UNIVERSITY of CAMBRIDGE

Department of Earth Sciences

CRUISE REPORT

R.R.S. Charles Darwin 34

Southern Lau Basin

CRUISE REPORT

R. R. S. *CHARLES DARWIN*
CRUISE 34

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Martin C. Sinha
Bullard Laboratories
Department of Earth Sciences
University of Cambridge
Madingley Rise
Madingley Road
Cambridge CB3 OEZ

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SUMMARY

This report describes Cruise 34 of RRS Charles Darwin. During the cruise a party of 16 scientists from Cambridge University, RVS Barry and IOS Deacon Laboratory carried out a geophysical study of a 40 km long segment of the Valu Fa ridge - a back-arc spreading centre in the southern Lau Basin, southwest Pacific. The techniques used were seismic reflection profiling, wide angle seismics using disposable sonobuoys, active source electromagnetic sounding, and gravity and magnetic profiling.

The seismic experiments were extremely successful, producing 1300 km of digitally recorded, 4-channel reflection profiles, including 38 profiles across the ridge and five parallel to it; and six wide-angle profiles recorded at ranges of up to 30 km. A bright, low-frequency reflector, believed to mark the top of a crustal magma chamber, is visible on most of the cross-ridge lines and also on a line running along it. Gravity and magnetics were recorded along all these profiles.

The electro-magnetic sounding work was unsuccessful. A series of equipment failures resulted in only a small amount of data in a severely limited frequency range being recorded. The data obtained will be insufficient to allow an analysis to be made of crustal conductivity structure. Two sea bottom EM recorders were lost.

Preliminary interpretations of the seismic reflection data indicate that the crustal magma reservoir is present continuously beneath the spreading centre, throughout the survey area. The reflecting surface appears to be up to 4 or 5 km wide, to lie at a depth of 3 to 4 km beneath the sea bed, and to be continuous beneath an overlapping spreading centre at the northern end of the work area. Processing and analysis of the seismic, magnetic and gravity data will provide new information on the continuity and shape of the magma body, and on the physical properties of the body itself and of the overlying crust.

1. Introduction and Cruise Objectives

The objective of *Charles Darwin* Cruise 34 was to carry out geophysical investigations of an active spreading ridge in the southern Lau Basin. The Lau Basin is a young (less than 4 Ma old) back-arc basin of roughly triangular shape, bounded to the west by the Lau Ridge, an extinct, volcanic, island arc, and to the east by the Tonga islands - a currently active arc system (Lawver *et al.*, 1976; Cherkis, 1980) (Figure 1). Subduction of the Pacific plate is occurring beneath and to the east of the Tonga islands, at the Tonga Trench. The Lau basin is therefore underlain at depth by the westerly-dipping, downgoing, subducted, Pacific slab.

Extension in the southern part of the Lau Basin is believed to be taking place by a process of sea floor spreading at the Valu Fa ridge. The ridge is an elongated bathymetric high which rises typically 400 to 600 m above the surrounding sea bed to reach water depths as shallow as 1700 m, is 4 to 5 km wide at its base, and extends for a distance of at least 300 km on a roughly NS trend, at a distance of between 20 and 40 km west of the western limit of the Tonga ridge.

The experimental work on this cruise was concentrated on a section of the Valu Fa ridge between 22°09′S and 22°34′S. This section of the ridge had already been extensively surveyed with 'sea beam' multi-beam echo-sounder by von Stackelberg *et al* (1985), and is believed to be currently one of the most volcanically active parts of the ridge system (von Stackelberg *et al.* 1988). Several multichannel seismic reflection profiles collected by the U.S. Geological Survey in this area show bright, low frequency reflectors at a depth of about 2 seconds TWT below the sea bed beneath the ridge axis, and these have been interpreted as representing the top surface of a crustal magma chamber (Morton & Sleep 1986).

The survey area selected contains a 35 km length of continuous spreading ridge, which is terminated near the northern end of the survey area by an overlapping spreading centre (OSC) system. Here, the spreading centre becomes progressively more subdued morphologically towards the north over a distance of some 10 to 15 km (Figure 2), and eventually dies out completely. A second spreading centre, offset by approximately 3 km to the east, overlaps the southern segment for about 10 km, and continues north beyond the limit of the survey area.

The scientific programme for the cruise consisted of two main elements, both aimed at studying in detail the geometry and physical properties of the axial magma chamber. The first planned element was a seismic experiment, principally employing seismic reflection profiling, and using an array of four to five airguns, a four channel hydrophone streamer and a four channel digital seismic acquisition system which had recently been acquired by NERC. A series of closely spaced lines were shot across the ridge, with additional lines running along the ridge axis and parallel to the axis at varying offsets from it. Additionally, wide angle seismic experiments were carried out using disposable sonobuoys, to obtain seismic velocities within the upper half of the crust. The objectives of the seismic experiment were to determine the shape and continuity of the reflector along a section of the ridge, to measure the seismic velocities in the crust above it and to either side of it, and to determine whether or not it coincides with the top of a low velocity zone.

The second element of the cruise programme was to carry out an electromagnetic sounding experiment, using the newly developed Cambridge active source EM sounding equipment (known collectively as EMU). EMU consists of two distinct sets of instrumentation (Figure 3). The first is the Deeptowed Active Source Instrument (DASI), which acts as the horizontal electric dipole transmitter. It is towed using the ship's electromechanical conducting cable at low speeds and at heights of 15 to 20 metres above the sea floor. It is fitted with a 3.5 kHz near bottom echo sounder, which allows its height off the bottom to be accurately monitored and controlled. DASI tows behind it a 180 m long streamer, which carries a pair of transmitting electrodes 100 m apart. Alternating currents of up to 200 Amps at frequencies of approximately 0.05 to 100 Hz are passed between the electrodes, setting up electromagnetic waves which propagate through the relatively resistive rocks of the sea floor.

The resulting oscillating electric fields are measured at the sea bed a few kilometres away by LEMURs - Low frequency, Electro Magnetic Underwater Recorders. These are free fall, sea bottom instruments that can be programmed to record data for the duration of an experiment, before being acoustically released and recovered. They consist of an instrument package fitted with floatation, an acoustic release system, and a disposable bottom weight and receiver antenna assembly. The receiver antennae consist of four low noise, porous electrodes which are attached to the bottom weight by 6 metre long plastic arms, to form an orthogonal pair of 13.4 metre horizontal dipoles. Signals from the two dipoles are amplified, digitised and stacked in the instrument package, and then digitally recorded for subsequent processing and analysis.

The aim of an electromagnetic sounding experiment is to measure the amplitude and phase of the transmitted signal at a number of locations and at many frequencies. Analysis of such data by forward modelling techniques allows the distribution of electrical conductivity within the crust to be determined (Chave & Cox, 1982). Electromagnetic sounding is therefore potentially an extremely powerful tool for mapping the presence of conducting phases, such as melt fractions or hydrothermal fluids, at crustal levels.

Accurate navigation is a prerequisite for detailed geophysical studies of this type. The Global Positioning System (GPS) provides sufficiently accurate fixes during periods of coverage by a suitable number of satellites. However such coverage is still unavailable for most of the time. The Transit satellite navigation system is inadequate, both because of the limited accuracy of fixes and because of the long time intervals that can occur between fixes. In addition, during E/M sounding operations it is necessary to know the position of the deep tow vehicle, as well as that of the ship. We therefore borrowed IOS Deacon Laboratory's 5 kHz deep water acoustic navigation system. This consists of a ship board system, a set of sea bottom acoustic transponder beacons, and a relay transponder which can be attached to the deep tow vehicle, allowing its position as well as that of the ship to be monitored. The combination of this system and GPS, which allowed the transponder net to be tied to absolute geodetic coordinates, enabled us to navigate with excellent accuracy for most of the cruise. A rubidium frequency standard interfaced to the GPS system allowed GPS fixes to be taken with reasonable accuracy when only two satellites were in view, greatly extending the time that GPS was usable.

2. Cruise Narrative

All times given in the following narrative are in the form of Julian Day Number/GMT. Local times are 12 hours ahead of GMT.

194/0300 The ship sailed from Auckland. Sailing had been delayed by more than 24 hours, due to a number of factors. The most important of these was the ship's late arrival in Auckland three days previously. This was entirely the result of unrealistic programming by NERC of the passage time from the previous port call in Tonga. Other factors included the difficulties of mobilising in Auckland over a weekend, the large quantities of heavy equipment that needed to be embarked, disembarked or moved, and the need to obtain spare parts for the Sea Crane mounted on the starboard quarter, which was to be used for RVS's new airgun deploying system.

The Tongan observer, who had been due to join the ship 48 hours previously, did not turn up, despite a Telex to the Ministry of Land, Surveys and Natural Resources in Nuku'Alofa. We therefore sailed without him. We also sailed without a full set of gas retractors and retractor refills for the acoustic release units on the LEMURs and 5 kHz navigation beacons. This situation arose out of a misunderstanding between Cambridge, IOS and RVS about the total number required. It proved impossible for RVS to air freight the necessary extra retractors and refills to Auckland in a reasonable time after the shortage was discovered, so they were despatched instead to Tonga, from where we planned to collect them at a suitable opportunity during the cruise.

198/0330 The ship arrived on station in the Lau Basin after a four day passage. The next 39 hours were occupied with preparatory activities, including wire testing the deep tow pressure vessels, the sea bottom instruments and the 5 kHz transponders; obtaining a water column sound velocity profile; laying a net of three acoustic beacons and fixing their positions using GPS; and balancing the seismic streamer.

199/1830 Began deploying the seismic profiling equipment, consisting of the four channel streamer, an array of four airguns totalling 22.81 l (1392 cu. ins), and magnetometer fish.

199/2300 Start of underway geophysical profiling on line 1A, the first of the across-ridge profiles (Figure 4). Line 1A was used as a test profile, while the seismic equipment was being tuned and set up. High quality data acquisition began at the start of the next line, line 3. Lines 5, 7, 9, 11, 13, 15, 16, 17, 19, 21, 23, 25 and 27 followed. The profiling speed throughout was 4.7 knots with a 20 second shot interval, to give a shot point spacing of 50 metres and hence four-fold coverage from the 400-metre, 4 section streamer.
The data quality on these initial lines was good, but problems with one of the airguns on the starboard boom led to two interruptions in profiling while leaks in the air hoses were repaired. This gun was fitted with a 7.64 l (466 cu. in.) chamber. At the end of line 27, it developed an air leak for the third time. We concluded that the 7.64 l chamber was too large for reliable operation on the boom, and exchanged it for a 4.92 l (300 cu. in.) chamber. This reduced the total volume of the array to 20.1 l (1226 cu. in.), made up of 4.92, 2.62 and 4.92 l (300, 160 and 300 cu. in.) guns on the boom on the starboard side, and a 7.64 l (466 cu. in.) gun towed separately from the port quarter. One of the 4.92 l guns on the boom was fitted with a Wave Shape Kit.

202/0757 Seismic profiling resumed at the start of line 6. A disposable sonobuoy (sb 1) was launched at 202/0821, near the start of line 6 (Figure 5). Lines 4, 2 and 1B were then profiled, followed by line 28, which was navigated using GPS along the axis of the main (southern) spreading segment. A second disposable sonobuoy (sb 2) was launched at 202/1950, at the start of line 28.
Line 28 was followed by line 29 - a profile which started on the axis of the northern segment of the OSC, and then continued parallel to the southern segment and between 2 and 3 km east of its axis. Disposable sonobuoy 3 was launched just south of the southern tip of the northern spreading centre on line 29.
The two profiles parallel to the axis were followed by the remaining profiles normal to the spreading axis in the northern part of the survey area - lines 8, 10, 12, 14, 18, 22, 24, 26 and 31. Finally a third profile (line 30) was shot parallel to the spreading axis, and at a distance of between 1 and 3 km east of the axis of the southern segment. Disposable sonobuoy 4 was launched shortly after the start of line 30, near its northern end.

204/1110 The completion of line 30 marked the end of the first phase of seismic profiling, which had lasted for a period of 4 days 18 hours.

204/1300 Started detailed bathymetric survey of a small, thinly sedimented trough on the east side of the ridge, to find a suitable location for the first LEMUR deployment. On completeion, began wire testing LEMUR 4 and its acoustic release system. On the first wire test, the release did not work. The instrument was recovered, the release unit was changed, and the instrument was wire tested again. The second test was successful.

205/0457 LEMUR 4 deployed for the start of E/M experiment 1 - a test experiment using a single LEMUR. Then overnight day 205, a 130 km long, WNW-ESE gravity profile was run perpendicular to the ridge (Figure 6).

205/2050 On completion of the gravity profile, began deployment of the DASI E/M deep tow instrument. E/M test transmissions began at 206/0630, with DASI a short distance off the sea bottom. At 206/0652, overheating elements in the DASI power supply unit caused smoke from scorching paintwork, which triggered the smoke alarm system. The elements were moved to a different location, and a larger fan was installed for cooling them. Test and calibration transmissions restarted at 206/1014, and continued until 206/1135.

206/1255 DASI and streamer brought back at the surface. We found that during the deployment, the streamer had become wrapped around the deep tow cable, causing serious damage to one of the electrode cables and one of the floatation sections, and extensive minor damage in many different parts of the array. We later attributed this behaviour to towing the deep tow too slowly (½ to 1 knot) and simultaneously heaving or veering the deep tow cable too fast (30 metres/minute or more). In addition, the towing arrangements by which the array was attached to the deeptow vehicle had proved unsatisfactory, since the streamer had evidently been corksrcrewing through the water for at least some of the deployment, winding up the tow ropes and damaging the electrical connections to the electrode cables. After completing recovery of the damaged deep tow and streamer - which took some time, due to the tangled state of the streamer and deep tow cable - we headed for Tonga, to collect the extra gas retractors which had been air freighted from Barry and had now arrived there, and also to obtain medical assistance for the third engineer who was suffering from a painful neck condition.

208/0500 Arrived back at the work area after spending the previous night anchored off Nuku'Alofa. Recovered one acoustic beacon, which was in need of repositioning to provide better coverage.

208/0535 Started attempts to recover LEMUR 4, which had been left recording on the sea bed during the visit to Tonga. The LEMUR failed to respond to acoustic signals from the ship. We began a search of the area in which the instrument had been deployed, transmitting on its communicate and release frequencies for alternate periods of several minutes each. Extra lookouts were posted in case the instrument surfaced without responding acoustically. However, we found no traces of it, so were forced to conclude either that its acoustic release system had failed completely or that it had surfaced prematurely and drifted away while we were out of the area.

208/1835 Abandoned search for LEMUR 4.

208/1905 Wire tested the fourth acoustic navigation transponder, and made a second sound velocity meter dip. Relaid acoustic beacon 2 and laid beacon 4 for the first time. On completion, streamed the seismic profiling equipment again. The airgun array and hydrophone streamer were deployed as before, except that the wave shape kit which had previously been fitted to one of the 4.92 l guns was omitted this time.

209/0904 Recommenced seismic profiling. Profiled lines 32, 34, 36, 38, 37, 35, 33, 39, 41A, 43, 44, 42, 41B, 40. Disposable sonobuoy 5 was deployed near the start of line 43, and sonobuoy 6 was deployed on line 42.

211/1052 Finished seismic profiling. Recovered profiling equipment.

211/1351 Began a second and more detailed echo sounder survey of the sedimented trough to the east of the southern spreading segment.

211/2309 Deployed LEMUR 3 in the trough, for E/M experiment 2 - a second instrument test experiment (Figure 7). On completion, began preparations to launch DASI. Several new problems were found on the deep tow antenna array, which had been repaired over the previous few days after being damaged on its first deployment. Repair work on the array continued overnight and for all of the following morning.

213/0030 Repairs to DASI streamer completed. The instrument was then tested at antenna currents of up to 140 Amps, with the deep tow on deck and the streamer towing astern of the ship just below the surface.

213/0700 Deployed DASI for E/M experiment 2.

213/1120 Began DASI transmissions, towing DASI just above the sea bed over the sedimented trough east of the ridge axis (Figure 7).

213/1930 Finished DASI transmissions, recovered DASI (undamaged this time) and then recovered LEMUR 3 without difficulty. This second test deployment of the E/M system appeared to have been successful after the initial problems with the transmitter array had been sorted out.

214/0100 Recovered acoustic transponder beacons 2 and 4, then relaid them in more suitable positions for the final E/M experiment. Used GPS window to survey new beacon positions.

215/0610 Began deploying LEMUR 3 for E/M experiment 3, at northern end of sedimented trough to east of ridge axis. This instrument deployment coincided with one of the brief spells of freshening winds, gusting to up to 30 knots, which occurred at intervals of a few days

throughout the cruise. The unfortunate result of this was that, seconds after the instrument was released, its stray line was caught by the wind and became tangled on the crane hook from which the LEMUR had just been slipped. The LEMUR was left suspended in the water beside the ship, with the float frame a few metres below the surface, for several minutes while the crane hook was brought in to the ship's side so that the stray line could be released. In retrospect, it seems likely that this incident resulted in the bottom weight and receiver antenna array becoming tangled with either the instrument package or the release system, leading to the eventual loss of the LEMUR.
LEMUR 2 was deployed next, followed by LEMUR 1. All three instruments were positioned on a roughly north-south line, in the sedimented trough on the east side of the ridge (Figure 8).

215/1645 Deployed DASI streamer and connected it to the deep tow. With the deep tow positioned on the after deck and the streamer towing astern of the ship, we powered up the E/M transmitter and passed currents at varying frequencies through the antenna in order to calibrate the current sensors fitted to the instrument.

215/1950 Test and calibration transmissions were interrupted by a major failure of several high power semiconductor components in the deep tow transmitter system. Repairs to DASI, together with further repairs to the streamer which were found to be necessary at this time, took 21 hours. The period was enlivened by a flood of sea water into the controlled temperature lab, which we were using as the LEMUR electronics lab. The flood was caused by the ship's engineers turning on the non-toxic sea water supply pump. A tap connected to this supply over the sink in the controlled temperature lab had been left on, and since the sink had been covered by a wooden bench top for the duration of the cruise, the resulting jet of sea water could not escape down the plug hole. Worse, the bench top also prevented the tap from being turned off. Mopping up and rinsing and cleaning electronic equipment which had got wet took several hours. Fortunately, no serious damage was done - mainly because the LEMUR electronics packages, which would have been directly in the path of the water, were sitting on the sea bed at the time.

216/1700 Completed repairs to DASI, and started deployment.

216/2014 Started E/M transmissions with DASI towing just above the sea bed, on the western flank of the ridge.

216/2315 Acoustic relay transponder on the deep tow broke free from its clamps and was lost.

217/0850 Transmitter power supply unit damaged and shut down after a fault developed in the deep tow cabling system. DASI was hauled up and towed in mid water while the power supply was repaired. The fault in the cable system, which was causing a small and intermittent earth leakage current, proved difficult to trace, so DASI was recovered completely while further cable tests were made. The problem was finally traced to intermittent breakdown at high voltage of one of the transformers in the communications channel coupling circuit at the inboard end of the deep tow cable.

218/0415 Fault finally fixed and DASI deployed again. After lowering DASI to near the sea bed, we found that the batteries on the echo sounder system had become seriously depleted in the meantime. It appeared that the charging circuits were not operating effectively while E/M transmissions were being made. To recharge the batteries, DASI was towed at a safe height above the sea bed for the next 5 hours, with power applied to the deep tow cable but the E/M transmitter system off.

218/1220 Restarted DASI transmissions, towing the instrument parallel to the ridge axis along the sedimented trough on its eastern flank. Problems with the echo sounder system continued, causing great difficulties in monitoring the instrument's height above the sea bed.

218/1840 DASI grounded on the sea bed on the side of a sea mount, during a turn at the northern end of the planned deep tow track.

218/2250 Deep tow, cable and streamer all recovered. The deep tow itself and the conducting swivel had received only superficial damage. However the outboard 650 m of the deep tow cable had suffered significant damage to its armour, and the deep tow antenna array was gashed and deeply abraided in numerous places. It was clear that, in the time available, no further deep tow operations would be possible.
Began recovery of the four acoustic transponder beacons, which were not fitted with lights so had to be recovered in daylight.

219/0320 All beacons recovered. Commenced recovery of LEMURs 1, 2 and 3.

219/0600 LEMURs 1 and 2 successfully recovered. LEMUR 2 caused some concern, because it took nearly a minute to leave the bottom after its acoustic release system had fired. This was most likely due to delayed operation of the cable cutter system. The precise reason is not known.

219/0620 LEMUR 3 responded correctly to acoustic command signals, but failed to leave the bottom. Command and release signals were sent repeatedly over the next 3½ hours, and each time the acoustic response from LEMUR 3 was correct. However it remained stubbornly on the bottom.

219/0950 Commenced preparations to drag for LEMUR 3, using its acoustic responses to guide dragging operations and using the outboard 680 metres of the deep tow cable, whch had been damaged when DASI ran into the sea bed, as the ground line.

219/1530 First attempt to drag for the LEMUR ended unsuccessfully. Prepared to make a second attempt.

219/2045 Second dragging attempt also ended unsuccessfully. Began recovering dragging wires etc.

219/2255 All scientific gear inboard. Scientific operations ended. Set course for Auckland.

223/1925 Cruise ended, Auckland.

3. Equipment Performance

3.1 R.V.S. Equipment

The equipment supplied by R.V.S. generally performed well throughout the cruise.

The new digital seismic acquisition system was a great success. One or two relatively minor bugs in its software came to light, and have been notified to its supplier, but they were not sufficiently serious to prevent its use or to lead to the loss of any data. The other new piece of equipment supplied by R.V.S., the Waverley line scan recorder, was also very successful. The instrument has far higher dynamic range than the conventional, E.P.C. type recorders, and unlike E.P.C. recorders it can plot seismic reflection data with little or no vertical exaggeration without loss of image clarity. The combination of Waverley recorder and the real time display on the digital acquisition system's monitor screen meant that it was possible to see the reflection data, including clear images of the magma chamber reflector, as they were being collected.

The seismic streamer was the object of a great deal of painstaking preparation by RVS staff at the start of the cruise. This effort paid off in both the complete reliability of the streamer once profiling had started, and the high quality of the data that we collected.

The new airgun deployment system on the starboard quarter made airgun operations safer and quicker than previous systems, and allowed us to use four large guns without difficulty. Experience suggests that for long periods of profiling, a 4.92 l (300 cu. in.) chamber is the largest that can be used reliably on the boom. A similar deployment system on the port quarter would allow the use of 6 to 8 guns, and would represent a further significant improvement.

GPS navigation was essential for the work carried out on this cruise. The rubidium frequency standard fitted to the GPS receiver greatly increased the length of time for which the system was available, and consequently allowed us to make much more effective use of ship time than would have been possible otherwise. The GPS and other navigational equipment worked well and reliably throughout the cruise, as did other routine sensors such as precision echo sounder, gravimeter, magnetometer and sound velocity meter.

Deploying the magnetometer fish is a far more arduous and time consuming task than it ought to be, especially when many other bits of gear are being towed simultaneously. The present system of streaming it and recovering it manually, and selecting a suitable fairlead or point from which to tow it on an *ad hoc* basis, should be improved upon. An electric winch and some purpose-built (and preferably moveable) fairlead arrangement would be an ideal solution.

The deep tow conducting swivel caused some concern during the cruise, when oil and water began leaking from the pressure equalisation vent. The swivel was stripped down and serviced at sea, but this was an extremely difficult process as the appropriate documentation and specialist tools (for example a pump suitable for repressurising the oil diaphragm) were not available. The connectors used with the swivel continue to cause me concern - on one occasion, one of the connectors evidently leaked, resulting in arcing across the contacts which wrecked both male and female connectors. I suspect that the voltages we use on the deep tow cable are very close to the safe working limit of these connectors, and I would urge R.V.S. to try to find a better alternative. In particular, I would feel happier if there were an effective means of locking pairs of connectors together once they are mated.

The computer system did not cause any serious problems at sea, and we were able to leave the ship with a complete set of plots and data tapes. However, the tapes are not quite in GF3 format - there appears to be a byte-swapping problem of some sort. This problem must be rectified on all of the ships as a matter of urgency. Better consultation between the RVS computer group and NERC staff at IOS Proudman Laboratory, who have written and distributed software for reading and manipulating data in the GF3 format, seems to be required. I repeat my perennial request for a user friendly, real time, graphic display of the ship's position (based on GPS or TRANSIT or any other navigation system) relative to fixed marks, track lines etc. to be implemented by the R.V.S. computer group. Such a facility was not available in any useable shape or form, despite my requests for it for this and previous cruises.

The acoustic release systems supplied by R.V.S. did not come up to the usual, high standards of preparation and maintenance. Neither of the electronics technicians from Barry had suitable experience of re-arming gas retractors, and no adequate documentation on how to go about it was provided. The acoustic release units were sent to the ship with some of their battery packs disconnected. Again no documentation was sent to explain which packs had been disconnected, or how to reconnect them. Most seriously, two of the units appeared to have faults when they were tested on board. Acoustic releases are of such crucial importance for the success of experiments that they and the deck units for operating them must be maintained to the very highest possible standards. Loss of a sea bottom instrument means not only the loss of the hardware, but also the loss of the data that it had recorded - which is usually far more valuable, and utterly irreplaceable. Total failure of its acoustic release system is the most likely reason for the loss of LEMUR 4, although it is impossible to be certain of this.

The confusion over how many retractors and refills were needed was primarily my fault, rather than the result of mistakes by R.V.S.

Recovery of sea bottom instruments also depends critically on the buoyancy used with them. Many of R.V.S.'s Benthos glass spheres are now quite elderly. Do R.V.S. have them regularly inspected or pressure tested? This would seem to me to be highly desirable, in view of the high risk to equipment that their failure would entail, and the rough handling that they sometimes receive during instrument deployments and recoveries. Failure of one or more glass spheres is another possible cause of the loss of the LEMURs.

3.2 I.O.S. Equipment

In order to navigate with high precision, and to be able to locate the deep tow package independently of the ship, we used the 5 kHz acoustic navigation system developed by I.O.S. (D.L.). The system consisted of four sea bottom acoustic transponders, the ship board interrogation and display system, and a relay transponder clamped to the deep tow cable 100 metres above DASI.

The ship board system and bottom transponders worked well. The new cursor/digitiser fitted to the graphic recorder display and the new software on the navigational computer represent a major advance compared to the last time I used the system, in 1986. Acoustic navigation proved invaluable at all stages of the cruise, whether seismic profiling, deploying sea bottom instruments or deep towing. The combination of acoustic navigation and GPS was particularly useful. GPS allowed transponder nets to be established and calibrated quickly and reliably. Also, programmes such as seismic profiling could (with a little care) be planned so that tracks in areas of good acoustic coverage were run during GPS down time, and vice versa. It also became clear during the cruise that acoustic navigation is far more reliable than the TRANSIT dead reckoning system. On at least two occasions when the DR and acoustic systems gave widely differing positions, and when principal scientist and watch-keeper were expressing grave scepticism as to whether the latter was working properly, it subsequently became clear that the acoustic fixes (based on weak signals from just two beacons) were in fact correct.

The relay transponder used with the deep tow worked well during E/M experiment 2. However, when it was recovered, we found that the relay transponder had sheared the bolts attaching it to its cable clamp. Fortunately it had also been attached by a length of nylon rope, so we did not lose it. For its second deployment, on experiment 3, larger bolts were used. However, a few hours after deep tow operations started, the transponder parted company from the deep tow and was lost. We can only speculate about the reasons. The clamps were still on the cable when the deep tow was recovered. Perhaps the reason for the loss was that the bottom end of the cable rotated as the strain on it varied with the heave of the ship, putting large shear stresses on the metalwork attaching the transponder to the clamps. I understand that I.O.S. had not previously used a relay transponder in a glass sphere housing, as was used here.

The lost transducer has been replaced, using funds from a Cambridge University insurance policy.

3.3 Cambridge University Equipment

The main item of Cambridge equipment used on the cruise was the elctromagnetic sounding system. This was also the item that caused the most serious problems. Considering that it was only the equipment's second time at sea, this was perhaps not altogether surprising.

The power supply unit for the E/M transmitter worked reasonably well and reliably, once the output filter circuit had been tuned for the capacitance of the deep tow cable (which is somewhat different from that of Discovery's). One problem that occurred early on in the cruise was that resistive elements in the output filter became very hot, heating the metal plate above them and blistering the paint on it. This set off the fire alarms in the scientific hold, where the unit had been installed close to the winch room bulkhead. The problem was overcome by attaching a powerful cooling fan, which prevented any further overheating, to the top of the unit. The only other problem with the ship board end of the system arose when a small transformer in the communications channel coupling circuit broke down under high voltage conditions. In the resulting shut down of the power supply, two of the semiconductor devices in the oscillator bridge failed and had to be replaced.

DASI, the deep tow transmitter instrument, suffered from some more serious problems. Firstly, it proved impossible in practice to monitor the echo sounder signals when the E/M transmitter was operating at anything other than extremely low power levels. This was because the power supply wave form was not perfectly sinusoidal, and caused regular, high frequency spikes on the communications carrier channel. A second problem was that, when current was being passed through the transmitter antenna, the rechargeable battery pack supplying power to the echo sounder system failed to recharge. This was because the charging cicuit drew power from the secondary side of the deep tow tranformer. The large current through the secondary caused a sufficient voltage drop at the charging circuit to prevent it working effectively. A third problem was that the arrangements for attaching the antenna array to the deep tow at the start of the cruise proved inadequate. The coupling system was rebuilt during the cruise between E/M experiments 1 and 2, and the modified arrangements appeared to work well.

The difficulties experienced with the communications channel between the ship and the deep tow had serious consequences. In general, the FSK digital communications with DASI's microprocessor were not badly affected by noise. The upcoming data from the echo sounder, however, were obliterated by noise for much of the time that the E/M transmitter was running at anywhere near full power. This inevitably caused great difficulties in using the deep tow close to the sea bed. We resorted to a mode of operation in which we ran the transmitter for 8½ minutes (the duration of a LEMUR recording block), and then turned the power down for 6 to 7 minutes to check and adjust the deep tow's height, before turning it up again for the next recording window. Problems with the echo sounder communications eventually resulted in the deep tow being crashed into the sea bed, prematurely ending E/M experiment 3.

Failure of one of the transformers in the communications channel coupling circuit at the ship board end of the deep tow cable during experiment 3 resulted in damage to the power supply unit, and the loss of a day while the fault was traced and repaired.

The LEMURs also suffered from a number of problems. The most serious of these was that two of the instruments were lost when they failed to return to the surface. The possible reasons for this have been discussed above. Three LEMUR deployments however did result in successful instrument recoveries. The data that have been analysed so far indicate widely varying noise levels between instruments and between instrument channels, which suggests that not all of the instruments were working correctly all of the time. Occasional noise spikes can be seen on parts of the data, and it also appears that the instrument as used in the Lau Basin can sometimes go into oscillation, generating a high amplitude apparent signal with 16 seconds period that is clearly not a real, electric field signal.

The data that were recorded by the LEMUR's indicate instrumental and environmental noise levels equivalent to between 10^{-8} and 10^{-7}V m^{-1} when recording with a 1/16 Hz cut off, high pass filter. This figure is close to the expected, combined electrode and background environmental noise levels that would be expected from the results of previous measurements of sea floor electric field noise reported by the

Scripps E/M group (Webb *et al.* 1985).

The problems found on the E/M sounding system are currently being investigated and rectified, in readiness for the equipment's next use on the East Pacific Rise in May-June 1989.

3.4 Ship's Equipment

All of the ship's equipment and systems performed well throughout the cruise. The only notable exception to this was the drainage system for the seal around the hatch cover above the scientific hold. For some reason, the drains allowed water running across the deck and into the outer channel to back up into the inner channel, and then spill over into the hold. This occurred during the passage back to Auckland at the end of the cruise. The result was a build up of several inches of water in the hold. Since the ship was rolling considerably at the time, the water found its way into the interior of the E/M power supply unit. Had this happened earlier on, the result would have been disastrous. Fortunately, it was possible to rinse and dry the power supply when we arrived in Auckland before it suffered any damage.

4. Initial Results and Conclusions

The major result from the cruise was the clear, seismic image that we obtained of the top surface of the axial magma chamber along a 40 km length of the Valu Fa ridge (Figures 9 and 10). The magma chamber is clearly continuous for the whole length of the main, southern, spreading centre segment within our survey area, and on line 28 has been profiled along strike for distances in excess of 10 km as a bright, flat lying and extremely continuous event. The apparent width of the event on the cross lines, combined with the observation that the reflector is also visible on the southern ends of lines 29 and

30 (the along strike lines located 2 to 3 km off axis to either side of the ridge) indicate that the magma chamber is probably at least 4 to 5 km wide at the southern end of the survey area. However, its width appears to vary significantly along strike.

An intriguing feature of the reflection data is that the magma chamber appears to run continuously beneath the overlapping spreading centre system at the northern end of the survey area. Rather than being truncated at the end of each individual segment, the magma chamber runs obliquely across the spreading centre beneath and between the ridge segments, and crosses from the southern segment to the northern segment without a break.

The wide angle seismic data show clear ground wave arrivals to ranges of up to 16 km, which will allow us to determine the seismic velocity structure in the upper half of the crust, and the across strike variations in seismic structure. Preliminary interpretations by J. Collier of the wide angle data confirm the result of Morton & Sleep (1985) that the reflector lies at a depth of approximately 3.5 to 4 km beneath the sea bed at the ridge axis.

The seismic element of the cruise was extremely successful, producing over 1300 km of high quality, digital seismic profiles of the Valu Fa ridge. Gravity and magnetic data obtained at the same time will, in combination with the seismic data, allow detailed structural models of the ridge to be developed and tested.

The electromagnetic sounding work was unsuccessful in constraining the electrical conductivity structure of the ridge. Numerous equipment problems occurred, the DASI was damaged when it collided with the sea floor, and two LEMURs were lost. However, our experience of using the equipment increased dramatically during the cruise, and the insights gained will allow us to make major improvements to the instruments before they are used again.

Acknowledgements

The work at sea would have been impossible without the active involvement and support of the ship's master, his officers and crew, and the R.V.S. staff who took part in the cruise. I thank them, the other members of the scientific party, and the many people in Cambridge who contributed to the instrument development and construction work that preceded the cruise for their unstinting efforts to make this project a success.

The electromagnetic sounding work relied heavily on experimental, instrumental and modelling techniques developed over the last decade by Chip Cox and his co-workers at Scripps Institution of Oceanography. I thank him and his colleagues Steve Constable, Spahr Webb and Tom Deaton, and Alan Chave of Bell Laboratories, for many hours of discussion, advice and encouragement, and for allowing us to make use of electric and electronic circuit designs developed for their E/M sounding equipment.

Ulrich von Stackelberg of B.G.R., Hannover provided us with detailed and partly unpublished SEA-BEAM data from the survey area prior to the cruise, which proved invaluable in its planning and execution. Jean-Paul Foucher of IFREMER, Brest also provided recently collected SEA BEAM data from the southern Lau Basin. Janet Morton of the U.S. Geological Survey gave us copies of a number of seismic profiles that the U.S.G.S. had collected in the survey area. I am grateful to all of them for allowing us to use their data in planning the cruise, and for the useful ideas which arose out of discussions with them.

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Appendix 1 - Scientific Party

M. Sinha (P. S. O.)	Cambridge
D. Lyness	Cambridge
P. Patel	Cambridge
C. Williams	Cambridge
P. Carter	Cambridge
M. McCormack	Cambridge
J. Leonard	Cambridge
J. Morgan	Cambridge
M. Unsworth	Cambridge
I. Rouse	I. O. S. (D. L.)
C. Paulson	R. V. S.
A. Cumming	R. V. S.
G. Knight	R. V. S.
K. Smith	R. V. S.
A. Poole	R. V. S.
M. Sampson	R. V. S.

Appendix 2 - Ship's Personnel

S. Mayl	Master
G. Harries	Ch. Officer
S. Sykes	2nd Officer
G. Proctor	3rd Officer
I. McGill	Ch. Eng.
G. Gimber	2nd Eng.
V. Lovell	3rd Eng.
D. Lutey	Electr. Eng.
J. Baker	Radio Officer
M. Harrison	C. P. O. (Deck)
H. Hebson	Seaman
D. Paton	Seaman
G. Crabb	Seaman
A. Marren	Seaman
S. Hardy	Seaman
K. Prately	Motorman
K. Peters	Cook Steward
J. Swenson	Cook
R. Stephen	2nd Steward
P. Whilding	Steward
S. Smith	Steward

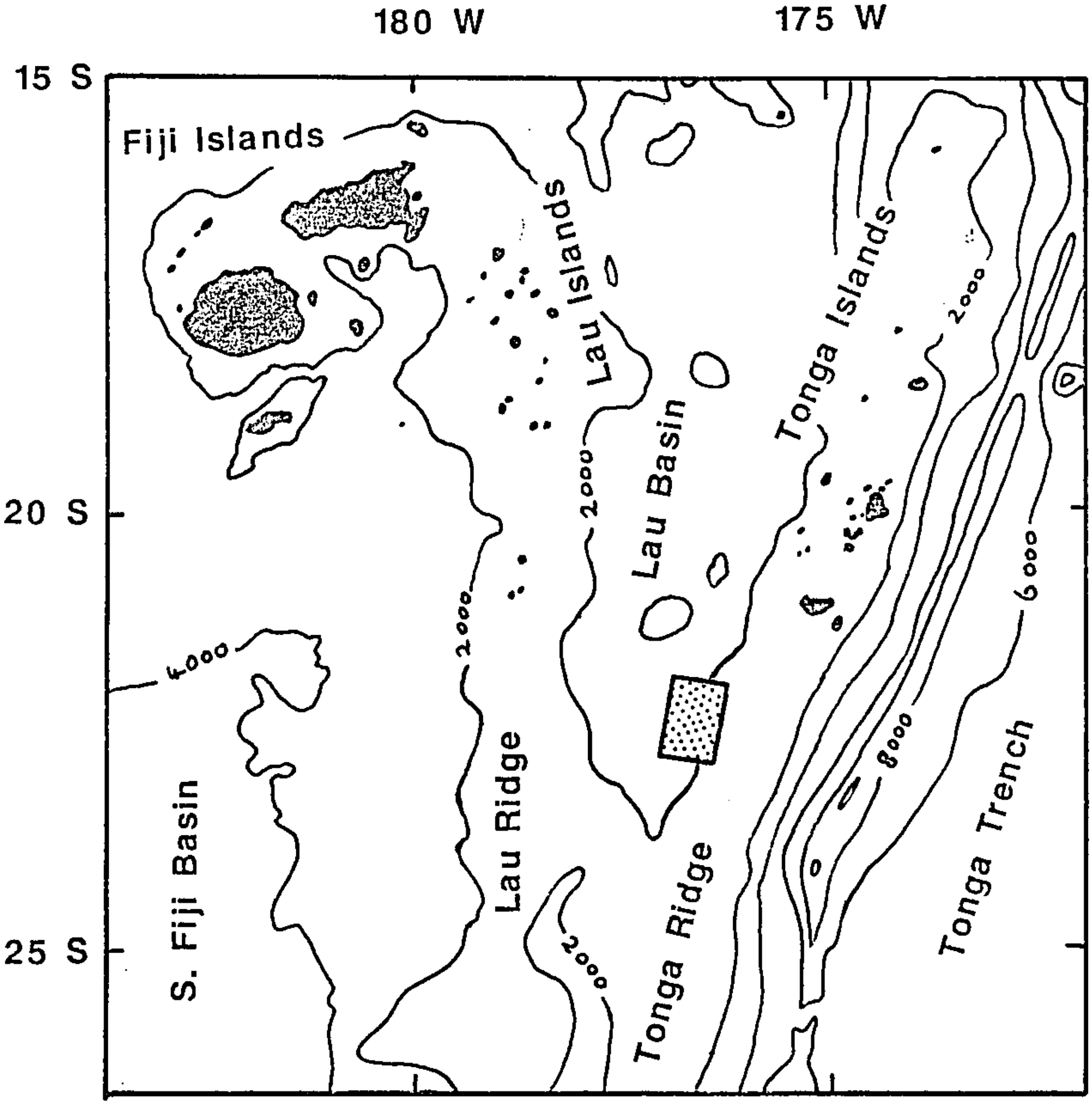

Figure 1. Simplified bathymetry of the Lau Basin and surrounding region. The location of the area studied during the cruise is indicated by the stippled box in the south-eastern part of the Basin.

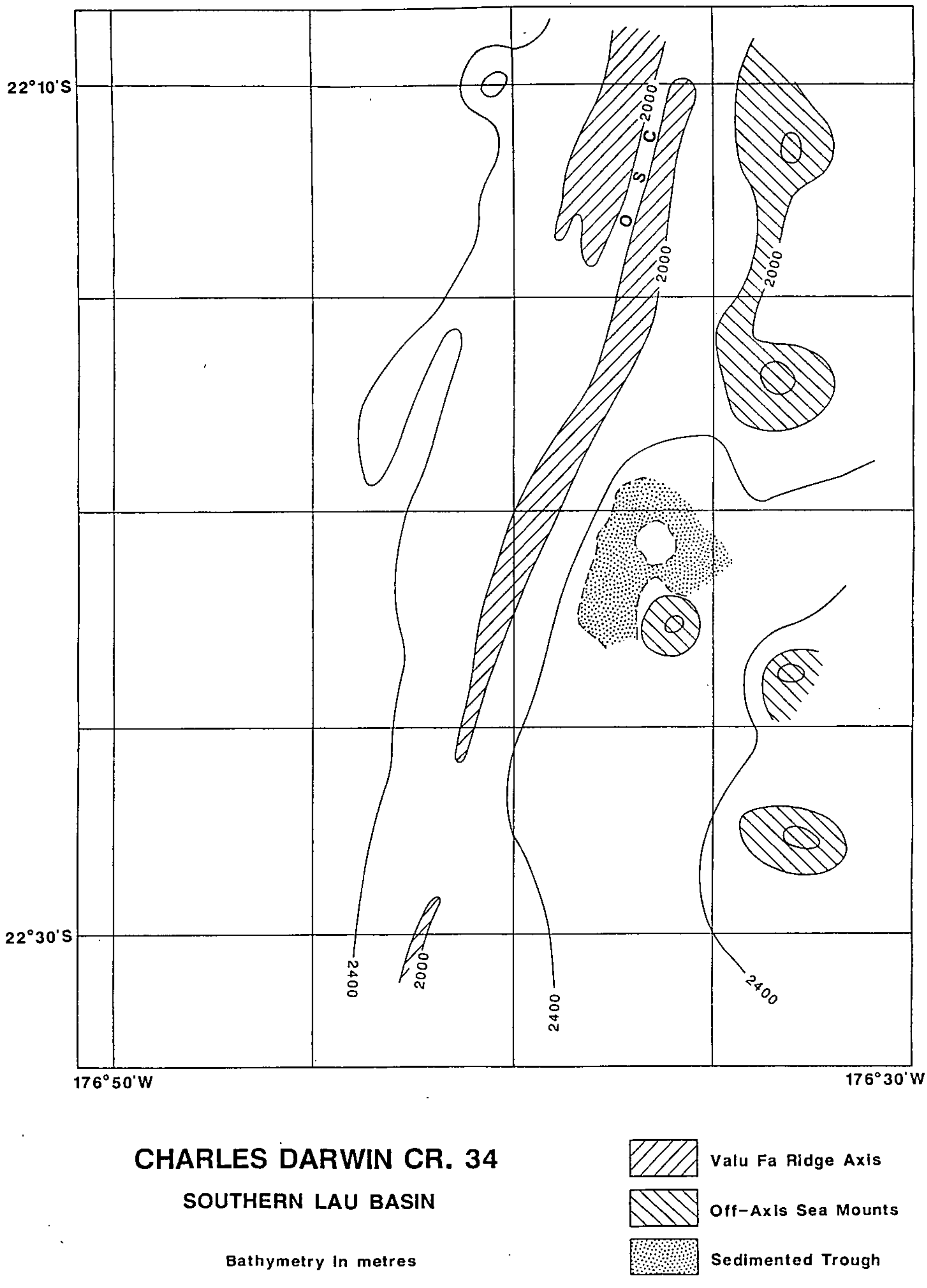

Figure 2. Simplified, preliminary bathymetry of the study area, showing the location and geometry of the ridge system and some off-axis sea-mounts. The contour interval is 400 metres.

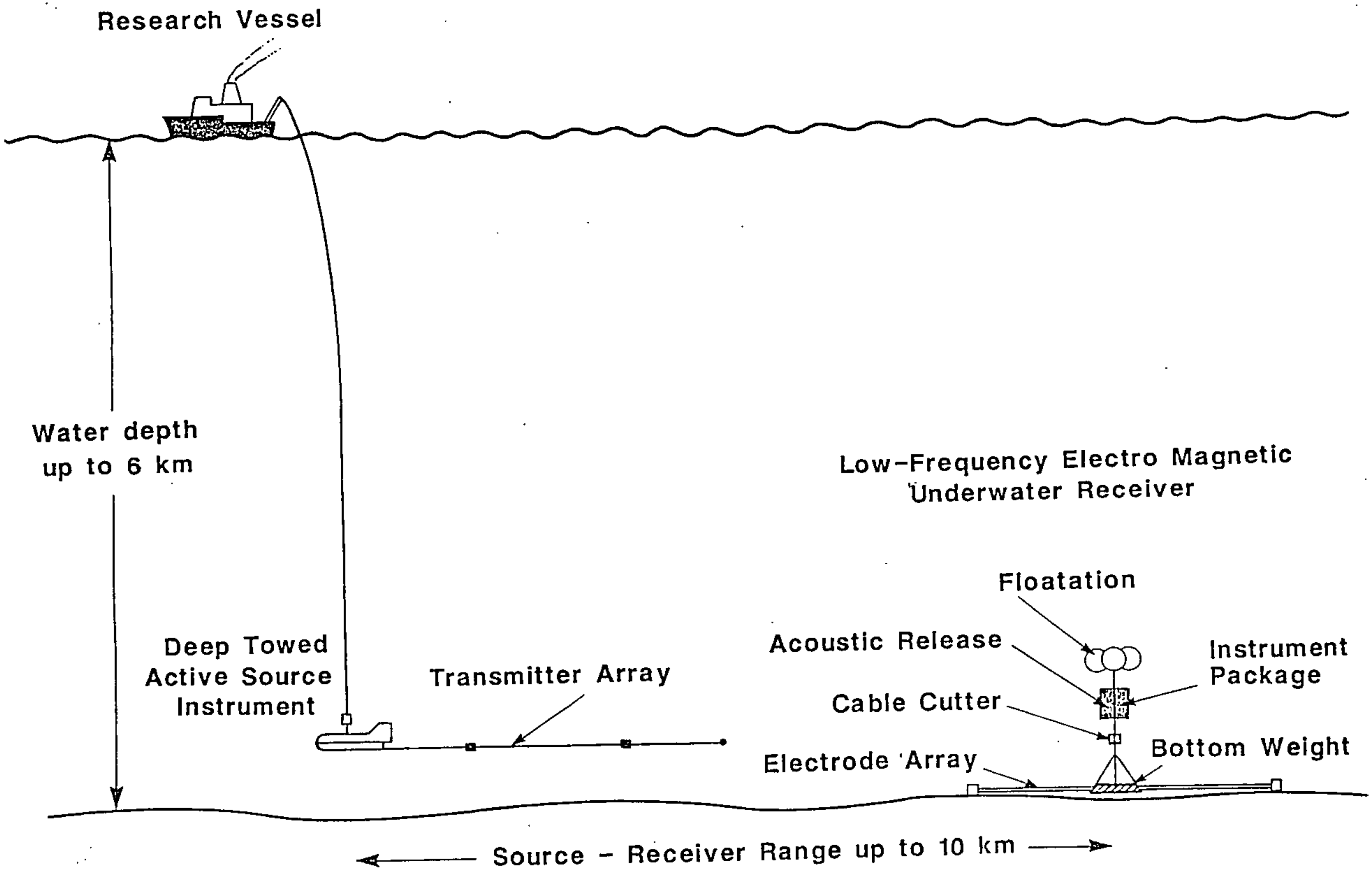

Figure 3. Schematic layout of an active source, electro-magnetic sounding experiment. Not to scale.

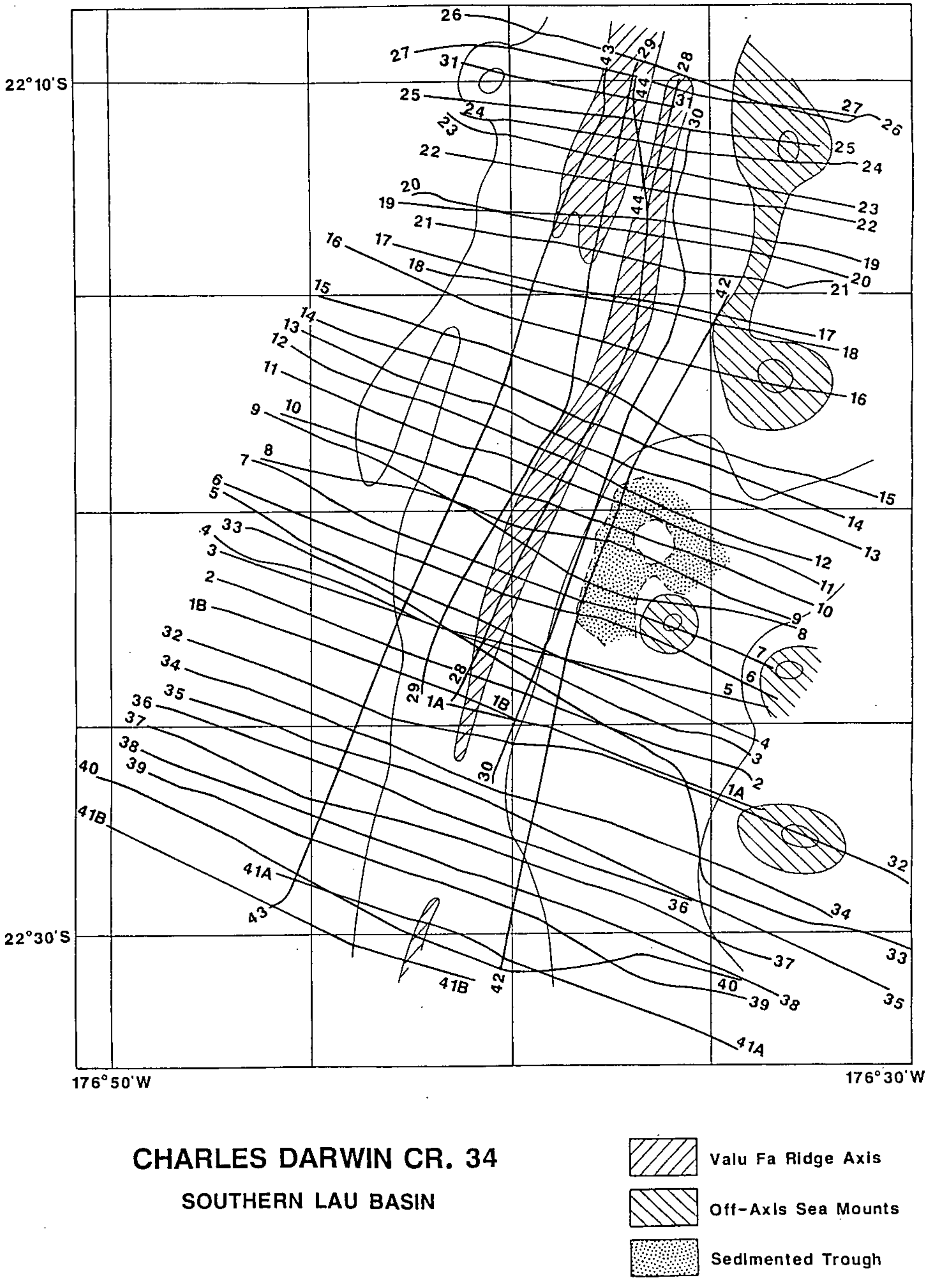

Figure 4. Location of digital seismic reflection profiles.

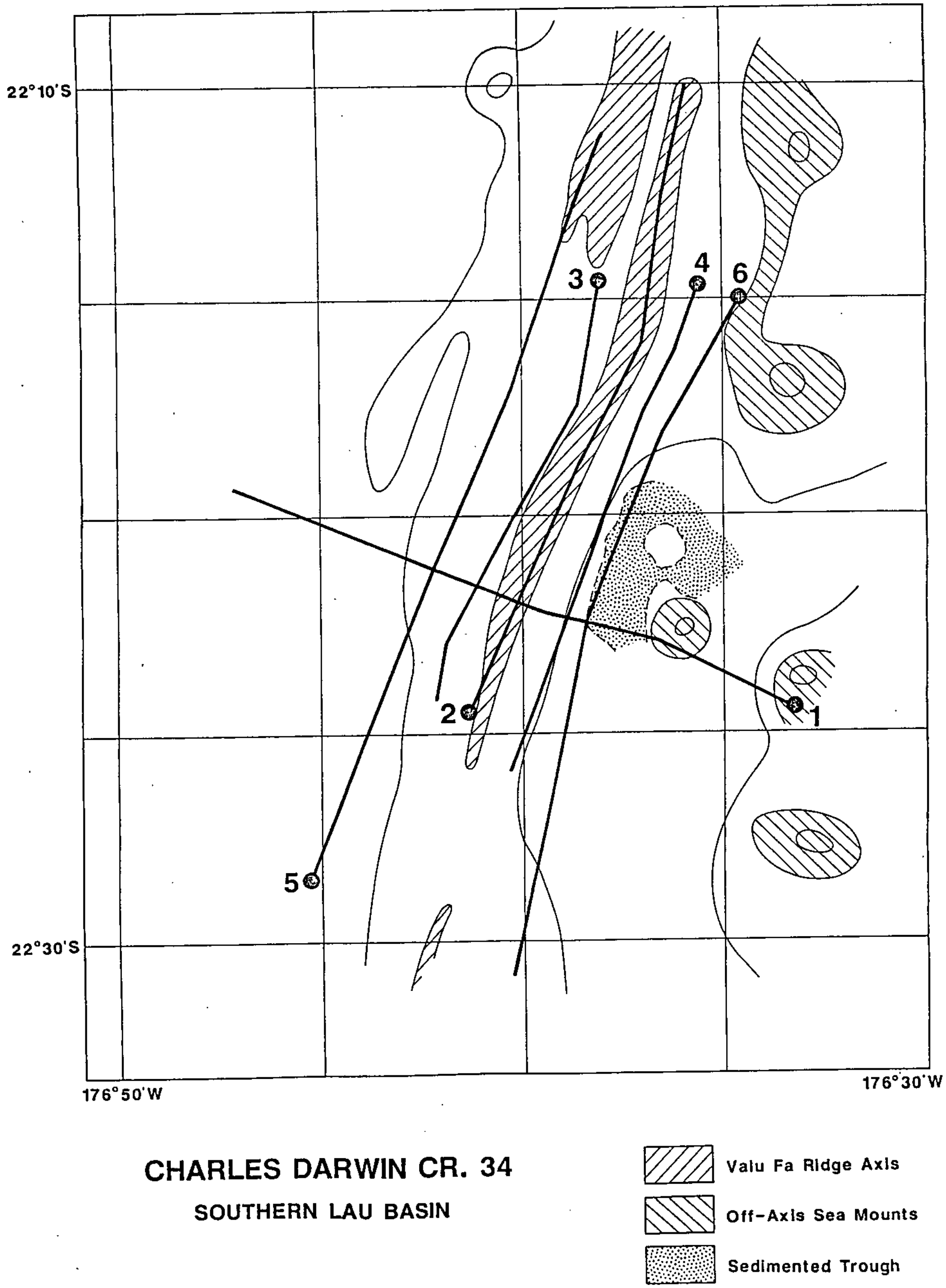

Figure 5. Location of disposable sonobuoys (solid circles) and wide angle shooting tracks.

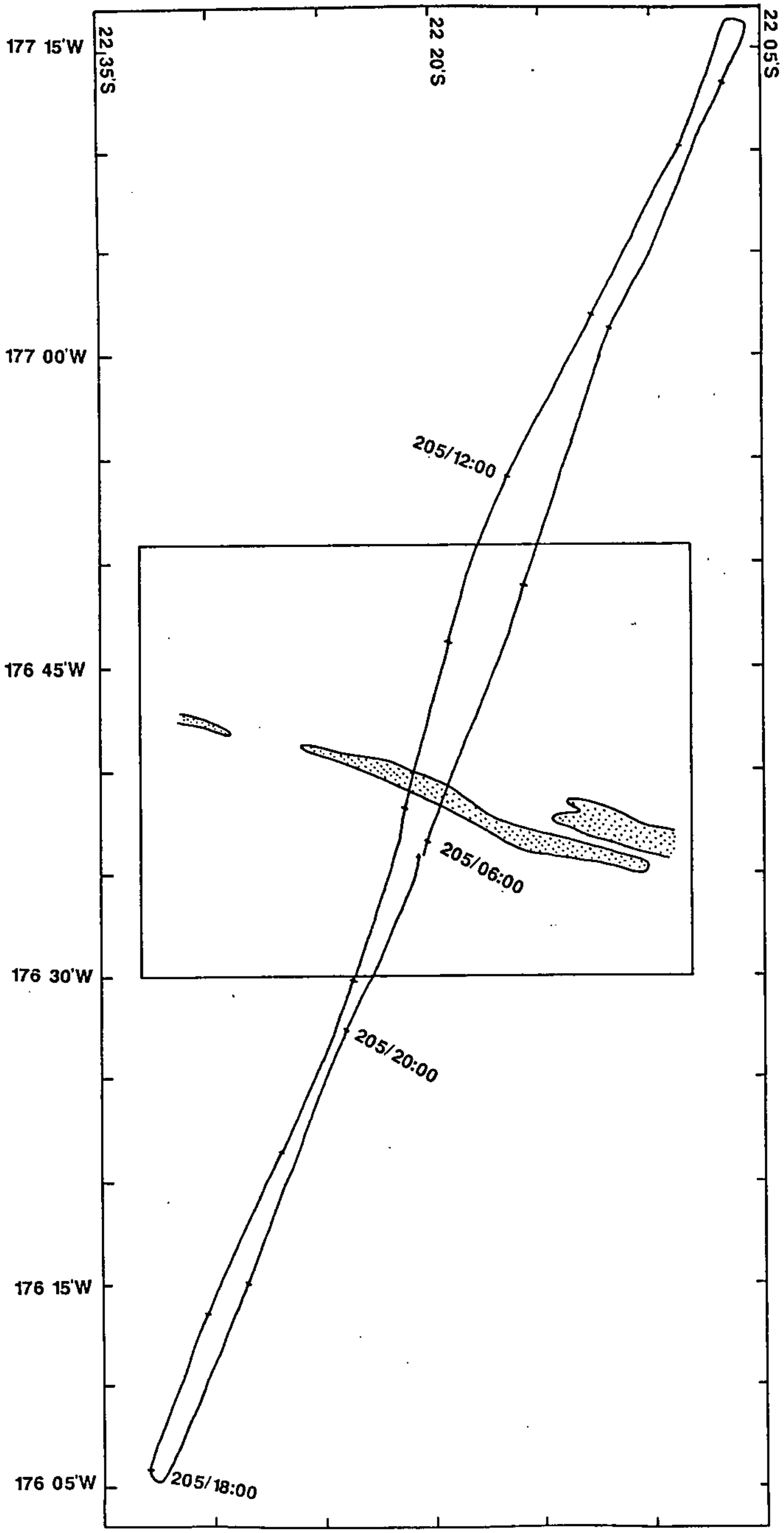

Figure 6. Track of long gravity and bathymetry profile obtained perpendicular to the ridge axis. The box indicates the area covered by Figure 2.

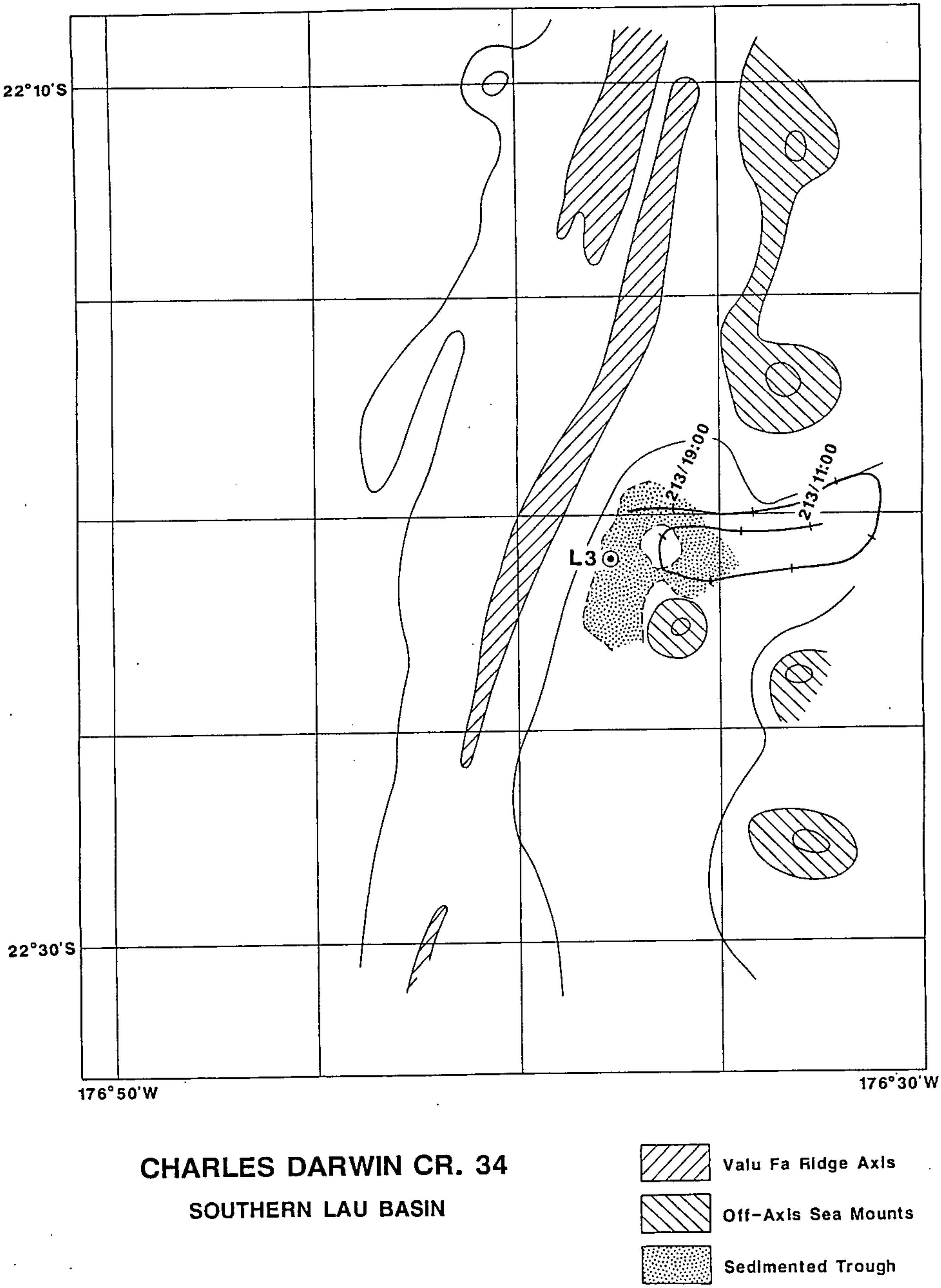

Figure 7. Position of LEMUR 3 and ship's track during DASI electromagnetic transmissions, E/M experiment 2.

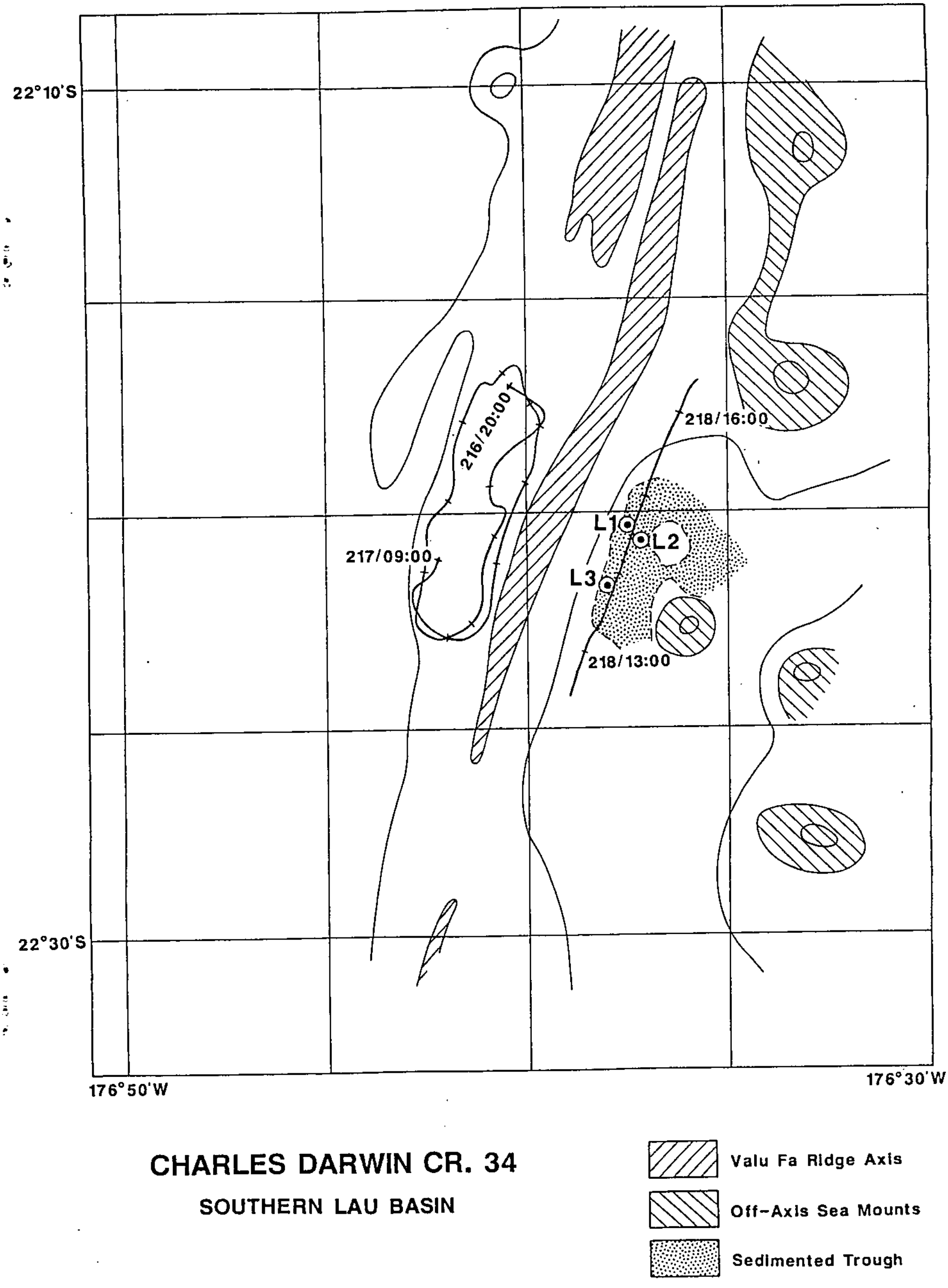

Figure 8. Position of LEMURs and ship's tracks during DASI electromagnetic transmissions, E/M experiment 3.

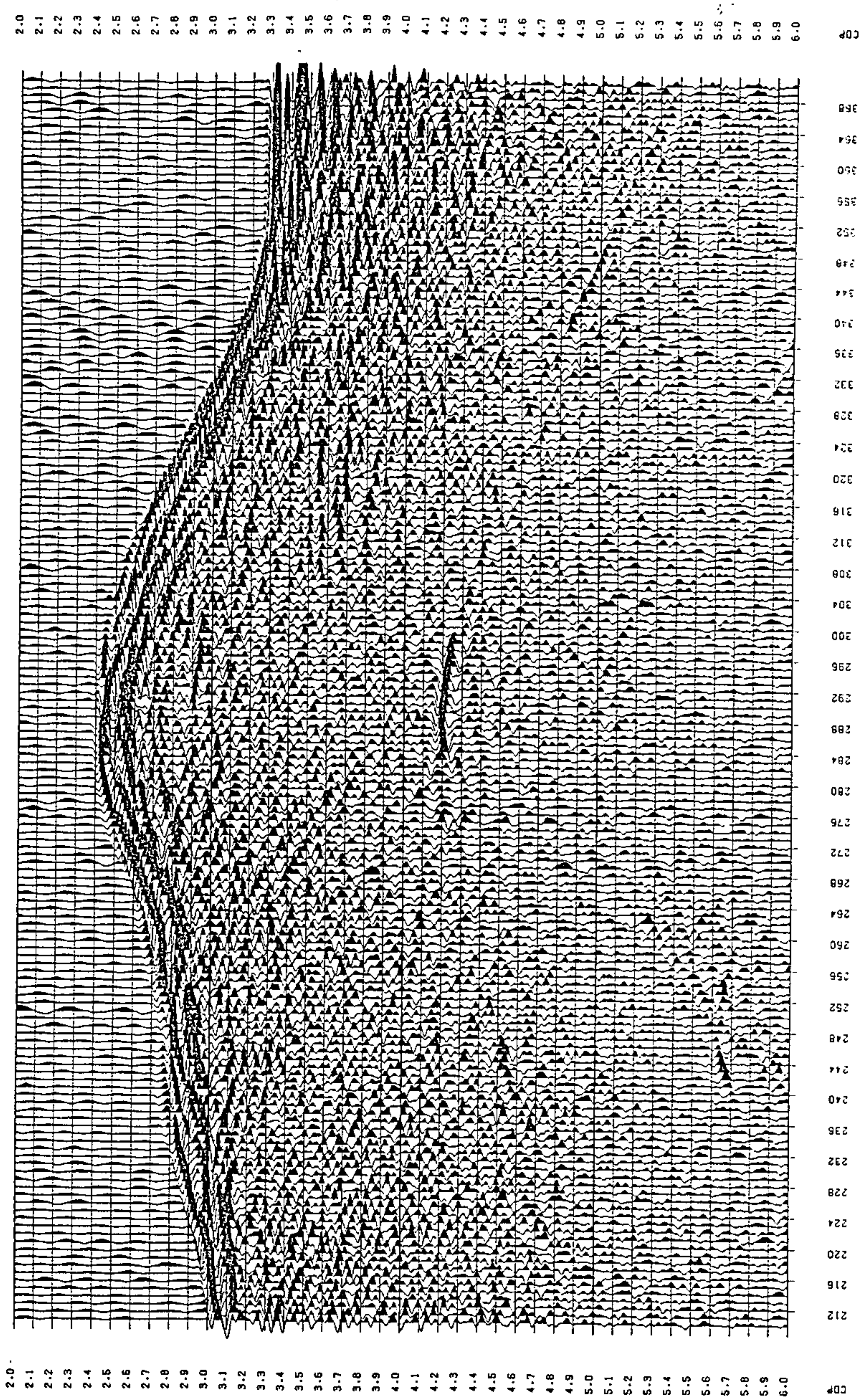

Figure 9. Preliminary stack of seismic reflection data from part of Line 9. The sea bed at the ridge axis is at 2.4 s TWT. The reflection from the axial magma chamber is clearly visible at 4.2 s TWT beneath the ridge axis, and dipping away from the axis for some distance to either side. The sea surface multiple is at 4.9 s TWT at the ridge axis, and is much fainter than the magma chamber reflection. The length of profile shown here is 7.5 km.

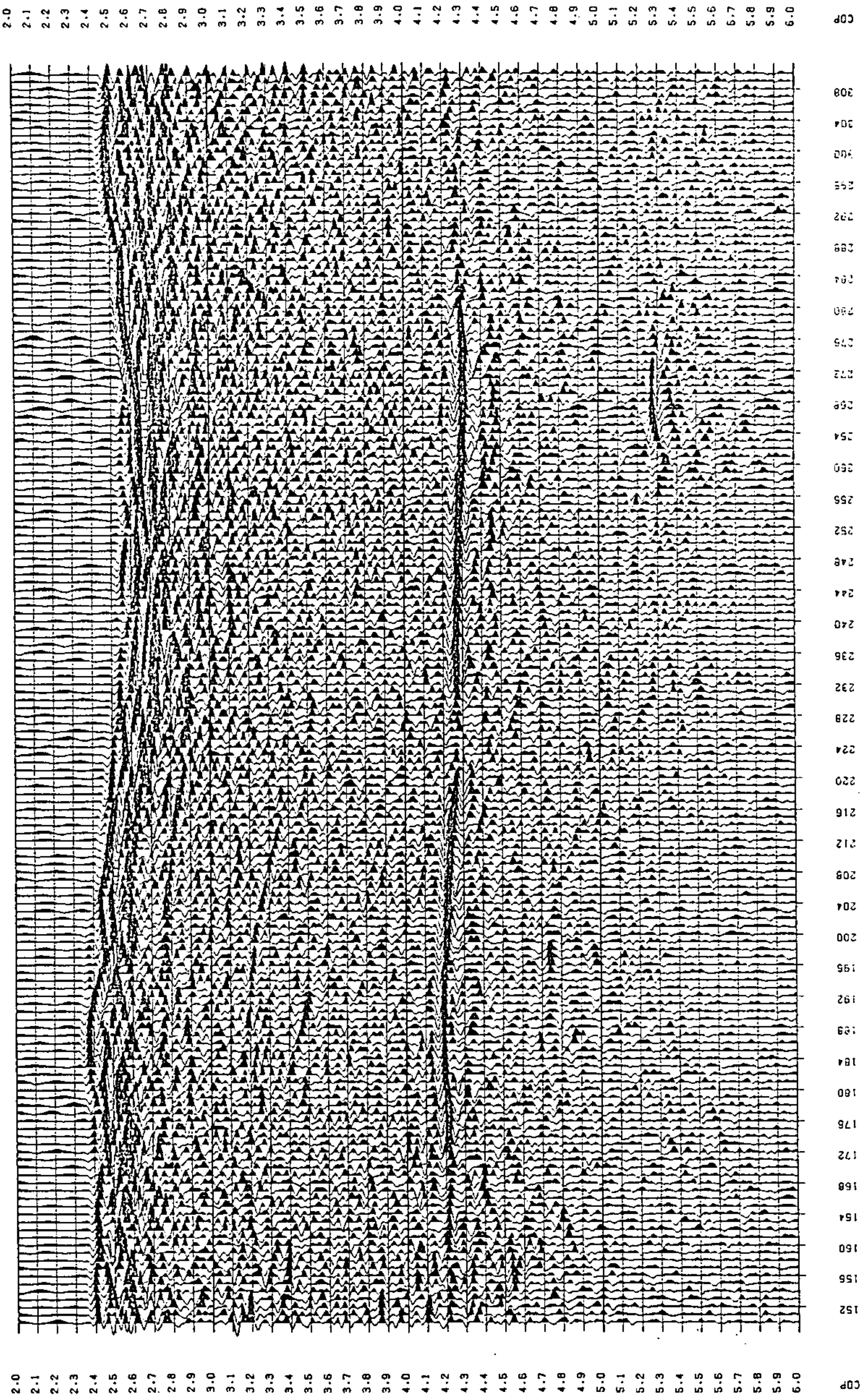

Figure 10. Preliminary stack of seismic reflection data from part of Line 28. The sea bed lies at between 2.3 and 2.6 s TWT. The magma chamber reflection is the bright, continuous, sub-horizontal event at betwen 4.2 and 4.3 s TWT. The sea surface multiple is faintly visible in a few places, for example at about 5.3 s TWT between CDP's 260 and 275. The length of profile shown here is 7.5 km.