UNIVERSITY OF CAMBRIDGE

DEPARTMENT OF EARTH SCIENCES

Cruise Report

R.R.S. Charles Darwin

Cruise 39

Electromagnetic Sounding of the East Pacific Rise at 13°15' North

May-June 1989

With the Compliments of

MARINE INFORMATION & ADVISORY SERVICE

INSTITUTE OF OCEANOGRAPHIC SCIENCES DEACON LABORATORY

Have written to Martin Sinha & hopefully you will receive the next report direct.

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R. R. S. Charles Darwin

Cruise 39

East Pacific Rise

Balboa to San Diego, 16 May - 16 June 1989

CRUISE REPORT

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Summary

The objective of Cruise 39 was to conduct a controlled source electromagnetic (EM) sounding over the East Pacific Rise axis at 9°30' North, in a region where seabeam bathymetry and high quality seismic data had previously been collected. Using the electric dipole-dipole sea floor method, we planned to conduct an extensive survey of crustal conductivity beneath the ridge axis and off axis to a distance of about 20 km.

Political and logistical factors ensured that the cruise got off to an extremely shaky start. We were due to mobilise in Balboa, Panama at a time coinciding with that country's ill-fated presidential elections, and their subsequent annulment by General Noriega after his favoured candidate lost. The resulting political uncertainty and civil unrest on the streets of Panama City formed the first strand of our difficulties. The second strand was that a 20 foot container packed with all the Cambridge equipment needed for the cruise failed to get to Panama, and stuck *en route* in Miami. It was decided to abandon plans to complete the mobilisation in Panama, and instead arrange for the ship, most of the scientists and the errant container to meet in San Diego and commence the cruise there. The ship eventually sailed for the work area from San Diego, after embarking the scientific party and equipment container, on the 28th of May. Because we had lost so much time, we relocated the experiment north along the East Pacific Rise axis from 9°30'N to 13°15'N - another site with excellent pre-existing seabeam and seismic coverage, and a day's steam closer to San Diego.

The ship reached the work area on the 2nd of June. Eight sea bottom EM receivers - four each from Scripps and Cambridge - were laid in two 10 km long lines, one along the ridge crest and one 5 km to the east. The Cambridge deep towed EM transmitter was then towed for two and a half days along the two lines, transmitting at frequencies from 0.125 to 8 Hz. Long base line acoustic navigation was used throughout. The deep tow and seven of the sea bottom receivers were recovered safely at the end of the experiment. One Cambridge receiver did not release, and was lost. All of the recovered instruments had recorded good data.

The ship departed from the work area on the 10th of June, and arrived in San Diego on the 16th of June, having achieved the major objectives of the cruise despite the early difficulties and consequent loss of time on station.

1. Introduction and Cruise Objectives

The objective of *Charles Darwin* Cruise 39 was to use active source electromagnetic sounding to investigate the presence and distribution of magmatic and hydrothermal fluids in the oceanic crust beneath the East Pacific Rise. The presence of a steady state, crustal magma chamber beneath fast spreading mid ocean ridges has long been inferred from petrological and other data, and more recently detailed seismic experiments have confirmed the presence of both crustal low velocity zones beneath the Rise axis, and bright reflectors associated with the top surfaces of the chambers. However conventional, wide angle seismic techniques are prone to difficulties in reliably characterising the properties of low velocity regions, while deep reflection profiling provides poor control on seismic velocities, even though its spatial resolution is good. In addition seismic parameters are relatively insensitive to the presence of small fractions of fluids, whether they consist of sea water saturating the cracks and fractures in the upper crust, or of partially crystallised magma in a magma chamber. The electrical conductivity of oceanic rocks, in contrast to seismic parameters, is extremely sensitive to the presence of even quite small fractions of fluid forming an interconnected, electrically conducting phase within a resistive matrix. Conductivity in oceanic crustal rocks also depends strongly on temperature. Electromagnetic sounding methods capable of determining crustal conductivity structure are therefore more sensitive than other geophysical techniques to the features of greatest interest beneath mid ocean ridges - namely, the temperature structure, the presence and proportion of melt in crustal reservoirs, and the porosity of hydrothermal circulation systems.

Using the electric dipole-dipole active source sea floor sounding method developed over the last ten years at Scripps Institution of Oceanography, and more recently at Cambridge University, we planned to conduct an extensive survey of crustal conductivity beneath the ridge axis, and off axis to a distance of about 20 km. The site initially chosen was at 9°30' North, where seabeam bathymetry and high quality wide angle and multichannel reflection seismic data had previously been collected. The electromagnetic source signal was to be provided by the Cambridge Deep-towed Active Source Instrument (DASI), which features a neutrally buoyant transmitter antenna which can be flown a few tens of metres above the sea floor in regions of rough, unsedimented terrain. (In contrast, the transmitter developed by Scripps needs to be towed on sea floor covered by sediment.) The transmitted signals would be measured by eight sea floor electric field recorders - four each from Cambridge and Scripps, called LEMURs and ELFs respectively - all equipped with an orthogonal pair of horizontal 12 m antennae.

This was to be a two phase experiment, with the first phase consisting of a survey on and along the ridge itself, and the second phase extending the experiment along a transect parallel to the spreading direction. Phase 1 was to be given by far the higher priority of the two. Completion of both phases would entail recovering and redeploying at least five of the eight receivers, and would require approximately 20 days on station. A 32 day cruise was scheduled, starting and ending in Balboa, which is approximately six days steaming time from the study area.

The project was originally conceived, and proposed to NERC, as a purely Cambridge University programme. However during the time interval between NERC awarding funding and ship time and the start of the cruise, it became clear during discussions with Dr Steven Constable and Professor Charles (Chip) Cox - who run the active source marine EM program at Scripps - that the Scripps group were keen to participate in the experiment. This would have two principal advantages. Firstly, the provision of another four receiving instruments by the Scripps group would be likely to double the amount of data collected, at no additional cost to NERC and at a modest cost to a U.S. funding agency. Second, the pooling of intellectual resources would increase the likelihood of success of this very innovative project. Accordingly, the Scripps group were invited to collaborate; Constable applied for and obtained the necessary funding from N.S.F.; and the experiment was redesigned in the form described above to make the best use of the extra receivers. The successful outcome of the ensuing collaboration between the Cambridge and Scripps groups is the subject of the remainder of this report.

2. Cruise Mobilisation

Mobilisation of the cruise was scheduled to take place in Balboa - the port at the Pacific end of the Panama Canal, and a suburb of Panama City - between the 12th and 15th of May 1989. In the event, this period coincided with a presidential election in Panama, which resulted in considerable unrest and tension in and around Panama City. The situation became uglier as Panamanian security forces committed acts of violence against opposition politicians and supporters, while international observers of the elections predicted a substantial majority for the opposition presidential candidate. Serious rioting broke out in Panama City when the country's military ruler General Noriega, whose favoured candidate had conspicuously failed to secure a mandate from the electorate, declared the results of the election annulled. The United States began a major airlift of troops and equipment into its bases in the Panama Canal Zone, placed its forces there on their highest state of alert, ordered all U.S. citizens in Panama either to leave or to confine themselves to U.S. military bases, and despatched a powerful naval task force to the area. Immediate U.S. military intervention to unseat Noriega appeared to be a real possibility. These worrying events unfolded as the scientific parties from Cambridge and Scripps began travelling to Panama, via Miami.

Over the same period, it was learned from the ship's agents in Panama that a 20 foot container loaded with all the Cambridge EM sounding equipment, vital for the cruise, had failed to reach Balboa. Eventually we learned that it had got stuck in Miami, after the ship that should have taken it from Miami to Balboa had been involved in a collision with another vessel at a previous port call. The shipping agent handling the container in Miami had failed to make immediate alternative arrangements to get the container to Balboa, or to contact Cambridge University, the shipping agents in the U.K., or the agents in Balboa.

The Principal Scientist, unwilling to take people unnecessarily into a potentially very dangerous situation, held over with the majority of the Cambridge scientists in Miami, to await developments in Panama and to try to sort out the problem with the container. Fortunately, the Cambridge party were carrying with them an original Bill of Lading for the container, which gave authority to take it out of the hands of the shipping line and agents and send it by alternative means to any destination. Meanwhile, an advanced group of 3 Cambridge scientists, the RVS personnel joining the ship in Balboa, and the ship herself all arrived in Panama; and Steven Constable flew from San Diego to Miami to find out what was going on. After many telephone calls and fax and telex messages between the ship, Barry, Swindon, Cambridge, Panama, San Diego and Miami, a decision was made to abandon mobilisation plans for Balboa, and steam the ship instead as fast as possible to San Diego, and mobilise there. Meanwhile the remaining scientists would make their way to San Diego to join the ship there, and the Cambridge container would be trucked across the U.S. to San Diego from Miami. An alternative plan, to mobilise instead at a port in Mexico closer to the work area, was rejected on advice from Mexican colleagues that customs problems with the container would be likely to take many days to sort out.

By the time that this decision was taken, GLORIA had already been unloaded from the ship in Balboa. NERC were unwilling to leave such an important piece of equipment to an uncertain fate in Panama. There was then a considerable delay before the ship could obtain craneage facilities to reembark Gloria, obtain the necessary charts, and complete taking on stores and bunkers prior to sailing from Balboa. However these tasks were eventually completed and the personnel already in Panama were embarked safely; the ship, container and remaining scientists all arrived successfully in San Diego; and after a 24 hour turn round there, the ship sailed at last for the work area, very late but with everything and everyone safely on board.

The timetable of these confused and frustrating events was as follows:

8th May: R.V.S. personnel and Cambridge advanced party - Evans, Unsworth and Carter - fly to Panama via Miami.

9th May: R.V.S. personnel and Evans, Unsworth and Carter arrive in Panama and find many signs of previous night's violence. They make contact with the Agent, but as far as possible remain in their hotel as travel is unsafe.

10th May: Sinha, Patel, MacCormack, Jones, Leonard fly to Miami, and decide to wait there until situation in Panama becomes clearer.

11th May: *Charles Darwin* arrives Balboa. Constable and Fowles fly to Miami to join others already there. We learn that the Cambridge container is in Miami, not Balboa.

12th May: News reports from Panama indicate deteriorating situation. U.S. begins military build-up and orders US civilians out of Panama. Unsworth in Panama reports medical problem. Container located in Miami, and local agents contacted. A lively night for those in Miami, when the hotel catches fire.

Decisions taken :

(i) *Charles Darwin* to reembark GLORIA and complete stores and bunkers, then sail from Balboa a.s.a.p. for San Diego. Cambridge container to be trucked from Miami to San Diego to meet ship there.

(ii) Scientists in Miami to join ship in San Diego, not Balboa.

(iii) Unsworth to fly back to Miami for medical attention; Carter to accompany him for safety; Evans and R.V.S. personnel to join ship in Balboa.

13th May: Evans and R.V.S. personnel join ship in Balboa. Carter and Unsworth fly to Miami and join others.

14th May: Sunday - a quiet day.

15th May: Customs etc. formalities for releasing container from docks in Miami completed. Container sets off on truck to San Diego. Constable, Sinha and Unsworth fly to San Diego to make preparations at Scripps for cruise and port call. Leonard, Jones, Carter, Patel, MacCormack, Fowles set off overland for San Diego. Ship continues preparations to leave Balboa.

16th May: *Charles Darwin* sails from Balboa, having re-embarked GLORIA.

18th May: Cambridge container reaches San Diego.

25th May: Cambridge overland party reach San Diego.

27th May: *Charles Darwin* arrives San Diego. GLORIA disembarked. Cambridge container embarked. Final mobilisation begins.

28th May: Mobilisation completed. *Charles Darwin* sails from San Diego for the work area.

Although the ship's passage from Balboa to San Diego took 11 days, the time was not entirely wasted. The scientists who had joined in Balboa worked hard on preparations for the cruise while at sea, and this effort minimised the turn round time needed in San Diego, and subsequently meant that no time was lost once we arrived on station in completing preparations before starting the experiment. Meanwhile Sinha, Constable and Unsworth at Scripps reviewed the experimental programme, and planned an alternative schedule and experiment configuration that would make the best possible use of the time on station that remained. They also decided to move the location of the experiment north along the East Pacific Rise axis from 9°30' North to 13°15' North. This site offered the main advantages of the original site - namely, excellent pre-existing seabeam swath bathymetry and wide angle and normal incidence seismic datasets - plus the additional advantage of being a day's steam closer to San Diego, thus increasing the time we would have in the work area by two days. The only significant difference between the two sites is that the rise axis at 13°15' N is shallower and has steeper flanks than that at 9°30'N; and multi-channel seismic data from 13°15' N show no evidence of an axial magma chamber reflection, while this reflector can be seen clearly on the data from 9°30'N.

3. Cruise Narrative

By the time that we sailed from San Diego, our worst problems were over. Passage to the work area went quickly in excellent weather, with final preparations of the equipment being made on the way. Once we arrived at the work site, the experiment ran according to our revised plan to within six hours for the remainder of the cruise, in good weather and with relatively little by way of instrument problems.

Our first task at the work site was to lay an array of six Oceano long-base-line acoustic navigation transponders, giving coverage of almost the entire area of operations (figure 1). The net was then calibrated and tied to absolute geodetic co-ordinates by G.P.S. Thereafter the acoustic navigation system worked almost continually and with excellent reliability for the remainder of the cruise. We then deployed the eight sea bottom electric field recorders in two 9 km long lines of four instruments each. One line was located along the axis of the Rise, and the other was offset by 5 km to the east onto crust approximately 100,000 years old. We carefully determined the positions of these instruments on the sea bed relative to the acoustic navigation net by acoustic ranging to the ELFs from several locations, and by acoustically determining the closest point of approach to each LEMUR along two orthogonal tracks crossing close to the instrument.

Deployment of DASI, the deep-towed EM transmitter, went smoothly, and we were able to tow the transmitter alternately along each line of receivers for two and a half days. With the aid of the high quality positioning information provided by the acoustic navigation system, it proved possible to keep the deep tow to within 200 metres laterally from the planned track lines for virtually all of the time, and to within 50 metres laterally for most of the time. Notwithstanding the contribution of the technology, this represents a most remarkable feat of ship handling skill maintained for long periods of time by the ship's bridge watch keeping officers. The deep tow's integral 3.5 kHz echo sounder allowed us to maintain it, by careful use of the winch controls, at a height of 30 plus or minus 10 metres above the sea bed throughout each transmitting run. Useful active source EM transmissions, with the deep tow operating at high power and close to the sea bed, totalled 32 hours and 39 line kilometres at frequencies between 0.125 and 8 Hz.

Gravity data were collected throughout the time spent in the work area. We ran three 15 km long gravity profiles parallel to the ridge axis, in order to test the validity of two-dimensional approximations for modelling the EM results (figure 2). Gravity line 1 was located 5 km east of the Rise axis, coincident with the off-axis line of EM receivers; gravity line 2 was run along the axis; and gravity line 3 was located 2.5 km east of the axis on crust approximately 50,000 years old.

The deep tow, all four Scripps sea bottom receivers and the six Oceano acoustic navigation transponders were recovered without difficulty. Two of the Cambridge receivers were also recovered easily, but the other two caused severe problems. One was eventually recovered despite partial failure of its acoustic release, but the fourth instrument failed to leave the sea bed despite the fact that its acoustics appeared to function correctly. All of the seven receivers that were recovered had recorded high quality electromagnetic data.

After abandoning the efforts to recover the last LEMUR, the ship left the work site on the 10th of June, and returned to San Diego. The following section relates the chronology of the cruise. Times are in GMT, which is seven hours ahead of local (ship's) time.

28 May	22:00	Sailed from San Diego
2 June	22:00	Arrived on station
	22:50	Deployed acoustic navigation transponder B7
3 June	00:17	Deployed acoustic navigation transponder B8
	01:36	Deployed acoustic navigation transponder B10
	02:54	Deployed acoustic navigation transponder B11
	04:28	Deployed acoustic navigation transponder B12
	05:49	Deployed acoustic navigation transponder B9
	07:07	Began sound velocity meter profile of water column, wire tests of acoustic release units and XBT profiles.
	14:13	Wire tests etc. completed. Began relative calibration of acoustic navigation net.
	20:52	Completed relative calibration of net. Started GPS calibration.
4 June	02:15	GPS calibration of acoustic navigation net completed. Began second wire tests of two dubious acoustic releases.
	03:45	Wire tests completed.
	05:09	Deployed ELF Quail.
	07:00	Deployed LEMUR 1.
	07:55	Began ranging on ELF Quail to determine its position on the sea bed.
	09:38	Finished ranging on Quail.
	10:25	Deployed ELF Jethro.
	12:06	Deployed LEMUR 2.
	13:02	Began fixing position of LEMUR 2.
	14:07	LEMUR 2 position fixed. Began ranging on Jethro.
	16:05	Jethro position fixed.
	16:42	Deployed ELF Maques.
	17:53	Deployed LEMUR 3.

	19:17	Deployed LEMUR 4.
	20:12	Began fixing position of LEMUR 4.
	21:05	LEMUR 4 position fixed.
	21:43	Began fixing position of LEMUR 3.
	22:20	LEMUR 3 position fixed.
	22:43	Began fixing position of LEMUR 1.
	23:43	LEMUR 1 position fixed.
5 June	00:57	Began ranging on ELFs.
	03:10	Finished ranging on ELFs.
	03:40	Began test deployments of DASI streamers.
	05:10	Started deck tests and calibration of DASI transmitter.
	05:46	Experienced problems with DASI transmitter.
	06:16	DASI streamer recovered.
	07:19	Deployed ELF Rhonda.
	07:28	Rhonda reappeared on the surface, due to fault on acoustic release board.
	07:49	Rhonda recovered.
	08:17	Began gravity survey lines 1 and 2.
	14:19	Finished gravity lines 1 and 2.
	15:29	Deployed ELF Rhonda again.
	16:45	Began gravity survey line 3.
	18:34	End of gravity survey.
	19:55	Began ranging on ELFs .
	20:13	Experienced problems with acoustic navigation system - transducer fish not working.
6 June	00:44	Began ranging on ELF Rhonda using GPS navigation.
	03:57	Rhonda position fixed.
	04:00	Deployed DASI streamer for second round of deck tests.
	06:00	Acoustic navigation fish and system working again.
	07:20	DASI deck tests completed. Headed for deployment position.
	08:18	Began deploying DASI.
	11:19	DASI deployed and being lowered towards sea bed.
	12:54	Commenced DASI transmissions, first run along off-axis line (line 1 run1).
7 June	00:39	Line 1 run 1 finished. Frequencies transmitted - 0.25, 0.5, 1, 2, 4 Hz.
	03:41	Commenced DASI transmissions, first run along ridge axis line (line 2 run 1).
	06:20	Problems experienced with DASI transmission wave form. End of line 2 run 1. Frequencies transmitted - 0.25, 0.5, 1 Hz. Began investigating DASI fault.
	08:20	Fault traced to lack of charge in DASI batteries. Transmissions left off to recharge batteries while heading to far end of line 2 ready to start line 2 run 2.
	14:28	DASI back on line with batteries recharged. Commenced DASI transmissions, line 2 run 2.
	22:08	End of DASI line 2 run 2. Frequencies transmitted - 0.25, 0.5, 1, 2, 4, 8 Hz. Began recharging DASI batteries again. Recovered deep tow acoustic relay transponder to fix problem with loose transducer cage causing spurious triggers, solved problem and redeployed it.
8 June	04:57	DASI batteries charged again. Commenced DASI transmissions on line 1 run 2.
	09:51	End of DASI transmissions on line 1 run 2. Frequency transmitted - continuous 8 Hz. Began recharging DASI batteries again.
	17:43	DASI batteries recharged again. Commenced DASI transmissions at 8 Hz on line 2 run 3.
9 June	01:00	End of DASI transmissions on line 2 run 3. End of deep tow operations. Began recovering DASI.
	03:56	DASI recovered.
	06:15	ELF Rhonda recovered.
	08:10	ELF Maques recovered.
	10:22	ELF Quail recovered.

	12:39	ELF Jethro recovered.
	13:48	Acoustic navigation transponder B8 recovered.
	15:05	Acoustic navigation transponder B10 recovered.
	16:25	Acoustic navigation transponder B11 recovered.
	17:50	Acoustic navigation transponder B12 recovered.
	19:07	Acoustic navigation transponder B9 recovered.
	20:33	Acoustic navigation transponder B7 recovered.
	22:18	LEMUR 4 recovered.
	23:40	LEMUR 3 recovered.
10 June	00:15	LEMUR 2 failed to respond to acoustic signals.
	01:00	Suspended attempts to contact LEMUR 2. Headed for LEMUR 1, keeping look-out for LEMUR 2 in case it had released prematurely and surfaced (in which case it would have drifted in the direction of LEMUR 1).
	01:30	LEMUR 1 responded acoustically but failed to release.
	03:53	Suspended attempts to release LEMUR 1. Returned to LEMUR 2.
	04:22	Resumed attempts to contact and release LEMUR 2.
	07:53	LEMUR 2 surfaced close to ship, having released without sending any acoustic responses.
	08:15	LEMUR 2 recovered.
	08:50	Resumed attempts to release LEMUR 1. LEMUR 1 continued to respond acoustically to release signals, but failed to leave the sea bed.
	15:00	Abandoned attempts to recover LEMUR 1. Began return passage to San Diego.
16 June	15:30	*Charles Darwin* arrived in San Diego.

4. Equipment Performance

This cruise depended crucially on the satisfactory performance of a range of equipment, much of it very new, supplied by Cambridge, Scripps and RVS. The generally reliable performance of all of this equipment was both gratifying and an essential ingredient in the cruise's ultimate success.

4.1 RVS Equipment

4.1.1 Acoustic Navigation System

The Oceano acoustic navigation system made a great contribution to the success of the EM experiment, by providing us with almost real time positions of the ship and deep tow with a reliability and accuracy that exceeded expectations. We experienced only two problems with the system. The first occurred when the connector between the ship transducer unit and its tow cable flooded. Fortunately this happened early in the cruise, while we were deploying and locating sea bottom instruments, and not during deep tow operations. Although it took several hours to fix, most of the down time coincided with GPS availability, so that very little ship time was wasted. The second problem was due to the wire cage which protects the acoustic transducer of the relay transponder unit working loose during deep tow operations. The cage then began to rattle in the water flow, generating noise which caused false triggers of the relay transponder unit and seriously degrading the acoustic navigation data for the deep tow. The problem was fixed by hauling up the deep tow, removing and repairing the transponder, and redeploying it. Again, relatively little time was wasted in this process, as the time was used to continue charging the deep tow's battery packs - something which needed to be done anyway.

4.1.2 Acoustic Release Units

The Cambridge LEMUR sea bottom receivers were fitted with I.O.S. type acoustic release units, supplied by RVS. We experienced serious problems with two of these. All the releases that were used for deployments were first wire tested successfully. Every instrument was watched after its deployment until it arrived safely at the sea bed, and was observed at that point to be responding acoustically to commands from the ship. The acoustics of each release were then used, again successfully, to locate the instruments accurately on the sea bed. Despite this, two out of four releases failed to function correctly when we attempted to recover them. One of the units released eventually after many hours of attempts, even though its acoustic system remained silent throughout the recovery phase. The release started pinging only after it was safely back on the ship. The recovery of the instrument despite the failure of the release system acoustics was largely due to good luck, perseverance and the vigilance of the bridge watch keepers who saw the instrument surface.

We were not so lucky with the other unit, whose failure led to the loss of the instrument and one eighth of the data from the experiment. This release appeared to be functioning acoustically, but repeated release commands failed to separate the instrument from its bottom weight. In the light of other users' experiences, as well as our own, the most likely explanation for this is that the gas retractors failed to activate properly. IOS(DL) and RVS now recommend that retractors are not used in deep water, but at the time we were following RVS recommendations by using retractors rather than pyro releases.

The deck units for the release system also gave some cause for concern. On one of the units, the power supply overheated during prolonged use, causing the unit to fail. There was some uncertainty as to whether the other deck unit on the ship was working correctly at all. The deck units are crucial to the success of experiments involving sea bottom instruments, and anything less than total reliability and the very highest standards of maintenance are unacceptable.

The crucial need for reliable acoustic release systems cannot be over stressed. Since mid 1989 we have lost four Cambridge sea bottom instruments through the failure of RVS supplied acoustic release systems. The loss is not only of the instruments, which are hard to replace due to both financial and manpower limitations, but also of the data that they contain, the real cost of which vastly exceeds that of the instrument, and which is impossible to replace. It now seems clear that most of these losses were due to malfunctioning gas retractors. Nonetheless my conclusion is that current procedures at RVS for servicing and testing these vital pieces of equipment before sending them to sea are inadequate.

4.1.3 Deep Tow Conducting Swivel

The deep tow conducting swivel system was used to connect the DASI instrument to the end of the conducting, deep tow cable. For most of the time it performed well, but we experienced one problem with it during deck testing of the DASI when one of the Crouse-Hinds 'Electro' type underwater connectors failed, going open circuit with a bang. This happened at less than half of the connector's rated current and voltage capacity. Fortunately we were able to replace it with a spare. However I conclude that this type of connector, although it is recommended by the manufacturers of the swivel system, is in fact unsuitable for this purpose, and I would urge RVS to try to replace the Crouse Hinds connectors with some better alternative.

4.1.4 Winches and cables

The winch and cable systems on the Darwin performed well. The only evident fault was in the wire out metering of the deep tow winch - after a few hours of use, read outs in different locations around the ship showed different values for the wire out, and this caused some anxiety when hauling in the deep tow cable.

4.1.5 Other equipment

A range of other RVS equipment, including expendable bathythermographs, EPC recorders, the Plessey sound velocity meter and the ship board computing system were used extensively and performed well and reliably throughout the cruise.

4.2 Cambridge Equipment

4.2.1 LEMURs

This was only the third time that the Cambridge EM instrumentation, consisting of LEMURs and DASI, had been used at sea. It proved to be by far the most successful deployment of the equipment to date.

The most serious problem encountered with the LEMURs was the unreliability of the acoustic release systems, discussed in the previous section. Two other problems of a comparatively minor nature, affecting the automatic gain ranging performance of the digital recording system and the optimisation of the on-board stacking parameters, came to light and software improvements are being made as a result. These problems had not prevented the three instruments that were recovered from recording many hours' worth each of high quality EM data.

4.2.2 DASI

The deep towed active source instrument in particular performed better on this cruise than on either of its previous trips to sea. The most serious problem that we encountered with it was that, following improvements to the deep tow to ship communications channel drivers which increased their power demand, the DASI's charging circuits - which draw power from the high voltage supply to the EM transmitter, to recharge battery packs which supply the instrument's electronic systems - were unable to keep up with the demand for current. As a result, the instrument's rechargeable battery packs were slowly discharged in the course of deep tow operations. The result was that we had to periodically suspend EM transmissions, turn off most of DASI's circuits to minimise the current demand, and then wait for several hours for the battery packs to recharge. This would then allow us several hours of EM transmission time with DASI in its full operating mode, before we had to pause to recharge the batteries again. This led to the loss of a certain amount of ship time, but the loss was minimised by using the time taken to make turns at the end of each transmitting run for battery charging. The charging circuits are currently being upgraded, to avoid a recurrence of this problem.

The second difficulty experienced was that the electrical impedance of the antenna array turned out to be greater than we had predicted. This resulted in the maximum current that we were able to pass through the antenna being limited to approximately 100 Amps peak, somewhat less than we had hoped for. An unrelated problem in the ship board high voltage power supply, which was almost certainly due to the insulation of a component in the output stage breaking down intermittently, contributed to this current limitation by restricting the maximum voltage that we were able to apply to the deep tow cable. A third problem which is in a sense unrelated but which almost certainly contributed to the higher than expected impedance of the transmitter antenna was that the underwater connectors between the deep tow and the antenna array proved to be unreliable when used in this application.

Relatively minor difficulties were experienced from time to time with the ship to deep tow communications systems and the deep tow's integral 3.5 kHz echo sounder system, but these did not prevent the system's effective use at any stage.

In summary, the Cambridge equipment suffered from some of the trials and tribulations that are to be expected with new and complex marine geophysical equipment, but most of the system worked very well for most of the time. The overall success of the design and construction of the Cambridge EM sounding system can be judged by the fact that for the first time ever, active source EM measurements were made over the extremely difficult terrain of an active mid ocean ridge - an end result that fully justifies the five year research and development effort that has gone into the system at Cambridge.

4.3 Scripps Equipment

The four ELF sea bottom EM receivers brought by Scripps are, by comparison with their Cambridge counterparts, tried and tested technology. One fault gave rise to difficulties - the acoustic release board on ELF Rhonda. This led to the instrument dropping a bottom weight and floating back to the surface during its deployment. The faulty board was replaced, and the instrument was redeployed with no further problems. Otherwise, all four instruments performed excellently.

4.4 Ship's Equipment

The ship's main, auxiliary and scientific machinery and equipment formed an almost unnoticed background to the scientific party's endeavours, simply because it all functioned flawlessly throughout the cruise. This extremely high level of performance on a sophisticated research ship towards the end of three years of continuous operations in distant waters is a remarkable tribute to the professionalism throughout that period of the ship's officers and crew, and especially of the Engineering department.

The only items that gave cause for concern were the sealing and draining arrangements for the main hatch cover which gives access to the scientific hold. In a repeat of our bad experience on a previous cruise (CD 34), the hatch cover leaked and allowed water to flood into the scientific hold - where the ship board EM transmitter power supply unit, which operates at up to 2000 Volts AC, was installed. The problem seems to be due to a design fault in the hatch cover drain system, and needs to be investigated and fixed.

5. Conclusions

Cruise 39 was a mixture of frustration, logistical mayhem and scientific success. Perhaps the most important thing to be said is that despite the developments that made Panama unusable as a mobilisation port, the main elements of the scientific programme were safely and successfully completed.

After the cruise was diverted to San Diego, the situation in Panama improved only in the short term. The abortive elections were followed a couple of months later by an attempted coup to unseat Noriega by sections of the Panamanian military. Despite US encouragement and belated small scale help, the coup was bloodily suppressed. After another short period of relative calm, Panama was invaded by U.S. forces in December 1989. The fighting in Panama City was heavy and lasted for over a week. Hundreds of people lost their lives - most of them civilians caught in the cross fire. At one stage, pro-Noriega units occupied an international hotel in central Panama City, and held a number of U.S. citizens hostage for two days.

Although these events happened after the cruise, the violence that transpired underlines the wisdom of our decision not to fly the bulk of the scientific party into Panama at a time when the course of future events was so uncertain. Diverting the ship to a safer mobilisation port was undoubtedly the correct decision, even without the added complications of the missing Cambridge container. The need to achieve scientific objectives must always take second place to the overriding priority which is the safety of the people involved.

San Diego turned out to be an excellent mobilisation port, and we received much help and support from our colleagues at Scripps which helped to ensure a very rapid turnround of the ship there. Everyone involved in the cruise worked furiously hard during the time until we arrived on station, so that once there no time was lost in getting the experimental work under way. In our eight days on station we achieved more than 50% of a programme that had been planned for 22 days on station, helped by good performances from virtually all the equipment and by ideal weather conditions. At the time of writing the data from the experiment are still being processed, but the indications are that all seven sea bottom instruments recorded high quality data, and that the data set obtained contains a great deal of information about the crustal conductivity structure of the East Pacific Rise. The cruise thus marks the successful culmination of a five year programme at Bullard Laboratories to develop an active source marine EM sounding system, as well as a successful outcome to the collaboration between Cambridge University and the Scripps Institution of Oceanography.

Finally I would like to note here that, during the visit of the Charles Darwin to San Diego, the many Scripps scientists who visited her in port were universally complimentary about the ship herself and about the R.V.S. sea-going technical support system. At the Research Vessel Services in Barry, N.E.R.C. has built up an extremely talented, highly motivated and experienced team of sea going and support technicians and engineers. The contribution made by this group is of the highest importance to the success of U.K. marine science, and goes a long way toward ensuring that the very large cost of keeping research ships at sea pays dividends in the form of high quality research findings. I use this opportunity to repeat my deep misgivings over NERC's plans to relocate R.V.S. to Southampton, as part of a new centre for deep sea oceanography. My fear is that many of the most experienced technical personnel from Barry will leave, and that the sea going and support teams will be broken up. The United Kingdom's most important assets for enabling the conduct of marine science are the people with the skills and experience to maximise the success of experimental programmes at sea. They are far harder to replace than ships, buildings or equipment, no matter how expensive or high technology the latter may be. At R.V.S., NERC have succeeded in creating over the last decade a first class technical support facility that is envied by marine scientists worldwide. Apparently, NERC are unaware of the value and importance of what they have at Barry - otherwise I find it hard to believe that they would be pressing ahead with plans to close the base down.

Acknowledgements

I would like to thank firstly the master, officers and crew of the Charles Darwin, whose professionalism and commitment had a profound impact on the success of the cruise. In particular, the scientific work could not have been completed to the high standard achieved without the skill of the bridge watchkeeping officers in navigating the deep tow package along track lines, at the end of 5 km of cable and at very low speeds; and the excellent level of reliability of the ship's machinery maintained by the engineering department. Secondly, thanks go to the support staff and sea going technicians of NERC Research Vessel Services - some of whom have been involved in the development of the Cambridge EM equipment since its earliest beginnings, and whose advice, suggestions and experience contributed to the development of that instrument. RVS technical support was a crucial component of the project. Finally I thank the people at Scripps who worked hard to prepare the ground for the port call, who secured shore passes for the crew on a public holiday weekend, and who went out of their way to ensure that the ship's visit to San Diego was an enjoyable one.

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Table 1. Scientific Party

M. Sinha (Principal Scientist)	Cambridge
R. Evans	Cambridge
S. Fowles	Cambridge
J. Leonard	Cambridge
N. Jones	Cambridge
P. Patel	Cambridge
M. Unsworth	Cambridge
M. MacCormack	Cambridge
S. Constable	Scripps
C. Cox	Scripps
M. Tolstoy	Scripps
A. Cumming	R.V.S.
K. Smith	R.V.S.
C. Rymer	R.V.S.
D. Booth	R.V.S.
A. Lord	R.V.S.

Table 2. Ship's Personnel

P. MacDermott	Master
R. Chamberlain	Chief Officer
S. Sykes	2nd Officer
P. Oldfield	2nd Officer
C. Brown	Radio Officer
G. Batten	Chief Engineer
G. Robertson	2nd Engineer
V. Lovell	3rd Engineer
P. Parker	Electrical Officer
M. Trevaskis	C.P.O. (Deck)
W. Dowie	Seaman
J. Roberts	Seaman
D. Bevan	Seaman
A. Olds	Seaman
P. Bennett	Seaman
K. Peters	C.P.O. (Catering)
P. Bishop	Cook
P. Acton	2nd Steward
S. Smith	Steward
A. Philp	Steward
D. Hanlon	Motorman

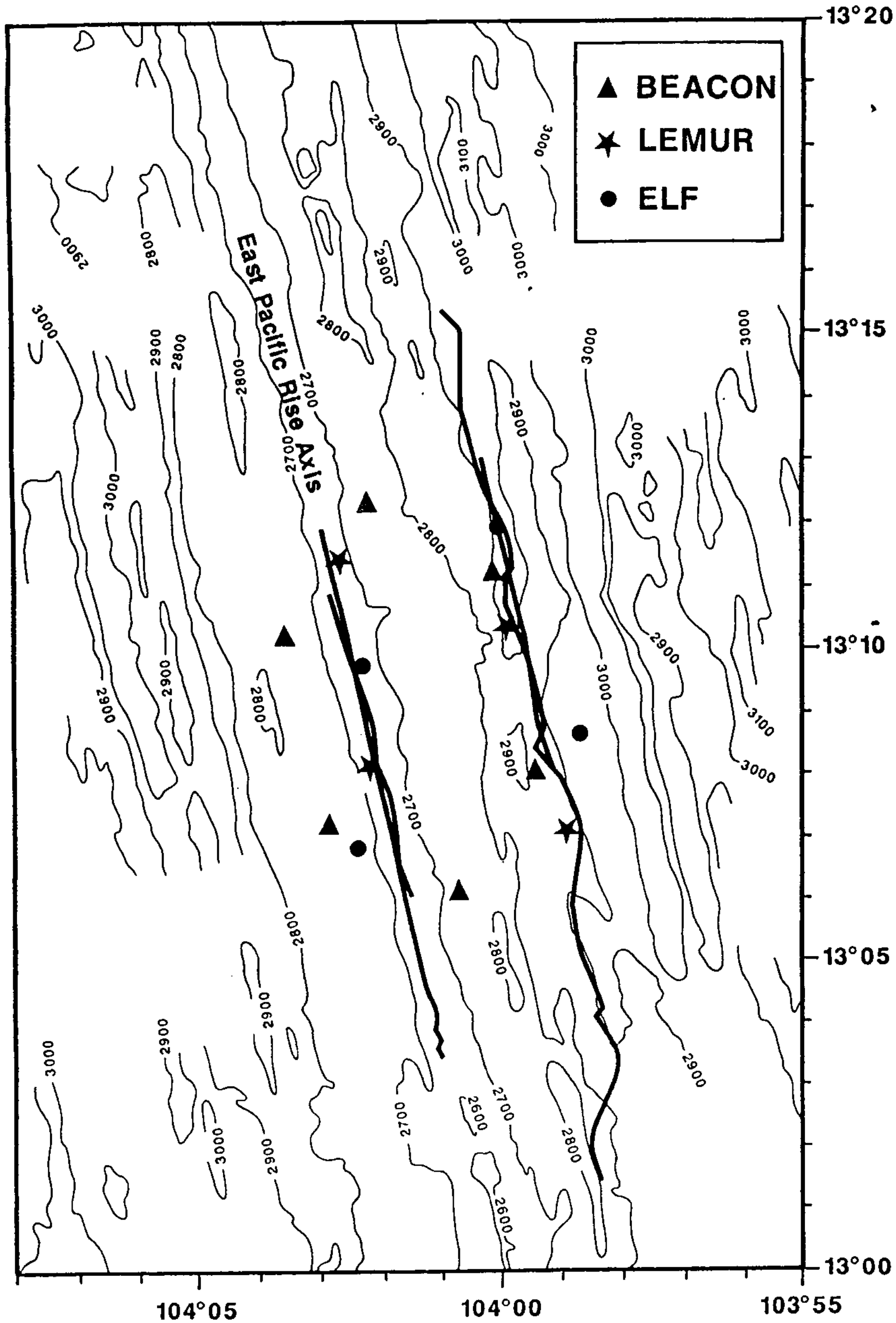

Figure 1. Location of the active source electromagnetic sounding experiment on the East Pacific Rise. Bathymetric contours are at 100 metre intervals. Triangles, stars and circles show positions on the sea bed of acoustic navigation transponders (beacons) and Cambridge and Scripps seafloor electric field recorders (LEMURs and ELFs) respectively. The heavy lines show the tracks of the deep towed EM transmitter, DASI (not the ship) during EM transmissions.

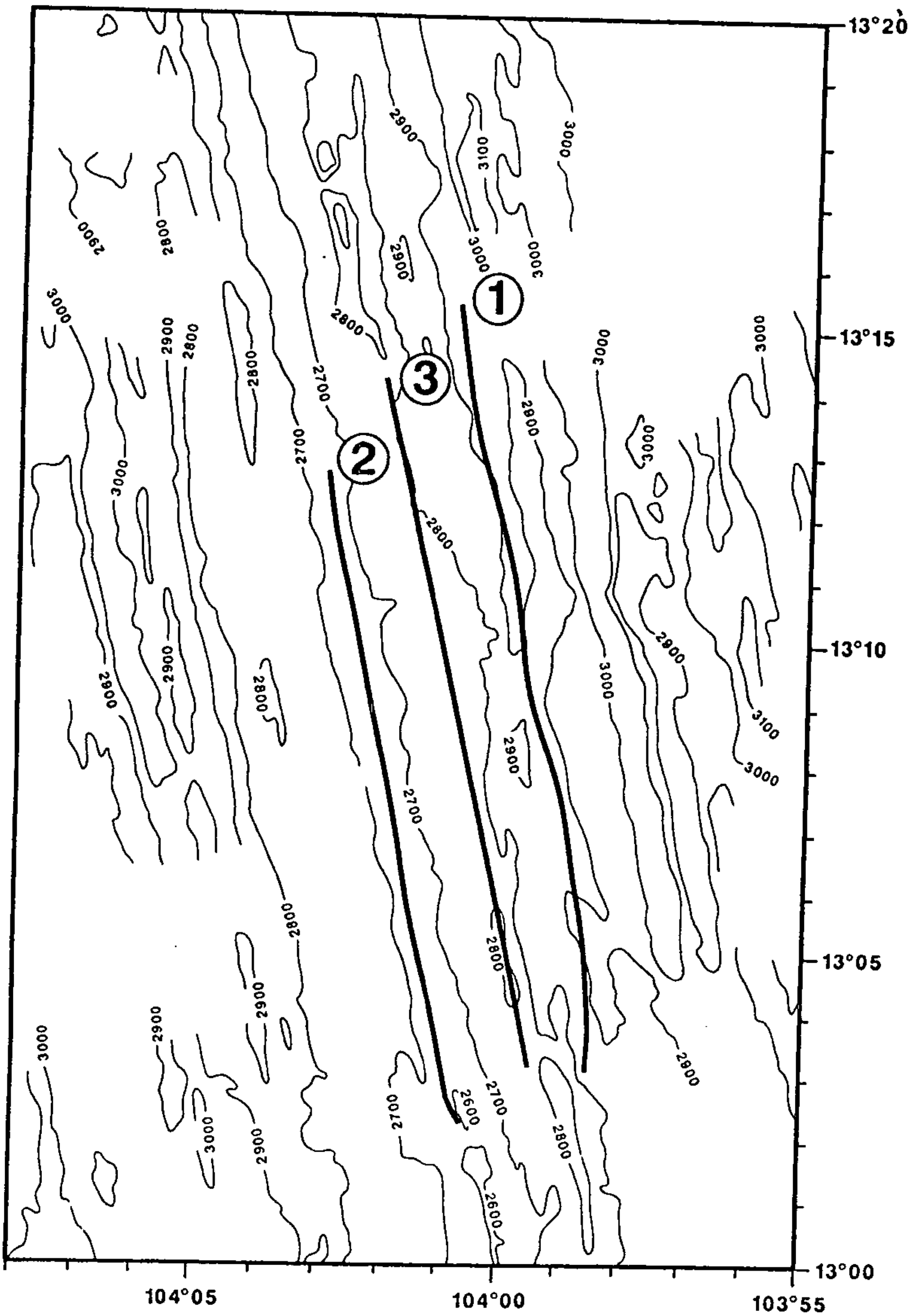

Figure 2. Ship tracks for the three gravimetric profiles carried out parallel to the ridge axis, to assess along strike variability and the validity of 2-dimensional approximations in electromagnetic modelling.