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UNIVERSITY of CAMBRIDGE

Department of Earth Sciences

Cruise Report

R. R. S. Charles Darwin

11 / 86

CRUISE REPORT

R.R.S. CHARLES DARWIN

11 / 86

Cambridge / I.O.S.

Barry to Falmouth

3 to 28 April 1986

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M. C. Sinha

1. Objectives

The objective of this cruise was to shoot two detailed seismic experiments in the northeast Atlantic, to investigate seismic anisotropy, anelastic attenuation and sub-basement reflectors in the oceanic crust.

The experiments were planned to take place at two sites. Site 1, located on young (<3 Ma) crust, is on the eastern flank of the mid-Atlantic ridge just south of Kurchatov fracture zone, centred on 40°15'N, 29°05'W. Site 2 is on older (~62 Ma), sedimented crust north of the Azores-Biscay rise, centred on 44°40'N, 17°45'W (Figure 1).

The plan at each site was to lay an array of 10 ocean-bottom seismometers (OBS) made up of 3 Cambridge digital, 3 Cambridge analogue and 4 IOS Wormley digital instruments. Measurements of anisotropy and attenuation would then be made by shooting large numbers of shots along a series of straight line and intersecting circular tracks, using a powerful airgun array and some small (6.25 kg) explosive charges. The seismic reflection properties of the crust were to be investigated by detailed surveys using the Cambridge Deep Tow profiling system. A conventional, single-channel, surface seismic reflection survey was also planned for site 2, to measure the variations in sediment thickness beneath the receivers and at the ray entry points beneath the shooting tracks. This information is needed to correct the observed seismic travel times for sea bed and basement topography before anisotropy can be detected.

2. Cruise Narrative

(N. B. - all times expressed in G.M.T.)

2.1 Mobilisation

Mobilisation for the cruise took place at RVS, Barry between Friday 28th March (Good Friday) and Thursday 3rd April. 1000 kg of Geophex explosives and 170 detonators were loaded at 1000 3/4/86, immediately prior to the planned time of sailing. At this point though, faults became apparent on one of the seismic compressors and on the overspeed trip of the port diesel alternator. It was essential to repair both of these items bfore leaving Barry, so sailing was delayed for several hours while the compressor was repaired and a spare part for the alternator was obtained and fitted.

We eventually sailed at 2230 3/4/86. Immediately afterwards some time was spent testing the ship's autopilot, which had been modified since the previous cruise. On completion the autopilot engineer returned to Barry on the pilot boat, and in the early hours of 4/4/86 the ship set course for the work area.

2.2 Passage leg to Site 1

The first science of the cruise was carried out between 0330 and 0800 5/4/86, when we recorded a bathymetric profile across the Celtic shelf continental margin between 48°N, 10°W and 47°30'N, 11°W for Peter Hunter of IOS Wormley.

Later on the morning of 5/4/86 the Chief Officer discovered that the humidity indicators on seven of our ten disposable sonobuoys had turned pink, indicating moisture in the packages. The safety instructions from the manufacturers and RVS are quite explicit that sonobuoys in this condition are potentially dangerous. (They are designed to fire a compressed gas charge, blowing off the top end covers with considerable force and inflating the aerial assembly as soon as they come into contact with sea water.) Reluctantly we were obliged to ditch the seven suspect sonobuoys, leaving only three for use in the seismic reflection survey of Site 2.

Our first objective after completing the continental margin profile was to obtain a single channel seismic reflection profile across the Site 2 area, to fill in a gap in the existing coverage and to allow us to pick the most suitable site for the old crust OBS experiment. This could be done conveniently whilst on passage to Site 1 (where we planned to shoot the first OBS experiment) since it involved only a small deviation of course.

The ship arrived at the northeastern corner of the Site 2 work area (44°45'N, 17°35'W) at 0820 6/4/86 after making good time from Barry in fine weather. While deploying the PES fish, some of the clips on its tow cable fairing were broken, so we were forced to recover it and rely on the hull transducer (which in the event worked very well). We then streamed a single airgun with 300 cu. in. chamber and wave shape kit, single-channel hydrophone streamer, magnetometer bottle and the fish for the IOS 3.5 kHz profiler. A fault on the fourth stage of one of the seimic compressors delayed the start of airgunning for a time, but by 1200 all equipment was working and we started the first reconnaissance survey across the Site 2 area. The profile first ran southwest to 44°33'N, 18°W, and then turned due west to 19°W where we arrived at 0200 7/4/86 (Figure 6).

On completion of the profile we recovered the airgun and hydrophone streamer before continuing on passage to Site 1. The PES, 3.5 kHz profiler and magnetometer were kept running for the passage leg between sites 1 and 2. Overnight 7-8/4/86 we were forced to reduce speed by southwesterly winds of up to force 7, but by midday 8/4/86 the weather was improving again. At 1830 8/4/86 we deployed the PES fish with its cable fairing repaired, and at 0200 9/4/86 we arrived at the northeastern corner of the Site 1 work area.

2.3 Seismic Experiment Site 1

Before our arrival at Site 1 we had selected a location for the OBS experiment on 3 Ma old crust, on the eastern flank of the MAR some 40 km south of Kurchatov fracture zone. The location was chosen on the basis of existing bathymetric data, which indicated relatively subdued sea bottom topography, and GLORIA sonographs which showed a great many continuous reflectors parallel to the nearby ridge axis - confirming that there are no fracture zones running through the area. To confirm Roger Searle's contouring of the bathymetry and to allow us to select suitable sites for the OBSs we began a 3.5 kHz, PES and magnetometer survey of the area immediately on arrival. The tracks of this initial survey are shown in Figure 2. We finished the survey at 0830 9/4/86.

Our next task was to wire test the two IOS 5 kHz acoustic transponder beacons which we planned to use for navigating the seismic experiment. Unfortunately the shipboard end of the acoustic navigation system, a 5 kHz transducer mounted in a PES fish, leaked as soon as it entered the water. While it was being recovered and repaired, we lowered the two transponder beacons together with a sound velocity meter on the CTD wire to 1700 m. While doing so we obtained a sound velocity profile and at the same time recorded an XBT profile to 800 m.

The problem with the 5 kHz fish turned out to be that the transducer base plate had not been sealed properly before it left IOS - the bolts were only done up finger tight. By the time it was repaired and deployed again, the CTD winch was giving problems because the spooling gear was out of alignment. At the same time a relief valve in the hydraulic power pack for the winch started to leak. By the time hydraulic power was restored and the spooling gear realigned, the velocity meter and beacons on the end of the CTD wire had come perilously close to the bottom as the ship drifted slowly.

With the winch and 5 kHz fish working we were at last able to test the two transponder beacons. Only one of them appeared to be working, so we recovered the wire, velocity meter and both beacons and headed to the site for the first beacon deployment. During the pause while the first beacon was rerigged ready for launching, we successfully wire tested one of the two brand new Cambridge digital OBSs, to check its flotation. The first acoustic beacon was finally deployed at position B1 (Figure 3) at 2100 9/4/86, almost twelve hours after the start of wire testing.

We next deployed the first OBS, a Cambridge digital instrument (CDOBS 9) at position R7, finishing just before midnight. Soon afterwards the repairs to the second acoustic beacon were completed. The beacon was wire tested again, this time satisfactorily, and shortly afterwards it was deployed at position B2. A series of tracks crossing the baseline between the transponders, to determine accurately the baseline length, took from 0330 to 0520 10/4/86, and at 0608 the next OBS (CAOBS 2) was deployed at position R3.

CAOBS 2 reached the bottom safely at 0628. The first of the IOS instruments (WDOBS 1) was then prepared on deck for deployment at the same site. Just before the Wormley DOBS was launched, the Cambridge analogue OBS unexpectedly reappeared at the surface about 200 m astern of the ship. We finished launching the Wormley DOBS, and while it was sinking to the bottom we picked up the errant analogue instrument. We found that one of its pyros had parted prematurely, releasing the bottom weight soon after the OBS reached the bottom. None of the pyros supplied by either RVS or IOS had been pinned (a precaution which RVS have adopted routinely in recent years to prevent exactly this problem), so a batch of pyros were pinned immediately for use in the remaining OBS deployments.

At 0900 we deployed Cambridge DOBS 11 at position R1, followed by CDOBS 10 at R2; WDOBS 2 and CAOBS 2 (deployed for the second time) at R4; WDOBS 3 at R5; CAOBS 1 at R6; CAOBS 4 at R3 (replacing CAOBS 2 which had popped up early); and finally WDOBS 4 at R6.

At 1800, we rerigged the 3.5 kHz fish (which we were towing from the side A frame and so had to recover during OBS work), and began preparations for streaming the five airgun array. By 0100 11/4/86, all five guns (fitted with 160, 300, 466, 700 and 1000 cu. in. chambers) were in the water and firing. Adjusting the towing cables and airgun delays to get all the guns firing simultaneously and at the same depth (15 m) took a further hour, and at 0206 the first properly synchronized shot was fired.

Airgun shotfiring continued uninterrupted for most of the day. The shot repetition rate was two minutes, at a speed of 4.5 knots, giving an average shot spacing of 270 m. The first track to be completed was an approximate circle of radius 5 km centred on R3 (circle B) (Figure 4). This was followed by a rough semi-circle, again at 5 km radius, to the north and east of R2 (circle A); another circle around R6 (circle C); and then the other half of circle A. Finally we ran two approximately straight line tracks across the site, the first running from NW to SE through R2, R4 and R7 (line X), and the second running from S to N through R6, R4 and R1 (line Z).

By the time we had completed line Z (2130 11/4/86), the weather had been deteriorating steadily for three hours as a small depression moved slowly past us to the south. We altered course eastwards in the hope of being able to shoot the last airgun line, line Y, from NE to SW through R3, R4 and R5. However over the next hour and a half the weather deteriorated very rapidly and at 2302 we were forced to abandon airgunning and heave to in a northeasterly gale, which soon reached force 9 gusting to force 10. The sea state had by now reached a point where recovery of the airguns would have been dangerous, so we left them out while we waited, hove to, for the weather to moderate.

The next day (12/5/86) proved to be an extremely frustrating one. We had planned to fire eighty 6.25 kg explosive shots around the three circles that afternoon, and all the OBSs were programmed to switch on and record them. Although by 0800 the weather had moderated from 50 to 30 knots, the sea was still much too rough for shotfiring. At 0830 we turned downwind and returned to the work area, and at 0930 we hove to again and were able to recover the airguns. By 1400, when shotfiring was due to start, there had been no further improvement. The wind continued at a steady 30 knots from the NE, with a considerable sea running, all afternoon and evening. As a result the day's shotfiring programme was a total loss.

By first light the next day (13/4/86), the weather had improved slightly. At 0600 we headed back to the work area again. By this time all the OBS's had run their tapes, so there was no point in shot firing. Instead we set about popping up the OBSs, starting at 0825 with WDOBS 1. OBS recovery went smoothly throughout the forenoon and afternoon, during which time we successfully recovered all three Cambridge analogue instruments and three of the four Wormley DOBSs. At 1730 we attempted to release the last Wormley instrument, WDOBS 3. Despite responding correctly to the acoustic release signal, this OBS refused to leave the bottom. The Wormley instruments are fitted with back-up timed releases, and WDOBS 3's timer was set to release at 2100, so at 1800 we left it for the time being and steamed instead to the acoustic transponder beacon at B1.

The acoustic beacon at B1 initially seemed reluctant to release; but at 1914, after we had been transmitting the release signal for 35 minutes, our patience was rewarded and it finally left the bottom. After picking up the beacon we returned to R5 in the hope that the WDOBS would pop up on its timer at 2100. Unfortunately it did not, and further attempts to release it acoustically also failed. At 2210 we reluctantly decided to abandon it. The reason for its failure to release is unclear. One possibility is that both its pyro-releases, which had been drilled and pinned rather hurriedly before we deployed it, had flooded.

At 2300 13/4/86 the first of the Cambridge digital instruments (CDOBS 9) was released. It reached the surface at about 2330, but all attempts to spot it failed. The reason, as we subsequently discovered, was that it had lost its flashing light. To make matters worse its pinger had only been working intermittently since it left the bottom. We started a low speed search for it, guided by the trace of its pinger on the PES record. Fortunately the night was fine and clear, with some moonlight, and soon after the OBS surfaced its pinger started working more consistently. The OBS was finally spotted from the bridge wing with an Aldis lamp, and we were able to recover it at 0030 14/4/86.

The other two CDOBSs were recovered without difficulty, and at 0500 we returned to R5 for a final attempt to pop up

WDOBS 3. This failed so we headed instead to B2 where we recovered the remaining acoustic beacon at first light.

After recovery of the OBSs, we discovered that only six out of the nine had recorded any data. None of the tapes in any of the Cambridge analogue OBSs had run, due to a software bug in the microprocessors which control the recording windows. All three Cambridge DOBSs had recorded good three-component geophone data, and one had also recorded good hydrophone data. Two of the Wormley DOBSs had recorded good three-component geophone and hydrophone data from all the shots, while the third had recorded all of the early shots but had missed most of the later ones, probably due to a fault in the tape controller. OBS performance is discussed further in Section 3.

2.3 Deep Tow Profile, Site 1

Work on deploying the deep tow began at 0830 14/4/86. This was the deep tow's first deployment from Charles Darwin, and also its first use in conjunction with the new 13.5 mm conducting cable. The first item to be streamed was a 160 cu. in. airgun, which we towed astern of the ship suspended by a 12 m rope strop from an A3 buoy. It was followed by the deep tow itself, which we deployed using the main winch and after A frame and the Hiab Sea-Crane. (We did not use the Heat Flow railway and platform, and in the event managed perfectly well without it.) The deep tow was used with its longer (30 metre) hydrophone streamer.

By 1210 the deep tow was in the water and had been lowered to a depth of 500 m. We then streamed two more airguns, fitted with 300 and 466 cu. in chambers and rigged in the same way as the 160 cu. in gun. By 1430 all three guns were synchronised and firing, and we were successfully recording data from both the 3.5 kHz and hydrophone channels of the deep tow. By this time though we had overshot the starting point of the profile, so we started a slow, 270° turn at 3 knots which took us until 1730. At 1750 we reduced speed to 2 knots and began lowering the deep tow to the bottom.

The deep tow profile across site 1 began at 1800 (Figure 5). At 1845 the deep tow arrived within 300 m of the bottom. The profile continued with all systems working well, and at 2240 we completed a traverse across the Site 1 survey area. We then continued profiling westwards towards the axis of the mid-Atlantic ridge, finishing at 0200 15/4/86 close to the eastern summit above the median valley wall. The deep tow and airguns were recovered by 0414, concluding our work at Site 1. We then set course at full speed towards Site 2.

2.4 OBS Experiment, Site 2

We selected the final location for the OBS experiment at Site 2 on the basis of the seismic reflection profile which we had run on the outward leg to Site 1, combined with other data previously collected by IOS. However before starting the OBS deployments we were anxious to make sure that an area of relatively subdued basement topography that we had selected was both unbroken by steep, isolated features that we had missed on on the previous lines, and large enough to fit the entire OBS experiment into. We therefore planned a second reconnaissance SRP survey of the site, to be completed before starting the OBS work.

The ship arrived at Site 2 at 1220 17/4/86. As before our first task was to make a sound velocity meter profile and to wire test the acoustic navigation beacons. As before we ran the sound velocity profile and beacon wire test simultaneously on the CTD wire as soon as we arrived at the site, and took an XBT profile to coincide with the velocity dip. One of the beacons failed shortly after entering the water, so we recovered it and continued the dip with only one beacon. This worked correctly, so we recovered the wire, reattached the other beacon (which had been repaired in the meantime), and repeated the test. This time the second beacon worked. During the wire tests, we again had problems with the CTD winch, including recurrences of the spooling gear misalignment and loss of hydraulic pressure due to the leaking bypass valve.

At 1830 we were able to start putting out the single-channel hydrophone streamer, followed by two airguns, each fitted with a 300 cu. in. chamber and wave shape kit. At 2000 we started the reconnaissance SRP survey, which we finished at 0645 18/4/86 (Figure 6).

The survey tracks confirmed that the site was suitable for the experiment, and allowed us to pick the best positions for the OBSs. After recovering the airguns and hydrophone streamer we headed for the location of the first beacon (B2, Figure 7), which we laid at 0852. The second beacon (B1) was laid just after 1030, and by 1300 we had measured the length of the beacon baseline. Soon after this we laid the first OBS (CDOBS 11) at R3, followed by WDOBS 4 at R7, CDOBS 10 at R6, CAOBS 1 and WDOBS 2 at R4, CDOBS 9 at R1, WDOBS 1 and CAOBS 2 at R2, and finally CAOBS 4 which reached the bottom at R5 at 0312 19/4/86.

One disturbing incident that happened while we were laying the OBSs was a wave that broke over the rail and through the gap in the rail under the starboard A frame during the afternoon. The wave flooded the deck while a Cambridge DOBS was being prepared for its launch. Both people working on the OBS at the time (Penny Barton and Peter Carter) were knocked off their feet, bruised and soaked. The OBS on its frame was knocked over and swept across the deck, parting one of the geophone cables at its connection to the OBS junction box. This happened in very moderate weather while the ship was steaming at 8 knots between OBS sites. As a result we were forced to abandon the practise of preparing OBSs for launch on deck, even in the prevailing fine weather, except when the ship was hove to on station.

At Site 2 we programmed the OBSs to record the explosive shots before the airgun shots. The first explosive shot window was timed for 1400 19/4/86. We initially planned to use suspended charges, attached by 50 m lengths of polypropylene twine to 5 litre bottles (which were punctured at both ends to ensure that they sank after a few minutes). The reason for this was to ensure that all shots went off at precisely the same depth. However by late morning a fresh breeze was blowing and when at 1346 we tried a test shot (without a detonator) using this arrangement we discovered that the 50 m length of twine could not be handled easily or safely with the ship steaming downwind. We therefore abandoned the idea of using suspended charges. At 1350 we successfully fired an unbuoyed test shot with a detonator, and at 1400 we commenced the explosive shot firing programme. A list of shot times is given in Table 2.

Experience at Site 1 had shown that, even with acoustic navigation, it is extremely difficult to steam accurate circular tracks. At Site 2 the explosive shots were scheduled to be fired at 10 knots, and at this speed the acoustic navigation receiver tended to be saturated by towing and propellor noise. We therefore planned the shooting tracks as hexagons (with mean radii of 7 km) centred on three of the OBS positions, rather than circles.

We started the shot firing heading clockwise around hexagon B, starting at its northwest corner (Figure 8). Shot firing went well until 1625, when we started the last leg of hexagon B, along its northen segment. On this course the fresh westerly wind and resulting sea made it impossible to maintain a safe speed for shotfiring. Shooting was suspended temporarily while we made our way to windward, and at 1710 we retarted shooting at the northeast corner of hexagon A, heading anticlockwise. We broke off again at 1830 for a meal break for the shotfirers, and restarted at 1935 at the southwestern corner of hexagon C. This last session took us anticlockwise around the outside of the pattern, back to the northeastern corner of hexagon B.

At 2300 we started streaming the airgun array. At 0400 20/4/86 we started airgun shotfiring, again using an array consisting of 160, 300, 466, 700 and 1000 cu. in airguns towed at a depth of 15 m. Shots were fired every three minutes at a speed of 5 knots, giving an average shot spacing of 450 m. Our airgun shooting track (Figure 9) took us first around hexagon C, then hexagon B. The next track was a straight line from SE to NW through R7, R4 and R2 (line X). During the turn onto this line we reduced speed and brought the 1000 cu. in gun, which had developed a leak, back inboard for repairs. At the same time we had to shut down one of the seismic compressors because of a problem with the electrical junction box on its drive motor. Fortunately the other compressor was able to maintain a three minute firing rate on its own. The 1000 cu. in gun was redeployed after repairs and line X was shot using all five guns.

After line X we began shooting the last hexagon (A). However by the time we had completed the second side, at 2106 20/4/86, the wind speed had reached 30 knots from the WSW and was increasing steadily. We started the third leg of hexagon A, heading southwest, but by 2200 it was clear that the weather was continuing to deteriorate. At 2212 we switched off the airguns and hove to to recover them. The guns were safely inboard by 2320, but not before a large wave had flooded the after deck, knocking over three of the people working there and tearing Vic Caruana's watch off his wrist and over the side. A few minutes later, as the working party returned to the main lab after securing the equipment on the after deck, Kevin Smith had a lucky escape when the after lab watertight door swung shut violently and just missed crushing his arm.

For the next two days (21-22/4/86) all work was prevented by continuing bad weather. The wind stayed at a steady 30 to 35 knots from just north of west as a large depression slowly passed us to the north. We were obliged to remain hove to and wait for an improvement.

By the morning of 23/4/86 the wind and sea had at last improved sufficiently to allow us to restart scientific work. At 0640 we turned downwind to head back to the work area, and at 0714 we popped up the first OBS. All nine instruments were then recovered without incident, finishing at 0200 24/4/86. All of the Cambridge digital OBSs had again worked well, this time all three recording hydrophone as well as three-component geophone data. Two out of the three Cambrige analogue instruments had also worked well, as had two of the three Wormley DOBSs. The last WDOBS had again recorded the early shots, but had missed some of the later airgun shots.

Our final task at Site 2 was to shoot a detailed single-channel seismic reflection survey of the work area, and in particular of the OBS positions and the ray entry points for all the explosive and airgun shots. Between 0245 and 0400 24/4/86 we streamed the single channel hydrophone array, two airguns each with 300 cu. in chambers and wave shape kits, and a magnetometer sensor bottle. We started the Site 2 detailed SRP survey (Figure 10) at 0410, and finished it at 1510 25/4/86. During this time we used all three of our remaining disposable sonobuoys. All three worked, and two provided excellent wide angle records. Between 1940 and 2030 24/4/86 we were forced to shut down one compressor because of a leaking fourth stage valve, which meant that for that period we could fire only one gun, but otherwise we had no problems during the survey.

After recovering the profiling equipment, we popped up the two acoustic navigation transponder beacons. While the second one was coming to the surface, we ditched all but three sticks of the remaining explosives that we had been unable to use. The second beacon was safely inboard by 1930, and we then recovered the 5 kHz and PES fish. At 1944 25/4/86 we finished scientific work at Site 2 and and set course for Falmouth.

At 0947 26/4/86 we used the last three sticks of Geophex to destroy the empty plastic packaging left over from the explosives. The ship docked in Falmouth at 0900 Z 28/4/86.

3. Equipment Performance

3.1 Cambridge Equipment

Three major items of Cambridge equipment were used on this cruise - the analogue OBSs, the new digital OBSs and the deep-tow seismic profiler.

3.1.1 Cambridge Analogue OBSs

Three of our four analogue OBSs were refurbished and modified between their last use (R/V Bannock in the western Mediterranean, summer 1985) and this cruise. The modifications involved the replacement and upgrading of the power supplies, partial rewiring of the back-planes and modifications to the battery pack mountings. The three modified OBSs were successfully tested in Cambridge before the cruise, and were shown to have substantially better noise characteristics with the new power supplies.

Another modification to the OBS system which was adopted for both the analogue and digital systems was the use of a new design of bottom weight assembly, made from mild steel and incorporating the geophone deployment arm as an integral part of the bottom weight.

At Site 1 all three analogue OBSs were deployed with geophone packages and the new bottom weights. The new arrangement appeared to work well, and certainly made deployment much easier and quicker than with previous systems. The balance point of the bottom weight assembly needed modifying, though, to make the arrangement more stable during deployment.

A much more serious problem at Site 1 was that none of the analogue OBSs ran their tapes. This was due to a bug in the software for the microprocessors which control the AOBSs' recording windows. The effect of the bug was to prevent the software clock from incrementing the day number correctly from 099 to 100. Since the OBSs were reset on day 099, and the first shot window was on day 101, this prevented the OBS tapes from turning on at all. This bug was completely unexpected, as the same microprocessor system has been used successfully on two previous cruises and in innumerable tests in the lab, although never over those particular day numbers. The implication is clear - software as well as hardware needs even more rigorous testing that we have applied in the past, to ensure that programs function properly under all possible combinations of circumstances.

The AOBSs were more successful at Site 2. Here one of the three again failed to record any data, this time because of a short-circuit on the tape head driver board that flattened the tape batteries. However both the other instruments worked well, one recording all four tapes and the other recording three out of four. The quality of the seismic data recorded by these two instruments is excellent.

Given the success of our digital OBSs on this cruise (see below) we have no plans to use the analogue OBSs in the future.

3.1.2 Cambridge Digital OBSs

Three new digital OBSs (CDOBS 9, 10 and 11) were built for this cruise, based largely on the successful prototype DOBS design used on Charles Darwin (cruise 4/85) and R/V Bannock in summer 1985, but making use of the new, larger diameter pressure cases. The instruments were all fitted with four digital cassette recorders giving about 25 Mbytes of data storage. The same design of geophone package and bottom weight assembly was used as for the analogue OBSs.

At Site 1 all three instruments recorded good, three component geophone data. However only one (CDOBS 9) recorded good first arrivals on the hydrophone channel. This was because a modification to the software accidentally overwrote some of the memory locations containing time constant parameters for the automatic gain ranging system. This bug was rectified by the time the instruments were used at Site 2, where all three instruments recorded excellent hydrophone, as well as three component geophone, data.

The only problem with the DOBS data is that when one particular gain range step occurs, the gain ranging amplifier applies a significant DC offset to the signal. Since these amplifiers are AC coupled to the next stage, the DC offset then decays away with the time constant of the coupling. The resulting steps in the record occur soon after the first arrival on most seismic traces recorded at both sites. Removing these steps from the data should be relatively straightforward, although given the quantity of data involved and the fact that the amplitude of the step is different on each trace, this part of the processing is likely to prove somewhat tedious and time consuming. The design of the gain ranging amplifiers is currently being modified to prevent a recurrence of this problem.

The geophone data recorded by the DOBSs at Site 1 show a curious difference in frequency content between the two horizontal geophone channels. At Site 1 the geophone packages were deployed on their sides, with the axis of the cylindrical pressure case horizontal. On all records that we have played back, the geophone component parallel to the cylinder axis has a dominant frequency almost twice that of the component normal to it. This is probably due to a difference in coupling between the pressure case and the sea bed in the two directions, as the pressure case is relatively free to roll from side to side. At Site 2, the geophone packages for both analogue and digital instruments were deployed so that they landed on their bottom endplates, and hopefully ended up standing vertically on the sea bed. This appears to have made the coupling of the horizontal components much more even, as the frequency content of the Site 2 data appears to be similar for both horizontal channels on all instruments.

At Site 2 all three digital OBSs were deployed with one pyro-release and one gas retractor. The retractors fitted into the mechanical release arrangement without difficulty, and during recovery all three pyros and all three retractors fired. A small modification of the fixing point for the geophone cable junction box is necessary (and is planned) to allow two retractors to be used on a DOBS. Apart from this, the experience on this cruise shows that retractors are a perfectly acceptable alternative to pyros. This should help to decrease the instrument's deployment costs.

After recovery of the DOBSs we found that in some cases the signal cables from the disposable geophone package had not been cut cleanly. Almost certainly the reason for this is that insufficient slack had been left between the cable junction box and the cable cutter. In future great care should be taken to ensure that a sufficient length of cable is left free above the cable cutter so that it can work effectively.

3.1.3 Deep Tow Seismic Profiler

The one deployment of the deep tow profiler made on this cruise was a complete success. Both the 3.5 kHz near bottom echo sounder and the deep towed SRP hydrophone streamer systems worked well. The monitor records show very good signal to noise ratios, with strong basement reflectors visible beneath the patches of sediment. The 3.5 kHz record shows a clear pattern of back-tilted, faulted blocks with steep scarps facing in towards the ridge axis. On the hydrophone data long diffraction tails are visible on the inward facing sides of the fault scarps. It will be interesting to correlate the deep tow results with GLORIA data collected by IOS from the same area. Given the quality of the monitor records and the size of airgun array used (3 guns totalling 926 cu. ins.) I am optimistic that we should be able to see sub-basement reflectors once the data have been processed.

This was the first time that the deep tow had been used in conjunction with NERC's new 13.5 mm conducting cable. It was immediately clear that the new cable greatly enhances the deep tow's capabilities. By loading the maximum number of weights onto the instrument weight stand it was possible to profile at speeds of 2 to 2½ knots, a great improvement on the previous deployments from Shackleton when the speed had to be kept down to less than 1 knot. Launching the deep tow and its 30 m hydrophone array through the stern A frame proved relatively straightforward. The winch control position in the main lab next to the PES recorder was ideal for controlling the deep tow instrument's height above the sea bed.

The only problem encountered with the deep tow system was that the endcap threads on the instrument pressure housing appear to have become distorted at some point in the past. Poor seating of the end caps and their O ring seals caused us a good deal of anxiety before the deep tow's launch, but there was little that could be done about the problem at sea. Skimming the sealing surfaces and recutting the endplate threads where necessary should be made a priority before the deep tow is used again in the Indian Ocean.

For the deployment on this cruise we used the old set of instrument electronics that were used on the Shackleton cruises to the Vema fracture zone. The new set of electronics built to replace those damaged while on loan to IOS last year were only completed at the last minute, and have still not been fully tested.

The aluminium fairing fitted around the weight stand proved to be a great nuisance while the instrument was being prepared for launching. It probably makes little difference to the drag of the instrument. If it were to be left off it would be possible to fit extra weights, which might prove more effective than the fairing at keeping the deep tow close astern of the ship. On the other hand leaving the fairing off might increase the towing noise enough to degrade the seismic signal. This should be investigated, because preparation and launching of the deep tow would be a great deal quicker and easier without it.

3.2 IOS Equipment

IOS equipment used on this cruise included four digital OBSs, the 3.5 kHz profiling system and the 5 kHz acoustic navigation system.

3.2.1 IOS Digital OBSs

The IOS party brought with them four digital OBSs. Two of these had been used at sea before, and two were brand new. All four instruments were deployed at Site 1, but as described in section 2 we were unfortunately only able to recover three of them. The reason for the loss of WDOBS 3 is not clear, but there are two main possibilities. The first is that the pyro releases (which had been pinned on board shortly before the

DOBS's deployment) had both leaked and consequently failed to fire. The fact that another pinned pyro from the same batch, which was fitted to WDOBS 2, failed to fire lends some support to this hypothesis. An alternative explanation may be that the stray line became caught either on the sea bed or on the bottom weight. One line of evidence tending to favour this explanation is that when we left the instrument, the traces from its pinger recorded on the PES were followed by a weak echo, apparently coming from a few metres below the DOBS. This echo was similar to sea bottom echoes often seen during deployment and recovery of the Cambridge instruments, which float a few metres above the sea bed tethered by their anchor lines. Both of these explanations remain at the level of hypothesis. It is unlikely that we shall ever know for certain why WDOBS 3 failed to surface.

Of the three instruments that we did recover at Site 1, two had worked perfectly. WDOBS 1 and 4 had recorded both hydrophone and three component geophone data from all the airgun shots. All traces appeared to be excellent recordings, with good signal to noise ratios. The last instrument, WDOBS 2, recorded the first few shots but missed the majority because of a fault that prevented its shot window programmer from working properly.

At Site 2 the three remaining WDOBSs were deployed again, and this time all three were recovered safely. WDOBS 1 and 4 had again worked perfectly, but the problem on WDOBS 2 had recurred, though not so seriously. This time it had recorded all the explosive shots and about half of the airgun shots.

3.2.2 3.5 kHz Profiler

The IOS 3.5 kHz profiling system worked well on this cruise, with no problems or breakdowns. The data from it are going to be of limited usefulness, however, since on the old crust site, the sediment cover was everywhere much thicker than the limited penetration of the system; while at the young crust site, the rugged and mainly unsedimented bottom topography proved an unsuitable target for it.

3.2.3 5 kHz Acoustic Navigation System

An essential requirement for this cruise was a means of navigating more accurately than is possible using the TRANSIT satellite navigation system. For this reason a Global Positioning System (GPS) receiver was requested as part of the ship time application. Unfortunately RVS were unable to provide a GPS receiver on the Darwin in time for this cruise, so instead we took the IOS 5 kHz acoustic navigation system, and its two remaining transponder beacons.

The 5 kHz system suffered from a number of minor problems, especially early in the cruise, which affected both the towed, fish mounted transducer and the beacons themselves. The difficulties encountered are described briefly in the relevant parts of section 2. Once the fish and beacons were working properly, acoustic navigation proved relatively straightforward at low speeds (less than 6 knots) and at ranges of 12 to 15 km or less from both beacons. The water column sound velocity structure at each site was fed into a program running on a BBC Master series microcomputer. This program then converted the two-way travel times from the ship to the two beacons into latitude and longitude positions.

At speeds above about 6 knots, towing and propellor noise seriously affected the 5 kHz record, making it impossible to see the responses from the beacons. At lower speeds, the beacons were only completely reliable at ranges of about 12 km or less. It was very rare to pick up the beacons at ranges greater than 20 km at either site. This is as much a function of the sound velocity structure of the water column as of the beacon's signal intensity or the receiver's sensitivity. These restrictions meant that we were unable to use acoustic navigation for any of the explosive shot firing at Site 2, or at the edges of the survey areas where we were at the limits of the transponders' ranges. We also experienced problems at Site 2 in obtaining fixes close to the beacon base line. This appears to have been because the three days of bad weather in the middle of our work there substantially changed the near surface structure of the water column, as we discovered when we ran a second XBT profile there.

There is no doubt that the 5 kHz acoustic navigation system was extremely useful, and we would certainly not have been able to navigate the experiment with sufficient accuracy without it. We would probably have been able to use the system much more effectively, though, if we had been able to lay three or four beacons at each site, rather than just two. A better towing position for the 5 kHz fish, further from the propellor, might enable the system to be used at higher speeds.

3.3 RVS Equipment

As usual, on this cruise we made very heavy use of a wide range of RVS equipment. The great majority of this functioned reliably throughout the cruise, and will not be mentioned in this report. The points raised below refer only to the minority of items that either caused problems or that would benefit from improvements.

3.3.1 Acoustic Release Systems

We borrowed five acoustic release units from RVS, to supplement the three from Cambridge (used on the analógue OBSs) and six from Wormley (used on the WDOBSs and acoustic navigation beacons). One of the RVS releases, which was used on CDOBS 9 at Site 1, caused concern when its pinger only operated intermittently while the instrument was returning to the surface. This may have happened simply because the unit was fitted with a tilt detector, but this release was not used again at Site 2. Another RVS release had a fault on one of its pyro firing circuits. This was repaired, and it was then used at Site 2 to replace the first unit on CDOBS 9.

Although we had with us two spare release units, we were in fact very limited in the choice of units that we could use at each site, because of the need to have a different release frequency for each instrument.

RVS supplied two acoustic command system deck units. One of these worked well, but the other appeared to have a fault on the 1 kHz oscillator output.

3.3.2 Pyro Releases

The problems encountered with pyro-releases at Site 1 have already been mentioned. We were lucky not to lose CAOBS 2 when it surfaced prematurely after a pyro-release (of the older design) parted under water. Leaks of pyros that were subsequently pinned on board may have been responsible for the loss of Wormley DOBS 3. There appears to be a continuing debate between IOS and RVS as to whether pinning is still necessary or advisable with the newer design of pyro release. The number of pyro failures on this cruise (one that parted, one that definitely failed to fire on a Wormley DOBS that we recovered at Site 1, and possibly both pyros on the instrument that we lost) is surprising, as experience from previous cruises is that they are normally extremely reliable.

3.3.3 Airguns

Airguns were used very heavily on this cruise, and the airgun team were kept constantly busy rerigging them in different combinations of arrays and with different chambers. Apart from a few minor leaks, their efforts paid off and the guns worked reliably throughout the cruise.

It is clear from our experience that the number of towing points and the compressor capacity on the Darwin make it possible to use relatively powerful, multi-airgun arrays to great effect. However if this capability is to be exploited effectively and safely in future, certain improvements need to be made. Firstly, we need a more reliable system for monitoring the depth at which guns are towing. Secondly, we need an automated system for controlling the firing delays on each gun. Thirdly, better facilities are needed on the ship for handling airguns, both in the lab and on deck during deployment and recovery. The handling facilities on the ship at present are essentially the same as those on the older ships, which were evolved at a time when airgun work typically involved the use of one, or occasionally two, small or medium sized guns. In my view they are really neither adequate nor safe if large, multi-airgun arrays are to be used routinely. In particular the amount of man-handling involved in getting the guns on and off the work bench and to and from the stern A-frame, and in deploying or recovering the guns, needs to be reduced.

3.3.4 Seismic Streamer

The hydrophone array for single channel SRP work was streamed from the small hydrophone winch mounted on the ship's capstan. This arrangement works reasonably well once the winch drum is safely fixed to the capstan, but unfortunately it is often inconvenient to leave it there while other work is going on on deck. The process of fitting it is both difficult and slow when the ship is moving around in even a moderate sea.

The hydrophone array worked very well on both its second and third deployments, when it was streamed with a relatively short tow cable and without the Ashbrook depth controller birds. The first time we used it we fitted the birds and veered out most of the tow cable, and on this occasion the array was extremely noisy. I conclude from this firstly that the front end of the array is too heavy when fitted with two weight sections - one should be enough; and secondly that the Ashbrook birds act primarily as noise generators, and probably do more harm than good.

3.3.5 Disposable Sonobuoys

Fortuntely the three disposable sonobuoys that we were able to use all worked well. The seven out of ten that we had to ditch represent a completely unacceptable proportion. RVS should make it a priority to take this matter up with the manufacturers, both to avoid the waste of money involved in throwing sonobuoys away and to prevent the potential waste of ship time when disposable sonobuoys loaded at the start of a cruise turn out to be unusable.

3.3.6 Shipboard Computing System

The Level 'B' data logger system worked well throughout the cruise, losing only one section of data when the ship's master clock stopped. The interface to the magnetometer caused a few problems initially, but there is a good chance that the data are recoverable.

The Level 'C' data processing computer, on the other hand, caused many problems to begin with. It had been loaded with a new, 'standard' system, intended to be a common Level 'C' system for all ships, before we sailed. The new system had not been adequately debugged, and a number of changes had to be made to the software before it would work. Even then it seemed less reliable and to have more irritating eccentricities than the system in use twelve months previously, on CD 4/85. To aim to have identical versions of programs running on all the ships is a sensible objective, but from the user's point of view, replacing a well-tried and reliable system with one that has not been properly debugged ashore first seems somewhat perverse.

There is still no proper 'live track plot' facility on the Level 'C' machine. I believe that such a facility would be useful on a wide range of cruises.

3.3.7 E/M Log

When we sailed from Barry the athwartships component of the E/M log appeared to be giving spurious readings. It was switched off, and zero voltage values were input to the data logger and satellite navigator interfaces. This did not appear to degrade either the processed navigation data or the DRs from the satellite navigator, which makes me suspect that an uncalibrated athwartships log is of dubious value.

3.3.8 Shipboard Master Clock

The master clock ran with remarkably little drift throughout the cruise. The drift that was observed against radio time signals was more or less consistent with the variations in radio signal propagation times to our different positions.

At one point, while on passage between Site 1 and Site 2, the clock inexplicably stopped. This was probably due to someone inadvertently pressing the reset button on the master clock front panel. As a result, four hours worth of data were lost on the logger. Fortunately, as we were on passage, the loss was not serious. A key to disable the reset switches, or even a plastic cover over the front panel, would avoid a recurrence of this particular problem.

3.4 Ship's Equipment

3.4.1 General

Before mentioning specific items of equipment on the ship, I have two criticisms of a more general nature. The first concerns the amount of water that regularly finds its way onto the ship's working decks, and the hazard that this represents. The second concerns the unsatisfactory nature of the scientific plot as a working space.

Water on deck is a serious problem on the Darwin. This is not only because of the few inches of water that are often slopping around the afterdeck, making it wet and slippery underfoot. What is more serious is that the water sometimes comes aboard as solid waves, and does so with considerable force. This happened twice on our cruise while people were working on deck, and many more times while we were hove to in bad weather. On the first occasion the wave came straight through the gap in the rail under the side A frame, with sufficient force to knock both people working there off their feet and sweep them and an OBS several yards across the deck. As I stressed in section 2, this happened in good weather with the ship making a speed of about 8 knots. On the second occasion, a large wave broke over the stern under the after A frame, while we were recovering an airgun array in deteriorating weather. The ship was head to wind making about 2 knots, and the wind had increased within the last hour from force 6 or 7 to force 8. On this occasion the force of the water knocked over three of the people working on deck, and caused a potentially dangerous situation when a pair of airguns, hanging under the A frame on a 2 metre beam, threatened to break free and swing uncontrollably across the deck.

Both of these incidents would have been avoided if the gaps in the rail beneath the midships and stern A frames had been closed off by steel gates, built to the same height as the bulwark elsewhere around the working decks. Such gates would be very effective at keeping most of the water off the decks. More importantly they would break the force of the water that did come on board, thus greatly improving safety in the working areas.

Although the gates would have to be quite heavily built, this should not cause impossible difficulties. They could also be designed so that they were removable for cruises during which they would get in the way - for example if GLORIA was going to be used. However I suspect that in practice they would only be opened quite rarely. On our cruise, for instance, we carried out many OBS deployments and recoveries and streamed various airgun arrays and the Deep Tow without ever needing to remove the wire guard rails that currently protect the gaps under the A frames.

Certainly something needs to be done to improve the current situation, which in my opinion constitutes a significant source of danger to personnel working on deck, and which must in the long run be unacceptable.

The problem with the plot is rather different. On this cruise we were obliged, reluctantly, to use the plot for watchkeeping, because the main lab was so full of equipment. The plot suffers from several separate drawbacks, as we soon discovered.

Firstly, the motion so high up in the ship is extremely uncomfortable, so that even experienced sea farers start to feel seasick after a short spell up there in bad weather. There is probably little that can be done about this, other than to try to avoid using the space at all.

Secondly it is very poorly equipped as a scientific plot. The navigation instruments are scattered around in an apparently random fashion, with no central watchkeeping position. There are no windspeed and direction indicator repeaters. The chart table is too small to take a standard sized plotting sheet, as are the drawers beneath it. Since the chart table top is recessed instead of flush, charts cannot even be laid on it and allowed to overhang its edges.

Finally the plot is extremely isolated, which is perhaps the biggest problem of all. Visibility of the working decks is non-existent. Communications with other lab spaces, the wheelhouse and the working decks are poor. It is also such a long way physically from the main lab that no-one is prepared to make the journey unless absolutely necessary. The choice of heavy wooden doors with tiny portholes for the doorway leading out onto the bridge wing completes the sense of claustrophobic isolation in the plot, and dashes any last hope of being able to see the working decks. During our cruise we kept these doors open whenever possible, which at least made some communication with the side deck possible. This option will not be available in the Indian Ocean, where the doors will have to be kept shut for air conditioning.

Three things could be done to improve the plot. Firstly, communications need to be improved. The existing intercom is unsuitable, partly because the sets are inconvenient to use, and partly becuse they do not cover the right places - for example, there is no intercom in the working area under the side A frame. The intercom system should be upgraded or replaced to resemble that on Discovery - with all scientific spaces permanently linked by a single intercom system; with volume controls on each station (the current intercoms are often inaudible from the far side of the lab); with waterproof stations equipped with powerful loudspeakers serving the main working areas on deck under the two A frames, and in the winch room; and with microphones on coiled leads, so that it is possible to talk into the intercom without having to do contortions around racks of equipment to get to the set.

Secondly, visibility could be improved by incorporating the after conning postion (which will probably never be used except as a bicycle store) into the plot, and by fitting much larger windows to the external doors. At the same time, perhaps, a decent watch keeping position and a proper chart table could be provided.

The third possibility would be simply to abandon the plot as a watchkeeping space, and use it instead for equipment that is less averse to being isolated and tossed around than scientists. There seems little reason, for example, why watchkeepers should be banished to the plot while computers occupy a prime site amidships on the main deck adjacent to all the other lab spaces.

Finally there would be no need to use the plot if more space was available in the main lab. On this cruise, a large section of the main lab was taken up by the airguns. This is not a very satisfactory arrangement either for people working on the guns, or for other people sharing the main lab with them. Provision of a container on the afterdeck fitted out as an airgun workshop, as has been previously suggested, would simultaneously improve the facilities for servicing airguns on the ship; improve the environment in the main lab for others working there; and solve the space problem on geophysics cruises so that the plot would not need to be used.

3.4.2 Compressors

For most of the cruise both compresors ran reasonably reliably. A number of problems in the first few days were apparently caused by a service carried out by the manufacturers just before we sailed, that was finished off very carelessly. There were some other problems too. One of the air filters literally fell apart from the vibration about halfway throgh the cruise. More seriously the vibration also sheared all the bolts holding the main junction box onto the motor on one compressor, and several of the bolts on the other compressor. While the junction box that had come completely adrift was being dismantled, one of the sheared bolt ends dropped inside the motor windings. The compressor was out of action for several hours while the motor was partially stripped down and the offending object fished out.

The ventilation in the compressor room suffers from the fact that the exhaust vent is right next to the inlet vent. Air circulation could be greatly improved if trunking were fitted to move the exhaust vent to the far end of the compartment. This might be important in hot climates.

3.4.3 Winches

The new deep tow cable and its winch performed very well on the cruise. The remote control position in the main lab was used during deep tow work. The conducting swivel (loaned by IOS) appeared to work well, although it had to be partly dismantled to get it through the centre sheave on the stern A frame.

The CTD winch caused some problems with the alignment of its spooling gear. This is nothing new - it is familiar from the winch's earlier days on Shackleton.

One persistent problem was a leaking pressure release valve on the the winch system's hydraulic power pack. Despite several attempts to fix it, the leak recurred every time we used the winches.

3.4.4 A Frames

The side A frame is excellently positioned for launching and recovering OBSs, and is just the right height for work of this kind. The small winches adjacent to it are a further improvement, although they are rather slow.

The stern A frame proved very useful for towing multiple airgun arrays and the Deep Tow profiler. However its hydraulics were exceedingly slow, which meant that equipment was sometimes left hanging clear of the water but out of reach of the deck for much longer than should have been necessary. Another problem is the sheer height of this A frame. When launching equipment using the sheaves at the top of the frame, the pendulum effect can be alarming.

I doubt if many cruises need to use the full height of the stern A frame. A removable beam fitted about halfway up it would be at a much more suitable height for towing airguns, or even the deep tow, and would make such equipment a great deal easier to deploy.

3.4.5 Watertight Doors

The watertight doors leading from the main lab and wet lab onto the working decks are unsatisfactory for several reasons. Firstly, the doors at the after end of the main lab are not particularly watertight - on several occasions water found its way from the after deck into the lab when the doors were shut and fully clipped down. Secondly the doors are extremely heavy, and dificult to open or close safely when the ship is rolling or pitching. Thirdly, with the exception of the starboard side main lab door, the clips for holding them open are inadequate.

It is not clear what should be done to improve the doors. Dampers might stop them from swinging around so violently, and better clips would also help.

4. Summary of Data Acquired

A large quantity of data was acquired on this cruise, as detailed below. The principal objective - to obtain wide angle seismic data from two sites using OBS arrays and explosive airgun shots, for investigating seismic anisotropy and attenuation - was achieved. In addition we completed a deep tow seismic reflection profile across the young crust site and a detailed, conventional, SRP survey of the old crust site, and collected many hundred kilometres of magnetic and bathymetric data.

4.1 Site 1

Data collected from the wide angle OBS experiment consist of 624 airgun shots recorded by 5 digital OBSs, providing 3120 shot-receiver pairs. Three of the OBSs recorded three-component geophone data plus hydrophone data, and the other two recorded three-component geophone data.

Underway data collected at Site 1 include 30 km of deep tow seismic reflection profile, 150 km of magnetics and 370 km of bathymetry.

4.2 Site 2

At Site 2 the wide angle seismic data consist of 352 airgun shots plus 70 explosive shots, most or all of which were recoreded by six digital and two analogue OBSs, all equipped with hydrophones and three-component geophones. The data provide approximately 3110 usable shot-receiver pairs.

The underway data from Site 2 include 380 km of magnetics, 490 km of seismic reflection profile and 770 km of bathymetry.

4.3 Data collected on Passage Legs

These consisted of 180 km of bathymetric profile across the Celtic Shelf continental margin; and 80 km of seismic reflection profile and 1030 km of magnetics and bathymetry between Sites 1 and 2.

Table 1

Scientific Party

M.C. Sinha	Cambridge	(Principal Scientist)
R.B. Whitmarsh	I.O.S.	
T.R.E. Owen	Cambridge	
P.J. Barton	Cambridge	
P.W. Carter	Cambridge	
P.R. Uniyal	Cambridge	
M. Joppen	I.O.S.	
S. Brooks	I.O.S.	
R. Kirk	I.O.S.	
I. Rouse	I.O.S.	
M. Saunders	I.O.S.	
J. Price	R.V.S.	
V. Caruana	R.V.S.	
H. Evans	R.V.S.	
P. Mason	R.V.S.	
K. Smith	R.V.S.	
L. Wedlock	R.V.S.	
C. Woodley	R.V.S.	

TABLE 2

SHOT POSITIONS AND TIMES

SHOT Nº	TIME (GMT)	Detonation Depth (m)	Latitude N	Latitude W
	:	:	:	:
1	14 01 01.885	72	44° 44.8'	17° 43.9'
2	14 05 58.797	68	44° 44.1'	44.8'
3	14 10 59.199	69	43.6'	44.9'
4	14 16 00.112	70	42.8'	45.5'
5	14 21 00.315	71	42.2'	46.0'
6	14 26 01.976	73	41.6'	46.7'
7	14 31 01.237	71	41.1'	47.5'
8	14 36 00.747	71	40.6'	48.4'
9	14 41 02.476	73	39.9'	47.9'
10	14 46 03.438	74	39.3'	47.0'
11	14 51 04.063	74	38.5'	46.2'
12	14 56 00.407	70	37.9'	45.4'
13	15 01 02.605	72	37.7'	44.3'
14	15 06 01.022	71	37.5'	43.0'
15	15 10 58.481	68	37.2'	41.9'
16	15 16 00.915	70	37.0'	40.9'
17	15 21 01.823	71	37.3'	39.4'
18	15 25 57.515	67	37.8'	38.2'
19	15 31 01.039	71	38.5'	37.9'
20	15 36 01.812	72	39.3'	37.3'
21	15 41 01.979	72	40.0'	36.7'
22	15 46 00.643	71	40.7'	36.6'
23	15 51 00.099	70	41.4'	37.0'
24	15 55 53.495	64	42.1'	37.6'
25	16 01 01.268	71	42.9'	38.0'
26	16 05 59.080	69	43.6'	38.6'
27	16 10 58.101	68	44.4'	39.0'
28	16 15 58.685	70	44.7'	39.6'
41	17 21 01.511	71	45.4'	44.6'
42	17 26 02.492	71	44.7'	44.3'
43	17 31 00.196	70	44.0'	43.8'
44	17 36 00.984	72	43.3'	43.3'
45	17 40 59.711	70	42.4'	42.9'
46	17 46 02.121	73	41.7'	42.6'
47	17 50 59.623	71	40.9'	42.9'
48	17 56 01.201	71	40.2'	43.3'
49	18 01 01.214	72	39.5'	43.7'
50	18 06 02.174	72	38.8'	44.1'
51	18 11 00.690	71	38.2'	44.6'
52	18 15 59.989	69	37.5'	45.2'
53	18 20 57.278	67	36.9'	45.5'
54	18 26 00.046	71	36.3'	46.0'
56	19 35 59.057	67	34.8'	47.6'
57	19 40 59.630	70	35.6'	48.0'
58	19 45 59.484	70	36.3'	48.6'
59	19 50 59.746	68	36.9'	49.2'
60	19 56 01.840	71	37.5'	49.6'
61	20 01 00.414	71	38.2'	50.1'
62	20 05 58.956	69	38.8'	50.6'
63	20 11 00.577	70	39.4'	51.1'
64	20 15 58.381	67	40.1'	51.6'
65	20 21 03.997	75	40.8'	52.1'

66	20 26 04.594	76	41.4'	53.0'
67	20 31 00.558	71	42.0'	52.5'
68	20 35 59.087	69	42.9'	51.8'
69	20 41 02.013	71	43.8'	51.0'
70	20 45 59.469	70	44.5'	50.4'
71	20 50 59.902	70	44.7'	49.3'
72	20 56 03.695	73	44.6'	48.3'
73	21 01 04.222	71	44.5'	47.3'
74	21 06 00.165	70	44.6'	46.3'
75	21 11 00.955	70	44.5'	45.3'
76	21 16 03.002	72	44.6'	44.3'
77	21 21 02.999	72	44.6'	43.3'
78	21 26 00.403	68	44.7'	42.4'
79	21 31 03.274	71	44.7'	41.4'
80	21 36 23.711	67	43.9'	40.5'
81	21 41 01.848	71	43.4'	39.6'
82	21 45 59.782	71	42.8'	38.6'

Table 3

OBS and Acoustic Beacon Positions

Site 1

Position	Instrument	Lat. N	Long. W	Depth (m)
R1	CDOBS 11	40°18.5'	29°09.1'	1690
R2	CDOBS 10	40°16.6'	29°11.6'	1945
R3	WDOBS 1	40°16.3'	29°07.7'	1652
	CAOBS 4	40°16.2'	29°07.7'	1648
R4	WDOBS 2	40°15.5'	29°09.2'	1875
	CAOBS 2	40°15.5'	29°09.4'	1835
R5	WDOBS 3	40°13.8'	29°13.2'	1838
R6	WDOBS 4	40°14.2'	29°09.5'	1810
	CAOBS 1	40°14.1'	29°09.6'	1880
R7	CDOBS 9	40°14.2'	29°05.9'	1960
B1	Beacon 1	40°10.3'	29°09.2'	1725
	Beacon 2	40°18.6'	29°04.7'	1945

Site 2

Position	Instrument	Lat. N	Long. W	Depth (m)
R1	CDOBS 9	44°44.4'	17°45.3'	4905
R2	WDOBS 1	44°41.1'	17°47.8'	5029
	CAOBS 2	44°40.8'	17°48.0'	5030
R3	CDOBS 11	44°41.1'	17°41.7'	4998
R4	WDOBS 2	44°40.0'	17°44.8'	4905
	CAOBS 1	44°40.0'	17°44.7'	4906
R5	CAOBS 4	44°37.8'	17°50.4'	4895
R6	CDOBS 10	44°37.6'	17°44.7'	5005
R7	WDOBS 4	44°37.1'	17°39.9'	4854
B8	Beacon 1	44°43.2'	17°46.2'	5002
B2	Beacon 2	44°37.8'	17°41.9'	5008

Note - Depths in Corrected Metres

(Canter Area 15)

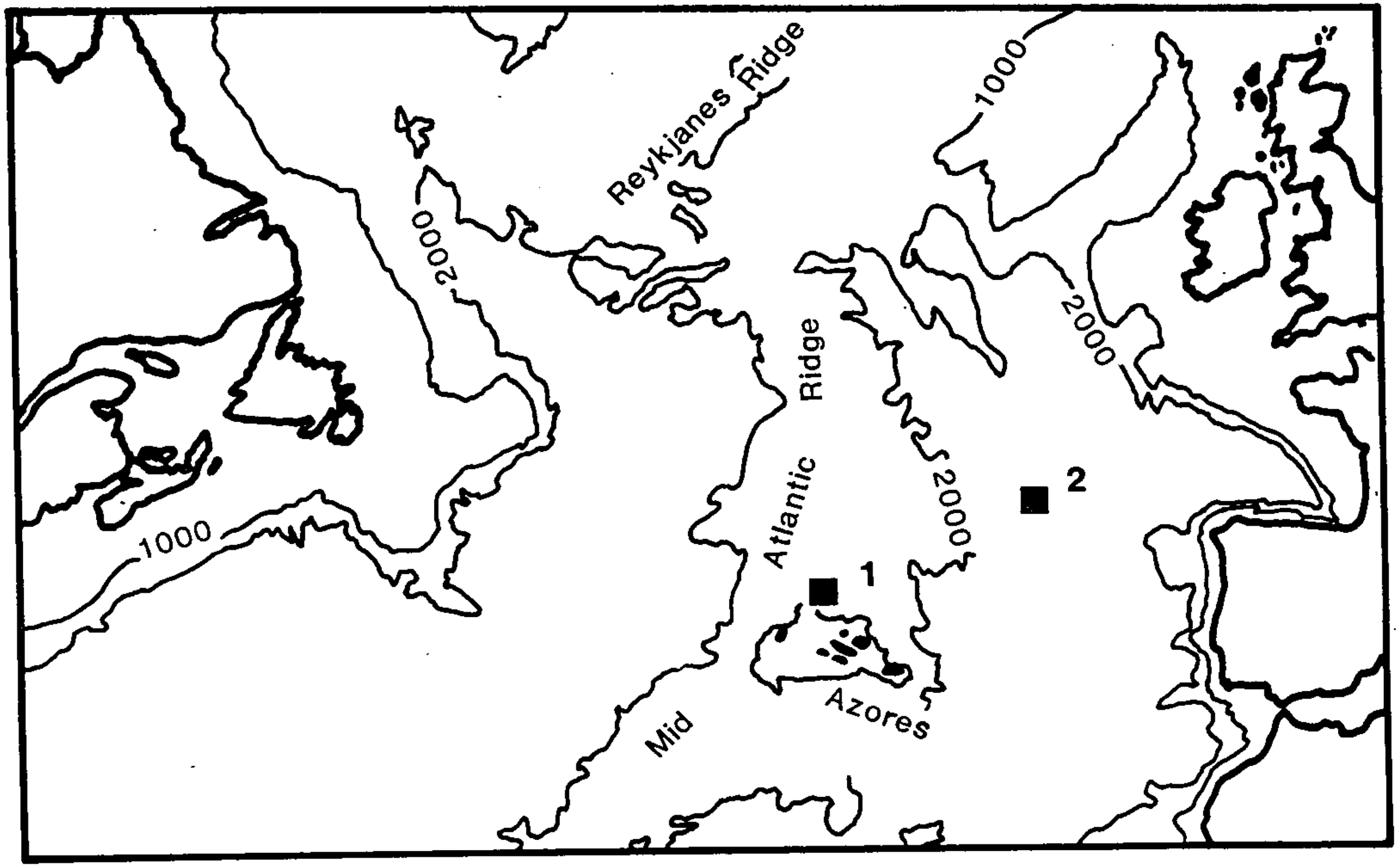


Figure 1. Simplified bathymetric map of N. Atlantic (contours in metres) showing locations of survey areas (boxes) on young (1) and old (2) crust.

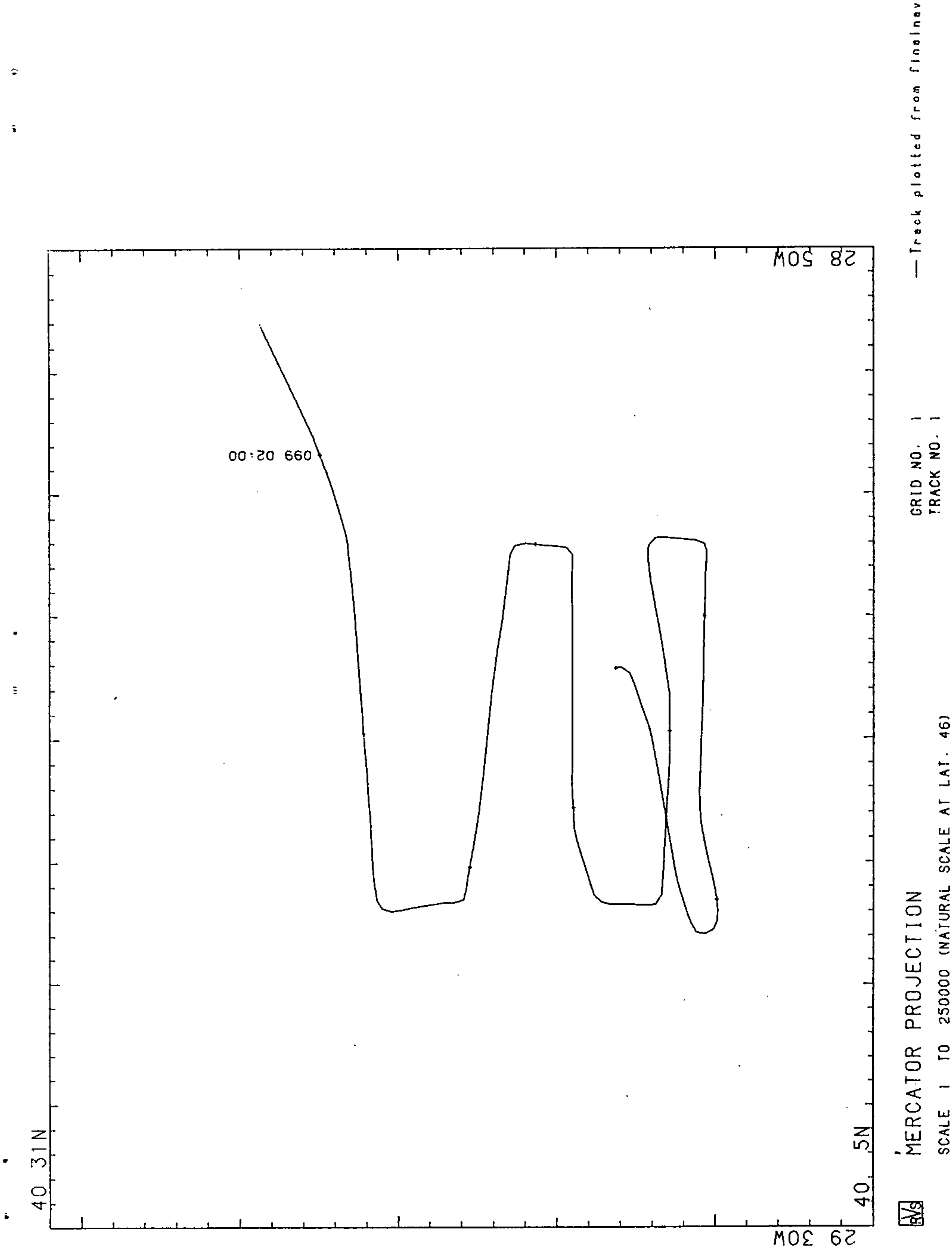


Figure 2. Track chart, Initial Survey, Site 1.

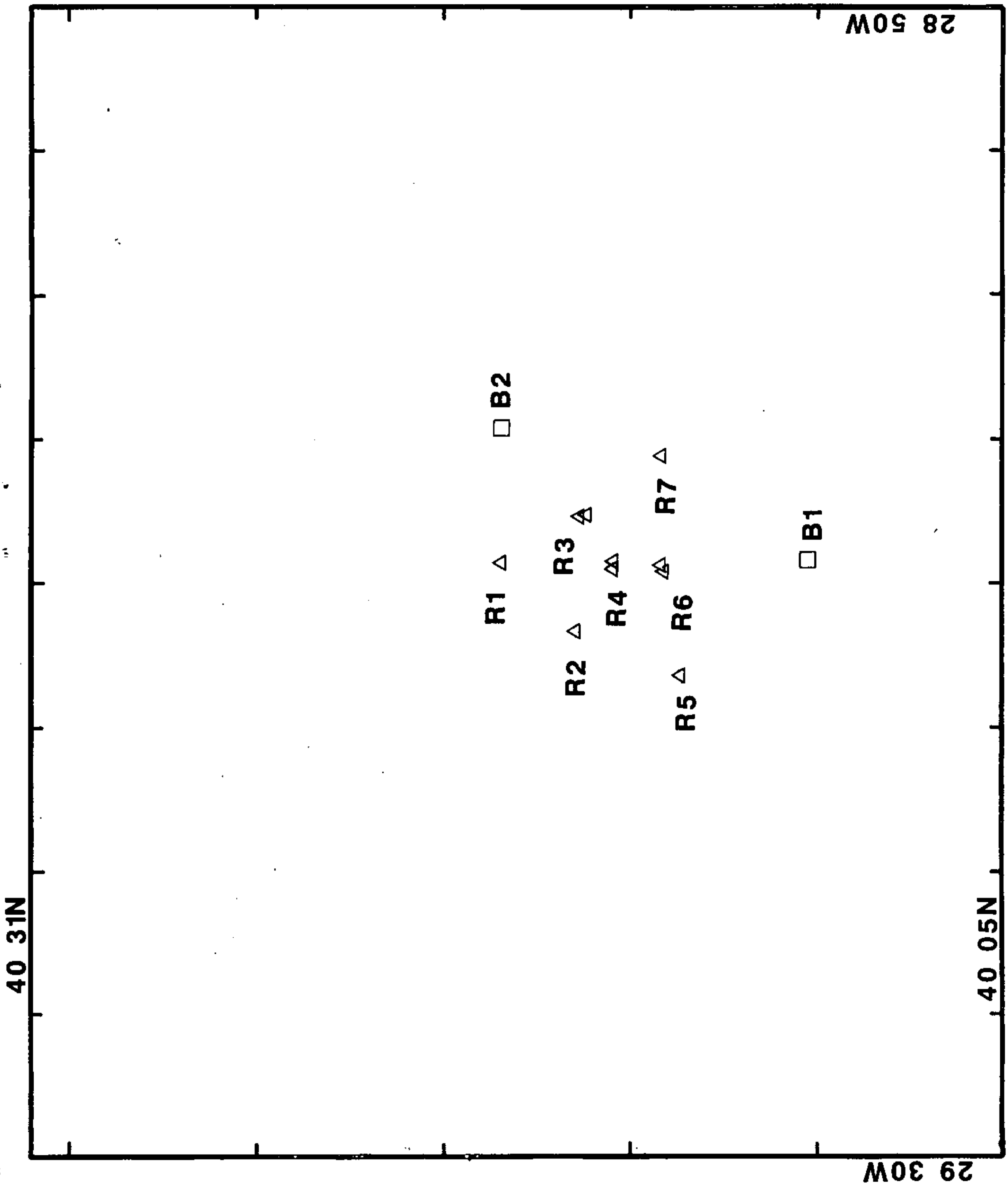


Figure 3. OBS and Beacon Positions, Site 1.

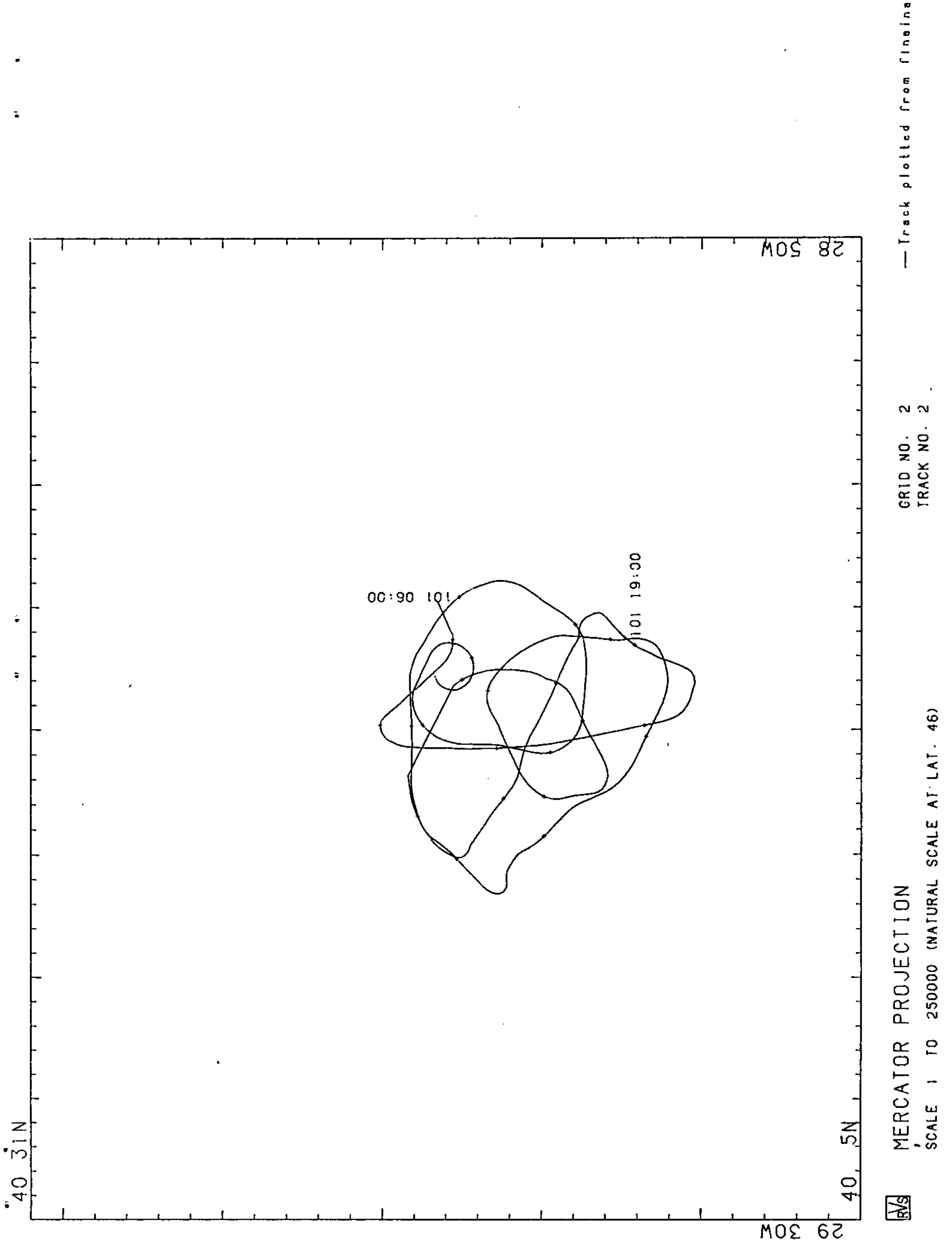


Figure 4. Airgun shotfiring Tracks, Site 1.

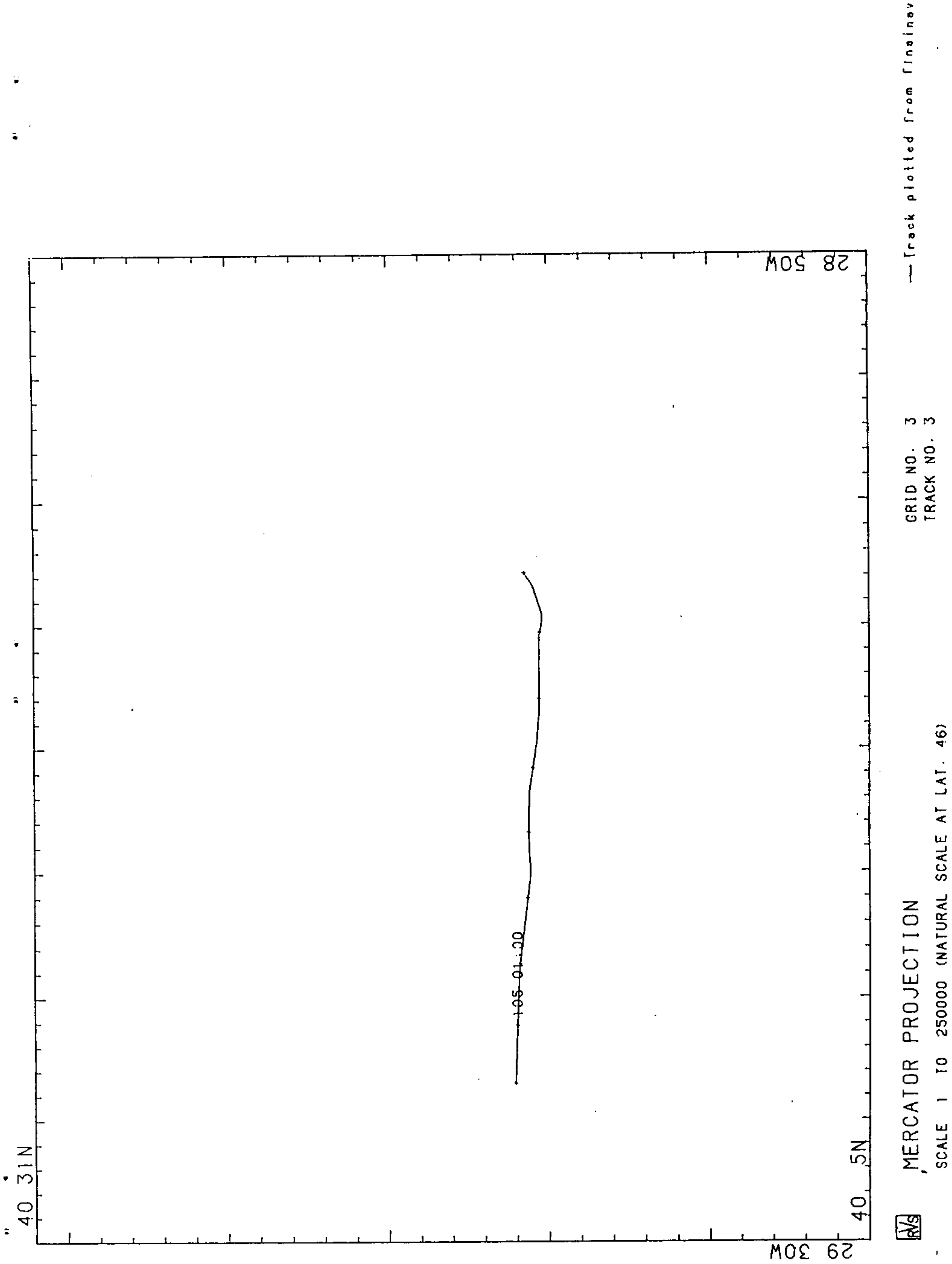
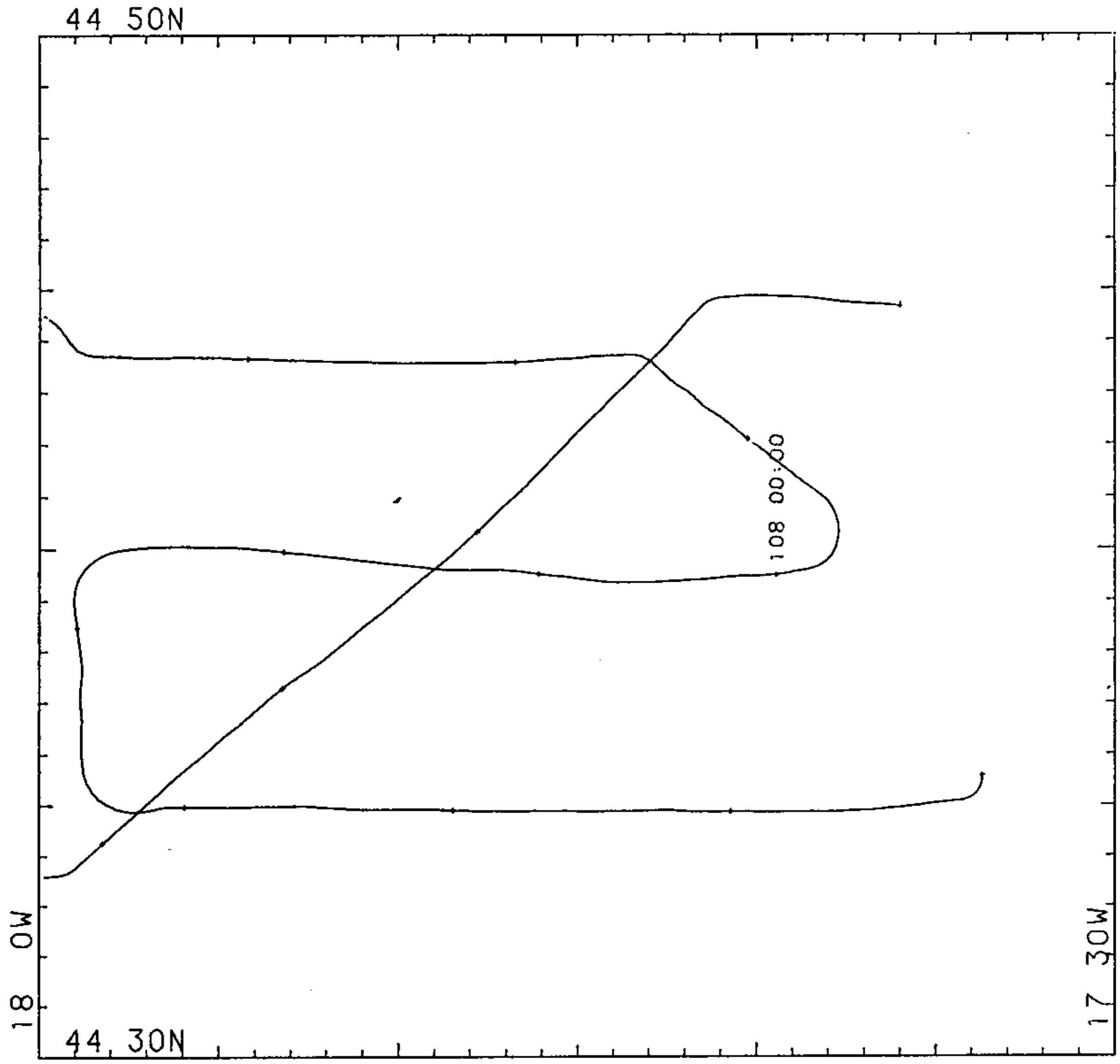


Figure 5. Track of Deep Tow Profile, Site 1.



MERCATOR PROJECTION

SCALE 1 TO 250000 (NATURAL SCALE AT LAT. 46)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO.
TRACK NO.

Charles Darwin 11/86

Figure 6. Track chart, Reconnaissance Surveys, Site 2.

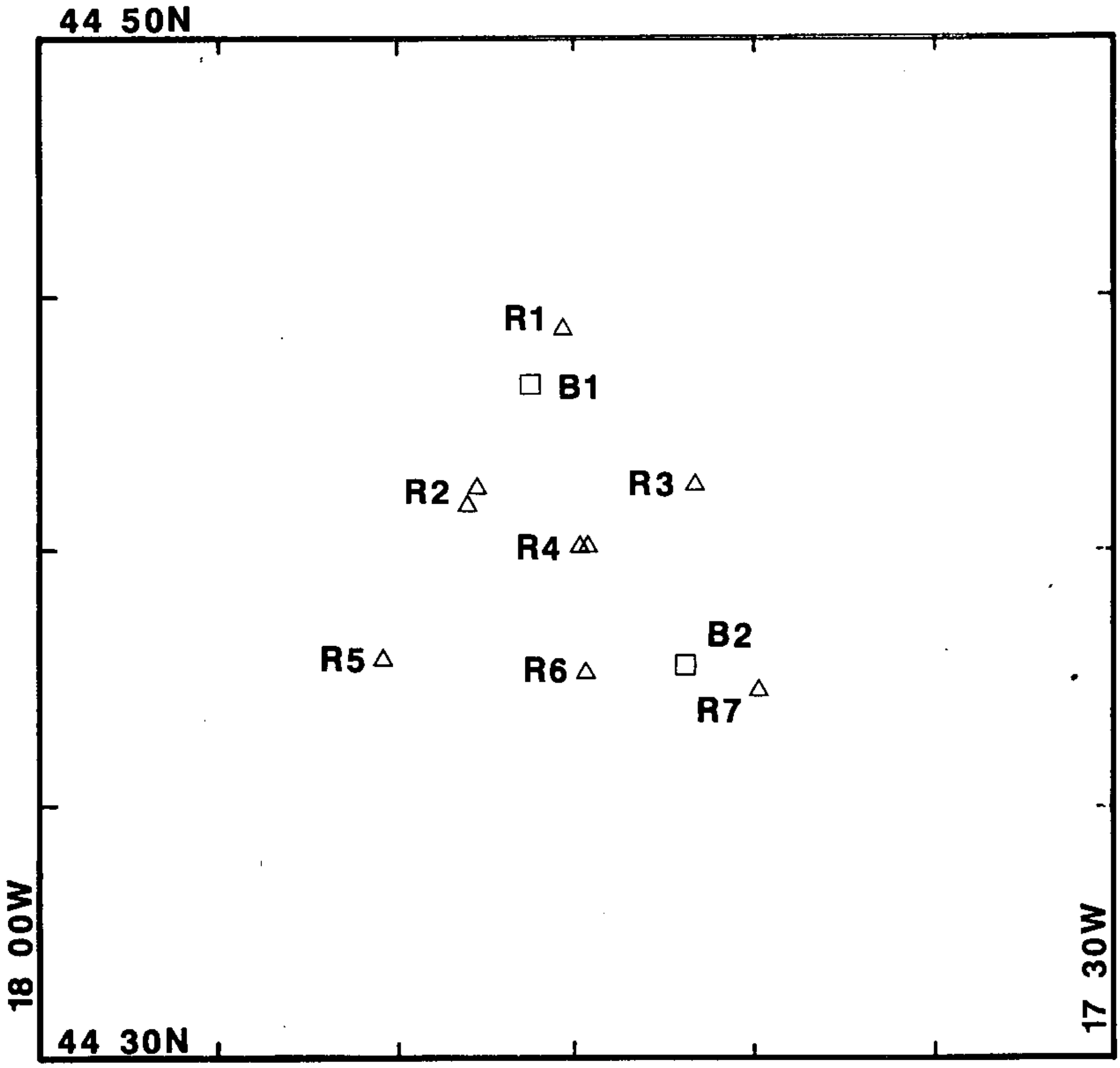
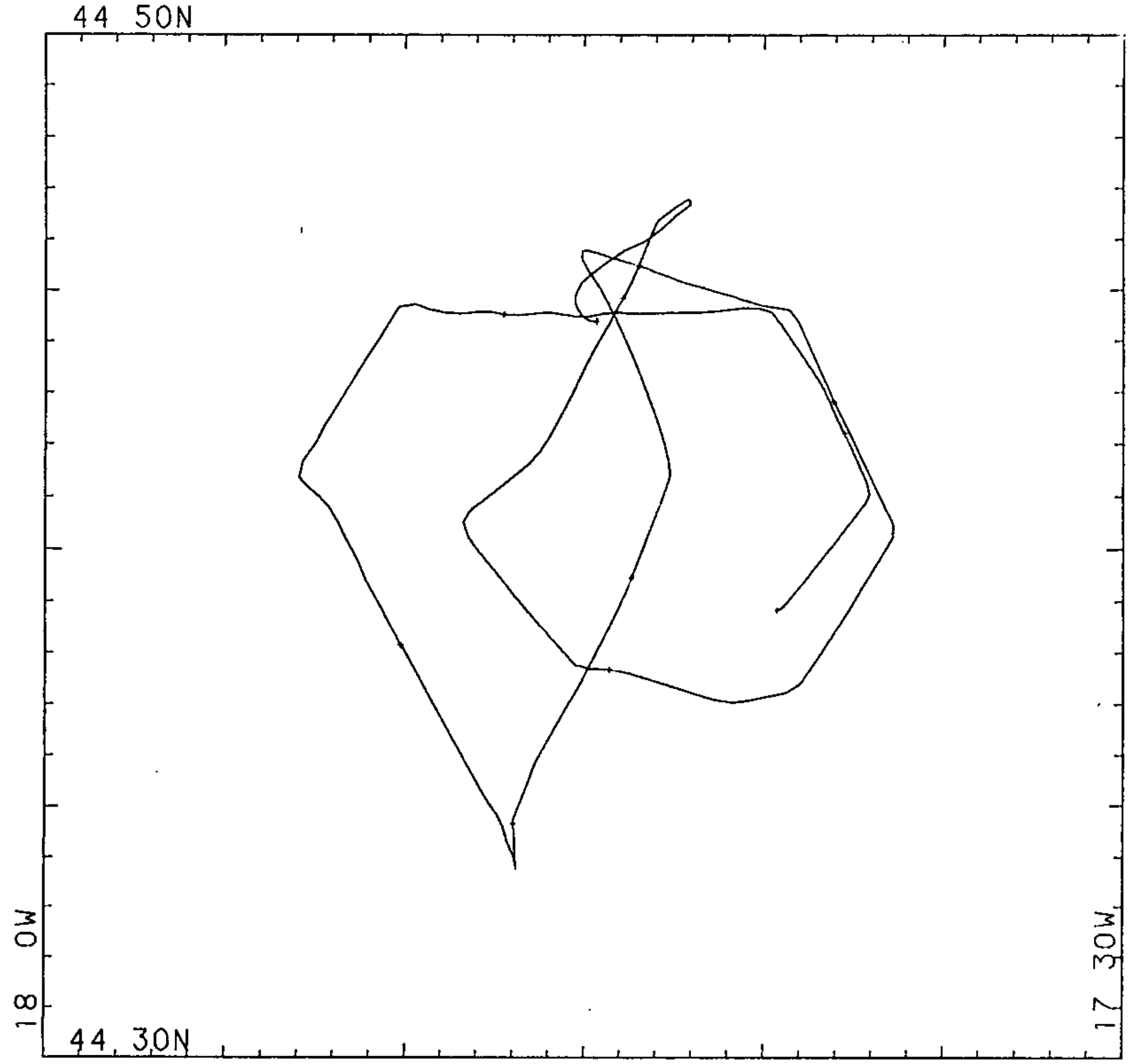


Figure 7. OBS and Beacon Positions, Site 2.



RVS MERCATOR PROJECTION

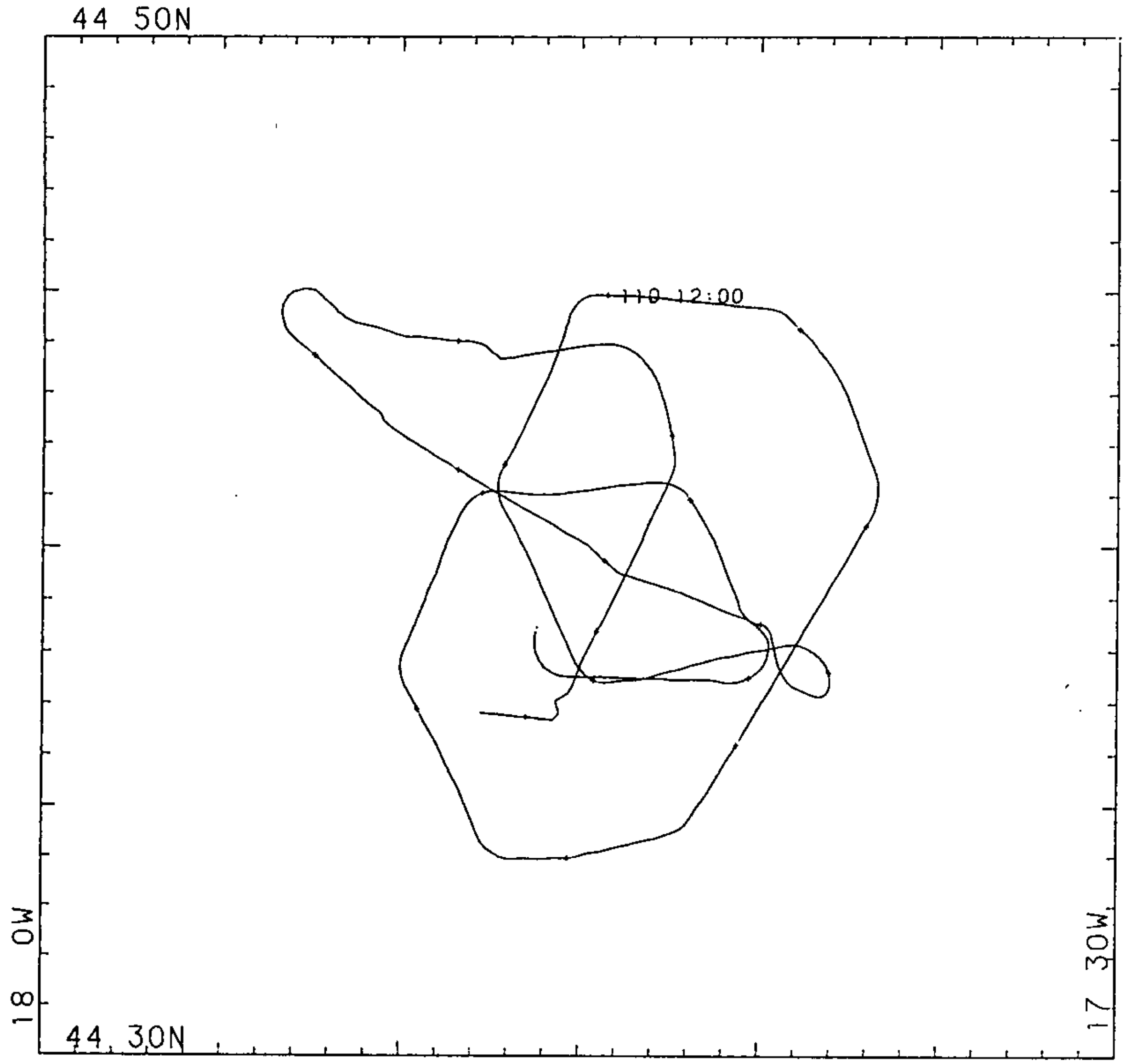
SCALE 1 TO 250000 (NATURAL SCALE AT LAT. 46)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO.
TRACK NO.

Charles Darwin 11/86

Figure 8. Explosive Shotfiring Tracks, Site 2.



MERCATOR PROJECTION

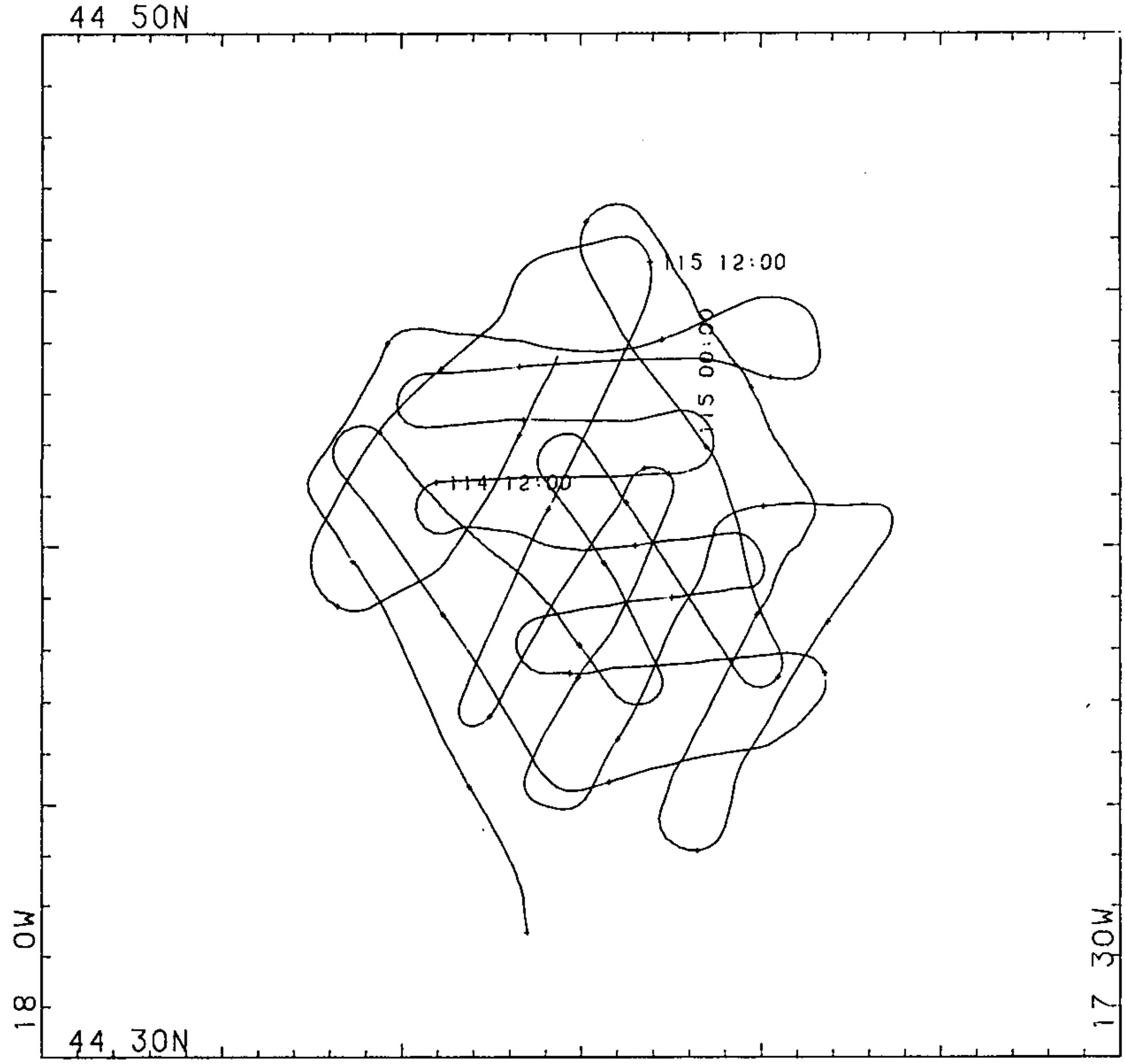
SCALE 1 TO 250000 (NATURAL SCALE AT LAT. 46)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO.
TRACK NO.

Charles Darwin 11/86

Figure 9. Airgun Shotfiring Tracks, Site 2.



MERCATOR PROJECTION

SCALE 1 TO 250000 (NATURAL SCALE AT LAT. 46)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

GRID NO.
TRACK NO.

Charles Darwin 11/86

Figure 10. SRP Detailed Survey Tracks, Site 2.