots (dependent on tow length)
Sidescan sonar frequency	30.414kHz (starboard) 32.904kHz (port)
Pulse length	2.8ms
Ouput power	600W each side
Range	3000m each side
Beam pattern	0.8° x 45° fan
Profiler sonar frequency	6 to 10kHz Chirp
Pulse length	26ms
Output power	1000W
Range	>50ms penetration over soft sediment
Resolution	0.25ms
Beam pattern	25° cone
Magnetometer	Ultra Electronics Magnetics Division MB5L
Range	+/- 100,000nT on each axis
Resolution	0.2nT
Noise	+/- 0.4nT
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° Celsius
Resolution	0.0001° C
Accuracy	+/- 0.005° C
Depth range	0 to 7000 dbar
Resolution	0.02 dbar
Accuracy	+/-0.12% F.S
Pitch/Roll	Dual Axis Electrolytic Inclinometer
Range	+/- 20 degrees
Resolution	0.2 degrees
Altitude	Taken from profiler sonar
Range	1000m
Resolution	1m

TOBI Deployments

TOBI was launched and recovered twice during the cruise. The times are listed below along with relevant comments:

Deployment	Start time/day	End time/day	Comments
1.	04:05/113	07:43/116	Curtailed due to sidescan problem.
2.	20:50/116	20:07/118	Continuation of run 1.

The M-O disks used and their relevant numbers, files and times are listed in JR 63 MO record.doc.

The James Clark Ross is equipped with a large stern mounted hydraulic 'A' frame capable of deploying and recovering TOBI in its normal athwartships mode. The main sheave was used for deploying and recovering both the TOBI vehicle and the depressor weight as well as towing during the survey. No problems were encountered during any of the launch or recovery operations, which is a great credit to the deck crews involved.

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 350 to 400m above the seabed by varying wire out and/or ship speed. This was made more difficult than usual because of the steep terrain and the failure of the profiler, meaning that altitude had to be derived from the first return of the sidescan. Ship speed was usually kept at 2.5kt over the ground with fine adjustments carried out by using the winch. As well as flying the vehicle and monitoring the instruments watchkeepers also kept track of disk changes and course alterations.

To aid TOBI flying a regularly updated position of TOBI along the ships' track was kept by the scientific watchkeepers. This position was plotted onto a bathymetric section of the current track. This gave a good indication of the vehicle's position relative to the local terrain. However, it was only as good as the bathymetric data put into the plot, and it became obvious very early on that the gravity-derived bathymetry had large errors both in position and magnitude. Errors of over 200m on ridge peaks were common and led, on at least three occasions, to 'near misses'. The vehicle came within 20m of the seafloor on at least one occasion. A close watch had to be kept on the Simrad EM120 multibeam output in order to correct the poor gravity bathymetry. This was

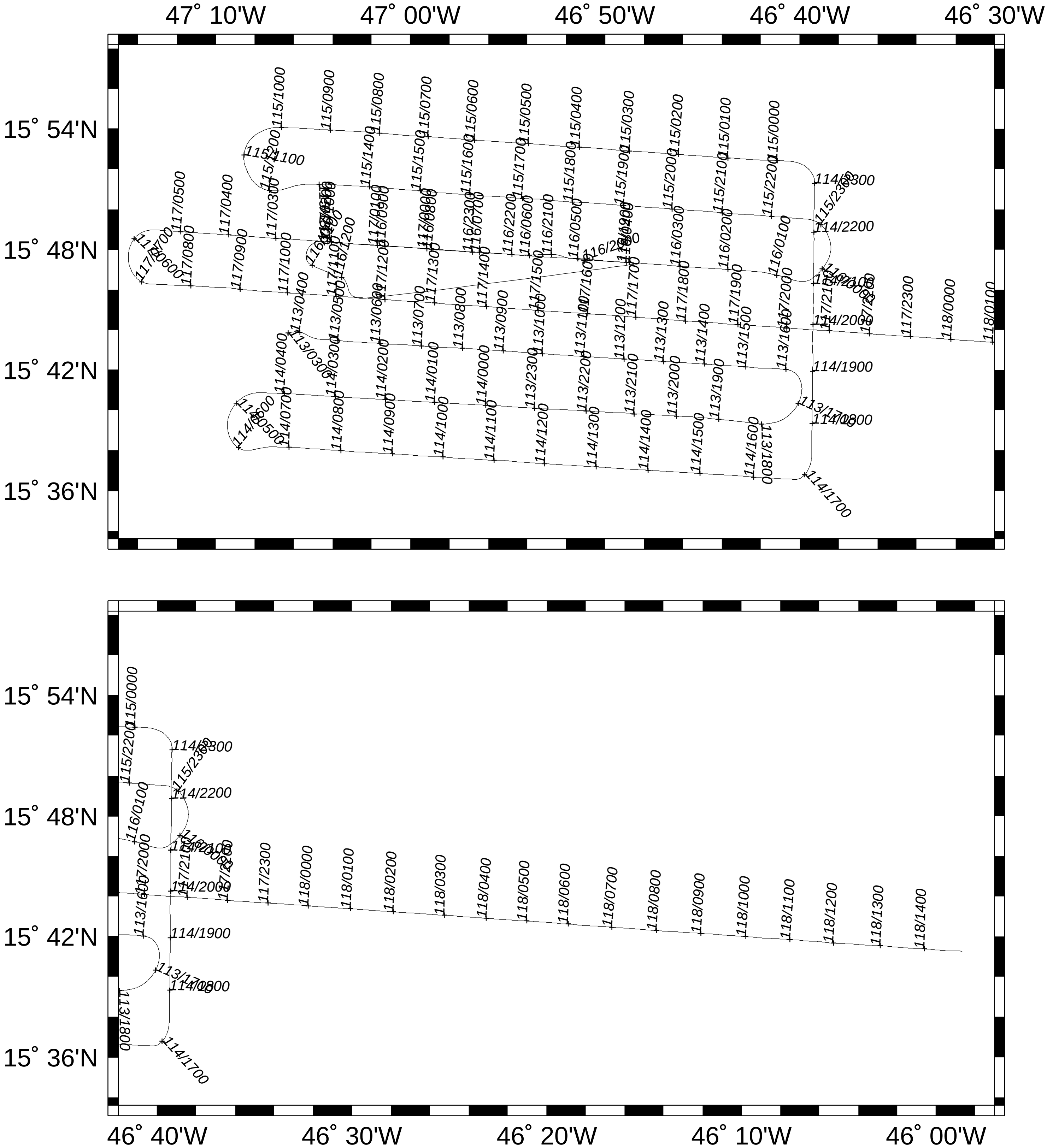


Figure 4: Track and time stamps of the TOBI vehicle navigation. The corrugated surface W of the axis, its lateral terminations, and the hanging wall have ~100% sonar coverage (top). The long track crossing the ridge axis (bottom) extends to the East flank, towards another striated surface. Lines are run sub-parallel to the spreading direction and to the striations (~094°).

made easier once a rolling hour-long output of the centre beam depth was displayed on the ship's computer system.

A remote readout for the winch system was sited on the rack of TOBI monitors so that the watchkeeper could easily observe winch parameters. At the end of each winch operation the wire out was noted and also manually input to the logging system.

Because of the lack of real-time profiler data, altitude had to be measured from the first return of the sidescan signal on an oscilloscope. A simple nonograph converted milliseconds to metres based on a sound velocity of 1500 ms^{-1}. Altitude changes were input manually into the logging system in 25m steps.

Instrument Performance: Profiler

During the passage to the work site the chirp profiler was set up and tested. A change of D/A converters in the sensitive data recombination circuit considerably reduced the system noise level.

On deployment on day 113 the chirp profiler operated correctly for approximately 35 minutes. The sea surface was observed clearly until, at a depth of 200m, the transmissions stopped. Fortunately no other instrument on the vehicle was affected so it was decided that the run should continue. On recovery on day 116 it was found that the profiler power amplifier had a damaged MOSFET transistor and driver chip. On further investigation the profiler array was found to be low impedance (<10kohms) due to water ingress into the ceramic ring transducers. This is certainly the cause of the power amplifier damage. The water probably got into the array via the cabling which from further inspection seemed to have been affected by UV/sunlight and become semi-porous. All the rings in the array were of less than infinite impedance when measured with a 1000V megger. A range of 20kohms to 180Mohms was observed for the seven rings. This precluded any further use of the array as there were only two spare rings in the TOBI spares kit. The electronics circuits were repaired and tested but for the remaining deployments the array was disconnected and transmissions disabled.

The profiler top end receiver level was set to 0.3 during the survey. The low gain value is a result of using the higher gain chirp correlator system. The gain in the profiler receiver was subsequently reduced by 20dB by making R20 100kohms instead of 10kohms. This should make the receiver setting a more normal 3.0 for future use.

Instrument Performance: Sidescan

As part of the on-going TOBI development plan and taking advantage of lessons learnt with the SOC TOBI a new grounding scheme, incorporating isolated chassis parts, was commissioned during the run up to the work area. This improves noise performance and gives the system immunity from unintentional sea earth paths. The electronic systems and arrays were checked and run on deck prior to the first deployment in order to highlight any problems.

Once deployed on day 113 the sidescan worked fine until a sudden loss of signals occurred on day 116. An increase in the current taken by the vehicle – up to 254mA from 208mA - was also noted indicating a problem in the vehicle. The vehicle was recovered and the sidescan electronics tube removed for inspection. No sidescan electronics problems were found. The starboard sidescan array harness, however, was found to be low impedance. This was replaced and the electronics tube replaced. A further problem was indicated as no sidescan signals were received at the deck unit. The hydro electronics tube was removed from the vehicle and the signals checked. All was found to be OK. The signals were then traced in the deck unit and the problem was eventually traced to the 50kHz local oscillator chip in the sidescan downshift circuit failing. A replacement was eventually found from the old spares from the John Biscoe! The vehicle was rebuilt and redeployed. The total downtime from the initial problem to getting back on line was approximately 15 hours.

For the remainder of the cruise the sidescan data and image quality were good apart from some low-level system noise creeping into the starboard sidescan channel at far range. This was eventually traced to array pick-up from the DPSK telemetry system. Changing the frequency of the DPSK telemetry from 29 to 27kHz subsequently eliminated this noise.

The sidescan top end receiver levels were 5.0 for the port channel and 1.3 for the starboard. These settings gave equal signal levels for both sides.

Instrument Performance: Magnetometer

The magnetometer functioned well throughout. The data had low noise – a few nT – and were smooth. The magnetometer data are used to give magnetic heading of the vehicle. This has to be adjusted by 18°W for magnetic variation to give true heading. 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.

No calibration of the magnetometer in the vehicle was undertaken. A difference of approximately 2000nT was observed between a vehicle magnetic heading of 290° (35000nT total field) and 110° (33000nT total field). The difference is due to magnetic fields created by currents within the vehicle and magnetic materials close to the magnetometer.

Instrument Performance: CTD

The CTD unit gave no problems at all and was totally reliable: a major achievement given its recent history. The CTD data are used to give derived local sound speed and salinity. In the work area a velocity minimum of 1489 ms^{-1} was observed at a depth of 850m.

Instrument Performance: Pitch/Roll

These were fine during the survey. It was noted that the raw output of this device is in the opposite sense to that of the SOC TOBI. This was easily overcome in software but needs to be repositioned so that there is compatibility between the systems.

Instrument Performance: Deck Unit

The failure of the sidescan downshift local oscillator chip on day 116 highlighted a lack in the spares kit for this TOBI system. Before the next cruise an audit of spare components will have to take place to ensure full coverage of repairable items. Otherwise the deck unit performed excellently throughout.

On the passage to the work area a Maplin GPS system was commissioned to provide the logging system with position and time information. The aerial was mounted on the ships' rail above the

UIC room. Despite being a cheap and cheerful unit it performed without error during the whole survey.

Data Recording and Replay

Data from the TOBI vehicle is recorded onto 1.2Gbyte 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. Data was recorded using TOBI programme LOG.

In order to establish a common standard for both SOC and ex RVS TOBI systems the SOC data structure has been adopted. This means that the data files are now of common format although in the ex RVS systems the swath and gyrocompass fields are blank. This makes for easier data processing as programmes need only cope with one type of data. During the cruise all TOBI programmes were brought up to date to use this new data format, altering header files and where necessary making them Y2K compliant – the ex RVS TOBI has not been used in anger since 2000.

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. DIGIO8A displays the real-time telemetry from the vehicle – magnetometer, CTD, pitch and roll – plus derived data such as sound speed, heading, depth, vertical rate and salinity.

LOG, PROFDISP and DIGIO8A 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. ERASDISC was used to generate anamorphically and slant range corrected data files that DISSCRAY could print out onto a Raytheon TDU850 thermal recorder. These paper records were used to quickly make up a mosaic of the survey area to assist in finding suitable drill locations. A program called TOBIEXRACT was used to strip off navigation, magnetic and CTD data from the raw TOBI data files and store it in ASCII format for direct importation into a spreadsheet. BLOWUP was used to generate large images of areas of interest, printing onto a Raytheon TDU850 thermal recorder and pasting together.

Although old the computer systems ran reliably throughout the cruise. The only glitch came during day 118 when the logging system froze for no apparent reason. The system was rebooted and logging continued. The file had to be closed using the Windows scandisk utility.

Summary

Apart from the profiler the system performed well with some excellent sidescan imagery producing a detailed mosaic of the survey area. This cruise provided the first opportunity to bring the two TOBI systems closer together. Although differences still exist these can be refined further prior to the next use of the system.

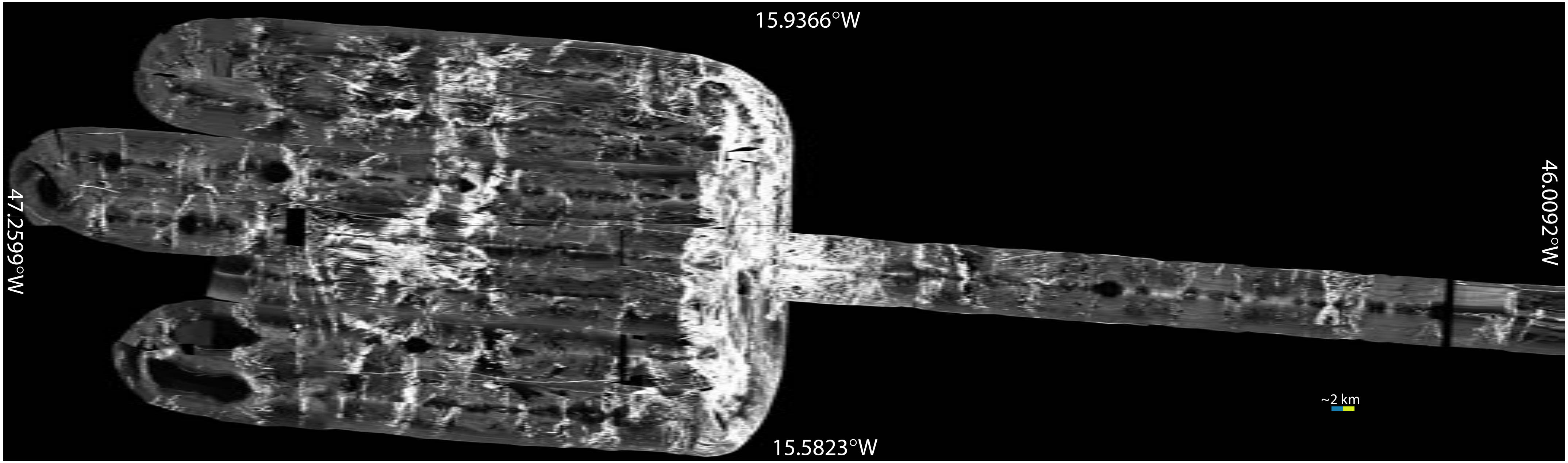


Figure 5: TOBI side scan sonar backscatter mosaic of the study area. Reflective zones e.g., axial valley volcanic structures) are white, and non-refelctive areas (e.g., sediments) are grey. The corrugated surface (Figure 2b) shows highly reflective striations parallel to the spreading direction (i.e., TOBI tracks). Similar striations are visible over the Eastern corrugated surface, at the end of the TOBI track. The western corrugated surface is bounded to the East (ridgewards) by a high-angle normal fault with mass-wasting structures, and to the West by a high-angle normal fault. with less scarp relief. The northern and southern limits are not well-defined. The hangingwall is highly sedimented and dissected by axis-parallel, high-angle normal faults dipping towards the ridge axis, as commonly found at slow-spreading ridges. The axial valley is highly asymmetrical, with a large hig-angle normal fault on the west flank, and a series of smaller, closely spaced faults on the East side.

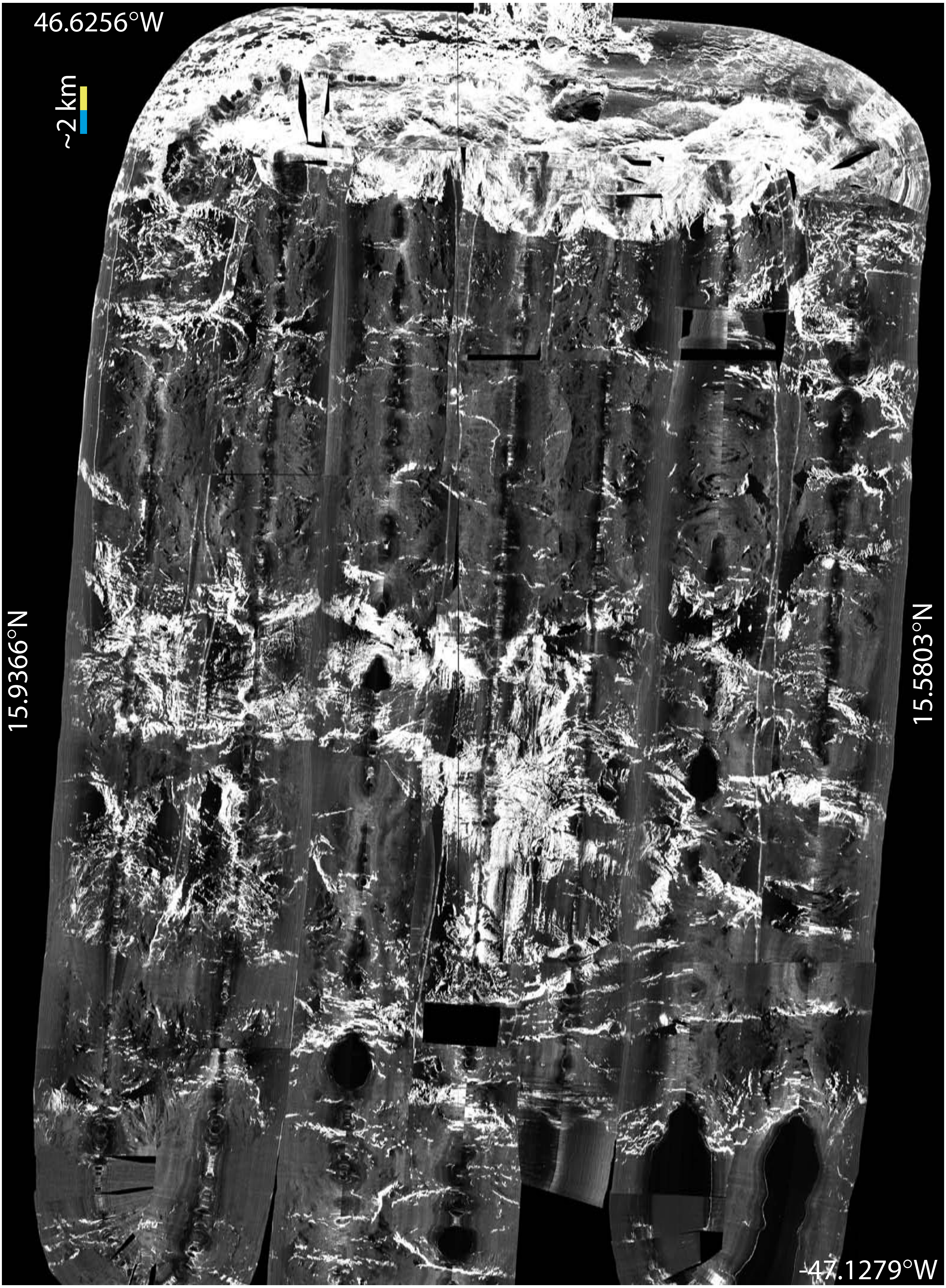


Figure 6: Detail of the TOBI mosaic over the western flank of the ridge axis, showing the striations over the corrugated surface.

9. TOBI Processing

Data Acquisition

TOBI was deployed 113/0400 to 118/2000 (Figure 4) with a gap between 116/0300 and 116/1200 due to an electrical fault in one of the TOBI transducer housings. There was a smaller gap between 118/1200 and 118/1230 due to a logging system reboot. The acoustic profiler failed on deployment and was inactive throughout the survey and there were regular periodic spurious readings (seemingly due to software buffer overflows) in the magnetic and pressure signals which affected orientation and location processing.

The lack of acoustic profiler resulted in poor altitude control. Hence altitude was predicted from both the EM120 bathymetry data cullected during this cruise, and from the satellite-derived topography [Smith and Sandwell, 1997]. However, the received side-scan imagery suffered from inappropiate corrections in vehicle altitudes, which varied between 20 and 1200 m.

The wireout logger from the ship's instrumentation also gave spurious readings on several occasions, due to buffer overflow problems. These values had to be calibrated to obtain appropiate wire out readings needed for the TOBI navigation.

Data Pre-Processing

The PRISM suite of software developed at SOC was intended for use in the pre-processing stage but the sparsity of usable data meant that much of the navigational information had to be constructed from a variety of sources.

Both ship's navigation and TOBI attitude (heading, roll and pitch) are not properly read and transfered to the file headers by PRISM. Ship's navigational information was used to define position in the header files, as the PRISM software contains a bug which prevents it from processing western longitude values correctly. TOBI attitude information (heading) was calculated from magnetic data, after calibrating and cleaning the raw data. Pitch and roll were read directly from the original TOBI headers then added to the PRISM header files, which contained spurious values. Processing to obtain heading, pitch and roll was done in Matlab.

Altitude was obtained by handpicking the sea bottom reflector from the raw sonar imagery. This was also carried out in Matlab using a stretched line length (1000 pixels per line) and rendered with a highly saturated colour palette. A reasonable fit was given for most of the survey.

The corrected wireout data was compared with the acoustic range. A good correlation was achieved during straight tows of the survey, but a poorer match was found at the turns, where the range was often greater than the cable length. Furthermore, a combination of poor wireout data and a weak algorithm in the calculation of TOBI position by the PRISM suite resulted in unrealistic TOBI tracks, with TOBI being 'pushed' outwards during turns. These tracks were corrected by hand in Matlab, and forcing a short wire lengths (1500 m) to produce more realistic navigation in the turns. A final vehicle navigation file was produced from all of these preprocessed sources in lieu of a PRISM-derived file. This navigation was then used to generate the imagery in the processing stage of PRISM.

Data Processing

The PRISM suite contains a set of algorithms for suppression of sea-surface reflectors, navigation and attitude correction, pixel registration and various despeckling and shading routines. The resulting tiles were subsampled to give 6 m pixel sizes over the 3000 m swath width at either side of TOBI. The imagery was generally of a good quality although the high altitudes (> 1000 m) sometimes achieved prevented the sea surface reflector from being removed. Secondly, the hand-picking of the sea bottom sometimes resulted in poor registration at the center of the TOBI track line, leaving “eyes” at the center of the TOBI swath. The resulting imagery (Figures 5 and 6) suffers from all of the above problems, but the final map tiles (referred to as maps in the GIS post-processing package) showed good geographic registration. This was confirmed where vehicle tracks crossed perpendicularly in map 3. The imagery had some faint instrument-induced striping in the far-field of the lines which could not be removed by PRISM. The source of this noise was identified after TOBI operations, and corrected for future deployments. Approximately 90% of the lines were usable, with most of the turns being too discontinuous and poorly registered (Figure 4).

The final tile coordinates (longitude, latitude) are given below as lower left, upper left, upper right, lower right, in decimal degrees. *N.B.* the southern and western borders of box 5 were manually altered to accommodate the 9th (final) line after the rest of the maps had been processed. The ones here are correct for the processed map.

map 1
-47.2374 15.6015
-47.0015 15.6015
-47.0015 15.7637
-47.2374 15.7637

map 2
-47.0015 15.5799
-46.7656 15.5799
-46.7656 15.7637
-47.0015 15.7637

map 3
-46.7656 15.5799
-46.5298 15.5799
-46.5298 15.7637
-46.7656 15.7637

map 4
-46.5298 15.6772
-46.2939 15.6772
-46.2939 15.7637
-46.5298 15.7637

map 5
-46.2939 15.5
-46.0092 15.5
-46.0092 15.7528
-46.2939 15.7528

map 6
-47.2599 15.7637
-47.0352 15.7637
-47.0352 15.9366
-47.2599 15.9366

map 7
-47.0352 15.7637
-46.8106 15.7637
-46.8106 15.9366
-47.0352 15.9366

map 8
-46.8106 15.7637
-46.6084 15.7637
-46.6084 15.9150
-46.8106 15.9150

Image Post-Processing

Each map was imported into the Erdas Imagine GIS package to allow stencilling of each layer where TOBI tracks overlapped. Generally a good join was made between anti-parallel tracks and where there were obvious differences in data due to opposite ensonification the section with the most information was selected for the final map. In the case of the perpendicular cross-over in map 3 the centre-lines could be removed and replaced with the good data from the overlapping track to good effect. The only gaps in the final mosaic were where TOBI had been steered (ploughed) too close to the seafloor, on the turns, and where the south-north track was not quite on top of the easternmost turns. Although a time-consuming job, we were able to alter the wireout values and map areas to optimise the amount of information being geographically registered, and the map boundaries listed above reflect these final map edges.

Image Presentation

All maps, map layers and the final mosaic were converted to JPEG format (Figures 5 and 6) for further use as imagery and the mosaic and maps were converted into an ARC-INFO accepted format for further data analysis. Attempts were made to drape the imagery over the bathymetry but it was found that the Imagine system could not export the data as lat-lon registered pixels. Furthermore, the raw file projection was distorted in position and form as it was registered to the UTM zone around the Greenwich meridian as opposed the zone 23 (45W). GMT reprojection of the ~2Gb data set was too time-consuming in terms of CPU cycles to try co-registering the data with bathymetry, so this will be done using ARC-INFO at a later date ashore.

10. Operations: Dredging

Rock dredging is a simple but effective way of sampling the seabed. On cruise JR63 we used dredging to complement the rock drilling operations: it is particularly suitable for sampling steep slopes and for lower resolution, more regional studies of the distribution of lithologies.

The dredges used were standard RVS/SOC issue rock dredges. They have a 3-foot (1m) wide mouth, no teeth, and a chain bag with internal rope bag. A cylindrical pipe is mounted by means of chains at the back of the main dredge. The dredge is attached by metal arms to a 10 foot (3m) chain via a main weak link, swivel and shackles. The arms are pinned to the dredge mouth, initially by 6-inch nail but later (see below) by stronger shear pins. Also attached, above the main weak link, is a 13mm wire safety strap which wraps around the chain bag to choke the dredge yet still recover it if the main weak link fails. The chain itself is attached to a 100m-long pennant wire via another, stronger weak link to the ship's main coring warp. The pennant was attached and detached at every deployment and wound onto a separate drum on deck. A 10kHz pinger (with 1 second transmission rate) was attached 50m up the main ship's cable, *i.e.* approximately 150m above the dredge itself.

The size of the main weak link used depended upon water depth, and was calculated so that the safe working load of the coring warp (7.8t) could not be exceeded. For a wire out of less than 3000m a 5t weak link was used, for a wire out of 3001-4200m a 4t weak link was used, and for a wire out of more than 4200m a 3t weak link was employed. In practice, given that wire out inevitably exceeds water depth during dredging operations, the 5t weak link could be used in starting water depths of a maximum of ~2800-2900m. Most dredges run during cruise JR63 used this weak link.

Dredges were controlled by monitoring cable tension on the winch control display and a hard-copy waterfall-type paper trace. The pinger was monitored (but not recorded) using a PES-4 waterfall display on a PC. This showed the direct arrival from the pinger plus a seabed reflection, and calculating the time difference between the two yielded the distance of the pinger off the seabed.

The strategy employed during operations was to drag the dredge uphill, typically a distance of 500-1000m. Wire was paid out until the pinger was 50-60m off bottom – *i.e.* the pennant wire was fully on the seabed – and then the ship was moved at ~0.5–0.75kt towards the designated end point. Wire was winched in or paid out to keep the pinger at a more or less constant distance off the bottom and cable tension was monitored. Once the ship was at the end position it held station and the cable was slowly winched in (typically at 5-10m/minute) until the pinger was more than 150m off the bottom. Once the dredge was undisputably off the bottom it would be winched in at a rate of up to 75m/minute. In practice few ‘bites’ were noted on the tensiometer while the ship was moving; many more would occur as the cable was being winched in from the end position. In a sizeable minority of cases the dredge would get stuck. In such cases the ship would be reversed down the track towards the start position, and we would try hauling in the cable until the dredge broke free. In a few instances this would take more than an hour.

Dredging during cruise JR63 was either from the starboard or the stern gantry, depending upon the wind direction (almost a constant ENE trade wind throughout the cruise) and the direction of the slope up which the dredge was being dragged. In practice dredges run in the direction of the quadrant between NE and SE were deployed from the stern, and all others from the starboard midships gantry. The ship’s head was kept to wind in all cases and she was moved in DP mode (dynamic positioning).

Following a major software crash on the ship’s winch control system during TOBI operations on day 118, the stored calibrations for wheel and cable diameter were lost and the system defaulted back to (incorrect) factory values. In all dredging operations the wire out when equipment was on bottom was consistently less than multibeam centre depths. The correction factor estimated by Simon Wright (Deck Engineer) is 1740/1700 x cable out for the dredge wire. ***All values in tables, appendices and the logs accompanying this report are given uncorrected.***

32 dredge sites were occupied during JR63, and at 29 of these some igneous rocks were recovered (Figure 7 and 8). Brief descriptions of rock types and other statistics are given in the Sample Description section below and in Appendices A14 and A15. Soft sediment – brown foraminiferal ooze – was found in the pipe dredge in almost all cases. The pipe dredge, in fact, was our main source of igneous material: the main dredge bag was empty in a majority of cases. Although we never broke the main weak link, the pins securing the dredge arms to the main mouth failed on many occasions. This resulted in the dredge mouth turning over on the seafloor and hence no material being able to enter the dredge. Stronger and stronger bolts were used in place of the six-inch nails but even 5t weak links were failing, principally because of the large shear forces put on them. In the end we tried welding the dredge arms to the mouth, but this resulted only in the arms becoming bent. The mouths, too, of some of the dredges were forced open. When operations finished only one of the six dredges brought on the cruise was operational. It was abundantly clear that these particular dredges were not robust enough to cope with the kinds of terrain encountered at mid-ocean ridges.

11. Operations: BRIDGE Rock Drilling

Introduction

The BGS BRIDGE drill is designed to take oriented hard rock cores and is so named because the original development of the drill was funded by the NERC BRIDGE (“British Ridge Inter-Disciplinary Global Experiment”) programme in 1996-98 [Allerton *et al.*, 1999; MacLeod *et al.*, 1998a, b]. All subsequent development, including the provision of a second drill rig complete with a full set of spare components has been funded by the BGS directly.

The prototype drill had undergone successful trials in 1998 on Atlantis Bank, from the RRS James Clark Ross (Cruise JR31), when 16 sites were cored, to a maximum water depth of 800m. Cruise JR63 was to be only the second utilisation of the system and the main target water depths were in the 1500-2500m range. It was also intended to carry out deeper attempts at the end of the planned programme of sites.

The Drill System

The drill is designed to be deployed from an armoured coaxial power and hoist cable such as the 17.5mm diameter one available on the James Clark Ross, using the vessel's main traction winch. All power, communications commands and data are transmitted via this coaxial cable. It takes a 35mm diameter core using a standard TT46 twin barrel system. The core is cut by the outer, rotating barrel and is scribed along its length with a single reference line as the core enters the inner, non-rotating barrel. During drilling, water is continuously flushed between the two barrels to cool the bit and to flush away the rock cuttings or any sediment. The scribed line is referenced to magnetic north using two flux-gate compasses mounted on the drill rig. As much as possible, the drill rig is constructed from non-magnetic stainless steel to minimise its magnetic signature. The compasses have an auto-compensation routine which allows them to compensate for the magnetic signature of the drill rig. The operation of the drill is monitored by a subsea computer which sends data from the suite of sensors on the drill to a computer on the surface for display to the operator. The same subsea computer receives operator commands via the surface computer enabling the drilling operation to be controlled in real time.

A monochrome stills camera on the drill rig is used to transmit seabed pictures back to the surface. This allows the site to be selected or rejected prior to coring and also provides a visual record of the site for archiving purposes.

Limitations imposed by the use of coaxial cable dictate the use of limited single phase power, onto which all data communications have to be transmitted. Though the use of modern, compact, motor controllers the drives for rotation, retraction and water flushing are driven directly fom 3 phase AC motors, providing a high degree of control and efficiency.

The original design of the drill permitted a maximum core length of 1100 mm. However, based on the Atlantis Bank experiences, modifications have been made to improve the stability of the rig and to give the drill bit/barrel more protection when landing on an irregular seabed. This has involved re-siting the main subsea electronics bottle to the bottom of the rig to lower the centre of gravity, reducing the possible maximum travel of the drill table. The overall length of the barrel has been reduced so that, on deployment, the drill bit does not extend as far below the centre of the rig frame, making it less likely to hit an irregular seabed on landing. The combination of these two adjustments has reduced the maximum drill bit travel, resulting in a maximum possible core length of 770 mm, when the drill is standing on a flat, level seabed.

Mobilisation

Mobilisation took place in Recife between 11th and 14th April. During this period one drill rig was fully assembled and compass calibrations carried out. Because of the location of the berth it was not possible to move the drill rig any significant distance from the vessel without encountering other large metal structures on the quayside. The compass auto-compensation routines were carried out by suspending the drill over the quayside from the vessel's aft crane. By raising the drill such that the feet were approximately 2m above the quayside, successful auto-compensation routines were carried out, to the compass manufacturers specification, by manually rotating the drill, slowly, through 360°. Both compasses achieved compensation noise counts of 9, (on a 0-9 scale), representing an accuracy of 0.5°. In both cases the magnetic environment count was 6, (again on a 0-9 scale). This gave an indication of the quality of the magnetic environment in which the compensation routine was carried out. This was within the manufacturer's specified acceptable range of 5 or greater.

The inner barrel orientation was fixed to line up with leg 2 on the drill rig and the angles between the compasses and this orientation were measured. These were then set into the compass software as fixed offsets. Thus all compass readings represent the *magnetic heading of the scribe.* No automatic correction is included for the magnetic deviation in the work area. Within the mechanical limitations of lining everything up it is estimated that the overall accuracy for the core orientation is within 5° (±2.5°). This must be regarded as an approximate figure for when the drill rig is vertical on the seabed. Any inclination must degrade the accuracy because the compasses can only compensate for rotation about a vertical axis and the errors increase with increasing inclination.

Operations

Drilling operations commenced in the evening of 28th April, on the completion of TOBI survey work when the common deployment cable became available and the drill cable termination could be made. The termination potting compound was allowed to cure overnight and the drill was first deployed the following morning (29th April 2001). During the first deployment (JR63-BR21) considerable problems were experienced with noise through the coaxial cable causing the surface operating programme to repeatedly hang. The flush motor on the drill failed and no core could be taken. Whilst recovering to the surface, the compass auto-compensation routine was run as the drill slowly turned in the water. The lower compass achieved a score of 9,7 and the upper one 9,8, reflecting the more stable magnetic environment in the water column compared with that at the quayside. On recovering the drill to deck the flush motor was changed for a spare and the drill redeployed.

With each successive deployment the noise problems were overcome with both hardware gain changes in the communications link, and with software changes in the surface controller. After the first 24 hours or so of shakedown, the operation settled into a smooth routine and continued for the next 12.5 days until the afternoon of 11th May. The detail of the operations on a site by site basis are fully documented elsewhere. The general procedure was to lower the drill to the seabed and take a photograph. On receiving the photograph at the surface control computer, the decision was taken whether or not to drill or pick up and move a few metres, taking a photograph at the next landing. In the event of the site being judged unsuitable, the pick up and move was repeated until a suitable site was found. On occasion this could take several hours, with the maximum number of landings performed at any one site being thirty (BR91).

In general the drill performed extremely well but did suffer a number of problems. These could be placed in two categories. Firstly, simple component failure and secondly, damaged components caused by landing the drill rig on very steep or irregular surfaces, causing it to fall over. On all occasions the problems were solved quickly by exchanging failed or damaged components for spares and, in most cases, no significant time loss ensued. The problems encountered in the first category included a change of drive chain (twice), a further motor failure(retract motor) and the loss of communication to the lower compass which resulted in changing to the spare main subsea electronics bottle. Of these failures only the first drive chain problem caused the current site to be abandoned. The second drive chain change was carried out after inspection between sites. The retract motor was changed between sites when its operation had been observed to be slow, and in the case of the compass failure the site was completed with the top compass reading only.

"four knolls" ocean core complex Mid-Atlantic Ridge visited by cruise JR63 May 2001

blue circles - BGS BRIDGE drill sites black lines - dredges scale 1:100 000

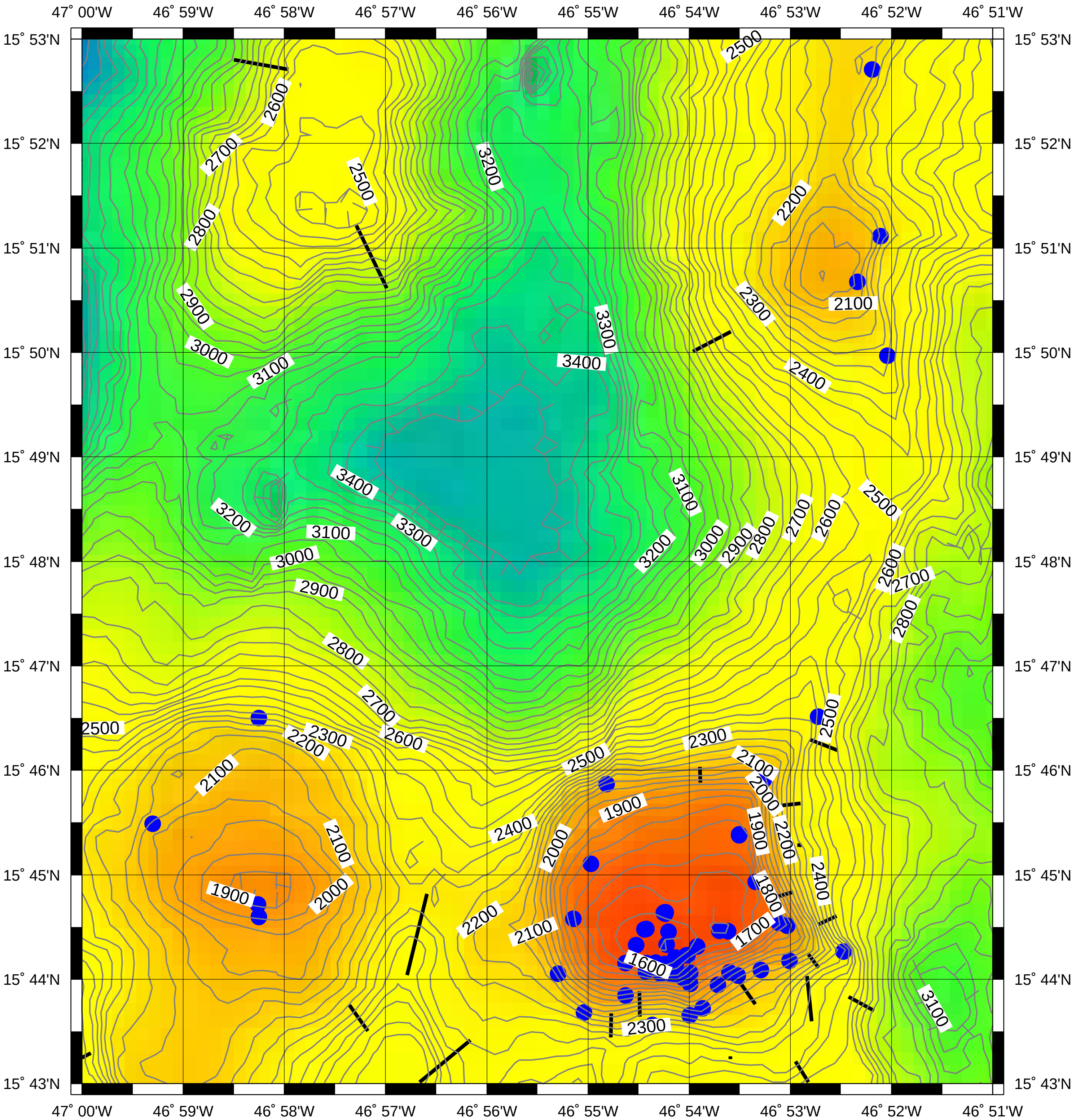
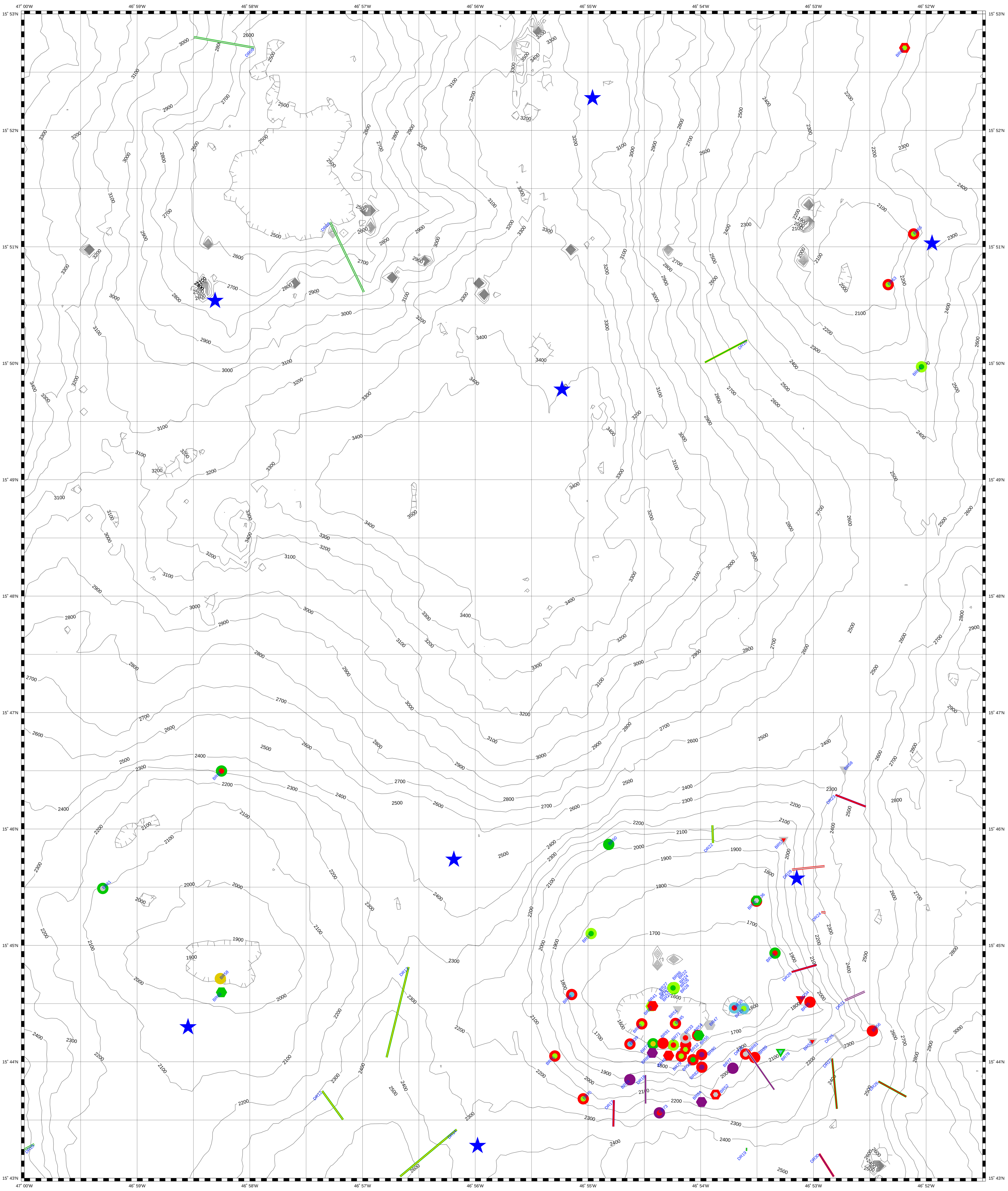


Figure 7: Location of dredges (black lines) and drill sites (blue dots) on the corrugated surface. Additional drill sites and dredges at the ridge axis (both N and S of the Fifteen-Twenty Fracture Zone) and in adjacent areas are omitted. Recovered lithologies are shown in Figure 8.

BGS BRIDGE drill JCR-63 sites BR21-BR91 "four knolls" ocean core complex

1 cm = 250 m = ~7.5 (60 grid squares) interpolated grid pixel size = ~45 m from 50 m bathymetry



LEGEND

inner circles, where present, indicate minor lithology

- sheared serpentinite
- serpentinized harzburgites (inc. peridotite, dunite and troctolite)
- gabbro
- dolerite
- basalt
- consolidated sediments
- unconsolidated sediments
- solid core
- igneous breccia
- sedimentary breccia
- gravel/talus depsoit
- sedimentary deposit
- acoustic transponder location

Figure 8: Location of dredges (lines), drill sites (colour symbols) and transponders used for acoustic navigation (blue stars). Sites at the ridge axis both north and south of the Fifteen-Twenty fracture zone are not plotted.

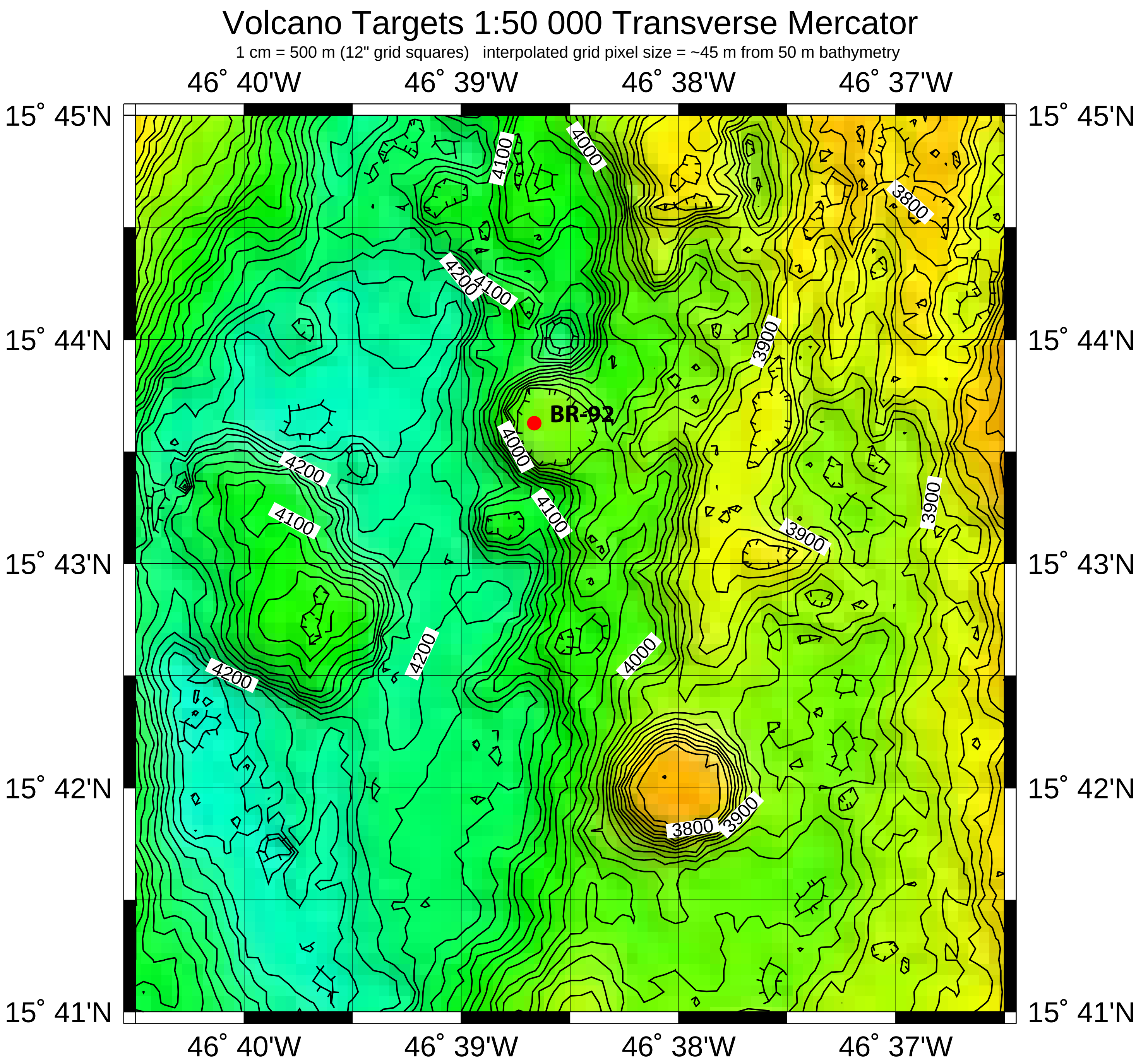


Figure 9: Bathymetry of the rift valley floor, showing flat-topped volcanoes and an axial volcanic ridge. The red dot corresponds to the drill site BR-92.

Failures in the second category, physical damage caused trying to land on the seabed, include one camera which went out of focus and one camera light which was broken. In both these cases the problem was rectified by spares. A more time consuming problem was caused by the breaking of the drill bit by hitting the seabed on landing and this occurred on four occasions. It was never clear on which particular landing this had happened and it only became apparent when starting to drill. This was often after many landings and photographs trying to select the site. The impregnated drilling bits were much more subject to damage in this way than the more robust surface set diamond bit. The large majority of sites were drilled using a surface set diamond bit. Where they were used, however, the impregnated bits produced significantly faster drilling rates.

The planned programme was completed after 71 sites had been drilled. These sites had been in the depth range 1500 m to 2500 m. After this two deeper sites were attempted in order to test the depth capability of the drill The first at a depth of 3973 m successfully cored 150 mm of pillow lava at the summit of a flat-topped volcano (Figure 9). At the second site, at a depth of 4520 m, only sediments were encountered and whilst all the drill functions operated correctly, including running the drill for thirty minutes, no core was recovered. The only sample was mud from the inside of the hollow drill frame legs.

Important note. Following a major software crash on the ship's winch control system during TOBI operations on day 118, the stored calibrations for wheel and cable diameter were lost and the system defaulted back to (incorrect) factory values. In all drilling operations the wire out when equipment was on bottom was consistently less than multibeam centre depths. The correction factor estimated by Simon Wright (Deck Engineer) is 1740/1698 x cable out for the conducting cable. ***All values in tables and the scientific logs accompanying this report are given uncorrected.***

Conclusions

Overall, 73 sites were drilled with core recovery from 63 (Figures 7 and 8). A total of 320 seabed landings were made and seabed photographs taken. On a further 87 attempted landings the drill rig fell over and had to be picked up again. The drill operated successfully at its maximum design depth of 4500 m. The BGS BRIDGE drill performance was very successful over a sustained period and the system has definitely progressed from prototype to a working system.

12. Sample Description

Introduction

Nomenclature and description of both dredge and core samples followed as closely as possible the convention adopted during RRS *James Clark Ross* cruise JR31 [MacLeod *et al.*, 1998a; the previous occasion when portable rock drills were used] and by the Ocean Drilling Program (ODP), for example on legs 147 [Gillis *et al.*, 1993], 153 [Cannat *et al.*, 1995] and 176 [(Dick *et al.*, 1998]. However, some of the material recovered using the BRIDGE rock drill – the sheared serpentinites in particular – have not previously been cored in the oceans. The methodologies for working with these kinds of sample are essentially derived herein, and their descriptions may be less rigorous than for more typical oceanic lithologies.

Sample nomenclature

Dredge samples were numbered according to the convention JR63-DR[dredge#]-[sample#] (*e.g.* JR63-DR01-2: the second sample from dredge 1). Initially we tried a more sophisticated convention that inserted a code for a lithological descriptor before the sample number: JR63-DR[dredge#]-[lithotype]-[sample#], with lithotype 1 = basalt, 2 = dolerite, 3 = gabbro, 4 = peridotite *etc.* (*e.g.* JR63-DR02-4-9: the ninth sample from dredge 2, a peridotite); however, this proved cumbersome in practice and was quickly abandoned.

Nomenclature for the JR63 cores is slightly simpler than ODP convention and that used during JR31. On the basis of our experiences during JR31 the BGS engineers had shortened the BRIDGE drill core barrel from 1.1m to slightly less than 1m in order to protect the barrel during landing. Because all cores could therefore fit within a 1m core box it was not necessary to include a core section descriptor. Hence we could simply use the convention: JR63-BR[drillsite number], [piece#], [interval], *e.g.* JR63-BR21, pc 1a, 7-10cm: the interval 7-10cm below the top of core BR21, in core piece 1a. Core *pieces* (1, 2, 3 *etc.*) are defined as intervals that cannot be fitted directly together, with the implication that material between them is missing; *sub-pieces* are broken fragments of core that can be pieced together and are numbered 1a, 1b, 1c *etc. N.B.* we decided that the first core drilled during cruise JR63 should be numbered BR21 (16 BR sites were drilled during JR31), so as to maintain a unique sample code for each site drilled to date using the BRIDGE wireline corer.

In practice this simple system became difficult to apply rigidly during JR63 because so much of the drilled material was so very fragmentary. When gravel and undrilled rubble fragments were recovered – often in between coherent, drilled pieces of core – it was impractical to number each fragment individually. In this case we put the fragments into a bag and labelled them as a single piece. Often there was no simple or completely consistent way of dealing with the material, and we made the best decision we could at the time.

Core description

The rationale used on JR63 was to follow the outlines presented in the explanatory notes of Legs 153 [Cannat *et al.*, 1995] and 176 [Dick *et al.*, 1998] as closely as possible, and therefore much of the discussion presented here is derived from that source. The methodology used is itself derived from earlier ODP basement legs (*e.g.* Leg 147: Gillis *et al.*, 1993), though these are all rather 'gabbro-centric' and therefore not entirely applicable here. Discourses on lithological nomenclature are not repeated. Useage is more or less standard, though with a preference for British rather than American useage (*q.v.* dolerite *v* diabase).

Observations on hard-rock petrology, structure and metamorphism were stored in Microsoft Excel™ spreadsheet files according to the definitions given below. Macroscopic observations on igneous and mantle-derived ultramafic rocks were also recorded on summary VCD (visual core description) forms next to digital images of the cores (Appendix A07).

After numbering, all core pieces were examined by both Yaoling Niu and Andrew McCaig, with the former concentrating in particular on primary igneous features and the latter on deformation, alteration, metamorphism and veins. Observation was restricted to the outside of the core, in some cases hand polished with silicon carbide paste. A x7 to x45 binocular zoom microscope was used to examine mineralogy and texture in more detail, but other than hardness and reaction to dilute acid, no additional investigations could be performed on board ship. Appendices A08 and A09 list the observations made by Yaoling Niu and Andrew McCaig respectively, with only column D differing between the two spreadsheets. In a few cases consensus could not be reached on mineralogy, rock type or interpretation; hence both are retained. Columns E to L (in both spreadsheets) are observations made by Yaoling Niu alone. In addition, a serpentine texture log (Appendix A12) and a vein log (Appendix A11) were prepared by Andrew McCaig. The core piece descriptions (Appendix A10) were also used to prepare brief summaries of each core for the visual core descriptions (Appendix A07). Finally, an estimate of the relative volumes of rock types was made by Andrew McCaig (Appendix A13).

Dredge description

After sorting, cutting and numbering by the entire scientific party, dredge samples were weighed and examined by either Yaoling Niu or Andrew McCaig. In some cases slabs were hand-polished briefly with silicon carbide paste – a few seconds with coarse paste greatly aided examination with the binocular microscope. Detailed examination and compilation of description of all dredge samples was then made by Yaoling Niu. This work is reproduced in Appendix A15 and is summarised on a dredge-by-dredge basis in Appendix A14. Appendix A14 is the closest equivalent in detail to the core descriptions given in the VCDs (Appendix A07) and core summary spreadsheet (Appendix A10). Slabs for thin sectioning and chemical analysis were taken from the majority of dredge samples at the time (using a rock saw brought from Cardiff University) and were stored separately from the main archive. A list of those taken is given in Appendix A20.

A variety of seafloor samples was collected from the 29 successful dredges occupied during cruise JR63 (32 sites were attempted: see Operations: Dredging section above). The major lithologies recovered, their amounts, and relative proportions are summarised as follows:

	Basalt	*Dolerite*	*Gabbro*	*Peridotite*	*Sediment*	*Other**	*Total Weight*
Weight (kg)	93.80	30.54	79.27	556.00	85.12	40.01	884.74
Wt. %	11%	3%	9%	63%	10%	5%	100%

*Biological materials or small unidentifiable pieces *etc.*

These lithological proportions by no means represent precisely those of the basement rocks exposed in the studied area, but do suggest the predominance of the mantle peridotite. It is thus not unreasonable to state that mantle peridotite is the 'host' of basalt, dolerite and gabbro *etc.* regardless of any genetic relationships they might have.

Alteration and Metamorphism

This account is based purely on observations on cut surfaces of dredge samples and core outer surfaces using hand lens and x7 to x45 binocular microscope. It proved virtually impossible to identify fine alteration minerals with any confidence under these circumstances, although many interesting textures have been documented.

High temperature alteration: Dark-coloured amphibole was observed in many of the gabbros rimming pyroxenes. Completely amphibolitised sheared gabbro was seen only in sample DR23-8. Sharp sided amphibole veins probably related to cooling were seen in a few dolerite and gabbro dredge samples (eg. DR23-4) and in one core (BR82).

Intermediate-temperature alteration: Many of the gabbros and dolerites appear to have been affected by hydrothermal alteration/metamorphism in the greenschist facies and below. Pyroxenes in gabbros often appear to be replaced by fibrous products, possibly actinolite and serpentine, while plagioclase is often recystallised and sometimes contains tiny grains of epidote/clinozoisite, suggesting replacement of calcic plagioclase by albite + clinozoisite. Dolerites show a variety of alteration colours from dark green (chlorite-rich?) to pale (albite-rich?), and some samples of dolerite and gabbro appear to be intensely silicified. Veins of actinolite and/or chlorite, prehnite and talc were seen in some samples. Peridotites are invariably highly serpentinised (see elsewhere for a review of textures), and sometimes contain talc.

Low temperature alteration: gabbros and dolerites often show weathering rinds with clay minerals such as kaolinite and smectites, iron oxides and hydroxides, manganese oxide, and probably other low temeperature phases such as zeolites. Similar alteration products are often present on small fractures in most samples, and weathered horizons occurred in the cores adjacent to brecciated and sheared horizons, and sediment veins. A key observation was the presence of true Mn-crust on the underside of many core pieces, indicating that pebbles or boulders had been drilled. More pervasive alteration of olivine and pyroxenes to orange 'iddingsitic' alteration products was observed in many gabbros. Orange Fe-carbonate grains and clots were frequently observed overgrowing mesh-textured serpentinite, with almost 100% alteration apart from relict bastites seen in some core pieces. In some cases this carbonate alteration was observed to die out downwards in the core suggesting a relationship to sub-seafloor weathering.

Deformation and microstructures

Pre-crystallisation fabrics: Magmatic fabrics were probably present in some gabbros, but were not prominent in either the cores or the dredge samples.

High temperature ductile fabrics: Many of the serpentinised harzburgites showed alignment of bastite pseudomorphs indicative of weak high temperature deformation in the mantle. Only one or two dredge samples showed intense high temperature fabrics in peridotite. High temperature ductile fabrics were also extremely rare in gabbro samples, with only DR23-8 showing fully developed amphibolite facies mylonite. Recrystallisation apparent in many feldspars may be strain-related, or may be related more to alteration.

Moderate-temperature ductile fabrics: Greenschist facies ductile fabrics were also extremely rare in both gabbros and dolerites. Thin shear zones with probable greenschist facies mineralogy were seen in cores BR31 (at the top), BR40, BR71 (but may be serpentinite) and BR85. Macroscopically ductile shear zones were common in serpentinite, including isoclinal folds and shear band fabrics in some cases. The deformation conditions and mechanisms are unknown, and could be quite low temperature. In some samples sheared serpentinite appeared to be co-deformed with cataclastic dolerite. Slickenside lineations were seen on several low angle serpentinite shear zones in core.

Brittle deformation: Faults and well-healed cataclastic seams are common in both dolerites and gabbros. In some cases cataclasis appears to have occurred in the greenschist facies judging by associated mineralisation and cross-cutting veins (eg. sample DR2-4). Most cataclastic zones were at moderate to low angles to the core axis. Slickensided surfaces were found in several dredge samples. Brecciated textures were common in serpentinite, often apparently overprinted by macroscopically ductile shear and flattening.

Veins: Veins of serpentine and calcite were most common, and occurred with a range of dips relative to core axis. One texture seen several times was short, shallow-dipping calcite veins cutting steep to oblique serpentine veins in mesh-textured serpentinite (eg. core BR50). These veins typically extend the serpentine vein by several % in a vertical (wrt core axis) direction, but die out rapidly in the matrix. They probably formed as a result of volume expansion in the matrix in the final stages of serpentinisation, with the already full-serpentinised veins having no choice but to fracture. The orientation of these veins suggests that σ_1 was sub-horizontal and σ_3 sub-vertical in the final stages of serpentinisation, which may have important consequences for fault and dyke orientations. Otherwise the most prominent veins were sediment veins from 1 to 8 mm thick containing foraminifera and sometimes lithic clasts, which exploit fractures in a range of orientations, particularly in cores of sheared serpentinite. These veins appear to be Neptunian dykes, possibly formed during seismically-induced fluidisation of the sediment.

Deformation and intrusion: In several samples dolerite intrusions with chilled margins clearly cut across sheared serpentinite fabrics (eg. BR31, 33, possibly 71, 75, 76, 90, 91). This shows that intrusive activity occurred in a regime where mantle rocks had already cooled to relatively low temperatures and hydrated. If igneous activity was restricted to the Axial Valley, this places constraints on both the thermal regime and the geometry of the extensional detachment surface.

In several samples, shearing had clearly continued after intrusion of dolerite, with slivers of dolerite incorporated into sheared serpentinite (eg. BR37, 40, 71, 75, and 76). The intense cataclasis, sometimes accompanied by hydrothermal alteration, seen in many dolerites and gabbros also attests to continuing deformation after intrusion.

Serpentine textures

Large numbers of serpentinised peridotites were collected both as dredge samples and as core. Serpentinites in core were studied in more detail, and a serpentine log was constructed (Appendix A12), in which they were classified by colour, texture and deformation state. It should be noted that in hand specimen the mineralogy of serpentinites is hard to determine, and in general this has not been attempted. The following serpentinisation textures were observed:

– mesh textures with or without bastites
– harzburgitic textures with bastites, with or without mesh texture
– 'cuspate' texture
– sheared (schistose) serpentinite
– brecciated serpentinite (including vein breccias)

Mesh texture appears to be the primary serpentinisation texture. Olivine is replaced by serpentine with a network of oxide-rich seams, which may be random or show a preferred orientation, probably determined by pre-existing fabrics in the peridotite. Mesh textures are generally either dark green in colour with magnetite, or brown to orange in colour with hematite seams (called oxidised mesh texture in some descriptions). Pyroxene is pseudomorphed by bastite, which is not affected by the mesh texture. In only a very few samples were unserpentinised relicts of olivine observed in hand specimen. Veins of serpentine or calcite commonly cut the mesh texture.

In a few samples, oxidised mesh texture is replaced by 'cuspate' texture adjacent to green serpentine veins. Cuspate texture consists of ragged patches (up to 7mm in size) of dark serpentine surrounded by apple green serpentine. The ragged patches are often elongate, and cuspate due to convex lobes of green serpentine apparently replacing dark serpentine. Samples consisting entirely of cuspate texture were common (*e.g.* core BR 22), and in several samples cuspate texture could be seen being progressively sheared. It is possible that cuspate texture is a hydrothermal alteration of mesh textured serpentine associated with the detachment.

Sheared serpentinite was common in the drill cores, forming around 14% of all hard rock recovered compared with 22% unsheared serpentinite. Losses on recovery probably make this an underestimate. Sheared serpentinite generally seems to form from cuspate-textured serpentinite or vein material. Sheared serpentine breccias with clasts from 2 to 10mm in size are also common. Serpentinite shear zones often contain shear sense indicators such as shear band fabrics and shear planes, and isoclinal folds were occasionally seen. Fabrics are generally shallow dipping with respect to core axis in cores which are thought to have penetrated intact rock, although in some cases moderate-dipping fabrics are cut by shallow shear zones associated with slickensided surfaces. Measurable slickenside lineations were observed in a few cores.

13. Cruise Narrative: Daily Log

The purpose of this section is to give a brief summary of operations on a daily basis, written at the time. It includes any other happenings of interest, and gives a brief perspective on how our ideas developed as the cruise progressed, both with respect to operational strategy and our scientific thinking. A visual summary of all operations is given in Figure 10.

9th April 2001 (Julian day 99)

RRS *James Clark Ross* arrived in Recife port (Barrio do Recife, 8°03.65’S 34°52.19’W), *en route* from the Falkland Islands.

10th April 2001 (100)

Most of the scientific party arrived. Laurence Coogan (Cardiff) did not fly and had to withdraw from the cruise after catching chicken pox during his Sea Survival course the previous week. George Stewart the Bosun was injured on the dockside in Recife whilst supervising loading operations: he fell down an open manhole and broke four ribs. He was taken to hospital and did not take part in the cruise.

11th April 2001 (101)

PSO was informed of an illness to the Master, Chris Elliott, that would prevent him from sailing with the ship. This would necessitate a delay of two days while a replacement officer was found and flown in.

12th April 2001 (102)

The scheduled departure date. The scientific party was informed that the original First Officer, Robert Paterson, would sail as Master during cruise JR63.

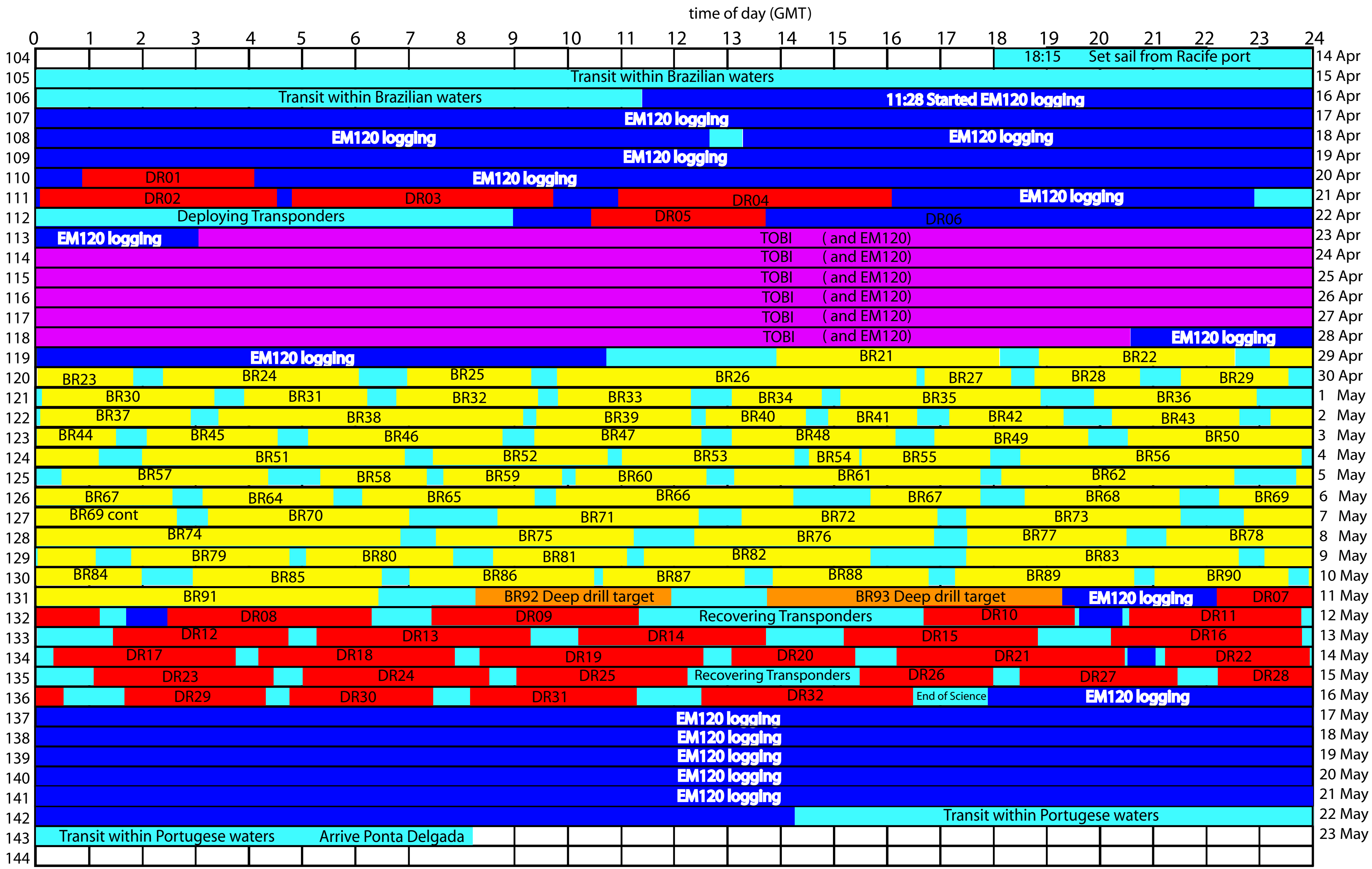
13th April 2001 (103)

Good Friday. Traditional Easter festivities, including a music festival in Ilha do Recife, held only a few hundred metres of the ship, provided entertainment for those on shore leave.

14th April 2001 (104)

Replacement Ship’s Officer Peter Moxom arrived, Moorings were slipped at 1515 local time (1815Z) and cruise JR63 commenced. The pilot left as we cleared the breakwaters at 15:45 local. Seas were calm and winds light.

Figure 10 - Calendar of operations - JR63



15th April 2001 (105)

On transit NNW towards field area. (Local) noon fix: 3°30.4'S 35°35.4'W, course 333°; average speed 14.1kt. Wind: light airs; sea: 1-2.

16th April 2001 (106)

Equator crossed at 0530 local time (0830Z) at 0°00.0N 37°21.7'W (water depth 4482m). The court of King Neptune sat in the afternoon and all of the science party (except Yaoling Niu, who had previously crossed the Equator) had the Freedom of the Seven Seas bestowed upon them. The ship's Simrad EM120 multibeam system was switched on when the ship had passed out of Brazil's 200nm territorial limit. The first of daily XBT sound-velocity measurements was made at 1101Z and the multibeam was switched on at 1126Z (at 0°27.05'N 37°35.33'W). Noon fix: 1°15.2N 37°59.1'W, course 333°; average speed 13.3kt, total elapsed speed 13.7kt. Wind: NExN; sea: 2-3.

17th April 2001 (107)

On transit NNW towards field area. Noon fix: 6°02.2'N 40°23.9'W, course 333°; average speed 13.4kt, total elapsed speed 13.6kt. Wind: NE5; sea: 4-5.

18th April 2001 (108)

On transit NW towards the field area. At 1453Z a waypoint was reached just south of the western ridge-transform intersection of the Vema fracture zone, at which point the ship was slowed to 12kt and turned north to follow the ridge axis. Thereafter we swath mapped the axial valley with the EM120. A figure-of-eight manoeuvre was performed in order to calibrate the shipboard three-component magnetometer. Noon fix: 10°01.3'N 43°43.0'W; average speed 13.1kt, total elapsed speed 13.5kt.. Wind: NE5; sea: 4-5.

19th April 2001 (109)

Transit swath mapping of the Mid-Atlantic Ridge axis between the Vema and Fifteen-Twenty fracture zones. At 2120 local (110/0020Z) dredging operations began (described below). Noon fix 12°47.5'N 44°43.2'W; wind NExE4, sea 4. Total average speed 13.1kt. Approximately 17 hours of the two days lost in Recife had been made up during the transit as far as here.

20th April 2001 (110)

Dredge site DR01 was sited at 13°47.05'N 44°59.05'W (3480m depth), near the shallowest portion of a prominent hummocky volcanic ridge a few km to the east of the floor of the axial valley, directly east of a flat-topped circular seamount. This was the closest dredgeable position to the reported location (13°46.67'N 44°59.50'W) of a French/Russian dredge of 'popping rocks', presumably related to the enriched 'hotspot' characteristics of lavas from the 14°N area. The dredge brought back basaltic glass and brown foraminiferal ooze, but unfortunately nothing popped. We continued to transit north, crossing the Fifteen-Twenty fracture zone and surveying the region east of the existing (French and Japanese/American) multibeam coverage using the EM120. On their most easterly swaths they had detected the western margin of another corrugated surface, at 15°40'N 45°55'W, ~70km east of the axis. We surveyed this in full,showing that it is approximately 20km x 10km in size (along x across axis). Processing of the EM120 multibeam data through the ship's 'Neptune' system was started ping by ping in order to eliminate bad data points. Noon fix: 15°24.4'N 45°57.1'W, Wind ENE, sea 5.

21st April 2001 (111)

Two dredges (DR02 and DR04) were sited on the steep western scarp of the eastern corrugated massif and one (DR03) on its surface. Dredge site DR02 (15°39.6'N 46°04.3W; 3500m depth) recovered ~20-30kg of heavily serpentinised peridotite and basalt. Some of the latter were clasts in a sedimentary breccia but some fresh glass was preserved. Dredge DR04 (15°41.79'N 46°03.47'W, 3433m depth) contained only a few Mn-covered fragments of serpentinised peridotite in mud in the pipe dredge: the shackles at the mouth of the dredge had snapped, turning it over. Dredge DR03 (15°44.50'N 45°58.49'W, 2673m depth), dragged across the corrugations on the surface of the massif, brought up several fragments of Mn-coated serpentinised peridotite in the pipe (no sediment). Again, the dredge itself was empty: the inner net had been dragged out of the chain bag. After these dredges we steamed west across the axis to the region of the four corrugated knolls on the west side of the axis to commence deployment of the acoustic transponders. Eight transponders were deployed in a double diamond configuration with the intention of obtaining coverage of as much as possible of the region of the corrugated knolls. Prior to the transponder deployment we tried running the TOPAS sub-bottom profiler on the top of the SE knoll (the shallowest, and site of Mike Braun's submersible dive). It was not easy to obtain any coherent signal, but there were no indications of any sub-bottom reflectors that might be indicative of sediment cover. Some coherent high-amplitude first arrivals appear to indicate a hard seafloor. Noon fix: 15°41.9'N 46°03.2'W, Wind ENE, sea 5.

22nd April 2001 (112)

Deployment of the transponders took up the first part of the day. In order to give Dave Booth a break we ran two dredges, in a region we knew would be outside of the transponder array, before attempting to navigate in the transponders. Dredges DR05 and DR06 were sited on scarps in the region between the ridge axis and the corrugated knolls to the west. Both recovered only sediment: unconsolidated, brown foraminiferal ooze and some shelly sand. The remainder of the day was taken up with navigating in the transponder net: sailing through the net in a variety of directions to get enough relative fixes to establish the relative and absolute positions of the eight transponders. Noon fix: 15°44.7'N 47°00.1'W, Wind ENE, sea 5.

23rd April 2001 (113)

After the transponder navigation survey we launched TOBI (at 113/0302Z) for what was intended to be a six day survey of the region west of the ridge axis, from the axial valley to the corrugated knolls, ending up with one long survey across the axis to the east. A burst hydraulic line on the aft gantry delayed deployment, as did difficulties with electrical connections on the TOBI swivel. After a delay of an hour and a half TOBI was launched successfully. The TOBI profiler failed almost immediately but the decision was taken to continue without it. This necessitated the scientific party calculating TOBI's position and altitude every 15 minutes using transponder range data (the transponder being mounted 50m above the depressor weight), TOBI depth (from its pressure sensor) and referring to the EM120 bathymetry. This was stressful at first but once a pattern was established then not too arduous. Noon fix: 15°42.2'N 46°42.8'W, Wind ENE, sea 4.

24th April 2001 (114)

TOBI surveying all day. Data quality looks excellent with, in particular, beautiful images of the neovolcanic zone in the axial valley. An average towing speed of 2.4kt (against the 2.0kt figure budgeted) could mean a significant saving on the six days projected for the total survey. Progress was made with processing of the transponder navigation, such that RMS errors on positions are now small (single figures), with offsets from the transponder drop positions now of the order of only 100m and in a consistent direction (NNE drift from the drop position). Noon fix: 15°36.8'N 46°45.1'W. Wind ENE, sea 4; occasional rain showers.

25th April 2001 (115)

Surveying with TOBI all day. When towing within the area of the acoustic transponder network we tried to obtain acoustically navigated locations for TOBI. A few possible fixes were obtained, but the acoustic returns were extremely noisy and many ranges were obviously in error. Noon fix 15°50.9'N 46°59.6'W. Wind ExS, sea 4.

26th April 2001 (116)

Our previous good fortune deserted us. TOBI sidescan imagery failed at 116/0739Z, although other parameters were still logging. The vehicle was recovered at 1138Z and investigated on deck by Team TOBI. It was eventually redeployed at 2027Z, recording usable data again from ~2300Z onwards, at approximately the position at which the vehicle had originally failed earlier in the day. A cable hose between the two main bottles was found to have failed and leaked; later it was also found that a circuit board in one of the surface electronics modules had also blown. Whereas these were repairable, the profiler could not be fixed with the spares available on board (low impedence on the ceramic rings in the profiler indicated water ingress in almost all cases), so we still lacked altitude data on the second TOBI deployment. The transponder was mounted 35m above the pinger for this run (having damaged the cable at 50m). JE and DHBI continued their heroic efforts with the processing of the extant TOBI data, writing a routine to pick first arrivals on the sidescan data in order to make slant range corrections (normally measured by the profiler). Because *James Clark Ross* has only one main winch system, necessitating at least 2 hours to change over to the coring (dredging) warp and the same to change back to the TOBI conducting cable, and because it was not evident at that stage how long it would take to fix TOBI, we decided not to dredge during the time TOBI was inoperable. Instead we sailed a series of lines within the transponder net, including several tight crossings around transponder F, to improve the absolute calibration of the acoustic net. This allowed us to eliminate several possible sources of uncertainty in the positioning of the net, which still shows absolute offsets relative to GPS with respect to the drop positions, and which we are still investigating. Noon fix: 15°45.2'N 46°55.0'W. Wind E, sea 3; occasional light rain showers.

27th April 2001 (117)

Normal service with TOBI was resumed, and surveying continued as planned all day. Beautiful images of corrugations were obtained. Noon fix : 15°44.9'N 46°53.4'W. Wind ExS, sea 3.

28th April 2001 (118)

Our planned TOBI survey was completed with a long line eastwards across the ridge axis, continuing as far as the eastern corrugated massif. Although some spreading-parallel spines of high-backscatter seafloor were visible on this surface most of it was clearly heavily sedimented, and the temptation to extend the TOBI survey to cover the massif was resisted. During the latter part of the survey the wire-out counter on the ship's winch system crashed and defaulted to values in the tens of thousands of metres. An estimate of wire out was back-calculated from the remaining figure on the winch control screen after TOBI was recovered. More serious, as we later found out, was that the stored calibrations for wheel and cable diameter were lost and the system defaulted back to (incorrect) factory values. In all subsequent drilling and dredging operations we found that wire out when equipment was on bottom was consistently less than multibeam centre depths. The correction factor estimated by Simon Wright (Deck Engineer) was 1740/1698 x cable out for the conducting cable, and 1740/1700 x cable out for the dredge wire (*i.e.* slightly less than for the conducting cable). All values in tables and the scientific logs are given uncorrected.

TOBI was finally brought up at 1748Z, and on deck at 2036Z. The TOBI termination on the coaxial cable was then cut off and the cable routed through to the starboard gantry so as to commence attaching BGS's electrical termination for the BRIDGE rock drill (a 12-hour job). The drill itself was moved to the starboard main deck, and the ship then commenced a multibeam survey of the eastern corrugated massifs (in part repeating an area of poor data surveyed earlier) and broadening the existing area of multibeam coverage to the east of the axis before heading to the area of the western corrugated massifs in order to start drilling. Noon fix : 15°41.3'N 46°58.4'W. Wind ExN, sea 4.

29th April 2001 (119)

The first day of operations with the BRIDGE rock drill, concentrating on the SE knoll. Communications problems with the camera bottle, probably caused by noise in the power cable, caused a delay of a few hours before the first deployment. The drill went in the water at 1245Z for tests and was ready for the first scientific drilling at ~1500. Sites BR21-BR23 were drilled during the remainder of the day, all within a couple of tens of metres of each other and with the intention of sampling a flat pavement of striated rock identified on Debbie Smith's seafloor camera tow over the centre of the SE knoll of the western corrugated area. On the first deployment, BR21, the flush pump on the drill failed and we recovered only soft sediment with a few pebbles of serpentinised peridotite. At BR22 we imaged and drilled into bare rock seafloor with prominent E-W striations; this yielded ~20cm of slightly sheared serpentinised peridotite. Core BR23 contained a few cm of schistose serpentinite with fine near-horizontal foliation: the first definite evidence, perhaps, that the corrugated surfaces are indeed sub-horizontal fault zones, and giving us some intriguing clues as to deformation mechanisms on these detachments. Noon fix : 15°44.6'N 46°54.3'W. Wind ENE, sea 4.

30th April 2001 (120)

Coring with the BRIDGE rock drill on the SE knoll: sites BR24–BR29 inclusive. These included more schistose sheared serpentinite and sedimentary breccias containing sheared serpentinite clasts. BR21–BR28 were sited within a few tens of metres of each other. Noon fix : 15°44.6'N 46°54.3'W. Wind ESE, sea 4.

1st May 2001 (121)

Coring with the BRIDGE rock drill on the SE knoll: sites BR30–BR36 inclusive. In contrast to the serpentinites recovered on the first two days, all of the cores drilled today were of dolerite. Core BR31 ('El Perfecto') was a particularly fine example, preserving a chilled margin: dyke v dyke, but with a selvage of sheared serpentinite between them along part of the contact. Noon fix : 15°44.5'N 46°53.0'W. Wind ExN, sea 4.

2nd May 2001 (122)

Coring with the BRIDGE rock drill on the SE knoll: sites BR37–BR43 inclusive. Operations at site BR38 were curtailed because of winch problems and no coring was attempted. Site BR40 yielded a beautiful sheared serpentinite that incorporates clasts of dolerite yet apparently also shows another dolerite body intruding the serpentinite. Noon fix : 15°44.5'N 46°54.4'W. Wind ExN, sea 5.

3rd May 2001 (123)

Coring with the BRIDGE rock drill on the SE knoll: sites BR44–BR50 inclusive. Sites BR44 and BR48 were unsuccessful, and BR47 was sediment with only a small fragment of serpentinite. In the case of BR44 we attempted to drill a small high on the top of the platform which turned out to be an artifact on the multibeam data, and we found only soft sediments and gravel on a flat surface; for BR48 wear in the chain drive from the drill motor caused the drill to jam. An undeformed serpentinised dunite at site BR50, just off the NW corner of the SE knoll, showed that deformation of the peridotites in the area was not pervasive. Noon fix : 15°44.6'N 46°55.1'W. Wind ENE, sea 5.

4th May 2001 (124)

Coring with the BRIDGE rock drill on the SE knoll: sites BR51–BR56 inclusive. Site BR51 recovered sediment only; sites BR52 and BR53 led to endless disgreements as to whether the cores were coarse dolerite or fine microgabbro. Operations were disrupted for several hours during the day by problems with the DGPS system and consequent inability of the ship to hold station reliably. An 11-year sunspot maximum and, in particular, a number of solar flares that were observed leaving the sun are leading to scintillation and difficulties in positioning, especially in low latitude locations. A DGPS dropout just as we started coring at site BR54 forced us to abort the hole. Because we thought no core had entered the barrel we decided to stay on the bottom, though when drillin resume drilling an hour later we weren't able to find the site again. We finally found outcrop approximately 20m west after a lot of effort and drilled there. In the core barrel we had more core than expected, and in the top was of fresh dolerite as opposed to the gravel over serpentinised peridotite in the remainder of the core. Because of the near certainty that the uppermost core is derived from the first dip we decided to give them separate site names: BR54 and BR55. Noon fix : 15°44.2'N 46°54.0'W. Wind E, sea 4.

5th May 2001 (125)

Coring with the BRIDGE rock drill: sites BR57–BR63 inclusive. We tried moving to the SW knoll, where we drilled six sites (BR58–BR62 inclusive); however, there was clearly little exposure there and so we moved on again to sample the NE knoll (site BR63). The sites on the SW knoll were mostly undeformed serpentinised harzburgites (only BR57 contained any obviously sheared serpentinite) with minor dolerite. Noon fix : 15°45.4'N 46°59.3'W. Wind E, sea 4.

6th May 2001 (126)

Coring with the BRIDGE rock drill: sites BR64–BR69 inclusive. Drilling on the corrugated surface of the NE knoll (BR63–67 inclusive) yielded sheared serpentinites and dolerite, very similar to the surface of the SE knoll. From sites BR68 onwards we returned to the SE knoll to try to sample in more detail the fault surface, trace the margins of the gabbro body identified on the Shinkai dive 422 and ascertain the relationships between the dykes, gabbro and the deformation. Noon fix : 15°52.7'N 46°52.2'W. Wind E, sea 4.

7th May 2001 (127)

Coring with the BRIDGE rock drill on the SE knoll: sites BR70–BR73 inclusive. At site BR70, where we were trying to find again the corrugated outcrop of site BR36 (dolerite), the camera failed (a cracked lamp). We drilled anyway, within a few metres of BR36, and brought back gravel made up of mm-cm sized fragments of sheared serpentinite. This is important: it shows that the eastern side of the knoll is not entirely made of dolerite and that, even if all other cores from here to date are of dolerite, the relative proportions we obtain are likely to be distorted because most of the exposure of sheared serpentinite has degraded and does not form obviously drillable targets. Site BR71 contained sheared dolerite and serpentinite, implying that magmatism must have been early with respect to the deformation; at site BR73 we recovered our first *bona fide* gabbro of the cruise (itself cut by a dolerite dyke). Noon fix : 15°44.1'N 46°54.4'W. Wind E, sea 4.

8th May 2001 (128)

Coring with the BRIDGE rock drill on the SE knoll: sites BR74–BR78 inclusive. These sites were drilled on the steep southern slopes of the SE knoll with the intention of tracing the boundaries of the gabbro body discovered on Shinkai dive #422. BR74 and BR77 were also gabbro, some cataclastically deformed. Farther to the east BR78 recovered undeformed serpentinised harzburgite; farther to the west BR75 and BR76 drilled into dolerites that intruded sheared serpentinite. These sites constrain the gabbro body to be of the order of 1.5km wide E-W. Noon fix: 15°44.0'N 46°55.3'W. Wind E, sea 4.

9th May 2001 (129)

Coring with the BRIDGE rock drill on the SE knoll: sites BR79–BR83 inclusive. These sites were also devoted to tracing the margins of the gabbro body, this time close to the top of the slope at the southern end of the SE knoll. At all but the last of drill sites dolerites were cored; one (BR82) brecciated by hydrothermal minerals. In the cases of BR80 and BR81 gabbro pebbles were also recovered. No core was recovered at site BR83: the bit (a surface set type) sheared off completely. Noon fix : 15°44.0'N 46°54.0'W. Wind ENE, sea 5.

10th May 2001 (130)

Coring with the BRIDGE rock drill on the SE knoll: sites BR84–BR90 inclusive. Once again at sites BR84 and BR88 the bits (also surface set) were ripped off and nothing was cored. Although penetration rates with the surface set bits look to to be faster than with the impregnated bits, they appear to be more vulnerable to the kind of abuse we are giving the drill. The deployment at BR84 had been particularly rough, with the drill falling over many times and twice becoming stuck, probably beneath overhangs. Fragments embedded in the frame upon recovery of the drill were identified as predominantly pyroxene and plagioclase, and the lithology at Site BR84 was therefore probably gabbro. Site BR85 yielded a beautiful 56cm-long continuous core of gabbro. BR87 and BR89 were dolerite, and BR86 and (in particular) BR90 showed unequivocally that intrusion of the dolerite dykes post-dates deformation of the schistose serpentinite. Noon fix : 15°44.0'N 46°53.5'W. Wind ExN, sea 5.

11th May 2001 (131)

The final day of coring with the BRIDGE rock drill on the SE knoll (sites BR91–BR93 inclusive), followed by the recommencement of dredging operations. BR91 was a classic illustration of Sod's Law: the "quick" last site before our planned deep-water test turned into a marathon, taking five hours and 32 'pogos' before finding a place to drill. After this site (sheared serpentinite over dolerite) we sailed east to the axial valley to find a suitable place to test the maximum depth capabilities of the BRIDGE drill. We chose the summit of a flat-topped volcanic seamount near the southern end of the neovolcanic zone (15°43.54'N 46°38.66'W). The drill landed at 3968m water depth and worked perfectly despite being well below the depth rating of many its components. The photo showed the landing site to be slightly sedimented pillow lavas, and we were able to drill a 12cm core of fresh plagioclase-phyric basalt without any difficulty. Spurred on by this success we decided to find a place to test the drill at ~4500m. We sailed south along the axial valley, eventually choosing a sharp-sided ridge on the axial valley floor at 15°33.79'N 46°37.92'W that we thought should be volcanic. We landed on the crest of the ridge at 4520m water depth and pogoed around a couple of times but saw only sediment plus a few boulders on the frame grabs. When finally we attempted to core on the least unpromising site the drill functioned perfectly once again, although unfortunately we only recovered unconsolidated brown ooze, mostly on the drill frame. Even so, this deployment was a great success in that it proved that the BRIDGE drill can function at water depths of 4500m and probably more. It was also a (successful) test of the ship's winch system and cable,which had not previously been used in this way at these loads. Noon fix : 15°33.6'N 46°38.0'W. Wind ExN, sea 5.

12th May 2001 (132)

After the end of rock drilling operations we resumed dredging. We also recovered (in ~5 hours) the four transponders from the more northerly diamond (A, B, C, and D). Dredge sites DR08 and DR09 were put down on the NW knoll and DR07 and DR10 were sited on the NE knoll. All were predominantly or completely composed of serpentinised peridotite (a couple of small pieces of gabbro were found in DR08, and some dolerite in DR10). Dredge DR07 was enormous (~300kg) and vexed the scientific party. Dredge DR11 was located farther northeast than the NE knoll, on the southern tip of one of the N-S spine-like abyssal hills that form the distinct 'linear' terrain to the north of the 'rugged' terrain in which the corrugated surfaces are found. This recovered pillow basalt and minor serpentinised harzburgite. Noon fix : 15°51.0'N 46°52.0'W. Wind ExN, sea 5.

13th May 2001 (133)

Dredging: sites DR12 to DR16 inclusive. These were concentrated around the SW knoll and to the south of it and the SE knoll. All recovered serpentinised peridotite except DR16, which contained a solitary piece of microgabbro. DR13 was sited on the saddle between the SW and SE knolls, on the striated high backscattering seafloor identified on TOBI. It recovered some dolerite as well as peridotite, and some of the serpentinite was highly sheared, exactly as seen in many of the drill cores from the striated surfaces. An hour or so was lost to winch problems, but everything was repaired more or less successfully (though the uncalibrated depths were still displayed; see entry for 28th April). Noon fix : 15°43.0'N 47°00.5'W. Wind ENE, sea 3.

14th May 2001 (134)

Dredging: sites DR17 to DR22 inclusive. These sites were focussed on and around the SE knoll to extend the results from the rock drilling operations. In particular we were keen to trace the boundaries of the gabbro body that was discovered on the south side of the SE knoll during the *Shinkai* dive [Matsumoto *et al.*, 1998] and which we had cored in a number of places. Most of the dredges had very sparse hauls, with the main dredge usually completely empty and blocks of (usually Mn-covered) rock found in the pipe dredge. Noon fix : 15°44.1'N 46°53.6'W. Wind ExN, sea 4.

15th May 2001 (135)

Dredging: sites DR23 to DR28 inclusive. The remaining four transponders (E, F, G and H) were also recovered (taking ~3 hours). The dredge sites were all located on the SE knoll, again with the primary aim of locating the boundaries of the gabbro body. From these dredges we discovered that it is also exposed around the eastern flank of the knoll, not just the southern part. Dredge haul DR28, in particular, was interesting. It was located on the uppermost slope on the eastern side of the knoll and covered the edge of the striated surface identified on the TOBI images. It contained gabbro, including what looks like the first evidence encountered this cruise for crystal plastic deformation in the gabbros (albeit very minor), and a beautiful striated Mn-coated slab, probably of cataclastic gabbro. The striations were fine, sub-millimetre scale slickensides and extend the length scale over which the wavelength of the corrugations has now been observed to 5-6 orders of magnitude. Noon fix : 15°44.7'N 46°52.5'W. Wind ExN, sea 3.

16th May 2001 (136)

Dredging: sites DR29 to DR32 inclusive. The final day of science operations. Sites BR29 to BR31 were again chosen to constrain the size and extent of the gabbro body around and to the south of the SE knoll. The final dredge, BR32, brought back pillow basalts from a target chosen from the TOBI data ~18km ENE of the SE knoll. This was a high-backscatter scarp, one of the few apparently non-sedimented areas in the region between the axial valley and the four corrugated knolls, and believed to be the hanging wall to the detachment fault. After the final dredge was brought aboard a second figure-of-eight manoeuvre was carried out to check calibration of the shipboard three-component magnetometer. At this point, at 1700Z (2pm local time) scientific operations for cruise JR63 were brought to a close and *James Clark Ross* set a course for the Azores. Noon fix : 15°49.4'N 46°45.2'W. Wind ExN, sea 3.

17th May 2001 (137)

Transit to the Azores. Noon fix: 19°23.4'N 43°34.5'W, course 041°; average speed 12.0kt. Wind: ExN; sea: 2-3.

18th May 2001 (138)

Transit to the Azores. Noon fix: 23°05.5'N 40°11.5'W, course 041°; average speed 12.2kt. Wind: light airs.

19th May 2001 (139)

Transit to the Azores. Noon fix: 26°48.4'N 36°41.3'W, course 041°; average speed 12.2kt. Wind: SxE; sea: 3.

20th May 2001 (140)

Transit to the Azores. Cruise dinner. Speeches. Mad panic getting this damn report together. Noon fix: 30°29.2'N 33°07.7'W, course 041°; average speed 12.6kt. Wind: WxN; sea: 2/3.

21st May 2001 (141)

Transit to the Azores. Portuguese territorial waters were entered at 1612Z (at 34°57'N 28°35'W) and the EM120 multibeam system was switched off. Noon fix: 34°17.1'N 29°16.8'W, course 041°; average speed 12.5kt. Wind: WxS; sea: 3.

22nd May 2001 (142)

Arrival in Ponta Delgada (Sao Miguel), for disembarkation of the scientific party the following day. *James Clark Ross* is expected in Grimsby on 29th May 2001.

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15. List of Figures

***Figure 1**:* Shiptrack for JR63 over ETOPO5 bathymetry. Numbers correspond to Julian days.

***Figure 2a**:* General bathymetry of the study area. The boxes correspond approximately to the areas shown in Figures 2a and 9. Seabeam multibeam data from an earlier NO Charcot cruise [Escartin and Cannat, 1999] has been complemented with topography predicted from satellite gravity and shipboard bathymetry [Smith and Sandwell, 1997]. The dashed line corresponds to the transition from terrain with linear, axis-parallel ridges, to irregularly faulted seafloor, where peridotites outcrop.

***Figure 2b**:* Multibeam bathymetry (SIMRAD EM120) of the study area, showing the striations running at ~095°. NWK, NEK, SWK and SEK correspond to the North West Knoll, North East Knoll, South West Knoll and South East Knoll, respectively. The blue line corresponds to Shinkai Dive #422 of the MODE'98 cruise (see Matsumoto et al. [1998]).

***Figure 3**:* Photo-mosaic of electronic still camera pics of center of platform at top of the South East Knoll (see Figure 2b). The images were taken along a N-S track over the top of the SE knoll by D. Smith (WHOI) in February-March 2001, onboard R/V Atlantis (USA). Numbers correspond to the time the picture was taken. No altimetry information nor camera attitude are available. The striations on the rock outcrop run E-W approximately, sub-parallel to those observed in the multibeam and TOBI data.

***Figure 4**:* Track and time stamps of the TOBI vehicle navigation. The corrugated surface W of the axis, its lateral terminations, and the hanging wall have ~100% sonar coverage (top). The long track crossing the ridge axis (bottom) extends to the East flank, towards another striated surface. Lines are run sub-parallel to the spreading direction and to the striations (~094°).

***Figure 5**:* TOBI side scan sonar backscatter mosaic of the study area. Reflective zones e.g., axial valley volcanic structures) are white, and non-refelctive areas (e.g., sediments) are grey. The corrugated surface (Figure 2b) shows highly reflective striations parallel to the spreading direction (i.e., TOBI tracks). Similar striations are visible over the Eastern corrugated surface, at the end of the TOBI track. The western corrugated surface is bounded to the East (ridgewards) by a high-angle normal fault with mass-wasting structures, and to the West by a high-angle normal fault. with less scarp relief. The northern and southern limits are not well-defined. The hangingwall is highly sedimented and dissected by axis-parallel, high-angle normal faults dipping towards the ridge axis, as commonly found at slow-spreading ridges. The axial valley is

highly asymmetrical, with a large hig-angle normal fault on the west flank, and a series of smaller, closely spaced faults on the East side.

Figure 6*:* Detail of the TOBI mosaic over the western flank of the ridge axis, showing the striations over the corrugated surface.

Figure 7*:* Location of dredges (black lines) and drill sites (blue dots) on the corrugated surface. Additional drill sites and dredges at the ridge axis (both N and S of the Fifteen-Twenty Fracture Zone) and in adjacent areas are omitted. Recovered lithologies are shown in Figure 8.

Figure 8*:* Location of dredges (lines), drill sites (colour symbols) and transponders used for acoustic navigation (blue stars). Sites at the ridge axis both north and south of the Fifteen-Twenty fracture zone are not plotted.

Figure 9*:* Bathymetry of the rift valley floor, showing flat-topped volcanoes and an axial volcanic ridge. The red dot corresponds to the drill site BR-92.

Figure 10*:* Timetable of ship operations.

16. Appendices

A01_TP_locns.xls

A list of the long baseline acoustic transponder frequencies, interferences with other shipboard equipment, and the best estimate of actual positions of the transponder beacons.

A02_BR_TP.xls

Raw data and Dave Booth's preliminary best-guess estimate of the acoustic positions of the JR63 BRIDGE drill sites.

A03_DR_TP.xls

Raw data and Dave Booth's preliminary best-guess estimate of the acoustic positions of the JR63 dredge sites. *N.B.* not all sites were sited within the acoustic net, and others were run after the transponders had been recovered.

A04_SCILOG.xls

The basic scientific master log of positions, operations *etc.*

A05_DRILLSITESUMM.xls

A summary spreadsheet of times, locations, orientations and results of BRIDGE rock drilling operations. *N.B.* core recoveries and lithologies given here are approximate; see VCDs and Core Description logs for detailed results.

A06_DREDGESITESUMM.xls

A summary spreadsheet of times, locations, orientations and results of dredging operations. *N.B.* descriptions of lithologies *etc.* given here are approximate; see Dredge Description logs for detailed results.

A07_CORE_VCDs

Pdf files showing digital images of cores, lithological units, curation information and brief summary description. Locations, orientations, seafloor frame grabs *etc.* are also given. A legend for the VCDs is included.

A08_YN_COREDESCR.xls

A detailed description of all the cores, piece-by-piece, made by Yaoling Niu.

A09_AM_COREDESCR.xls

Detailed macroscopic description of all the cores, piece-by-piece, made by Andrew McCaig. This was based upon and includes most of the information in Appendix A08. Columns A to C and E to L are identical, but column D differs in having additional description and interpretation, particularly *re* aspects of deformation and alteration. *N.B.* Yaoling Niu's and Andrew McCaig's views are not always identical. *Caveat emptor.*

A10_AM_CORESUMM.doc

A one-per-core summary description of the BRIDGE drill sites, made by Andrew McCaig. This document is a more verbose version of the text used on the VCDs (Appendix A07).

A11_AM_VEINS.xls

A brief description of veins and vein mineralogy in the BRIDGE drill cores.

A12_AM_SERP.xls

A brief description of serpentinite textures and fabrics in the BRIDGE drill cores.

A13_AM_VOLESTIM.xls

A brief discourse on stimulating voles, or maybe an estimate of volume estimates. Dunno.

A14_YN_DREDGESUMM.doc

Not really a summary but quite a long description of what's in each dredge, made by Yaoling Niu.

A15_YN_DREDGE_DESCR

Really long this time. Loads of macroscopic description of the dredge rocks, sample by sample, again made by Yaoling Niu.

A16_CURATION.xls

Detail of piece lengths and other curation information for the BRIDGE core samples.

A17_DRILLPOSN+COMP.xls

Summary of drill site positions (in decimal degrees) and primary and secondary lithologies. Maybe useful for plotting.

A18_TOBI_JPEGS

Reeeally big .jpg files of the (still sub-sampled) TOBI mosaics.

A19_TOBI_DAYLOGS

Scientific log for the period of TOBI operations, giving positions, calculated laybacks, ranges *etc.*

A20_PACKLIST.xls

List of slabs cut from the dredge samples on board ship.