National Oceanography Centre, Southampton

Cruise Report No. 4

RRS *Charles Darwin* Cruise 167
23 NOV – 21 DEC 2004

Sub-seafloor physical properties at Saldanha Seamount, Mid-Atlantic Ridge, and controls on the spatial distribution of hydrothermal venting

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2006

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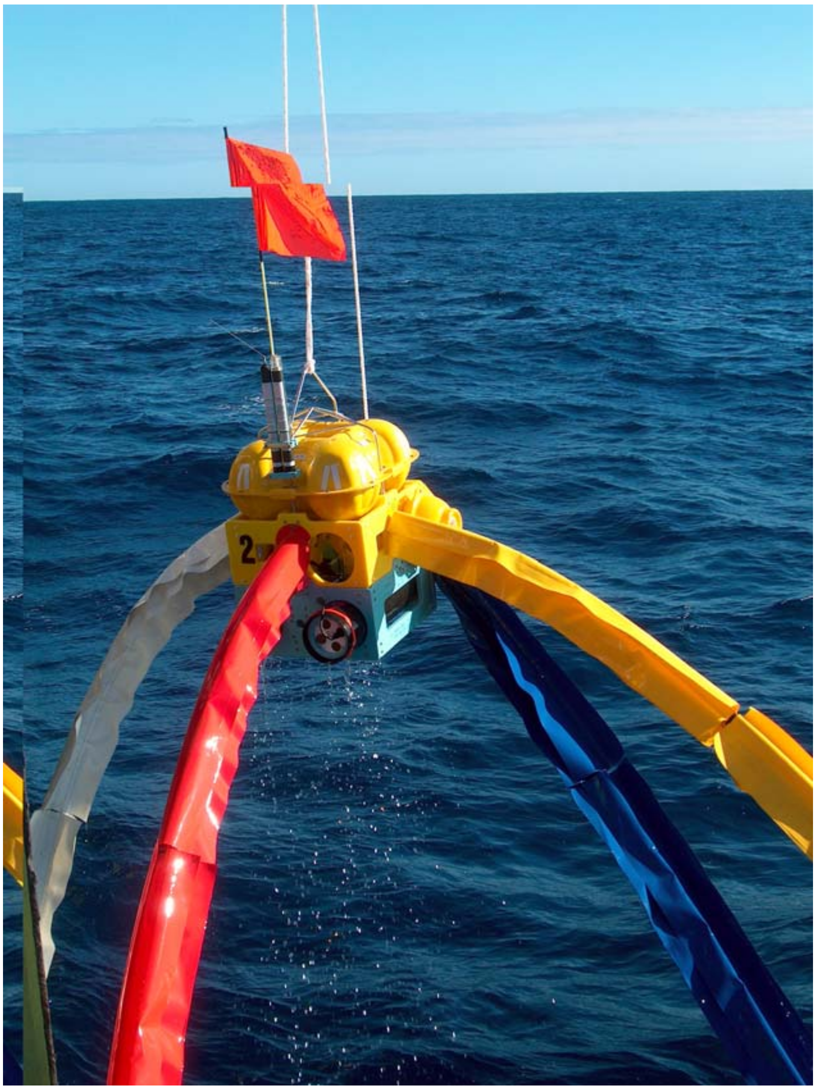

Charles Darwin 167/2004

Cruise Report

Sub-sea-floor physical properties at Saldanha Seamount, Mid-Atlantic Ridge, and controls on the spatial distribution of hydrothermal venting

DOCUMENT DATA SHEET

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ABSTRACT

Charles Darwin 167 (CD167) was a joint research project carried out by UK and Portuguese scientists from the National Oceanography Centre, Southampton, the University of Durham and the University of Lisbon. The task of CD167 was to carry out geophysical and geological studies at the Mid-Atlantic Ridge. The work area was a ridge offset centred on 36º 34' N, 33º 26' W - about 200 n.m. south of the island of Flores in the Azores. At this location, the median valley of the ridge is offset by about 20 km right-laterally, forming a non-transform discontinuity. Of particular interest is a site known as the Saldanha Massif, where previous studies have revealed an area of exposed, tectonically-unroofed mantle rocks and unexpectedly significant hydrothermal circulation with venting near the summit of the massif.

A three-dimensional controlled source electromagnetic (CSEM) survey of sub-sea-floor electrical resistivity was carried out over a 10 km^2 area centred on the Saldanha Massif. Following CSEM data analysis, the resulting images of electrical structure will be translated into constraints on porosity distribution, interconnectedness and pore fluid properties by means of geophysical effective medium modelling methods. This in turn will address the questions of whether the Saldanha vent site owes its existence to the presence of a deep fracture network, whether this network completely penetrates the thin crustal carapace within the ridge offset, and how far it extends downwards into the underlying mantle rocks.

A secondary objective was to collect a series of ridge-perpendicular (approximately east-west) profiles of bathymetry and of gravity and magnetic anomalies, to contribute to regional tectonic studies through improving an international European compilation of such data. This was successfully achieved, and the data have been passed on to our international collaborators.

A third objective was to collect sea bottom geological samples, by gravity coring and dredging, for analysis at CREMINER in Lisbon. This objective was also achieved.

KEYWORDS

Charles Darwin, cruise 167 2004, Mid-Atlantic Ridge, Saldanha Seamount

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S. Dean	CSEM survey/ DASI system
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A. Maxey	Watchkeeper
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J. McIntosh	LC2000 systems

University of Durham

A. Burchell	LC2000 systems

University of Lisbon

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E. Rourke	Shipboard computing systems
C. Crowe	Current meters and moorings

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P.W. Robinson	M/Steward
J. A. Osborn	Steward
G. M. Mingay	Steward

Summary

Ship: RRS *Charles Darwin*

Cruise no.: CD 167

Ports: Funchal, Madeira to Ponta Delgada, São Miguel, Açores
Dates: 23 November - 21 December 2004

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1. Scientific background and objectives

1.1 Scientific background

Along the great majority of the global ridge system, new crust forms by intrusive and volcanic magmatic processes which typically produce 6 to 7 km thickness of basaltic composition crust. Magmatism is accompanied by vigorous hydrothermal circulation, which in turn leads to chemical exchanges between the lithosphere and the ocean. Much of our understanding of ridge hydrothermal systems is based on the association of convective fluid circulation with magmatic processes.

An important question is: is the presence of magma either currently or in the very recent geological past in significant crustal accumulations a precondition for high temperature hydrothermal circulation? Or is the presence of magma only one of the possible driving mechanisms for hydrothermalism, with the most important precondition being the availability of cracks and fractures forming an interconnected network extending for some distance beneath the seafloor?

An analysis by German *et al.* (1996) of the distribution of vent sites along two major sections of the Mid-Atlantic Ridge concluded that hydrothermal activity can coincide with tectonic activity at non-transform discontinuities between adjacent segments. This indicates that ‘tectonic activity may be instrumental in controlling the location and distribution of high-temperature hydrothermal activity on mid-ocean ridges by providing and renewing sub-surface pathways for fluid circulation’

If the hypothesis is correct, then sites of active hydrothermal venting located away from significant recent magmatic activity in the discontinuities between slow spreading ridge segments should be associated with an unusually high density of interconnected fractures extending to considerable depth beneath the seafloor. At such sites, we would expect the permeability structure to be significantly different from that of the majority of ridge localities, where intrusive and volcanic magmatic processes occur and mediate the effects of tectonic strain. The presence of interconnected fractures filled with seawater or hydrothermal fluids will strongly affect the bulk electrical conduction properties of the seafloor. This is because of the very high (up to five orders of magnitude) contrast in electrical resistivities between basaltic or gabbroic rocks, serpentinised or unaltered ultramafic rocks, and seawater. As a result, measurements of electrical resistivity distribution beneath the seafloor provide a powerful method for investigating the presence, volumetric proportion, and degree of interconnectedness of fluid-filled fracture pathways, and the resistivity of the pore fluid phase (e.g. MacGregor *et al.*, 2001). The resistivity of aqueous pore fluids in turn depends strongly on their temperature and salinity. Because in most crustal rocks the conductivity of the fluid phase far exceeds that of the solid matrix, the bulk electrical properties of the sub-surface are dominated by the fluid, even at low porosities. This is in contrast to the seismic case, where at low to medium porosities the elastic properties of the bulk rock are strongly influenced by the properties of the solid matrix.

Along the Mid-Atlantic Ridge south of the Azores archipelago there are three documented hydrothermal sites located not within spreading segments, but at ridge offsets. One of these, on the wall of a large offset fracture zone, is at 15^{o} 05' N (Charlou *et al.*, 1991); while the other two (Rainbow and Saldanha) are located within the 35-38^{o}N region SW of the Azores. All three are associated with outcrops of serpentinised ultramafic rocks. Rainbow and Saldanha are both located on small local bathymetric highs within non-transform ridge discontinuities at right-lateral offsets of the ridge axis. In all these cases, the venting is associated with large methane anomalies in the overlying water column (Charlou *et al.*, 1991; Bougault *et al.*, 1998). This is believed to be at least partly a product of hydration reactions between ultramafic rocks and seawater. The serpentinization reaction is exothermic, and it has been suggested that this might provide a heat source for the circulation, but this remains contentious (German *et al*. 1998).

What is not contentious is that the serpentinization reaction between seawater and mantle periditite results in significant changes in the density and rheology of the rocks. The serpentinites produced have much lower density than the surrounding peridotite, and tend to be readily remobilized as serpentinite diapirs, leading to frequent occurrence of lower crustal and altered mantle rocks in outcrop on fault scarps at and close to slow spreading ridge offsets.

1.2. Primary Scientific Objective

The aim of this research is to test the hypothesis that vigorous hydrothermal circulation systems that are hosted within non-volcanic, predominantly ultramafic rocks at non-transform discontinuities along slow-spreading mid-ocean ridges result from the presence of interconnected fracture pathways which extend deep into the lithosphere, and which result from tectonic activity. To do this the electrical resistivity structure of the seafloor beneath the Saldanha seamount hydrothermal system was measured by carrying out a 3-D controlled source electromagnetic (CSEM) survey over a 10 km^2 area centred on the Saldanha Massif. The sub-sea-floor electrical resistivity structure will be related to the distribution and interconnectedness of fracture porosity, and the properties of the pore fluids, by means of modelling based on effective medium theory.

We shall compare the resistivity structure beneath this site in particular with that beneath the nearby, but volcanically-hosted, Lucky Strike hydrothermal field, at which a similar CSEM survey was successfully completed in 1999 (Barker, N.D., 2001). We shall also compare the result against the resistivity structures at other contrasting ridge sites on the East Pacific Rise, Valu Fa Ridge and Reykjanes Ridge.

1.3. Secondary objectives

Our second objective was to collect a set of bathymetry, gravity and magnetic anomaly profiles across the ridge both north and south of the non-transform offset, to complement and add to existing French and Portuguese compilations. A third objective was to collect seabed samples by gravity coring and dredging, for subsequent analysis in Lisbon.

The work was carried out within the context of, and in collaboration with, the Portuguese national SEAHMA project, which is aimed at a multi-disciplinary and large-scale study of the Rainbow and Saldanha sites, building on recent European Union FRAMEWORK (MAST) programmes MARFLUX/ATJ and AMORES.

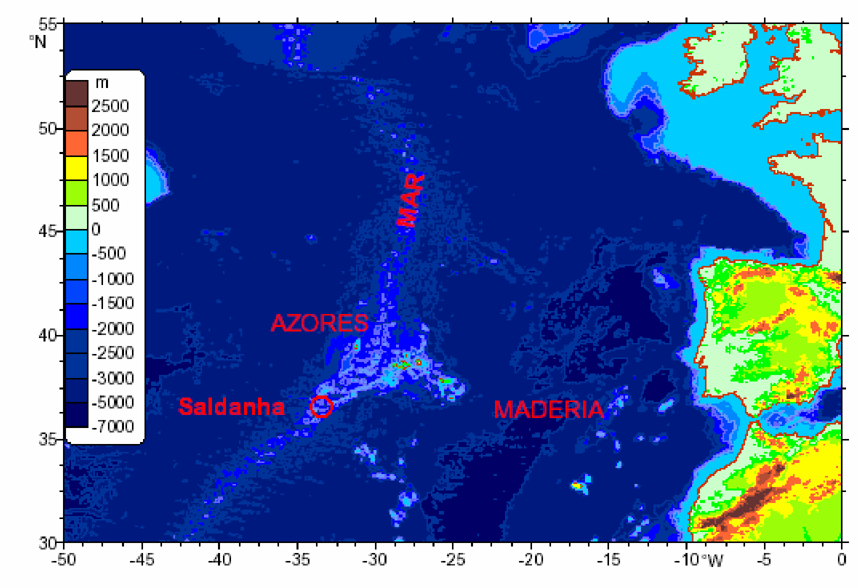

Figure 1.1. Location map of the *CD167* work area in the central North Atlantic, on the Mid-Atlantic Ridge axis SW of the Azores archipelago. (*Etopo 2' W.H.F. Smith & D.T. Sandwell, 1997)*

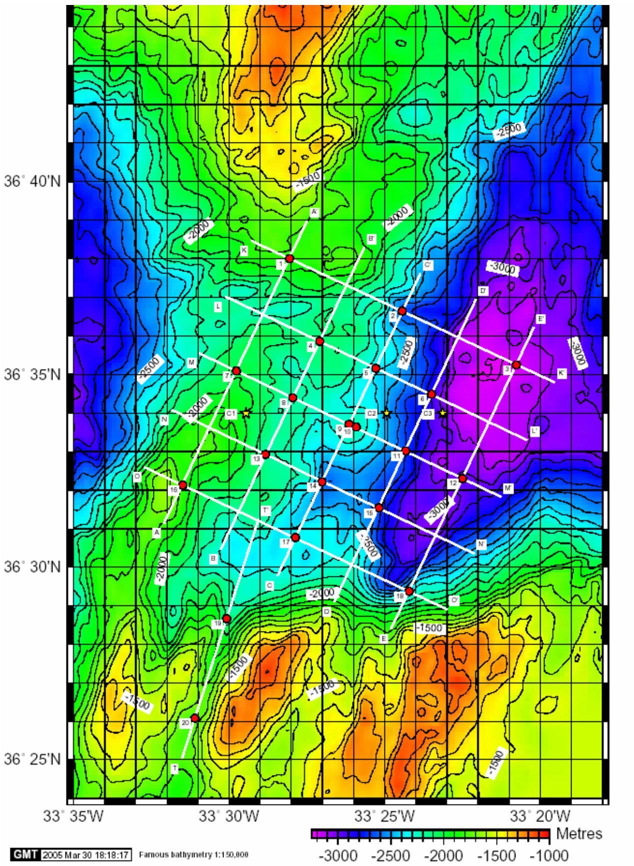

Figure 1.2. Swath bathymetry of the Saldanha site. Contour interval is 100 m. Also shown is the planned geometry of the CSEM study: transmitter tow lines (white) and receiver positions (red symbols).

2. Instrumentation and work carried out

2.1. CSEM Transmitter System

Southampton's Deep-towed Active Source Instrument (DASI) was used to transmit electromagnetic signals from a neutrally buoyant, 100 m horizontal electric dipole transmitting antenna through the seafloor into the receivers along a set of four N-S and two E-W tow lines. The DASI system outputs a continuous wave signal for frequency-domain sounding, with most energy at the fundamental frequency and its third and fifth harmonics. Most of the transmission lines were towed at a frequency setting of 0.25 Hz to provide deep penetration data across the entire survey area. Two profiles were made at a frequency setting of 1 Hz, to provide higher resolution resistivity structure in the upper 1 to 2 km beneath the central part (6 x 6 km) of the survey area. The pattern of receivers and DASI tows employed provides for data acquisition in directions both parallel and orthogonal to the axis of the transmitting dipole, as this has been shown to improve resolution substantially (Sinha, 1999; MacGregor, 1999; MacGregor & Sinha, 1999).

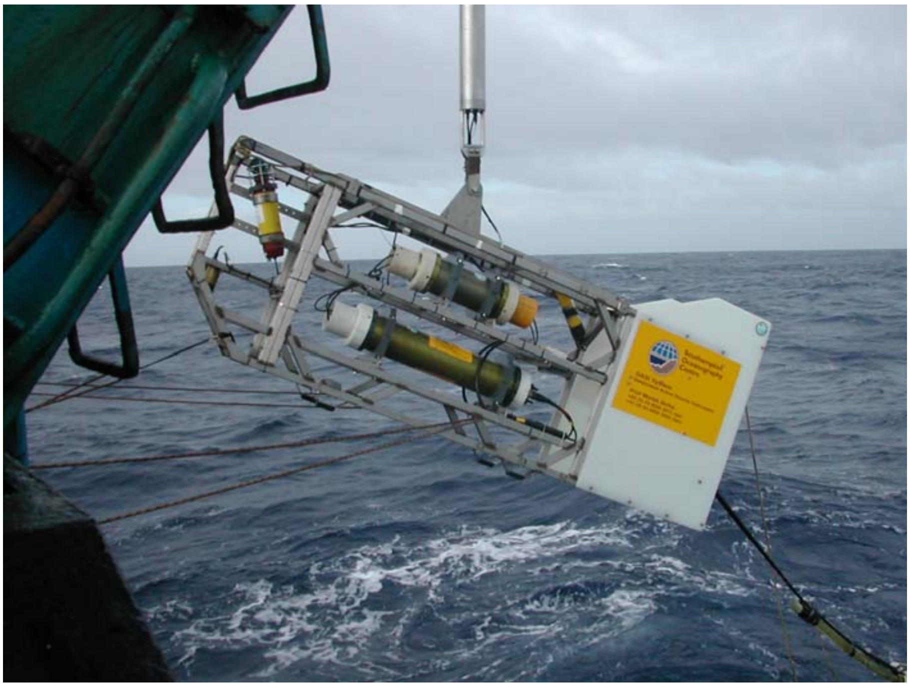

Figure 2.1. The DASI deep-towed transmitter system during deployment. Part of the neutrally buoyant antenna streamer can be seen in the lower right of the picture.

Although the DASI system has been used successfully and reliably on a number of previous projects, during CD 167 we experienced a series of technical difficulties with the system that seriously impacted on the overall science programme. These included:

- Intermittent failure of fibre-optic communications between the deep-tow vehicle and the surface ship
- Intermittent failure of the acoustic altimeter used to maintain tow height above the sea bed during transmissions
- Intermittent failure of data telemetry from the acoustic altimeter and pressure sensor on the deep tow vehicle to the surface ship
- An insulation breakdown at the outboard termination of the deep-tow cable, requiring complete re-termination of the tow cable
- Intermittent performance at long slant ranges (i.e. in the deeper water parts of the survey area) of the Ultra-Short Baseline (USBL) acoustic positioning system – which provides the location of the DASI vehicle with respect to the ship.

2.2. Receiver instruments

All of the receiver instruments used are autonomous ocean-bottom geophysical recorders, each measuring two orthogonal horizontal components of electric field. One receiver is operated by University of Lisbon. The remaining 17 receivers are operated by Southampton or by the UK Ocean Bottom Instrument Consortium (OBIC).

The Lisbon instrument and the three Southampton instruments are 'LEMUR's: Low-frequency Electromagnetic Underwater Recorders. Five of these instruments were taken, but due to pressure of time only four were deployed. All were safely recovered, although one took an unexpectedly long time to surface due to inadequate buoyancy.

The 14 OBIC instruments were LC-2000EM instruments – with frames and data logger systems developed at Scripps Institution of Oceanography, and release systems and electromagnetic sensors and amplifiers fitted by OBIC. All were recovered safely, although two – which were fitted with heavier, rechargeable, battery packs – took unusually long times to reach the surface.

Figure 2.2. Deploying a LEMUR. The sensor electrodes are housed in the ends of the flexible arms. The bottom weight can be seen underneath the instrument frame.

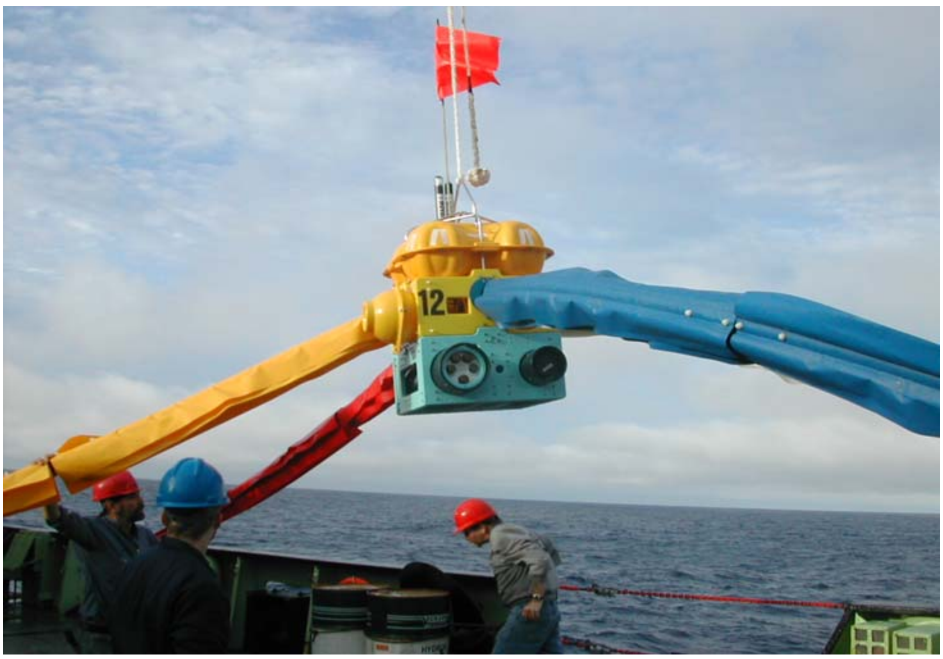

Figure 2.3. Recovering an LC-2000EM. The concrete bottom weight has been jettisoned and left on the sea bed. The electrodes are housed in the ends of the flexible arms.

3. Cruise Narrative

All times GMT (UT/Z)

Colour convention:
Red – Instrument and mooring deployment/recovery/survey
Green – DASI operations
Blue – Swath bathymetry, gravity, magnetic profiling
Purple – Dredging/coring

23/11/04 (328)
NOC Scientific party travelled to Funchal, Madeira. Mobilization for CD167 commenced.

24/11/04 (329)
Scientific party working on board (scientific mobilization).

25/11/04 (330)
Gravimeter base station tie completed at local high water, ~1300.
Lisbon science party travelled to Funchal, Madeira.

26/11/04 (331)
Lisbon scientific equipment embarked. Science party embarked pm.

27/11/04 (332)
09:00 Departed Funchal. Set course for work area.

28/11/04 (333)
All day – on passage.

29/11/04 (334)
All day – on passage.

30/11/04 (335)
02:00 Ship's clocks retarded by 1 hour to GMT-1. Scientific logging continued in GMT.
17:00 Commenced scientific watchkeeping.
17:20 Deployed EA500 echo-sounder fish and magnetometer.
17:54 Resumed passage at full speed to work area, logging EA500 and EM12 bathymetry and gravimeter. Magnetometer not serviceable.
18:45 Magnetometer now operating and being logged.

01/12/04 (336)
05:35 Arrived on station at Receiver Site R12. Recovered magnetometer. Swath system off.
06:10 Commenced first wire test: 7 off LC-2000 acoustic release units. Water depth 2960 m.
07:40 Wire out 2800 m, winch stopped. Tested acoustic systems.
09:20 First wire test completed: all equipment back inboard.
09:51 Commenced second wire test: remaining 7 off LC-2000 acoustic release units.
11:17 Wire out 2800 m, winch stopped. Tested acoustic systems.
12:51 Second wire test completed: all equipment back inboard.

13:00 Commenced third wire test: sound velocity meter profile.
14:30 Sound velocity meter at maximum depth (2800 m). Commenced hauling in.
15:30 Sound velocity meter profile completed, all equipment inboard. Set off to Site C3 to deploy current meter mooring.
16:18 On station at Site C3. Commenced deployment of current meter.
16:28 Deployed Current Meter at Site C3.
16:50 Current meter on bottom. Set off to Site C2 to deploy next mooring.
17:24 On station at Site C2. Commenced deployment of current meter.
17:36 Deployed Current Meter at Site C2.
18:00 Current meter on bottom. Set off to Site C1 to deploy next mooring.
18:31 On station at Site C1. Commenced deployment of last current meter.
18:43 Deployed Current Meter at Site C1.
19:02 Current meter on bottom. Set off to Site R3 to deploy LC-2000.
22:25 Deployed LC-2000 #18 (data logger #2) at Site R3.
23:55 Instrument on bottom. Set off to Site R12.

02/12/04 (337)
01:09 Deployed LC-2000 #7at Site R12.
02:18 Instrument on bottom. Set off to Site R18.
03:18 Deployed LC-2000 #8 at Site R18.
04:14 Instrument on bottom. Set off to Site R15.
05:03 Deployed LC-2000 #12 at Site R15.
06:13 Instrument on bottom. Set off to Site R6.
07:02 Deployed LC-2000 #5 at Site R6.
08:12 Instrument on bottom. Set off to Site R5.
09:00 Deployed LC-2000 #13 at Site R5.
10:22 Instrument on bottom. Set off to Site R9.
11:08 Deployed LC-2000 #3 at Site R9.
11:58 Instrument on bottom. Set off to Site R10 to deploy LEMUR instrument.
13:05 Deployed LEMUR 14 at Site R10.
14:18 Instrument on bottom. Set off to Site R11.
15:19 Deployed LEMUR 15 at Site R11.
16:36 Instrument on bottom. Set off to Site R14.
17:36 Deployed LEMUR 18 at location approx 300 m east of Site R14 (drop position modified due to severe topography at original location).
18:20 Instrument on bottom.
18:40 Commenced acoustic survey of instruments on bottom at Sites R14, R15 & R18 at speed 8 knots.
20:47 Completed acoustic survey. Set off to Site R20 to deploy LC-2000 instrument.
22:06 Deployed LC-2000 #9 at Site R20.
22:54 Instrument on bottom. Set off to Site R17.

03/12/04 (338)
00:31 Deployed LC-2000 #16 at Site R17.
01:20 Instrument on bottom. Set off to Site R13.
02:29 Deployed LC-2000 #6 at Site R13.
03:14 Instrument on bottom. Set off to Site R8.
04:00 Deployed LC-2000 #4 at Site R8.
04:52 Instrument on bottom. Set off to Site R1.
05:53 Deployed LC-2000 #11 at Site R1.
06:40 Instrument on bottom. Set off to Site R7.

07:35 Deployed LC-2000 #15 (data logger #17) at Site R7.
08:25 Instrument on bottom. Set off to Site R16.
09:27 Deployed LC-2000 #1 at Site R16.
10:20 Instrument on bottom. Set off to position north of A' to commence DASI deployment.
14:00 Hove to on station 5 n.m. N of location A'. Commenced DASI deployment. DASI tests on deck revealed fibre optic communications problems. Eventually resolved these after considerable effort.
17:15 Fire and boat drill & emergency muster exercise. On completion, reviewed status of DASI.
18:10 Concluded that key personnel had insufficient working hours left to commence DASI operations at this time, and that a rest period was called for prior to DASI deployment. Decision was made to carry out acoustic survey of seafloor instrument positions overnight to allow this.
19:00 Commenced acoustic survey of receiver sites R1, R7, R16, R13, R8, R9, R11, R12, R3, R6, R5, R9, R14, R17 and R20. This was mostly successful, but no acoustic responses were received from R3, R16 or R20. For the latter two instruments this turns out to have been the result of using the wrong acoustic codes for these two instruments. Their acoustic units had been swapped, but this information had not been recorded in the watch-keepers' records. However the two acoustic surveys to date had provided good relocation data for R1, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 17 and 18.

04/12/04 (339)

09:12 Commenced USBL spar and DASI streamer deployment at location 4 n.m. N of site A'.
09:54 Commenced DASI deck test.
10:15 Deck tests completed successfully. Started to deploy DASI vehicle.
10:36 DASI in the water and successfully powered up & communicating. Start of DASI TOW 1.
10:46 Started paying out cable to lower DASI to seafloor.
11:29 Problems with DASI altimeter and pressure sensor – hence operators are unsure of depth below sea surface or height off bottom. Stopped paying out tow cable at 1600 m wire out. Unable to rectify the problem with DASI in the water. Abandoned this DASI tow and started recovery.
12:17 DASI back on deck. End of DASI TOW 1. Began investigating problems. Found suspect cable connection to altimeter. Began dismantling DASI for further tests and fault finding.
16:20 Concluded that DASI repairs would take several more hours. Planned alternative overnight programme.
16:30 Commenced recovery of USBL spar and DASI streamer. Started preparations for coring stations.
16:39 Deployed 3.5 kHz sub-bottom profiler fish.
17:03 Set off to first coring station.
18:32 Started gravity core station CD167-1.
19:56 Core CD167-1 on the bottom.
21:07 Corer recovered.
21:27 Set off to Site R10 to carry out acoustic survey of position of Lemur 14 on the sea bed.
21:45 Started acoustic survey, R10.
22:35 Completed acoustic survey, R10.
22:53 Started gravity core station CD167-2.

05/12/04 (340)

00:09 Core CD167-2 on the bottom.
01:09 Corer recovered.
01:58 Started gravity core station CD167-4.

03:00 Core CD167-4 on the bottom.
04:15 Corer recovered.
04:48 Started gravity core station CD167-5.
05:40 Core CD167-5 on the bottom.
06:46 Corer recovered.
07:24 Started gravity core station CD167-6.
08:20 Core CD167-6 on the bottom.
09:17 Corer recovered.
09:56 Started gravity core station CD167-3.
10:59 Core CD167-3 on the bottom.
12:09 Corer recovered.
13:09 Started gravity core station CD167-8.
14:10 Core CD167-8 on the bottom.
15:50 Corer recovered. All cores except CD167-1 had recovered useful sediment samples. The coring programme was complete for now, and the personnel involved needed a rest period. However continuing problems with the DASI system required further time for attention and fixing. In particular, there was a problem in the electronics module in the lower pressure case, which would therefore need to be opened, drained of oil and repaired – a long job. We therefore commenced the first of a series swath bathymetry/magnetometer/gravimeter survey sections, along E-W tracks designed to complement existing survey data.
16:02 Commenced magnetometer deployment.
16:15 Commenced swath/gravity/magnetic survey along Lines CP1, CP2, CP3, CP4.

06/12/04 (341)

12:00 Completed survey line CP4. Set off for DASI deployment site (4 n.m. N of A') again.
14:29 Recovered magnetometer and 3.5 kHz profiler fish, deployed USBL spar.
14:40 Commenced DASI streamer deployment.
15:59 Commenced DASI deck tests.
16:30 DASI vehicle deployed. Start of DASI TOW 2.
16:38 DASI system powered up, began paying out tow cable to lower system to sea floor.
18:04 Ship passed through point A'.
18:15:30 Started continuous DASI transmission at 1 Hz.
18:35 DASI vehicle passed through point A'.
20:51 DASI altimeter readings and current output become unstable. Began heaving in tow cable.
20:52:30 DASI transmissions stopped. It became apparent from the altimeter record that the DASI vehicle had collided with the sea bed.
20:59 Abandoned DASI TOW 2, after 2 hours 35 minutes of successful transmissions at 1 Hz fundamental frequency. Began DASI recovery.
22:19 DASI vehicle back on board.
22:48 DASI streamer back on board. No significant physical damaged had been sustained by either vehicle or streamer. Nonetheless DASI would need considerable further attention before another deployment could be attempted. It was decided to carry out further swath bathymetry, gravity and magnetic survey overnight.
23:10 Deployed magnetometer.
23:19 Magnetometer and swath bathymetry operating. Began survey along remainder of Line A'-A, followed by Line B-B', followed by line C'-C.

07/12/04 (342)

04:30 Magnetometer switched off due to excessively noisy readings.

04:38 Completed survey along Line C'-C. Set off for Site R-1 to recover LC-2000 receiver #11 for data quality control analysis.
07:12 Recovered magnetometer.
07:24 Commenced recovery of LC-2000 receiver #11 at Site R-1.
07:36 Instrument off the bottom.
09:40 Recovered USBL spar.
10:05 Instrument on the surface.
10:29 Instrument on deck. Set off to Site R-7 to recover LC-2000 receiver instrument there.
11:04 Commenced recovery of LC-2000 receiver at Site R-7.
11:26 Instrument off the bottom.
12:00 By now it was apparent that this instrument was rising extremely slowly through the water column. We subsequently learned that this was because this instrument was fitted with a rechargeable battery pack – heavier than the normal battery pack. This reduced its buoyancy to a critically marginal value. However we had no option but to wait, tracking the instrument by acoustics, until it surfaced.
18:52 The instrument finally surfaced.
19:10 Instrument #15 (data logger #17) safely back on board.
19:26 Commenced a further attempt to acoustically survey the positions on the sea bed of the outstanding receivers. The survey took us over Sites R16, R13, R6, R3, R12, R15 and R20. However despite continuous efforts over a period of 9 hours, no further useful acoustic data were obtained.

08/12/04 (343)
04:30 Acoustic survey abandoned. By this time the weather had deteriorated very significantly, with 35 knots of wind from the west and a corresponding sea. The forecast for the next 36 hours was no better – wind cyclonic, Force 8 or higher; sea state rough or very rough. The vessel hove to to await an improvement.
09:00 Daylight brought a lull in the wind, so we decided to deploy another receiver – Lemur 13 at Site R19. However a bathymetry survey of the site showed an excessively rough sea bed in the planned location, so the deployment site was moved 0.7 n.m. southwards to a flatter location. The new site was designated R19'.
10:22 Commenced deployment of Lemur 13 at Site R19'.
10:24 Instrument deployed.
11:20 Instrument on the bottom. Commenced an acoustic survey of its position on the sea bed.
12:44 Completed acoustic survey of Lemur 13 at Site R19'.
13:02 Set off to Site M' (at eastern end of Line M-M') to attempt another DASI deployment. This deployment position had been chosen because the weather conditions (wind – W to NW, upper end of Force 6; significant sea and swell) would best permit controlled DASI towing into wind and sea, i.e. towards the WNW.
16:50 Commenced deploying USBL spar and DASI streamer.
17:58 DASI deck tests successfully completed.
18:08 Deployed DASI vehicle. Start of DASI TOW 3. Began paying out cable and lowering device to sea bed.
18:50 DASI ship-board power supply cut out due to an insulation fault. Subsequent investigation showed that this was due to high voltage insulation failure of the outboard termination of the deep-tow cable. It was evident that this would yet again require some considerable time to repair, so DASI would have to be recovered again.
20:10 DASI vehicle inboard.
20:34 DASI streamer inboard, following instrument recovery in marginal weather conditions (wind Force 7). End of DASI TOW 3.

21:00 USBL spar recovered. We decided to use the time while the deep tow cable was being repaired to carry out further swath bathymetry surveying.
21:30 Commenced swath bathymetry and gravity survey along Line M'-M at best speed achievable in prevailing weather conditions (5.5 knots).
23:27 Completed swath survey line at Point M. However the swell precluded us from proceeding to our next survey line start point, O, because we would have been beam on to the weather – leading to unacceptable rolling. Instead we turned and headed for Point O', with the seas on our quarter.

9/12/04 (344)

00:28 Start of swath survey line O'-O.
02:55 End of swath survey line O'-O.
03:30 Start of swath survey line N-N'.
04:50 End of swath survey line N-N'.
06:10 Start of swath survey line L'-L
08:02 End of swath survey line L'-L
08:25 Start of swath survey line K-K'.
09:37 End of swath survey line K-K'. We reviewed the state of the deep tow cable termination, and realised that a further considerable delay would ensue before we could deploy DASI again. So, we planned a further series of long, E-W, swath bathymetry/gravity/magnetic profiles to complement the existing regional profiles. In the meantime, the work on the deep tow cable could most easily be carried out with the cable removed from the central towing sheave on the stern A frame. This meant that this was an opportunity to unrig the deep tow cable, and temporarily rig the dredging wire through the A-frame. We therefore planned a schedule of dredge stations, allowing sufficient time for the work of unrigging the deep tow cable and rigging the dredging cable to be carried out beforehand.
14:05 Deployed magnetometer at eastern end of Line CP5.
14:12 Commenced swath survey line CP5 from east to west.
15:00 Magnetometer output very noisy.
18:44 Completed survey line CP5 at western end.
19:04 Recovered magnetometer sensor.
19:20 Deployed XBT.
20:00 Deployed spare magnetometer sensor in hope of improving quality of magnetic data.
20:42 Commenced swath survey line CP6 from west to east.
21:00 Magnetometer data still poor.
23:20 Broke off swath survey line CP6 to commence dredging operations.
23:53 Recovered magnetometer.

10/12/04 (345)

00:17 Commenced dredging operations at Station CD167-DR-2.
01:40 to 02:28 Intermittent winch problems delayed dredging operations.
03:20 Dredge CD167-DR-2 on the bottom; 5000 m wire out.
03:39 Commenced hauling in.
05:55 Dredge recovered. Set off to Site DR-1.
06:43 Commenced dredging operations at Station CD167-DR-1.
08:30 Dredge CD167-DR-1 on the bottom; 4000 m wire out.
09:12 Commenced hauling in.
12:35 Dredge recovered. Preparing to resume survey lines.
12:58 Commenced deploying magnetometer.
13:10 Deployed XBT.
14:12 Resumed swath/magnetic/gravity line along CP6, from west to east.

14:40 Magnetometer no longer working.
15:42 End of swath line CP6. Altered course to start point of line CP7.
16:00 Weather conditions forced a reduction in speed on the new course to 4 kts.
16:13 Commenced swath line CP7 from east to west.
17:10 Force 8 weather conditions – obliged to profile at 3 to 4 knots.

11/12/04 (346)
01:18 Completed swath line CP7.
02:33 Started swath line CP8 from west to east.
07:04 Completed swath line CP8.
08:15 Commenced swath line CP9 from east to west. Wind NW 35 kts. Ship's speed gradually decreasing to less than 3 knots over the ground.
11:40 Obliged to heave to due to weather conditions. Science programme suspended.
18:52 Weather moderated sufficiently to allow vessel to manoeuvre back to Line CP9 again.
21:34 Resumed swath line CP9.

12/12/04 (347)
01:45 Completed swath line CP9.
02:49 Started swath line CP10 (western half) from west to east.
04:45 Completed swath survey at mid point of line CP10. Set off for current meter position C3.
07:30 Wind NNW, Force 8. Gravimeter working only intermittently and with poor accuracy due to sea state. Awaiting daylight, to assess sea state and possibility of starting recovery of current meter moorings.
09:05 Recovered magnetometer sensor.
09:08 Hove to at current meter site C3 to recover current meter mooring.
09:25 Current meter mooring C3 released.
10:00 Current meter C3 on surface.
10:06 Deployed XBT.
10:24 Current meter C3 all recovered. Set off for position C2.
10:48 Arrived at site C2.
11:05 Released current meter mooring C2.
11:37 Current meter C2 on surface.
11:57 Current meter C2 all recovered. Set off for position C1.
12:40 Arrived at site C1.
12:44 Current meter mooring C1 released.
13:08 Current meter C1 on surface.
13:30 Current meter C1 all recovered. Set off to Site R19'.
14:50 Arrived at receiver site R19'.
14:55 Released Lemur 13 at Site R19'
16:11 Lemur 13 on the surface.
16:26 Lemur 13 recovered. Set off to position 2 n.m. SW of Point C, to commence DASI deployment for DASI tow along Line C-C'.
17:00 Arrived at DASI deployment position. Start of DASI TOW 4.
17:32 USBL spar deployed
17:40 Began deploying DASI streamer.
18:10 Commenced DASI deck tests.
18:30 Deployed DASI vehicle. Calibrated DASI current output with 143 m wire out. Then commenced paying out tow cable to lower DASI to sea floor.
19:44 Ship passed through point C.
20:00 Deployed XBT.
20:20 Began intermittent transmissions at 1 Hz with DASI close to sea floor.

21:44 Problems with DASI altimeter telemetry: uncertainty about height off sea floor continuing. We eventually decided that it would be necessary to continue with DASI transmissions but with the vehicle considerably higher than usual above the seafloor, and relying on USBL data (including acoustically telemetered COMPATT depth sensor data) as the primary source for vehicle position and altitude.
22:13:35 Started DASI transmissions at 0.25 Hz.

13/12/04 (348)
02:22 Completed DASI tow along Line CC' @ 0.25 Hz.
04:13 Started DASI transmissions @ 0.25 Hz, towing along Line B'-B.
04:30 DASI vehicle passing Point B'.
09:50 Deployed XBT, but XBT failed due to broken wire.
09:59 Completed DASI tow along Line B'B @ 0.25 Hz.
12:35 Started DASI tow along Line AA' @ 0.25 Hz
18:45 Completed DASI tow along Line AA' @ 0.25 Hz.
19:22 Deployed XBT.

14/12/04 (349)
00:08 Started DASI tow along Line MM' @ 0.25 Hz
04:05 Completed DASI tow along western half of Line MM' @ 0.25 Hz.
05:30 Started DASI tow along western half of Line N'N @ 0.25 Hz
08:32 Completed DASI tow along western half of Line N'N. Switched off DASI transmissions. Commenced hauling in tow cable for DASI recovery, to have one last go at fixing the DASI altimeter and depth sensors and their telemetry.
09:25 DASI on the surface: commenced recovery. End of DASI TOW 4.
09:30 DASI recovered. Set off at 3.5 knots for Point D, for next DASI deployment, towing DASI streamer astern of ship and with USBL spar still deployed.
12:42 Arrived at next DASI deployment site, 1.5 n.m. S of position D.
13:55 Began DASI deployment after successful deck tests. Start of DASI TOW 5.
15:13 Started initial, intermittent transmissions at 1 Hz on Line D-D'.
16:22 Started transmitting in regular 90-second duration bursts, at 1.0 Hz, along Line D-D'. Pauses between bursts of transmission were used to check height above seafloor.
21:34 Ship passing Point D' at northern end of Line DD'.
21:36 Stopped transmitting at 1.0 Hz. DASI altimeter data no longer usable, even between transmission bursts. Began slowly hauling in deep tow cable.
21:42 Started continuous DASI transmission at 0.25 Hz.
22:00 End of DASI transmissions at 0.25 Hz. Started hauling in tow cable for DASI recovery.
23:26 DASI vehicle recovered on deck. End of DASI deployment 5.

15/12/04 (350)
00:13 DASI streamer recovered.
00:40 USBL spar retracted. Set off to Site R17 to recover LC-2000 instrument.
02:15 LC-2000 was released, but – since this was one of two LC instruments fitted with the heavier, rechargeable, battery pack – it was not expected at the surface until 08:30. Set off to Site R15 to release and recover another LC-2000 instrument.
03:15 LC-2000 instrument at R15 released.
06:50 R15 instrument on the surface.
07:30 R15 instrument recovered. Set off back to Site R-17.
08:57 R17 instrument on the surface.
09:10 R17 instrument recovered. Set off to Site R14 to recover instrument Lemur 18.
09:50 Arrived at Site R14.

10:16 Instrument R14 released.
10:38 Determined that Lemur 18 instrument at R14 was rising very slowly, so set off to Site R13 to recover LC-2000 instrument.
11:23 R13 instrument released.
14:10 R13 instrument on the surface.
14:34 LC-2000 instrument at R13 recovered. Returned to R14 to check on ascent progress of Lemur 18. Confirmed its position acoustically, and determined that it was still 1100 m below sea surface.
15:36 Set off to Site R11 to recover Lemur 15.
16:09 R11 instrument released.
17:30 R11 instrument on the surface.
17:53 R11 instrument recovered. Set off back to Site R14.
18:33 Lemur 18 at R14 less than 260 m below sea surface.
19:34 Lemur 18 spotted on the surface. Its positive buoyancy was so marginal that only the stray line float was awash at the surface, with the main instrument hanging beneath this.
19:38 Our initial attempts to recover the instrument were unsuccessful – we were unable to grapple the instrument while it was alongside. The ship had to stand off and make a fresh approach, while longer hooks were prepared for the difficult grappling operation.
20:45 Finally succeeded in grappling R11 instrument, Lemur 18.
20:50 R11 instrument recovered on deck. Its lack of buoyancy had been due to it being deployed without one of its buoyancy spheres – which due to oversight had not been fitted after its shipment to Madeira from Lisbon. Set off to Site R9 to recover LC-2000 instrument.
21:26 Released R9 instrument.

16/12/04 (351)
00:50 R9 instrument on the surface.
00:54 Instrument Lemur 14 at adjacent Site R10 released.
01:48 R9 instrument recovered.
02:28 R10 instrument on surface.
03:32 R10 instrument recovered. Set off to Site R3 to recover LC-2000 instrument.
04:12 R3 instrument released.
08:09 R3 instrument on surface.
08:36 R3 instrument recovered. Set off to Site R12 to recover LC-2000 instrument.
09:23 R12 instrument released.
13:40 R12 instrument on the surface.
14:30 R12 instrument recovered. Set off to Site R18 to recover LC-2000 instrument.
15:05 R18 instrument released.
18:14 R18 instrument on the surface.
18:32 R18 instrument recovered. Set off to Site R6 to recover LC-2000 instrument.
19:12 R6 instrument released.
22:23 R6 instrument on the surface.
22:57 R6 instrument recovered. Set off to Site R5 to recover LC-2000 instrument.
23:32 R5 instrument released.

17/12/04 (352)
02:05 R5 instrument on the surface.
02:40 R5 instrument recovered. Set off to Site R8 to recover LC-2000 instrument.
03:34 R8 instrument released.
05:38 R8 instrument on the surface.
06:02 R8 instrument recovered. Set off to Site R16 to recover LC-2000 instrument.

07:04 Repeated attempts to release or communicate acoustically with the instrument at R16 were unsuccessful. We then realised that this was due to the swapped records of acoustic codes for the instruments at R16 and R20. At this point, the release code for the R20 instrument had been sent, but that for R16 had not been – hence the R16 instrument was still on the sea bed, while that at R20 might possibly have been released already. Set off for Site R20 to check on status of receiver there.
08:00 Hove to at Site R20. Instrument released.
10:04 R20 instrument on the surface.
10:23 R20 instrument recovered. Set off back to Site R16 to recover last LC-2000 instrument.
11:04 Started acoustic survey of position of R16 instrument on the sea bed.
12:07 Acoustic survey at R16 completed.
12:26 R16 instrument released.
15:20 R16 instrument on the surface.
15:39 R16 instrument recovered. This completed the safe recovery of all instruments. Set off to Site CD167-7 to carry out gravity core.
17:17 Started gravity core station CD167-7A.
18:05 Core CD167-7A on the bottom.
18:52 Corer recovered.
19:35 Started gravity core station CD167-7B.
20:23 Core CD167-7B on the bottom.
21:19 Corer recovered. Both of these core stations were taken close to the summit of the Saldanha massif, and core 7A recovered sulphide minerals within the sediments.
21:46 Started gravity core station CD167-9.
22:48 Core CD167-9 on the bottom.

18/12/05 (353)
00:01 Corer recovered.
00:25 Started gravity core station CD167-10.
01:25 Core CD167-10 on the bottom.
02:15 Corer recovered. Fortunately this was our last core station: one strand of the coring wire pennant had parted at the splice, so the wire pennant would not be useable again.
02:35 Deployed magnetometer sensor.
02:53 Set off for mid point of swath/gravity/magnetics Line CP10.
04:30 Started swath Line CP10 (eastern half).
06:33 Completed swath line CP10.
06:51 Started swath line CP11 from east to west.
10:44 Completed swath line CP11.
11:09 Started swath line CP12 from west to east.
15:20 Completed last swath line, CP12. Recovered magnetometer sensor and EA500 echo sounder fish.
15:48 End of science. Set off at full speed for Ponta Delgada.

19/12/04 (354)
All day – on passage.

20/12/04 (355)
All day – on passage.

21/12/04 (356)
08:00 Arrived Ponta Delgada, São Miguel, Azores. End of Cruise CD167.

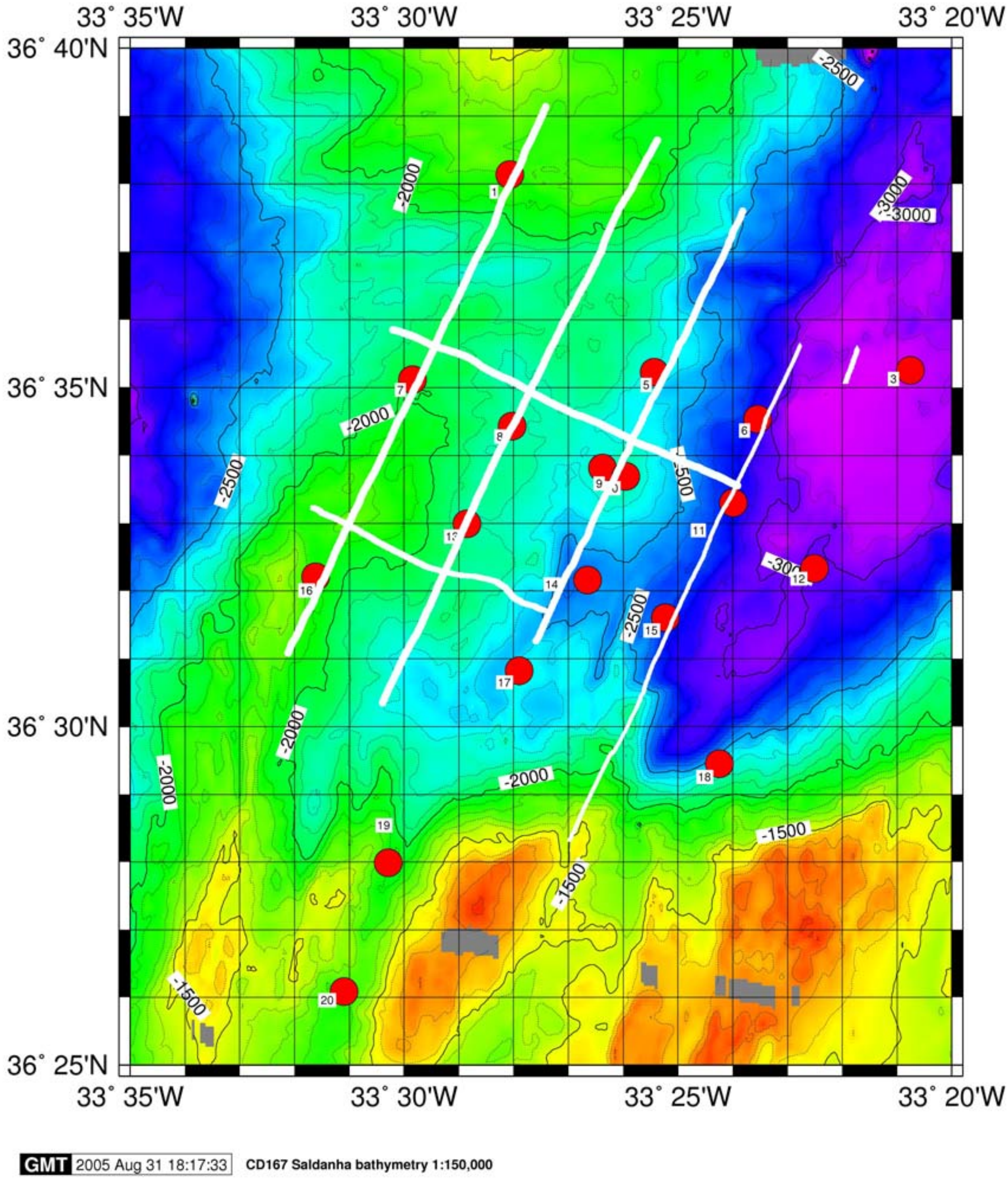

Figure 3.1. Completed DASI transmission tow tracks (white lines), and the positions on the sea bed of all the receivers as deployed (red symbols). The base map is water depth from swath bathymetry (contour interval 100 m).

4. Data and Samples Collected

4.1. CSEM data

Figure 4.1 shows an amplitude spectrum from one of the receivers – LEMUR 14 – during a period of DASI transmission at 0.25 Hz. The fundamental frequency is clearly visible, as are the 3rd harmonic (at 0.75 Hz) followed by the odd harmonics up to 23 times the fundamental, all with a reasonable signal to noise ratio.

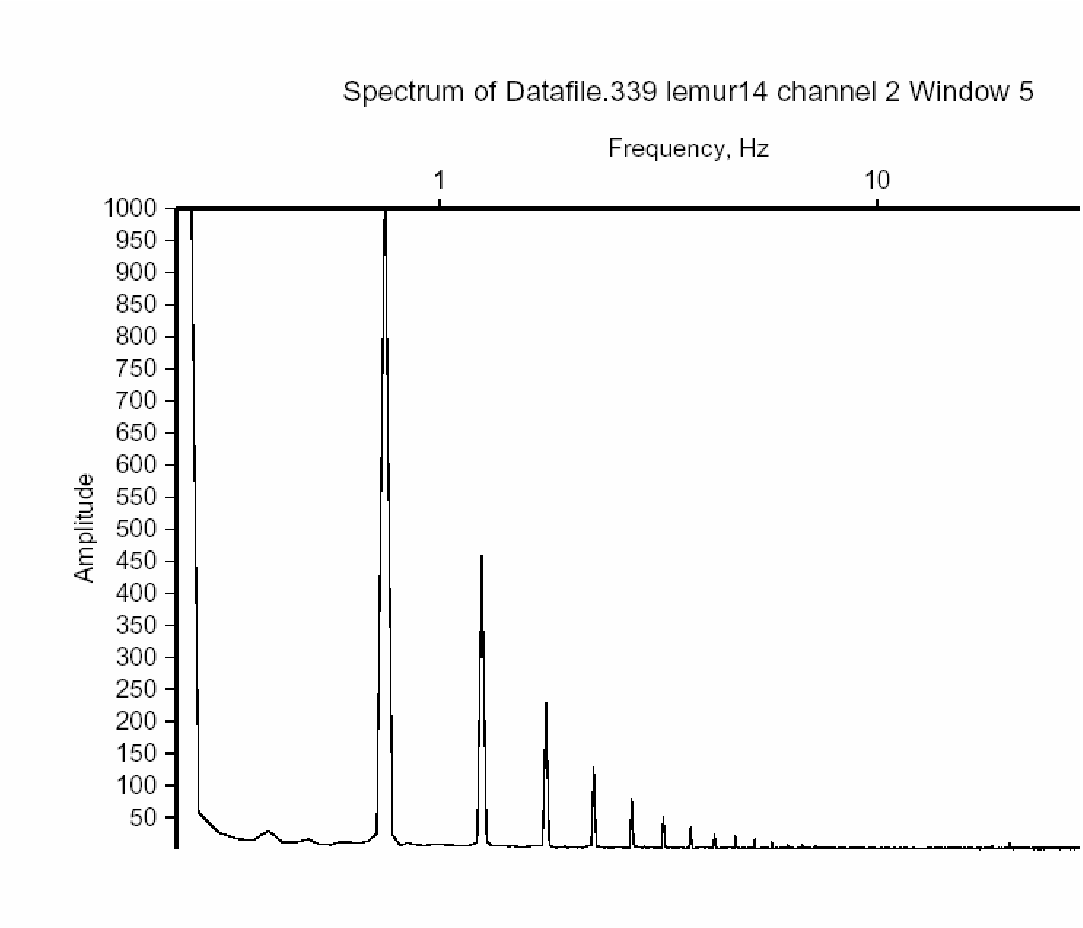

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Fig 4.1. Amplitude spectrum of horizontal electric field data from channel 2 of LEMUR14. The DASI transmission signal was a square wave at 0.25 Hz.

Figure 4.2 shows an example of receiver electric field data in the form of a spectrogram: which plots amplitude as a function of frequency and elapsed time during a DASI tow.

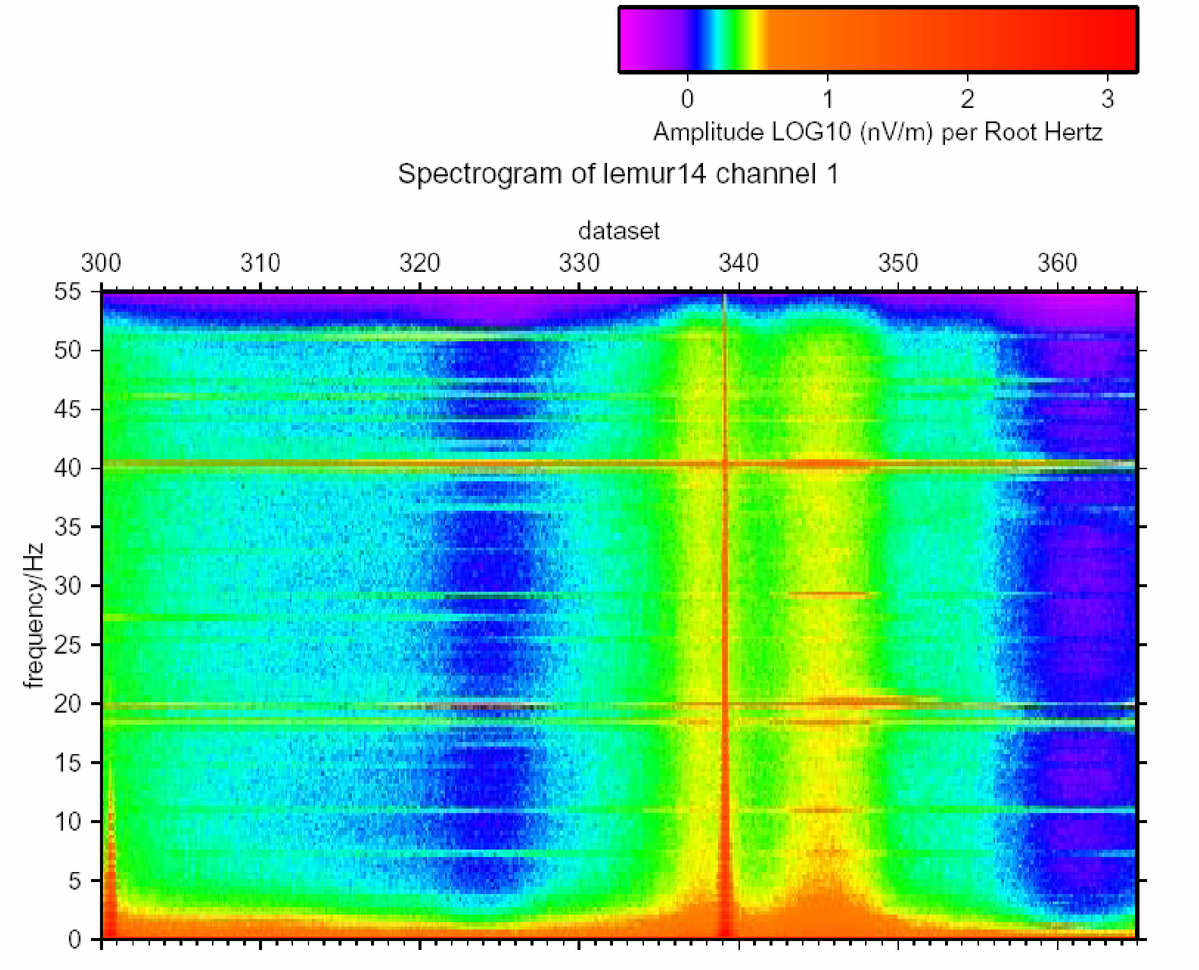

Fig 4.2. Spectrogram showing a time interval of approximately 48 hours, derived from time series electric field data recorded by the channel 2 of LEMUR 14. The large peak in the graph at about file number 339 occurred when DASI was transmitting along line AA' at 0.25 Hz on 13 December 2004.

Analysis to date of recorded CSEM data indicates that a substantial volume of high quality data were recorded. Ongoing work at the time of writing is directed to extracting amplitude and phase parameters and associated errors for the major axis of the horizontal polarization ellipse of electric field at the sea floor, for each receiver, for each frequency (harmonic), and for each DASI tow.

4.2. Coring and dredging

A total of eleven gravity cores were attempted, and of these, ten provided useful samples of sediment and/or basement rock fragments. These samples are undergoing geochemical analysis by A. Dias at the University of Lisbon. See Appendix 2.

Two dredges were successfully completed, and these provided samples for geochemical analysis at the University of Lisbon by F. Marques.

4.3. Other data collected

A number of other data types were collected during CD167, as indicated below.

4.3.1. Current meters

A set of three current meter moorings, providing current speed and direction plus temperature and salinity records, were deployed across the survey area to provide background data for the CSEM study. All three current meters were recovered safely, and had recorded data. See Appendix 3.

4.3.2. Expendable bathythermographs (XBT)

Additional data on water column physical properties was obtained by launching a series of expendable bathythermographs (XBT). We launched a total of 14 bathythermographs, of which 7 recorded good quality data. See Appendix 3.

4.3.3. Gravimeter

The vessel was fitted with a Lacoste and Romberg sea gravimeter (meter no. S40). This worked reliably throughout most of the cruise, but it suffered from intermittent gyro problems especially during the worst of the weather. Base ties were made in Funchal at the start and in Ponta Delgada at the end of the cruise. The drift during the cruise was found to be less than 1 mGal.

4.3.4. Magnetometer

A proton precession magnetometer was towed throughout the DASI towing period, and at some other times when the scientific programme permitted. This instrument suffered from numerous intermittent failures. Consequently substantially less magnetic anomaly data were collected than had been anticipated.

4.3.5. GPS navigation

Ship positioning for every second was achieved by differential Global Positioning System (GPS).

4.3.6. Bathymetry

During the cruise, swath bathymetry data were collected using the ship's fitted Simrad EM-12 system, or using the single-beam EA-500 precision echo sounder, or both – except during periods of acoustic operations related to moorings and receivers when interference needed to be avoided. The bathymetry, gravity and magnetic data have been shared with the partners in the European Union Marie Curie Research Training Network, 'MOMARnet', coordinated by Dr Mathilde Cannat at Institut de Physique du Globe, Paris.

4.3.7. Computing

All underway geophysical and navigational data were logged using the shipboard standard computing network. Full electronic copies in archive format were provided to both Southampton and Lisbon scientific parties prior to disembarkation.

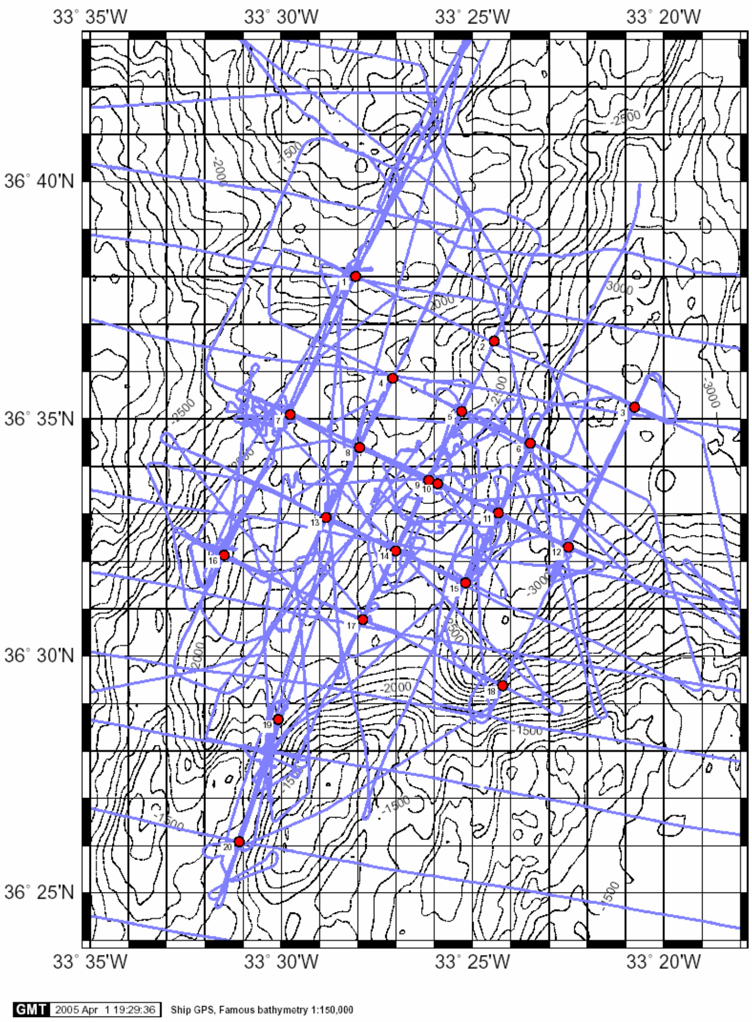

Fig. 4.3. GPS derived track chart for all CD-167 scientific operations, overlaid on swath bathymetric contours and planned receiver positions (red symbols).

4.4. Lost Days

Twelve and a half hours were entirely lost due to adverse weather, when the vessel was hove to. Some further time was lost due to weather, both during the passage to the work area when the vessel was forced to slow down, and during survey operations when weather conditions only permitted underway survey work at low speed. The major cause of lost time was technical down-time due to the problems with the DASI system; and a further loss of time due to insulation failure in the deep tow cable electrical termination. However in all of these cases of technical down time, every effort was made to employ the vessel usefully in achieving alternative objectives. Thus although the total time lost to our primary objective (CSEM survey) due to technical problems amounted to in excess of three days, the total technical down time when the ship was not in use for any scientific objective amounted to only a few hours.

5. Equipment Performance

5.1. DASI system

As noted above the DASI system suffered from a number of equipment problems which limited the time spent successfully transmitting CSEM signals, and the amount of CSEM survey data collected.

5.1.1. DASI and the Deep tow Cable

The first problem encountered came from a flooded five pin connector that had been fitted incorrectly before the launch of DASI. This cable was responsible for serial communications between the top and bottom pressure cases. The DASI instrument had to be recovered and the MAX232 ICs replaced in both tubes as they had become damaged. The cable remained relatively undamaged but it would be advisable to obtain spares for future cruises.

Further problems were caused when the oil-filled, pressure balanced, outboard termination 'bottle' on the deep tow cable developed a leak. This provides the links for both fibre optic data transmission and power between the ship and the deep-tow vehicle. The failure caused the live and neutral parts of the power supply to short circuit. Unfortunately this termination of the deep tow cable must be remade for every DASI cruise, as other deep tow vehicles that use the cable require different termination configurations.

The most significant problems were with the altimeter. This was a Simrad Mesotech 807. It is still unclear whether the depth sensor was at fault, or the circuitry inside the top pressure vessel responsible for reading the altimeter data. The altimeter appeared to operate intermittently and would lose "lock" for periods. Unfortunately the unreliability of the altimeter led to DASI being crashed into the sea floor. The frame sustained some minor damage but that did not impact on the cruise. For future cruises, all the altimetry should be checked thoroughly and operated with a suitable power supply. The top pressure vessel electronic systems should be reviewed and rebuilt on printed circuit boards.

5.1.2. Shipboard Power Supply

The 10kW ship-board power supply system had been replaced since the previous DASI cruise. The new system consists of two cabinets. The power supply control systems had been much improved with this version. The clock circuit had been replaced with a smaller clock circuit which fitted easily into the cabinet. The new power supply system performed well throughout the cruise. In order to prevent back reflections form the deep tow cable, two resistors (one 22Ω and one 47Ω) were fitted in series with one side of the high voltage output. These as expected produced a lot of heat and temporary fans were fitted to control the temperature in the cabinet. With the exception of the current monitor on the front of the cabinet, the new power supply system performed well.

5.2. LEMUR electric field recording instruments

Five LEMUR instruments were taken on the cruise, and four of these were deployed. All four were recovered, but one ascended only extremely slowly following release of its bottom weight. It was also difficult to recover once it had surfaced. This was because it had been shipped from Lisbon with one buoyancy sphere missing from its plastic hard hat, and this was not spotted during deployment or preparation. Procedures need to be improved to ensure that all buoyancy is fully checked prior to deployment.

The LEMUR instruments have recording systems that are complicated to operate and consequently can be unreliable. The LEMUR data logger systems, first used at sea in 1995, have reached the end of their useful operational lives and should now be scrapped. The instrument frames, sensors, pressure cases and release systems are still perfectly usable. The Southampton instruments have, since the end of the cruise, been transferred to the OBIC (UK ocean-bottom instrument consortium) laboratory at Durham University where the logger electronics will be upgraded using LC-2000EM components.

5.3. LC-2000EM instrument

These are based on combined seismic and electric field instruments, developed and built at Scripps Institution of Oceanography and purchased by OBIC. As purchased, the OBIC instruments were fitted only for seismic use. The OBIC and seafloor EM teams at Southampton therefore developed electric field sensors and appropriate deployment modifications for EM applications; and worked with a commercial partner, SeaMap Ltd, to acquire suitable electric field pre-amplifiers. The new EM instruments were field tested in Loch Fyne (western Scotland) in May 2004; but this was their first full-scale deployment in the deep ocean. Fourteen LC-2000 instruments were modified for electric field measurements, and all of these were deployed and safely recovered. All except one had recorded data. The buoyancy and ballast weight arrangements for these modified instruments require fine adjustment, and with hindsight it is clear that we had not got this right prior to the cruise or during instrument deployment. Two instruments were deployed with rechargeable (rather than lithium) battery packs. These weigh more than the lithium packs, and the two instruments returned extremely slowly to the surface. We were lucky to recover all 14 instruments without loss.

5.4. Gravimeter system

The ship's Lacoste & Romberg sea gravimeter system was operated throughout the cruise, with base station ties at port calls at both the start and the end of the cruise. Gravimeter drift between base ties was less than 1 mgal. In general, gravimeter data are of good quality. However there were a number of occasions when gyro cycling errors occurred. This led to the loss of a few hours of gravity data overall.

5.5. Magnetometer system

One of the secondary objectives was to collect long profiles of total field magnetic data across the ridge axis. The magnetometer provided by UKORS for the cruise was a decades-old instrument, clearly at the very end of its useful life. Despite much care and attention by UKORS staff at sea, the magnetometer broke down frequently – as noted in the Cruise Narrative. Typically it would work well for a few hours; its output would then become noisy; and after another couple of hours the data would be entirely useless. This magnetometer should certainly not be sent to sea again – it is fit only for disposal. At the time of writing we understand that

UKORS are in the process of acquiring modern magnetometer instruments to replace all the older systems.

5.6. Other instruments and permanently installed equipment

With the exception of those systems mentioned above, all other items of equipment provided from the National Marine Equipment Pool or permanently installed on the vessel performed well.

6. Mobilization and demobilization

Both mobilization and demobilization of the cruise were straightforward. Much of the heavy equipment had been installed before the scientific party arrived. This included the DASI streamers on their winch drum.

Standards of organization and planning for mob/demob by RSU and UKORS were good. At the end of the cruise the Southampton equipment - DASI system, and five LEMURs - were disembarked and shipped back from Ponta Delgada to NOC.

After a short port stop in Ponta Delgada, the ship transited to Lisbon. Thus, Lisbon equipment (one LEMUR) and all geological samples were disembarked in Lisbon in early January 2005. All fourteen OBIC LC-2000 receivers were shipped by air freight to Central America to be used on a subsequent cruise.

7. Conclusions

The primary objective was to carry out a controlled-source electromagnetic sounding survey of the seafloor at and around the Saldanha massif. For this purpose, an array of eighteen seafloor recording instruments were deployed. All 18 instruments were recovered without loss; seventeen of them having recorded data.

The DASI deep-towed transmitter system was used to generate the controlled source signals. Technical difficulties with the DASI system resulted in the loss of some of the planned DASI tow lines, and in some other lines being towed at a greater height above the sea floor than would have been ideal.

The CSEM survey objective was therefore only partly achieved. Nonetheless we expect to be able to analyse the data collected to provide important new information about the target area.

A water column sound velocity profile was collected, to allow calibration of acoustic positioning systems. The data from this was supplemented by seven XBT stations. To provide information on near-sea-bed hydrographic conditions an array of three current meter moorings was deployed.

Our second objective was to collect a set of bathymetry, gravity and magnetic profiles across the ridge at and to the north and south of the Saldanha massif, to complement and add to existing French and Portuguese compilations. This objective was achieved, with high quality bathymetry data provided by the EM-12 swath system. However the magnetometer worked properly for only parts of the cruise.

Our third objective was to collect a series of short gravity cores of sediments on and around the massif, for the purpose of investigating the history of hydrothermal activity and assessing the extent of hydrothermal circulation through and reactions within the sediments. A total of 11 cores were collected, with 10 of these providing useful materials.

Our fourth objective was to dredge for hard rock samples from sites around the Saldanha massif. Two dredges were completed, and both of these returned useful samples.

In summary: our primary objective was largely met, and our supplementary objectives were fully met. All seafloor instruments/moorings that we deployed were recovered safely.

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References

Barker, N.D., and the Madrigals cruise scientific party. Investigation of crustal fluids at the Lucky Strike hydrothermal site using controlled source electromagnetic sounding. European Geophysical Society, Nice, March 2001. In: EGS Newsletter, **78**, 93.

Bougault, H., M. Aballea, J. Radford-Knoery, J.L. Charlou, P. Jean Baptiste, P. Appriou, H.D.Needham, C.German & M. Miranda, 1998. FAMOUS and AMAR segments on the Mid-Atlantic Ridge: ubiquitous hydrothermal Mn, CH_4, d3He signals along the rift valley walls and rift offsets. *Earth Planet Sci. Lett.*, **161**, 1-17.

Charlou, J.L., H. Bougault, P. Appriou, T. Nelsen & P. Rona, 1991. Different TDM/CH4 plume signatures: TAG site at 26^{o} N and serpentinised ultrabasic diapir at 15^{o} 05' on the Mid-Atlantic Ridge. *Geochim. Cosmochim. Acta*, **55**, 3209-3222.

Detrick, R.S., Needham, H.D. & Renard, V., 1995. Gravity anomalies and crustal thickness variations along the Mid-Atlantic Ridge between 33N and 40N. *J. Geophys. Res.*, **100**, 3767-3787.

Dias A. and Barriga F. Mineralogy and geochemistry of hydrothermal sediments from the serpentinite-hosted Saldanha hydrothermal field (N36º34'; W33º26') at MAR. 2005 (in press)

German C. R., Parson L. M., and Team H. S. Hydrothermal exploration near the Azores Triple Junction: Tectonic control of venting at slow-spreading ridges? Earth and Planetary Science Letters 138, 1996, 93-104.

German, C.R. & Parson, L.M., 1998. Distributions of hydrothermal activity along the Mid-Atlantic Ridge: interplay of magmatic and tectonic controls. *Earth Planet Sci Lett.*, **160**, 327-341.

German, C.R., Parson, L.M., Murton, B.J. & Needham, H.D., 1996. Hydrothermal activity and ridge segmentation on the Mid-Atlantic Ridge: a tale of two hot-spots? In: *MacLeod, C.J., Tyler P.A. & Walker, C.L., Eds., Tectonic, magmatic, hydrothermal and biological segmentation of mid-ocean ridges,* Geological Society Special Publication No. **118**, pp 169-184, London, 1996.

Gràcia E., Bideau D., Hekinian R., Lagabrielle Y., and Parson L. M. Along-axis magmatic oscillations and exposure of ultramafic rocks in a second-order segment of the Mid-Atlantic Ridge. Geology 25(12), 1997, 1059-1062.

Gràcia E., Charlou J.-L., Radford-Knoery J., and Parson L. Non-transform offset along the Mid-Atlantic ridge south of the Azores (38ºN-34ºN): ultramafic exposures and hosting of hydrothermal vents. Earth and Planetary Science Letters 177, 2000, 89-103.

Greer, A., 2000. A joint effective medium method for geophysical properties of two-phase materials. In: Singh, S.C., Barton, P.J. & Sinha, M.C., Eds., *Lithos Science Report, March 2000*, pp 123-131, University of Cambridge.

Greer, A., 2001. Hydrothermal venting at mid-ocean ridges: properties of zero-age oceanic crust. PhD Thesis, University of Cambridge.

MacGregor, L. M. & Sinha, M.C. Use of marine controlled source electromagnetic sounding for sub-basalt exploration. *Geophysical Prospecting*, **48**, 2000, 1091-1106.

MacGregor, L., Sinha, M. & Constable, S. Electrical resistivity structure of the Valu Fa Ridge, Lau Basin, from marine controlled source electromagnetic sounding. *Geophys. J. Int.*, **146**, 2001, 217-236.

White, R.S., Detrick, R.S., Sinha, M.C. & Cormier, M.H. Anomalous seismic crustal structure of oceanic fracture zones. *Geophys. J. Roy. astr. Soc.*, **79**, 1984, 779 - 798.

Appendix 1. CSEM survey operations

Table A1.1. Deployment positions of seafloor electric field instruments

Site	Instrument Number	Data Logger No.	Latitude Degrees North	Latitude Minutes North	Longitude Degrees West	Longitude Minutes West
1	LC11	11	36	38.11	33	28.08
3	LC 18	2	36	35.28	33	20.81
5	LC 13	13	36	35.20	33	25.30
6	LC 05	5	36	34.50	33	23.50
7	LC 15	7	36	35.10	33	29.80
8	LC 04	4	36	34.40	33	27.96
9	LC 03	3	36	33.70	33	26.20
10	LM14	LM14	36	33.63	33	25.87
11	LM15	LM15	36	33.01	33	24.34
12	LC 07	7	36	32.29	33	22.48
13	LC 06	6	36	32.92	33	28.79
14	LM18	LM18	36	32.15	33	26.60
15	LC 12	12	36	31.60	33	25.20
16	LC 01	1	36	32.20	33	31.4
17	LC 16	16	36	30.7	33	27.8
18	LC 08	8	36	29.37	33	24.20

19	LM13	LM13	36	27.90	33	30.37
20	LC09	9	36	26.0	33	31.10

LC – LC2000EM instrument

LM – LEMUR instrument

Note: No instruments were deployed at sites 2 or 4 due to the proximity of a submarine telecommunications cable.

Table A1.2. DASI transmitter deployments and tow lines

Tow Number	Line	Frequency (Hz)	Start Date/Time	End Date/Time	Comments
1	A'-A	-	339/1036	339/1129	No transmissions
2	A'-A	1	341/1815	341/2059	Northern half of line
3	M'-M	-	343/1808	343/1900	No transmissions
4	C-C'	0.25	347/2213	348/0222	Whole line
4	B'-B	0.25	348/0413	348/0959	Whole line
4	A-A'	0.25	348/1235	348/1845	Whole line
4	M-M'	0.25	349/0008	349/0405	Western half of line
4	N'-N	0.25	349/0530	349/0832	Western half of line
5	D-D'	1	349/1622	349/2136	Whole line

Appendix 2. Geological sampling

Table A2.1. Positions of gravity core samples

no	Sample	Latitude N	Longitude W	Depth, m	Length, m	General description
1.	CD167-1	36 33.34	33 21.64	3169	**0**	
2.	CD167-2	36 34.70	33 25.45	2350	**1.5**	Whitish sediment
3.	CD167-4	36 33.72	33 24.74	2480	**1**	Brownish sediment.
4.	CD167-5	36 32.79	33 25.75	2241	**0.7**	Brownish sediment at the top and whitish at the bottom.
5.	CD167-6	36 33.50	33 33.57	2289	**0.4**	Whitish sediment. Brownish and coarse for the first 20 cm
6.	CD167-3	36 34.37	33 26.70	2248	**1.5**	Brownish sediment.
7.	CD167-8	36 30.54	33 29.90	2300	**1**	Brownish sediment.
8.	CD167-7A	36 33.91	33 25.86	2198	**0.3**	Grey and green at the top. At the bottom the sediment has whitish and grey layers intermixed. The sediments contain oxides at the top, and at the bottom steatites and millimetric grains of sulphides could be observed
9.	CD167-7B	36 34.02	33 25.99	2192.9	**0.1**	Mainly composed by fragments of basalts
10.	CD167-9	36 33.92	33 25.76	2259.5	**1.2**	Brownish sediment.

11.	CD167-10	36 32.62	33 27.98	2181	**0**	Fragments of basalts

Table A2.3. Positions of dredge samples

No	Sample	Start Latitude (N)	Start Longitude (W)	End Latitude (N)	End Longitude (W)
2	DR1	36 34.7	33 24.5	36 34.4	33 25.2
1	DR2	36 32.85	33 25.20	36 32.97	33 25.38

Appendix 3. Gravity/magnetic/swath bathymetry profiles

Table A3.1. Western and eastern ends of across-axis underway geophysics profiles.

	Western end					Eastern end			
Line No.	Lat Degrees North	Lat Minutes North	Long Degrees West	Long Minutes West		Lat Degrees North	Lat Minutes North	Long Degrees West	Long Minutes West
CP1	36	26.796	33	51.074		36	21.236	33	11.929
CP2	36	30.780	33	50.102		36	25.220	33	10.914
CP3	36	33.777	33	49.611		36	28.212	33	10.404
CP4	36	40.787	33	48.140		36	35.098	33	08.881
CP5	36	28.9	33	51.0		36	23.3	33	11.3
CP6	36	32.28	33	49.85		36	26.71	33	10.66
CP7	36	35.523	33	49.27		36	29.98	33	10.03
CP8	36	39.03	33	48.52		36	33.47	33	09.25
CP9	36	42.20	33	47.71		36	36.59	33	08.42
CP10	36	45.34	33	47.03		36	39.81	33	07.69
CP11	36	47.01	33	46.74		36	41.40	33	07.38
CP12	36	50.05	33	46.06		36	44.49	33	06.66

Appendix 4. Water Column Measurements

Table A4.1. Current Meter deployment sites

Site	Instrument No.	Date & Time	Latitude Degrees North	Latitude Minutes North	Longitude Degrees West	Longitude Minutes West
C1	1	336/18:43	36	34.0	33	29.5
C2	2	336/17:37	36	34.0	33	25.0
C3	3	336/16:28	36	34.003	33	23.180

Table A4.2. XBT Site positions

	Data file name	Date/Time	Latitude Degrees North	Latitude Minutes North	Longitude Degrees West	Longitude Minutes West
1	T7$00003.RDF	12/09/04 19:13:39	36	29.36	33	52.66
2	T7$00004.RDF	12/10/04 12:59:01	36	33.18	33	25.00
3	T7$00005.RDF	12/12/04 10:02:22	36	33.7	33	23.17
4	T7$00006.RDF	12/12/04 19:54:11	36	30.07	33	28.28
5	T7$00007.RDF	12/13/04 09:42:16	36	30.07	33	30.52
6	T7$00008.RDF	12/13/04 20:17:29	36	40.62	33	29.50
7	T7$00009.RDF	12/14/04 19:28:37	36	34.27	33	23.60