UNIVERSITY of CAMBRIDGE

Department of Earth Sciences

Cruise Report

R.R.S. Discovery 150

CRUISE REPORT

R.R.S. DISCOVERY CRUISE 150

S. Shields to Falmouth

23 August - 6 September 1984

M.C. Sinha

November 1984

1. Objectives

The primary objective of DISCOVERY 150 was to carry out a multichannel, wide-angle seismic experiment using the newly-developed Pull-Up Multi-channel Array (PUMA) on the continental shelf west of the Outer Hebrides. Our first priority was to shoot a 130 km-long profile (line A, Figure 1) using airgun and explosive shots recorded by the PUMA (Figure 2), six Pull-Up Shallow-water Seismometers (PUSS's) (Figure 3) and land stations on Lewis. A secondary objective was to shoot the shorter (40 km) line B using airgun shots only, at right-angles to line A. We also intended to use the seismic experiments to carry out operational trials of our new, prototype, digital Ocean-Bottom Seismometer (OBS).

Seismic velocities near the base of the continental crust are difficult to investigate using conventional seismic refraction or reflection techniques, since at refraction ranges seismic waves from this region generally reach the receiver as second arrivals behind the Moho refraction; while in reflection experiments the moveout observed on reflections from these depths is so small that no reliable velocity determinations can be made. In order to image such regions reliably at wide angle, therefore, it is necessary to use reflection-type multi-channel seismic techniques in experiments with large shot-receiver offsets. Our objective on DISCOVERY 150 was to carry out such an experiment using a single ship, by firing a large number of shots into the PUMA, a 1.2 km long, 12-channel hydrophone array placed on the sea-bed. A major advantage of the PUMA technique over alternative

2-ship methods is that the use of a fixed receiver removes the severe time constraint on shot firing which is otherwise imposed by the need to tow the receiver at a speed of 4 to 5 knots. It is therefore possible to fire more, and larger, shots, enabling the profile to be extended to much greater ranges than is possible in a 2-ship experiment.

Line A, which runs along part of BIRPS "WINCH" deep reflection profile, was designed to investigate in detail the seismic velocity structure in the lowermost continental crust beneath the Lewisian rocks of the Hebridean Shelf. The principal receiver would be the PUMA at A1, backed up by 3 PUSS's. Three more PUSS's at A3 would provide reversed coverage, while the OBS and one PUSS at A2 would provide split coverage from the centre of the line. In addition a land station (SCRAP 2) near the northern tip of Lewis would extend the maximum offset on the profile to 165 km.

The second line, B, was designed to provide an independent measurement of seismic velocities in the possibly anisotropic Lewisian upper crust in a direction normal to line A. We planned to shoot this line using airgun shots recorded by PUSS's at B2, the PUMA at B1 and a land station on Lewis (SCRAP 1).

2. Cruise Narrative (All times B.S.T.)

2.1. Preliminaries: 22-25 August

The first wave of the Cambridge party (M. Sinha, P. Barton, J. Leonard, P. Carter, C. Powell) joined DISCOVERY in the Middle Docks, South Shields at 0800 22 August. Our equipment was loaded between 0900 and 1030, and at 1100 DISCOVERY moved up river to the Tyne Dock. There we were joined by the remainder of the Cambridge party (T. Owen, A. Goudie, G. Spence and J. Morgan). During the move, the directional control on the ship's bow-thruster failed. This signalled the start of a long-running battle between the bow-thruster and the ship's engineers, which was to last for the duration of the cruise.

AM on the 23rd we embarked explosives, and at 1330 we left the Tyne Dock to carry out compass adjustments. On completion we returned to a berth in N. Shields to await bow-thruster spares, and for repairs to the DECCA main-chain receiver, which had broken down in the meantime. We eventually sailed from N. Shields at 2220/23rd, with the bow-thruster working but only at up to half power.

Overnight the autopilot failed, and despite the engineers' efforts remained U/S for the rest of the cruise. Dense fog slowed us down the next day (24th), but had cleared by the time we arrived off Aberdeen to calibrate the E/M logs on the measured mile. We were about to start the first calibration run at 1800/24th when we were forced to abort it due to a total main engine failure. By 1930 we had sufficient main engine power to start again, and we were able to complete four measured mile runs by 2040. Both logs, their various repeaters, and the interfaces to the satellite navigation and data-logger were subsequently calibrated.

On completion we attempted to rig the outboard transducer for the Simrad echo-sounder. The arrangements for clamping the transducer boom to the ship's side proved totally inadequate. At 5 knots the boom started to vibrate badly, and at higher speeds the whole arrangement looked likely to carry away. We therefore gave up on the Simrad, and used the PES for the remainder of the cruise.

The following day (25th) was spent in completing our passage to the work area and in making final preparations for instrument deployments.

2.2. Early Efforts: 26-29 August

The scientific programme in the work area commenced at 0600/26th, when we started to deploy the PUMA at position A1. The first part of the deployment went well, and by 0700 the first buoy and its anchor had been successfully laid. At this point, however, hydraulic power to the auxiliary winch failed. We attempted to continue the deployment by declutching the winch barrel and paying out the PUMA ground-line using the brake. Unfortunately this meant that we had only poor control over the recording package as it swung outboard using the Schatt davit. The result was that, before we could lower it, or take up the slack on the PUMA array with the array winch, the recording package swung hard, end-on, against the stern of the ship, splitting the array sleeving and damaging the array-to-pressure-case connector. At this point we were forced to abort the PUMA deployment, recover the damaged recording package, and buoy and slip the inboard end of the ground-line.

It was clear that repairs to the PUMA would take a day or so to complete. We therefore chose to cut our losses and shoot the airgun section of line A using an array of 6 PUSS's as receivers. PUSS's 1 to 6, plus the OBS set up to record a hydrophone channel only, were deployed between 0930 and 1430. We then streamed an array of 4 x 1000 cu. in. airguns, consisting of one pair towed from the Schatt davit and one pair towed from the port A-frame, all guns being towed at a depth of 15 m. We encountered various minor snags during this process, so it took until 1930 to get all the guns streamed and firing. At 2000 we started the airgun line, firing the guns every 3 minutes at a speed over the ground of 4.3 knots, to give a shot spacing of 400 m. We finished shooting at 0200/27th, and recovered the airguns before heading back to A1. The shots had been successfully recorded by the PUSS's and by SCRAP 1 on Lewis (Figure 4).

Our plan for 27th August was to recover the PUSS's used for the airgun line, and simultaneously to start laying receivers for the explosives line. We began recovery of the instruments at 0600 with the OBS, which had suffered serious external damage to the pressure case, apparently caused by an extremely hard, rocky bottom. The OBS had not recorded any useable data. Next we recovered PUSS 6, which was also badly damaged but had recorded data, followed by PUSS 5. We then laid PUSS 9, which was set up to record the explosive shots, recovered PUSS 4 (undamaged),and laid PUSS 10.

At about this time the weather forecasts began warning of an imminent south-westerly gale. We decided to recover the remaining airgun-line PUSS's before laying any more fresh ones. PUSS 3 was recovered damaged, but with data; PUSS 2 and PUSS 1 were recovered undamaged. By now (1530) the weather was deteriorating and the forecast was for a Force 9 blow. Reluctantly therefore we were obliged to abandon our plans for shot-firing the next day, and recover the 2 PUSS's that we had laid that morning. Next we recovered the bits of PUMA mooring left over from the previous day. At 1900 we ran a sound-velocity meter dip at A1, while we revised our plans.

Although it would clearly be impossible to carry out shot-firing the next day, it was possible that we would still be able to run a seismic reflection profile along line A, especially if we ran it from south to north, with the weather on our quarter. It was essential to run the reflection profile at some stage, to measure the thickness of superficial sediment cover for making static corrections on the main, wide-angle line. On completion of the SVM dip, therefore, we set off south along line A in rapidly worsening weather.

By 0400/28th the wind had indeed reached Force 9, reducing our speed to 3 knots. However, later that morning it moderated, and we were able to reach a point 10 miles beyond the SSW end of line A by midday. We streamed a 40 cu. in. airgun, hydrophone streamer and magnetometer fish; changed the airgun for a 40 cu. in. with wave-shape kit, which gave much better results; and at 1600 started a gravity/magnetics/seismic reflection profile along line A. Profiling continued overnight in moderating weather, and was completed at A1 at 0530/29th.

By the time we had recovered the profiling equipment, the weather was deteriorating again, and more gale-force winds were forecast. It was clear that explosive shot-firing on line A would have to be postponed for the second time. Rather than do nothing, we decided to shoot line B immediately, while it was still possible to work. We therefore steamed to B2, where we laid two PUSS's (1 and 2) using doubled anchor clumps. The rapidly worsening weather prevented us from laying any more instruments here or at B1, so we streamed a pair of 1000 cu. in. airguns from the Schatt davit. By this time the wind had reached Force 8 again and a considerable sea was running, so it was unsafe to stream the other pair of airguns from the port A-frame. We started the airgun profile at B2 at 1400; at 1418 we decreased the firing interval from 3 to 2 minutes; and at 1730 we completed the profile at B0 (Figure 4). By now, it was clearly impossible to attempt any further scientific work until the weather improved, so we recovered the airguns and the PES fish and proceeded to anchor for the night in East Loch Roag.

2.3. Second Attempt: 30 August - 6 September

DISCOVERY spent the morning of 30 August sheltering in East Loch Roag. During the morning the Z-boat went ashore, to buy cigarettes etc. and so that MCS could talk to Carol Williams et al. who were running the SCRAP stations on Lewis. The field party had found some good seismometer sites, and had made excellent recordings of the airgun profile on line A. However the land stations were very much noisier in bad weather, and the results from line B (on which it had only been possible to use two airguns) were less impressive.

By midday, the weather had improved again, and it began to look as if we might get the 3-day fine weather window needed for our explosives programme. At 1600/30th we weighed anchor, and steamed to B2 to recover the two PUSS's that had been left out during the gale. PUSS 2 proved very difficult to recover. The pellet line was thoroughly tangled around the buoy and its radar reflector, making it difficult to grapple. In addition the mooring wire had been badly damaged - on some sections only two out of the six strands were still intact - and subsequently had to be scrapped. We were not surprised when the PUSS itself came back seriously damaged. Unfortunately it had not recorded any data - the tape cassette had been bounced right out of the tape deck even before it had started recording. The buoy on PUSS 1 had lost its radar reflector during its launch, and this made it much easier to recover, since the pellet line was not tangled in the same way. The absence of a radar reflector probably also reduced the drag on the mooring, and PUSS 1 was recovered undamaged and with good data.

After recovering the two PUSS's from line B we headed south overnight to A3, where at 0600/31st we started laying receivers for the explosive shots (Figure 5). Despite no less than three breakdowns before breakfast - the bow-thruster again, a shear-pin on the double-barreled winch, and the crane wire which jumped off its sheave - PUSS's 4, 5 and 8 were successfully deployed at A3 by 0800. At 1100, we laid the OBS, configured to record data from a 3-component deployed geophone package as well as its hydrophone, at A2. We were unable to lay the PUSS that we had planned to position at A2 because of the loss of the mooring wire which had been damaged at B2.

By the afternoon of the 31st, the weather had improved a great deal, so we decided to deploy the PUMA next. The array and its end-connector had been successfully repaired since our first deployment attempt; however we were unhappy about the state of the bottom at A1. The damage to PUSS's and the OBS already laid and recovered there indicated that it was much too rocky to be suitable for the PUMA. We therefore placed the PUMA on an area of sandy bottom indicated on the chart some 4 miles off-line to the ESE of A1. We started the deployment at 1530 and finished at 1645, with no serious problems except that the final orientation of the array was less closely parallel to the direction of the line than we would have liked.

At 1900/31st we began laying the last group of 3 PUSS's at A1. During the deployment of the first of these, PUSS 9, the ship's main engines failed again. This occurred when the PUSS was on the bottom and the anchor weight was suspended about 70 m below the ship. For 20 minutes we were unable to manoeuvre, or heave in our pay out on the winch, and as a result the PUSS was dragged some distance across the bottom. As soon as power was restored we recovered it, but found it to be seriously damaged. We therefore laid the next two PUSS's, 10 and 11, and meanwhile prepared and programmed PUSS 12 to take the place of the damaged PUSS 9. We finished the deployment of PUSS's 10, 11 and 12 at 2130/31st.

On 1st September we finally started the explosive shot-firing. Shot 1 detonated successfully at 1402, followed without incident by shots 2 to 16. However when shot 17 went off at 1522, the main engines failed when an excitation relay bounced, causing the system to shut down. This was quite unexpected as the calculated shock factor for this shot size (25 kg) was only about 30% of the permitted shock factor. Shot 18, at 1525, had to be abandoned while the ship built up speed again, and the next shot, 19, at 1532, caused the main engines to shut down for a second time. It became apparent that the presence of a shallow bottom, consisting of hard rock with high seismic velocities, was resulting in a much stronger shock-wave at the ship than predicted by the usual formula. Since even 25 kg shots were shutting down the ship's main engines, and we were about to increase the charge size from 25 to 50 kg, we had no choice but to increase the fuse length to the maximum available, which extended the flight time from 120 to 130 s; and to increase the ship's speed from 7 to 10 knots. Unfortunately, this upset the spacing of the remaining shots for that day. Shot 20 had to be missed out, and we were obliged to fire shots 21 to 40 at a coarser spacing than planned, heading south along the line at 10 knots. We then turned north again, back along the same section of line, and fired the remaining shots, 41 to 50, between the shot-points previously occupied. Shot 45, a 50 kg charge, was the only misfire. The last shot, 50, was detonated at 1847.

Shots planned for the second day included a number of 100 and 150 kg charges, as well as more 50's. The need to fire all of these shots at speeds greater than 10 knots meant that overnight we had to revise all our plans for the next day. The solution we decided upon was to carry out the shot-firing run at 10.8 knots, covering the line 3 times and interleaving the shot-points on each run in order to achieve the required shot-spacing.

We recommenced shot-firing with shot 51 at 1000/2nd. Shot 56 (50 kg) misfired, but all the remaining shots (57 to 103) were fired successfully. The last shot went off at 1922/2nd.

On completion of shot-firing that evening we steamed back to A3, where we recovered PUSS's 4, 5 and 8, all undamaged, between 2130 and 2330. Overnight we continued north to A2, where we recovered the OBS, also undamaged, between 0600 and 0710/3rd. On completion we steamed to East Loch Roag, where we put our much valued but now redundant shot-firer John Price, who was more urgently needed elsewhere, ashore.

We had now completed all of our scientific programme except for the airgun shots into the PUMA on line A. We therefore recovered the PUMA pressure-case end, removed the recording package, and relaid the array-end on its mooring without the pressure case. We then returned to A1, and recovered the 3 PUSS's there. Meanwhile, fresh tapes and batteries were inserted into the PUMA recording package, and the shot-window timer was reprogrammed to record airgun shots overnight.

At 1900/3rd, after safely recovering the PUSS's at A1, we returned to the PUMA, recovered its end again, and reattached the recording package. On completion, we started streaming the airgun array. Unfortunately at this point one of the two compressors failed, due to a faulty 2nd-stage valve. The single working compressor was unable to supply sufficient air to fire a four-gun array with an acceptable shot interval; we therefore streamed only a 2-gun array, with guns firing every 3 minutes. At 2315/3rd we started shooting the final airgun line, passing between the two buoys at either end of the PUMA array. We continued the line at 4 knots until it intercepted the main line A south of the first shot-point (Figure 4), finishing at 0200/4th when we recovered the airguns. We subsequently discovered that damage to the array between hydrophones 1 and 2 prevented 11 of the 12 hydrophones from recording the airgun shots. The airgun line was therefore only recorded by hydrophone 1, closest to the recording package.

Finally, at 0800/4th we started the recovery of the PUMA. We were somewhat gloomy when the first two sections came on board with numerous holes and gashes in the sleeving; however the next 8 sections came in quite easily, with no evident damage other than superficial abrasions. The last two sections, closer to the recording package, again had one or two holes in the sleeving, but the recording package itself was recovered safely and undamaged. The last anchor and buoy were recovered by 1000/4th. We then set course via the Butt of Lewis and the Minch for Falmouth, where we arrived at 2000, 6th September.

3. Equipment Performance

3.1. Cambridge Equipment

(a) The PUMA

This was the PUMA's second trip to sea, the first having been its test cruise on Challenger 1/84. On that occasion we experienced problems from two sources. The first was that the array could only be recovered from one end - the opposite end to the recording package. This made recovery difficult on Challenger, since we were forced to recover the PUMA starting from its windward end. The second problem was with tape recorders turning on at the wrong times. To solve the first problem, we had built a dummy end for the array to take the place of the recording package connector; and a clamping arrangement, to allow us to remove the recording package from the array end, with the remainder of the array still outboard. This proved most effective on the Discovery cruise, especially since it allowed us to replenish the tapes and batteries in the recording package without recovering the PUMA array itself. To solve the tape recorder problem, Peter Carter put in a great deal of work on the electronics and power supplies both before and during the Discovery cruise. His efforts were evidently successful, since on both deployments all eight tape recorders ran correctly.

Problems we did experience with the PUMA were as follows:

(i) The array to recording package connector was damaged during the first deployment attempt. This was largely due to problems with the winches, and no such difficulties arose during the PUMA's second deployment.

(ii) The alignment of the PUMA ended up at about 50° to the direction of the desired profile. This was not ideal, but would have been hard to avoid given the prevailing wind and tide conditions. In future programmes, extra time should be included to allow the PUMA to be deployed at slack water.

(iii) While replenishing the tapes and batteries in the recording package before the airgun line, at least one conductor must have parted between the first and second hydrophones. The result was that only single-channel data were recorded from the airgun shots.

(iv) During the first day's shot firing, a heavy swell was running. This put a low-frequency (period ~12 s) signal with an amplitude just large enough to cause occasional clipping onto all 12 hydrophone channels. A sharper cut-off at the low-frequency end of the amplifier response would solve this problem.

(v) The worst damage to the PUMA occurred during recovery. Five out of twelve array sections were damaged, three of them badly. Almost certainly this damage would not have occurred had the PUMA been laid on a softer bottom of fine sand or mud.

Unfortunately no such site was available in our work area.

Despite these difficulties, the PUMA made excellent 12-channel recordings of 99 explosive shots, and single-channel recordings of over 50 densely-spaced airgun shots.

(b) The PUSS's

Our twelve PUSS's must by now count as veteran instruments. Bearing in mind that they were designed 10 years ago and built on a budget of less than £500 each their continuing reliability is very gratifying. Unfortunately on this cruise they suffered considerable internal and external damage from the rocky bottom, and by the end of the cruise very few were still in working order. Nevertheless, out of 17 PUSS deployments, 11 worked perfectly, and 2 more recorded good data, even though their clocks had stopped by the time we had recovered them. (The damage to the clocks was probably caused during recovery; we should still be able to use the data from these two PUSS's.) Two more deployments were aborted because of bad weather, and another had to be aborted when the ship's main engines broke down. Only one PUSS deployment (on line B) actually failed to record data.

(c) The OBS

On its first deployment, the Digital OBS was set up as a hydrophone-only recorder. Unfortunately it was seriously damaged by being dragged across a rocky bottom on its deployment. One pressure-case end-cap assembly, including the protective cage containing the hydrophone and the electrical lead-through connectors was particularly badly damaged. No data were recorded. For its second deployment, the OBS was configured to record data from a deployed 3-component geophone package as well as the hydrophone. This time the OBS was recovered undamaged, and with its clock still running. Unfortunately however it appears that the seismic amplifier gains were set too high, with the result that the recorded signals were badly degraded by clipping for most of the experiment.

A complete list of the damage suffered by Cambridge equipment appears in Table 2.

3.2. R.V.S. Equipment

Generally speaking, most R.V.S. equipment performed well. Problems experienced were:-

(a) The Data Logger/Computer System

The most serious problem with this system was that, as installed, it was unable to log or reduce DECCA values, which we had specified as our primary means of navigation. An ad-hoc system for logging DECCA was set up after we sailed, initially using a teletype and later using the processing computer. However even this system suffered from innumerable crashes and timing errors. The problem of reducing DECCA values remains unsolved.

Calibration of the E/M log to obtain a correct recording was excessively complicated, involving hardware modifications to the E/M log interface. Other sensors were logged correctly, but without DECCA the values could not be merged with the navigation. Numerous faults occurred at various times on both the logger and the processor, and towards the end of the cruise, when we were hoping finally to be able to process and plot some of the data, the plotter broke down.

Since the cruise the data have now been processed and plotted. However the navigation has had to be calculated using satellite fixes rather than the DECCA fixes originally specified.

(b) SIMRAD echo-sounder

The arrangements for clamping the overside transducer boom to the hull are inadequate, as described above. We were not able to use the SIMRAD during the cruise.

(c) New Clock System

Several days into the cruise, the new master clock was found to be in error by over a minute. We think this was due to it jumping after it was set up but before we sailed. Subsequently it jumped another minute later on in the cruise. The reliability of the system clearly needs careful checking. Secondly, the clock was unable to provide a trigger signal to fire the airguns at three-minute intervals. As a general comment, the availability of trigger pulses and event markers from this clock appears to be unduly restrictive.

(d) Radar Reflectors

Unfortunately, the radar reflectors on the Toroid and Selco buoys proved to be rather vulnerable to damage during deployment and recovery of PUSS's. A total of 4 radar reflectors were lost during the cruise.

3.3 I.O.S. Equipment

Several important systems on Discovery have been installed and are operated by I.O.S. Problems experienced with these systems were as follows:-

(a) Auxiliary Winches

We used these both for towing airguns and for deploying and recovering the PUMA. The auxiliary winches only broke down once, but on that occasion the breakdown contributed to damage to the PUMA, causing its deployment to be abandoned.

(b) Compressors

One of the two VHP-36 compressors failed just before the last airgun line, halving the size of airgun array that we could use. The breakdown was due to a faulty second-stage valve.

In addition to the actual breakdowns, the handling equipment on Discovery calls for some general comments. Much of the equipment is extremely slow. This includes the double-barrelled winch forward, but is particularly true of the Schatt davit and winches on the poop. Streaming a pair of large airguns from the Schatt davit in marginal weather would have been both easier and safer had it been possible to traverse the davit or heave and veer cable faster. The port-side A-frame is too small to handle large airguns comfortably - the guns have to be lifted outboard using the crane, and this can only be attempted safely in fine weather. Airgun handling on deck could also be made safer if the I-beam for the overhead lifting gantry on the deck-head of the after rough lab. were extended from the lab. doorway to the after end of the overhead decking.

The starboard side A-frame on the foredeck is large enough for handling PUSS's but would be marginal for the Cambridge OBS's. A major disadvantage of the arrangements on the foredeck is that there is nowhere from which to hang off a toroid or selco buoy while launching an instrument. For the PUSS's we had to suspend and slip the buoys from the crane - a dubious practice from a safety point of view.

In general I think it is fair to say that handling equipment on Discovery is not as good as that available on other NERC research vessels. A striking illustration of this is the fact that it takes 2 to 3 times longer to launch or recover a PUSS on Discovery than it used to on Shackleton or John Murray.

3.4 Ship's Equipment

Three major items of ship's equipment suffered from breakdowns during the cruise:

(a) Main Engines

The main engines failed on four separate occasions. Quite apart from the navigational hazard and the loss of time, each failure had undesirable consequences for the scientific work.

The first breakdown occurred at the start of our measured-mile runs off Aberdeen. The ensuing power dip caused serious damage to a Cifer microcomputer. Fortunately we had brought a spare Cifer with us, otherwise the consequences would have been very serious.

The second failure occurred during a PUSS deployment. This resulted in serious internal and external damage to the PUSS.

Fortunately, again, we had a spare PUSS available which we were able to get ready in time to use in place of the damaged one.

The third and fourth breakdowns occurred during the first morning's shotfiring. The engines shut down twice following shots whose shock factors, calculated according to the NERC safety manual formula, was only 0.0031 - compared to an allowable shock factor for Discovery of 0.01. As a result we were forced to alter our planned shot-firing programme, which caused problems with the shot-point spacing for the remainder of the experiment. Even spacing of shot points was an important requirement for this experiment, and considerable effort before the cruise went into producing a programme. It was frustrating to have to change it half way through.

It is possible that the unexpectedly strong shocks experienced on Discovery were due to the combination of shallow water (~100 m) and the very hard sea-bed with high seismic velocities.

(b) The Bow Thruster

The clutch assembly of the directional control on the bow thruster failed while Discovery was moving berth in South Shields. Despite repairs both before and after we sailed, it continued to cause considerable anxiety, and the bow thruster was limited to half power or less for the rest of the cruise. Although problems with the bow thruster did not prevent us from working, they certainly did not help on a cruise which involved the deployment and recovery of many sea-bottom instruments, often in poor weather.

(c) The Autopilot

The autopilot broke down on our first night out from the Tyne. It remained U/S for the rest of the cruise. Fortunately this did not affect the scientific programme or results.

4. Conclusions

This was a difficult cruise, involving an intensive scientific programme and the use of a good deal of new equipment. Our first week was beset by equipment breakdowns and bad weather, and at times progress towards our objectives seemed depressingly slow. The second week however was a great improvement. The weather moderated, equipment problems were sorted out and by the end of the cruise we had successfully completed our programme.

Of the 103 explosive shots planned for line A, 99 were fired successfully. (There were 2 misfires.) All 99 were recorded by the PUMA and by 2 SCRAPS on Lewis, and 6 PUSS's each recorded 12 of them. One hundred and twenty airgun shots from a 4000 cu. in. array were recorded by a group of 6 PUSS's at the northern end of line A and by SCRAP 1, and a further 55 shots from a 2000 cu. in. array were recorded on a single hydrophone channel by the PUMA. One hundred and two airgun shots from a 2000 cu. in. array were fired on line B, and these were recorded by SCRAP 1 and by one PUSS. A 140 km long gravity/magnetics/single channel seismic reflection profile was obtained along line A. A summary of the data collected is given in Table 3.

One general conclusion which I draw from our difficulties at the outset of the cruise is that it is unreasonable to expect a research vessel to sail straight out of refit and into scientific work. Many of our early problems were of the post-refit shake-down variety. A short passage leg before the start of scientific work (in our case say from the refit port to Ardrossan) would have given the ship's staff, and especially the engineers, the opportunity to sort out these problems without the pressure of a scientific programme to complete - to say nothing of making life subsequently a little less fraught for the scientists.

Finally, the very respectable measure of success we achieved despite the difficulties was entirely attributable to the energy, enthusiasm and perseverance of everybody on board. I should like to thank Captain Harding and his officers and crew, the R.V.S. team, and Ace Wallace and Doug Spurlock - not only for all their hard work, but also for their cheerfulness and encouragement beyond the call of duty which made Discovery 150 a bearable, and often even enjoyable experience, as well as an ultimately successful cruise.

Table 1

Scientific Personnel, Discover 150

Dr. M.C. Sinha	(P.S.O.)	Cambridge
Dr. P.J. Barton		Cambridge
Mr. T.R.E. Owen		Cambridge
Dr. G. Spence		Cambridge
Dr. A. Goudie		Cambridge
Mr. J.R. Leonard		Cambridge
Mr. P.W. Carter		Cambridge
Ms. C.M.R. Powell		Cambridge
Ms. J.V. Morgan		Cambridge
Mr. R. Wallace		I.O.S.
Mr. D.J. Spurlock	(Shotfirer)	N.E.R.C.
Mr. J. Price	(Shotfirer)	R.V.S.
Mr. K. Smith		R.V.S.
Mr. R. Lee		R.V.S.
Mr. C. Paulson		R.V.S.
Ms. D. Jones		R.V.S.
Mr. P. Mason		R.V.S.
Ms. K. Potter		R.V.S.
Mr. C. Prescot		Durham

Table 2

List of Damage to Cambridge Equipment

1) PUMA

(a) Array to Pressure-Case Connector damaged on 1st deployment

(b) 2 array sections punctured and in need of minor repairs

(c) 3 array sections badly damaged and in need of major repairs and re-skinning

2) Digital OBS

External damage to pressure case on 1st deployment. One end-cap badly damaged and requiring replacement of protective cage and 4 multi-way underwater bulkhead connectors

3) PUSS's

(a) 7 gymbaked geophone sets broken

(b) 2 tape deck mountings broken

(c) 1 hydrophone lost

(d) 6 hydrophones irreparably damaged

(e) 6 endplate protective covers lost

(f) ALL O-ring sealing surfaces on tubes and endplates need re-machining.

4) CIFER Microcomputer

Power supply damaged by mains power failure

Table 3

Summary of Scientific Data Acquired

1) Wide-Angle Seismic Experiment - Line A

(a) 99 Explosive shots of 12.5, 25, 50, 100 and 150 kg fired

99 x 12-channel recordings by PUMA

99 x 1-component recordings by each of SCRAPs 1 & 2

12 x 4-component recordings by each of 6 PUSS's

(b) 120 Airgun Shots (4 000 cu. in gun array)

20 x 4-component recordings by each of 6 PUSS's

120 x 1-component recordings by SCRAP 1.

(c) 55 Airgun Shots (2 000 cu. in gun array)

55 x Single-channel recordings by PUMA

2) Wide-Angle Seismic Experiment - Line B

102 Airgun Shots (2 000 cu. in. gun array)

19 x 4-component recordings by 1 PUSS

102 x 1-component recordings by SCRAP 1

3) Underway Geophysics

140 km of gravity/magnetics/single channel shallow seismic reflection profile along line A

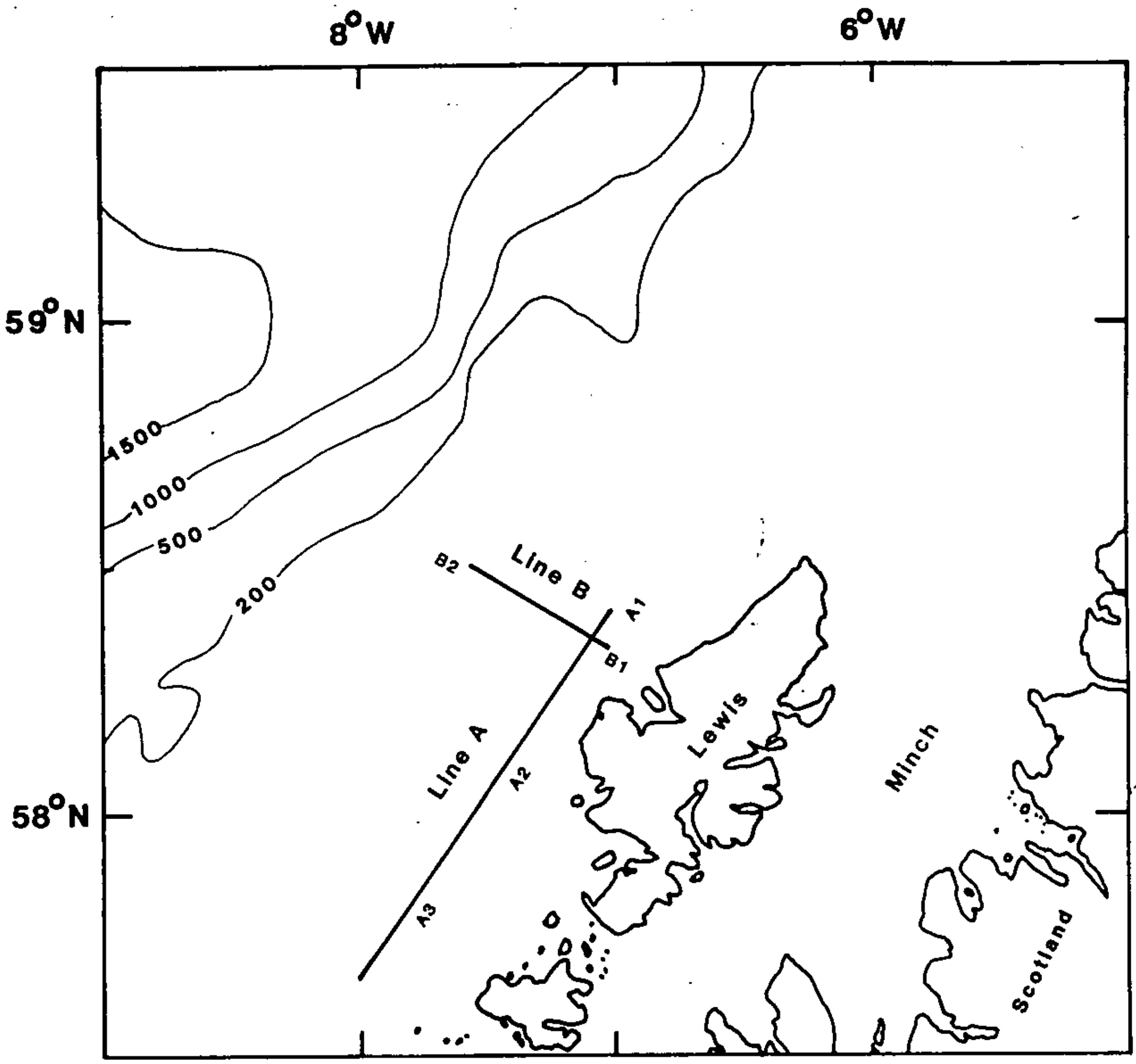

Figure 1. Location map of seismic lines, DISCOVERY 150.

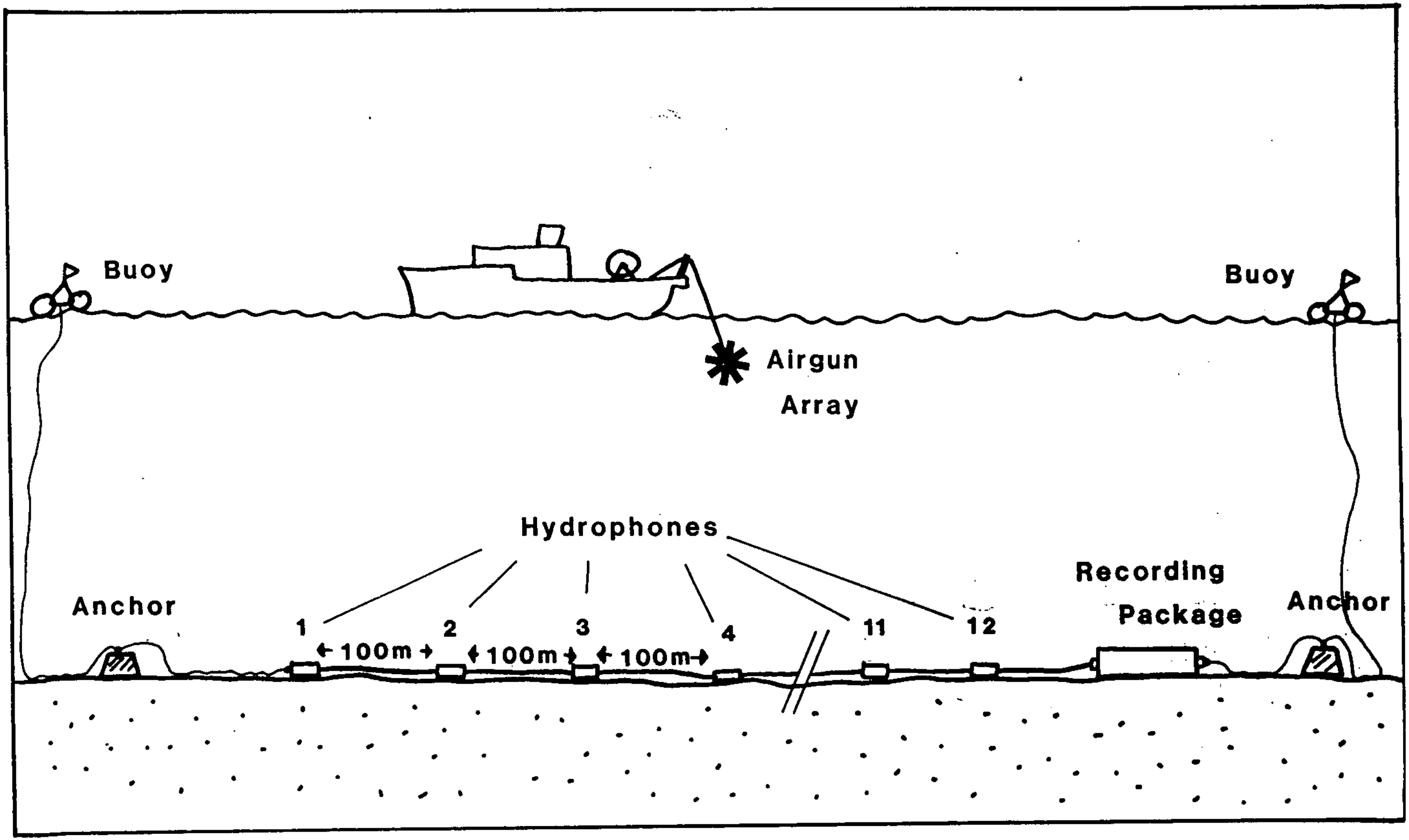

Figure 2. Pull-Up Multichannel Array (PUMA).

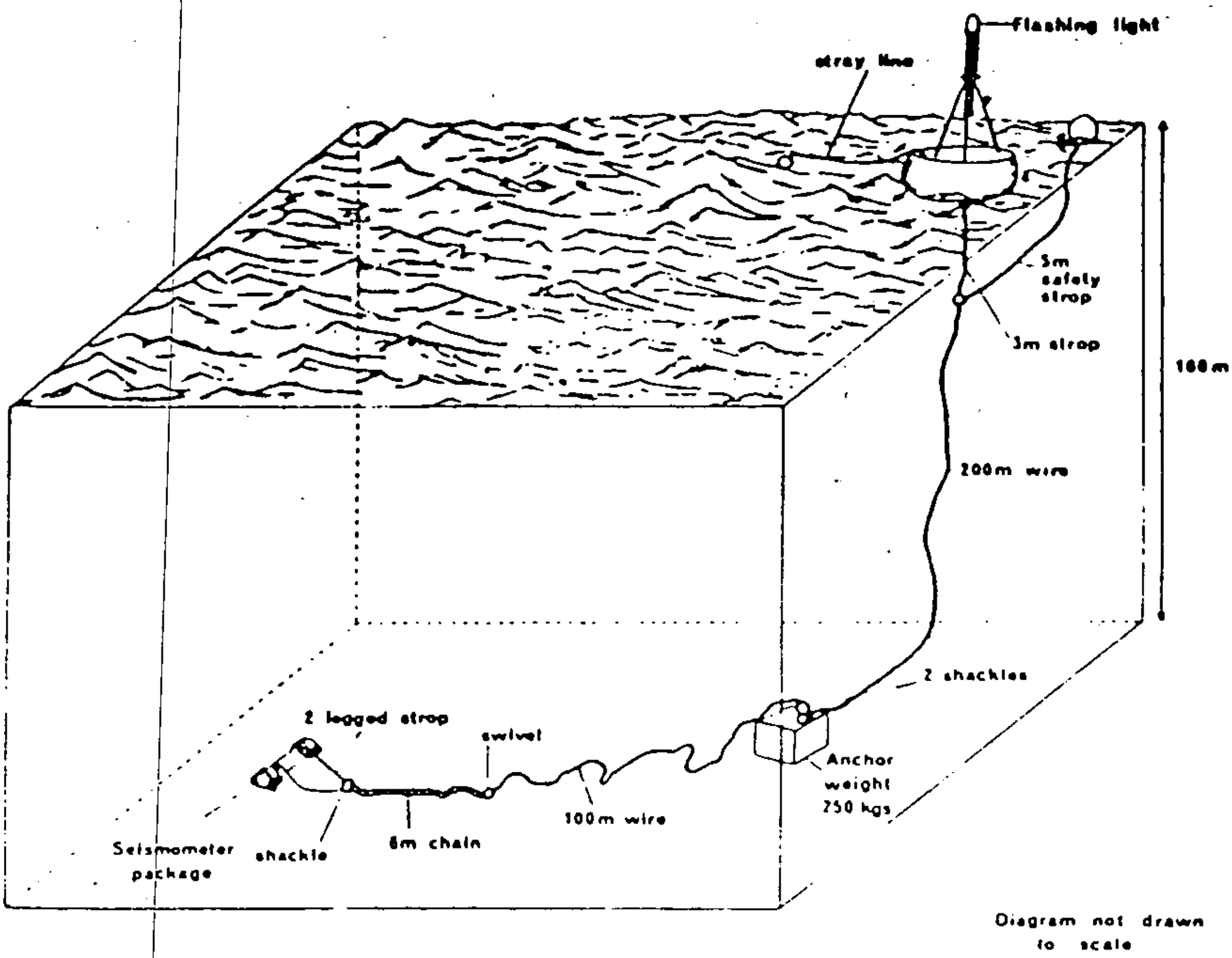

Figure 3 . Pull-Up Shallow-water Seismometer (PUSS).

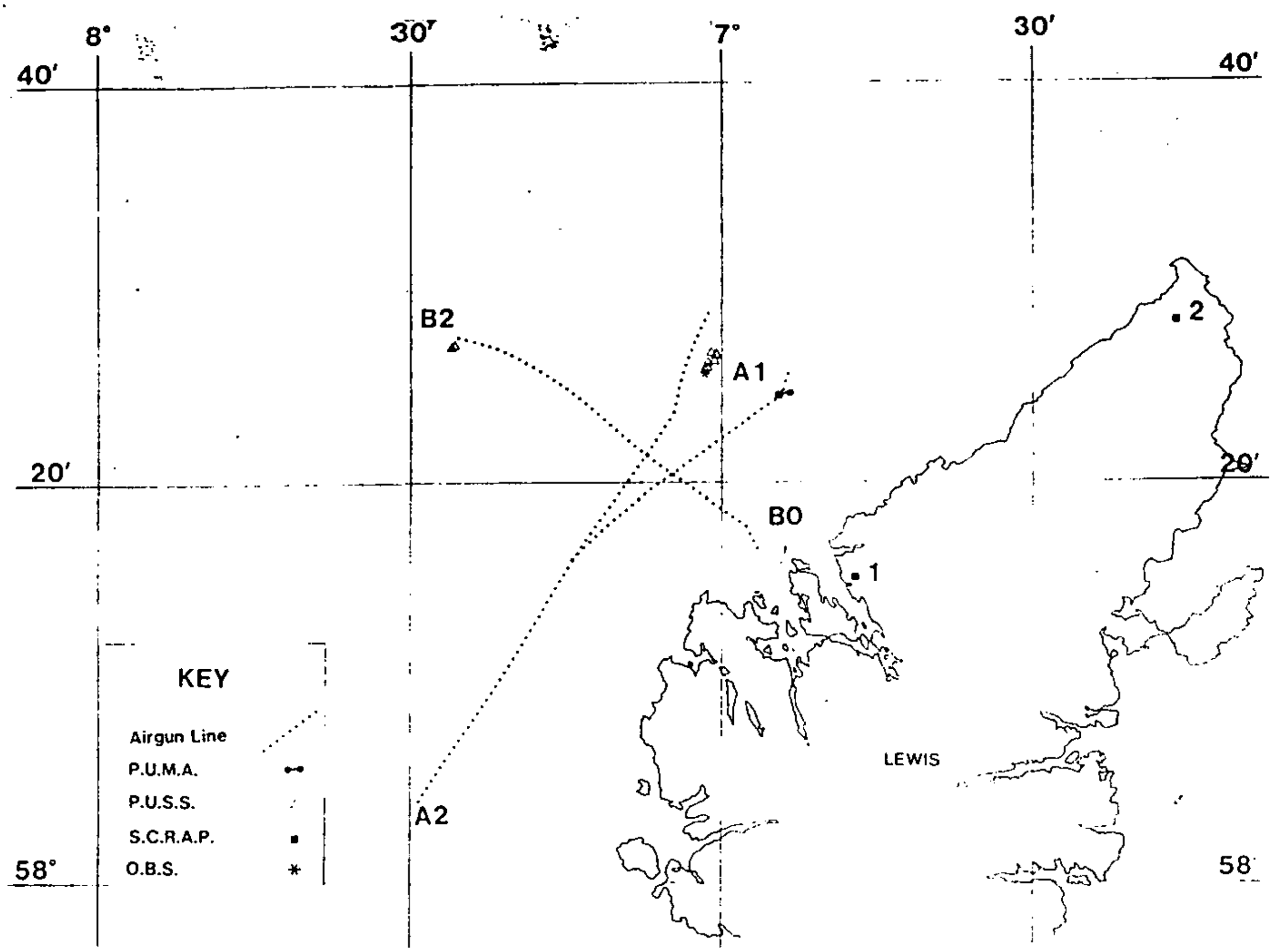

Figure 4. Location map of airgun lines and receivers, DISCOVERY 150.

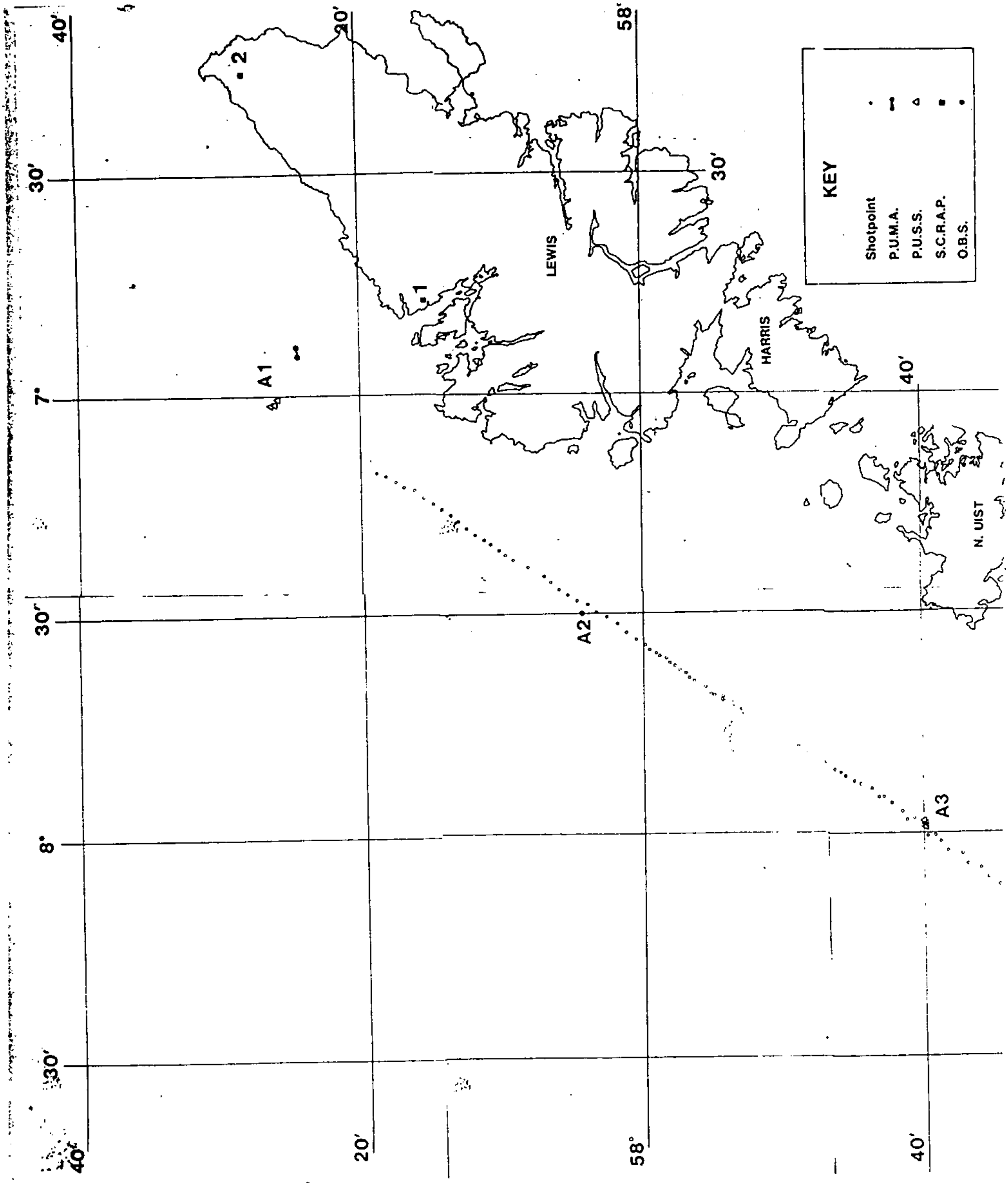

Figure 5(a). Location map of explosive shot-points and receivers, Line A, DISCOVERY 150 (northern part).

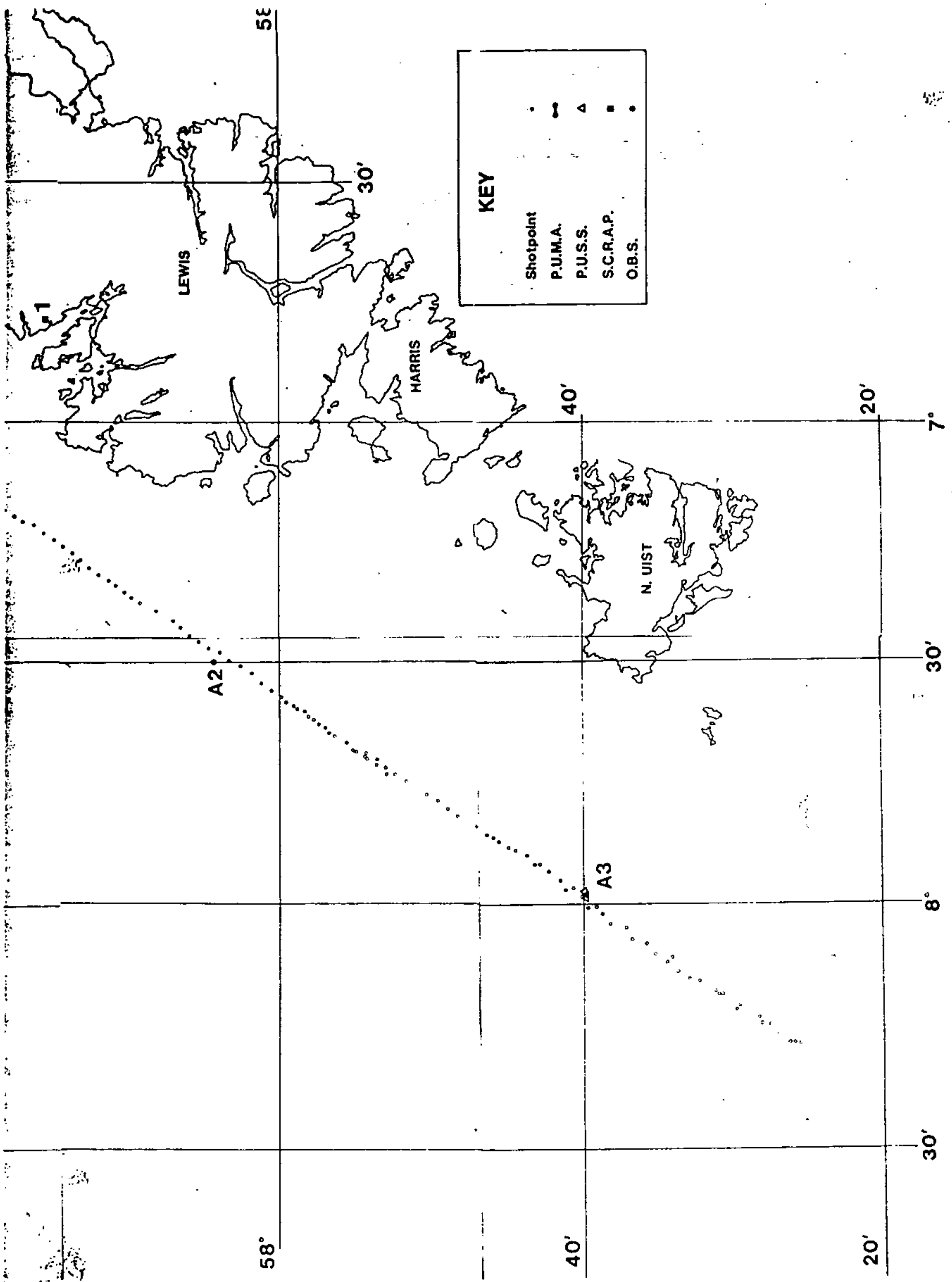

Figure 5(b). Location map of explosive shot-points and receivers, Line A, DISCOVERY 150 (southern part).

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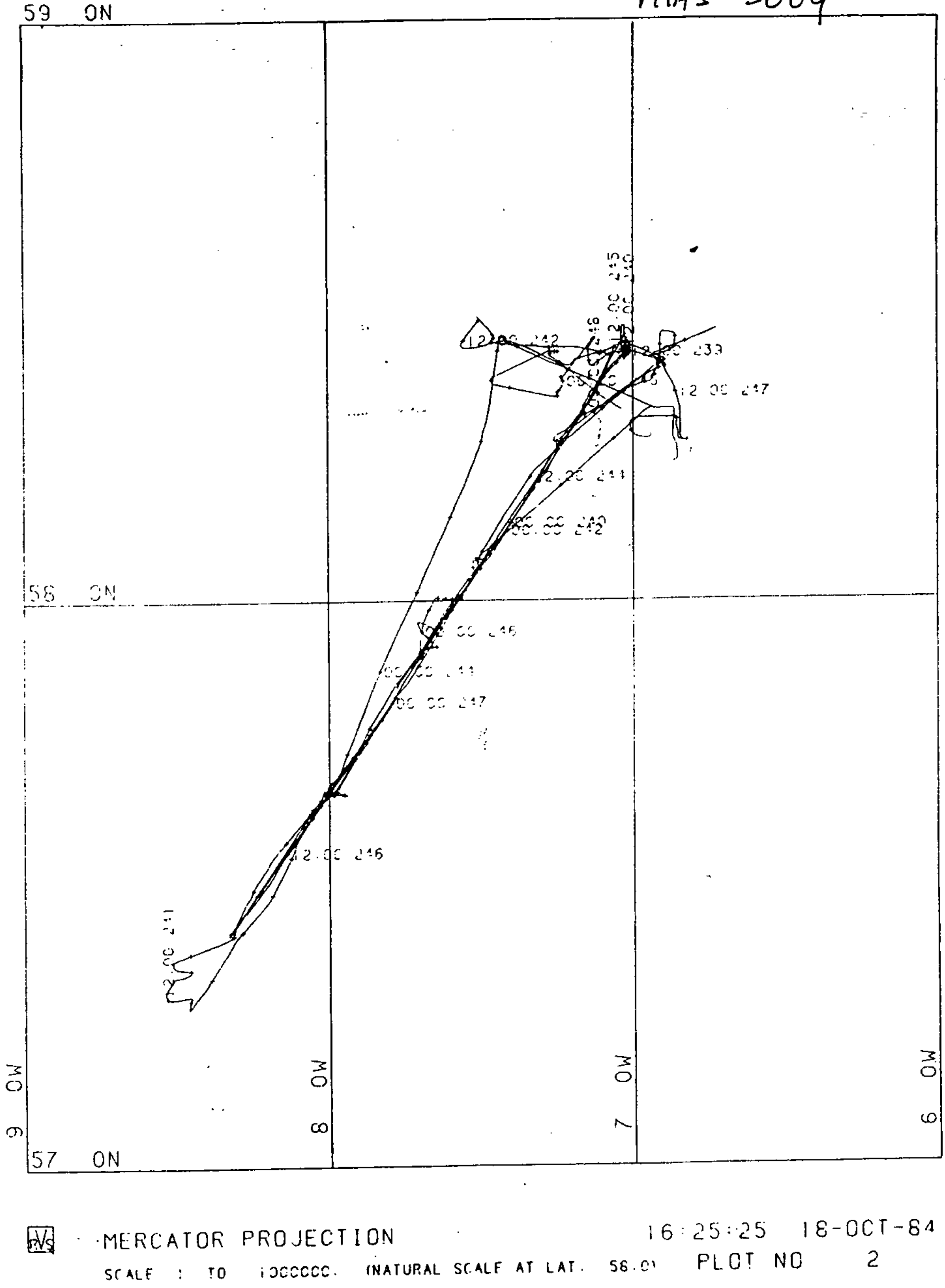

Figure 6. Track Chart, DISCOVERY 150 (by Sat. Nav.).

Ref: P10/150/84

SHOT FIRING : RRS DISCOVERY/CAMBRIDGE : CRUISE 150

This cruise involved using 6325 Kg of Geophex and charge sizes of between 12·5 Kg and 150 Kg. The depth of water was from 90 to 120 metres. The charges were all exploded on the seabed which was hard and rocky and had a very high velocity of propagation in excess of 5 Km/sec. The shock factors expected, using the formulas in the N.E.R.C. Training Manual, are given below:

TABLE

$$S = 0.23 \left(\frac{1 + \sin \alpha}{R} \right) W^{\frac{1}{2}}$$

$$1K = 0.5148 \text{ m/s}$$

Size	Speed	Depth	Fuse Length	R	Shock Factor
12.5 Kg	7K	110m	2 min	446	0.0023
50 Kg	7	110m	2 min	446	0.0045
100 Kg	10	110m	2 min	618	0.0044
150 Kg	10	120m	2 min	618	0.0054

Speeds were increased to 10K for the smaller charges and about 11.5K for larger. Fuse lengths increased to 2m 7 sec.

Size	Speed	Depth	Fuse Length	R	Shock Factor
12.5 Kg	10	110m	127 sec	662	0.0014
50 Kg	10	110m	127 sec	662	0.0029
100 Kg	11.5	110	127 sec	760	0.003
150 Kg	11.5	120	127 sec	762	0.0042

It was impossible to reduce the shock factors below these values because of the length of safety fuse supplied.

As can be seen the calculated shock factors are well below the 0.01 limit used in previous experiments. However, the effect on the ship was disproportionate and when firing the 12.5 Kg charges the main engine failed on several occasions - an excitation relay bounced causing the system to shut down. The shock factors were reduced by modification to the program, and a speed increase, also lengthening the burn time to 2 min 10 sec.
The effect of the charges varied depending on the slope of the bottom and discussions after the run indicated that the formula should be modified

in shallow water on high velocity rocks. It is probable that a wave guide effect is directing more energy to the ship than anticipated.

All the effects on the ship are at present qualitative and depend very much on the observer. It would seem to be possible to measure the effect of the shot using accelerometers and enable a quantitive assessment of the shot factor to be made. This would enable us to refine our calculations and also ensure that where unusual propagation conditions are encountered, the charges may be fired sufficiently far enough away from the ship to cause no difficulty.

On this experiment the maximum length of fuse was 2m. These had a tolerance of $\pm$ 2.5 cm which meant that some fuses were slightly short, after trimming the end (The end is usually damaged and it is recommended that about 10 cm is removed). In future the fuses should be purchased so that they are at least 10-15 cm longer than the longest expected fuse length or enough detonators and a roll of safety fuse be provided so that the shot firer might make his own fuses, using the bench crimper.

During this experiment two shots failed to detonate for no known reason. It should be recommended that ALL charges except the small single stick ones should be double fused for extra safety, especially in shallow water as the time taken for the charge to break up is unknown.

The new bulk packed explosives are easier to use and band than the earlier tubes and there is no chance of lumps of geophex being left on the deck. They are also cheaper than the older types.

The cruise proved successful and initial results from the PUSSES,DOBS and ground stations have been encouraging.

JP/ME
6th Sept.1984.