I.O.S.

R R S DISCOVERY
CRUISE 107

28 DECEMBER 1979 - 9 FEBRUARY 1980

LESSER ANTILLES DEEP LITHOSPHERE EXPERIMENT (L A D L E)

CRUISE REPORT No 100

1980

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF OCEANOGRAPHIC SCIENCES

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LESSER ANTILLES DEEP LITHOSPHERE EXPERIMENT
(L.A.D.L.E.)

28 DECEMBER 1979 (362) - 9 FEBRUARY 1980 (040)

R.R.S. DISCOVERY

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Institute of Oceanographic Sciences
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CONTENTS

CRUISE OBJECTIVES

This cruise was part of a major collaborative international seismic experiment in the western North Atlantic involving not only RRS Discovery but also CSS Dawson as well as seismic recording stations ashore on many of the islands of the Lesser Antilles. The objectives of the experiment, which has become known as LADLE (Lesser Antilles Deep Lithosphere Experiment), was to study the oceanic lithosphere's seismic structure using sea-bed recordings of both large explosions fired at sea and earthquakes occurring beneath the Lesser Antilles island arc. To this end Discovery began the cruise with sixteen ocean-bottom seismographs (and Dawson with six) most of which were to be deployed as part of a 1020 km array along longitude 61°30'W north of the Lesser Antilles. Shots varying in size from 1 to 8 tons were also to be fired from RRS Discovery and CSS Dawson.

The ocean bottom seismographs (OBS) had varying recording capacities and techniques. The objective was to keep the array of OBS active (i.e. recording) for up to about a month in order for there to be a reasonable chance of recording at least several Lesser Antilles earthquakes over the whole array. Consequently the tapes in many of the OBS had to be changed on a 7 to 10 day cycle and this activity together with the necessary steaming involved, was expected to consume a large proportion of the time available to both ships.

NARRATIVE *

Leg 1. Discovery sailed at 0600/362 from anchor in San Juan harbour to the Army Terminal to load 30 drums of Tovex explosive into the main Magazine and after deck Ready-use Locker. This operation was completed by 1315 and the ship finally sailed at 1610 for a position east of Guadeloupe at which the first Blacknest OBS was to be laid. The Precision echo-sounder (PES) fish was deployed at 0915 the next day.

The OBS position (A1) was reached at 0545/364, whereupon a short bathymetric survey was conducted, and OBS 3A was laid at 0710. The next OBS position (A2)

* all times in this Narrative are Local Times (G.M.T. -4). Shot and buoy positions referred to in the text are given in Figure 3 and Tables I and II.

was reached at 1705 and again after a short bathymetric survey the OBS was laid at 1934.

The next objective was to fire an 1800 lbs shot east of Anguilla to act as a "calibrated" event to assist in the development of regional models for locating earthquakes in the Lesser Antilles region. The shot location was reached at 0430/365 and the shot was fired at 1025. The ship then got underway to position B1 at the south end of the main array of OBS/PUBS aligned along longitude 61°30'W. On arrival at B1 (0330/001) a short bathymetric survey was conducted after which the OBS was laid at 0525. The next four days were occupied in laying OBS (or PUBS, an IOS Wormley ocean-bottom seismograph) at twelve further equally spaced positions 60 km apart from south to north along 61°30'W. This passed mainly without incident, the lay positions being given in Table I. Each OBS (or PUBS) was followed acoustically down to the sea-bed on this occasion because it was the first time that each of the instrument spheres had been used to depths in excess of 5700m. At position B4 the PUBS transponder failed while the buoy sank but as no visual contact was made at the surface (it was night and the release frequency had been used sparingly in attempting to switch on the transponder thereby involving a slight risk that the PUBS had resurfaced) and since the risk of leaving the buoy was no greater than trying to recover it the PUBS was left on the sea-bed. During these operations the first 5800m of new 4mm wire on the electric winch were tensioned (0930-1343/003). At position B11 a search for water less than 6000m deep had to be made before the buoy could be laid since 6000m was the maximum rated depth for the NERC 28-inch spheres.

The last OBS was laid at position B13 at 1451/004 and shortly afterwards the ship got underway to begin a gravity profile to the north end of the LADLE array as far as position B18. The end of the profile was reached at 0650 whereupon we altered course to begin a parallel track, ten miles to the west back to the south.

At 0600/006 two 161 (1000 ins^3) airguns, a 0.641 (40 ins^3) airgun and the array were deployed in order to begin a combined seismic reflection/refraction profile south of position B13. At 1424 a disposable sonobuoy was deployed, and again at 0353/008. Profiling continued until 1609/009, except for a few gaps while leaks in the 0.641 gun were repaired.

At 1510/009, after a two hour wait for crane repairs, Tovex drums were brought up from the Main Magazine in preparation for shooting the following day. Seismic reflection operations were abandoned to allow the Tovex packages to be assembled on the after-deck. We finally got underway again at 1945/009 en route for shot-point S4 which was reached at 0630/010. Final preparations were made while hove to and the charge, consisting of two 1800 lb packages each of three drums in a rope net suspended from a cluster of surface floats was fired at 1008. Once all the firing cable and rope were inboard (at 1150) we got underway for shot-point S2, a second 2 x 1800 lb shot, which was fired at 1652. When all the shooting gear was inboard again at 1925 the seismic profiling equipment was deployed and a profile obtained along the line of shots proposed in that area. Profiling ended at 0230/011 and the ship returned southwards to the vicinity of shot-point S3. However on attempting to bring up drums of Tovex from the Main Magazine at first light it soon became clear that there was too much ship motion for safe shot firing. The shot was therefore postponed and the first refurbishment of the LADLE array was begun from south to north starting at position B2. On arriving at B3 we were prevented by the Captain from recovering that buoy at night on account of the sea conditions. The ship hove to until first light the next day. At 0610/012 the wind and sea had increased to 35 knots and 2.6m respectively so that we proceeded northwards to the next buoy. There was no improvement there but after two hours at B5 the weather moderated enough for the Captain to agree to a recovery attempt. This was accomplished by 1805. We then steamed slowly to B6, to avoid a night-time recovery and recovered the OBS at that point by 0643. At B7 there was some delay while the OBS data tape from B7 was examined before deciding on new event detection parameters. OBS/PUBS recovery and redeployment continued northwards during days 013 and 014. At B10 OBS D was recovered and not replaced until 0016/015 as the ship returned to the south. Thence we got underway to B5 to begin to relay buoys southwards at those positions where poor weather had earlier prevented us from doing so. B3, the final position, was reached at 0845/016. Unfortunately the OBS at this position could not be released acoustically.

At 0948/016 we began to deploy packages of Tovex for shot S3 which was to be a 5 x 1800 lb shot. When three packages had already been floated away and a fourth was hanging below the stern the furthest package began to sink pulling the dan buoy with it. Quite rapidly the floats of the other two packages sank. The fourth package was cut away and then the lines to the first three packages

were also cut. The ship got underway and seven minutes later there was an underwater explosion probably caused by self-initiation of a detonator under hydrostatic pressure. The fifth and last package, which was still on deck, was deployed and fired by itself at 1439. Passage to B2 was resumed at 1520 and the OBS there was released at 1800 and recovered $2\frac{1}{2}$ hours later. A velocimeter dip was then attempted but was abandoned due to a faulty instrument. The ship returned to OBS A at B3 to await release of the buoy by its back-up clock, but this did not occur, and a second OBS was laid in its place. At 0842/017 OBS A was abandoned and a course set for San Juan, Puerto Rico which was reached the following day at 1240.

While in San Juan contact was made with two US Naval officers who had been detailed to provide information about a large naval exercise due to take place during Leg 2 in the LADLE area. These naval activities severely constrained our plans for Leg 2 and led at short notice to some changes in the scientific planning.

Leg 2. We cast off from the Army Terminal, San Juan, having loaded 30 drums of Tovex, at 2215/021. The PES fish and magnetometer were streamed by 0930 next morning on passage to position B3 which was reached at 0815/023. Attempts to release OBS F acoustically at B3 were unsuccessful and a wire-test of two sediment trap acoustic releases was begun while we awaited for the OBS F back-up clock to release. Shortly after the test was begun however an OBS beacon was heard on the radio; the test was immediately stopped and as soon as all the gear was inboard a search for the OBS was begun. Once it was on board at 1324 it was then prepared for relaying at B3, this being completed by 1743.

The next several days (upto early on Day 027) were spent in refurbishing the OBS/PUBS along the LADLE array for the second and last time. The interval from B3 to B4 was re-shot with two 161 airguns, the Leg 1 recordings of this profile having been of poor quality. OBS E at B5 could not be released acoustically and had to be temporarily abandoned until its back-up clock should operate. This meant that no OBS/PUBS was available for laying at B6. The PUBS recovered at B9 was not immediately replaced to gain time for the preparation of the replacement buoy. The interval from B11 to B10 was re-shot with two 161 airguns on the return south down $61^{o}30'W$ for the same reasons as above. At 1503/026 an OBS was laid in the gap left at position B9 and similarly a PUBS was laid at 0206/027 in the gap at B5.

From B5 the ship proceeded to shot position S1A which was reached at 0830, the Tovex explosive having been brought on deck en route. Shot 1A, a 4 x 1800 lbs shot, was fired at 1346. On beginning to recover the firing cable and floats however it was found that the third charge laid had not detonated. This charge was cut away at the rail and immediately the ship steamed at full ahead for five minutes towing the remaining floats and dan buoy astern. Gear recovery was then resumed without incident and ended at 1535. For the next hour and 40 minutes a fore-and-aft calibration of port and starboard e/m logs was carried out in near calm conditions.

On completion of the log calibration the ship hove to at B5 to await the back-up clock of OBS E. In the meantime a second attempt was started at 1759 to carry out an acoustic test of the sediment trap release units. This time at 1910 the OBS at B5 was noticed to have lifted off from the bottom. The test was stopped and only resumed at 2005 after OBS E had been recovered, finally ending at 2235.

The ship hove to until dawn the next day to rest the large team of people involved in the shooting operations. At first light enough drums of Tovex were brought on deck for shot S1B which was to be a 5 x 1800 lb shot. This shot was deployed without incident and, after a minor firing circuit difficulty, was fired at 1458/028. Once all the firing gear had been recovered the shortened sediment trap mooring was laid in a depth of 5830 u.c.m. and the ship then got underway to shot-point S11 just mid-way between, and east of, Barbuda and Antigua.

This relatively long passage was made even longer by the fact that we had to sail around the circumference of the naval exercise area. En route the 4.81 (300 ins^3) airgun was used to obtain shallow seismic refraction data from disposable sonobuoys, as well as a reflection profile.

Shot-point S11 was eventually reached at 1200/030 and the charge was fired at 1311. On recovering all the firing gear course was set for A1 to recover the first laid Blacknest OBS. This was reached at 2225. A short seismic reflection survey was executed before the buoy was released. On recovering the OBS at 0539 course was then set for position A2 which was reached at 1323. Attempts to release this Blacknest OBS acoustically were apparently to no avail and after steaming a search pattern in the early evening, to ascertain that the

buoy had not surfaced, a reflection profiling survey was carried out until 0236/032 shortly before the OBS's back-up clock was due to operate. On returning to the A2 position the OBS pinger was found to have switched on one hour early at 0300 (due to an error in the back-up clock setting) and to be indicating that the OBS was surfacing. OBS 6A was recovered at 0530 and passage resumed to position B1.

B1 was reached at 2322/032 and OBS 5A recovered by 0235/033. The next three days were spent recovering all the remaining OBS/PUBS from south to north along the LADLE array at the rate of three to four buoys per day. This procedure went smoothly until we reached the last OBS at B13 at 1838/035. A prolonged unsuccessful attempt to release it acoustically was abandoned at 2050 in the face of a gale blowing and a rising sea. A fresh attempt was made next morning at 0227/036, shortly before the back-up clock was due to release the buoy, and this succeeded. OBS 4A was on deck at 0515 and the ship began its long passage to the south where the remaining scientific work was to be carried out.

Due to our delayed departure from B13 it was doubtful whether we would reach the position of the penultimate shot before sunset on Day 038. Therefore permission was sought from RVS to increase speed by using three engines and this was granted the following morning.

At 1300/037 we briefly hove to over position B3 and confirmed that OBS A was still on the sea-bed and could not be released. On departure three engines were brought on line and we steamed at full speed until shortly before reaching shot-point S14 at 1330 the next day. Shot 14 was fired at 1519 and we departed at 1602. En route to S12 (the last shot) two French OBS were laid. These buoys formed part of a set of five which were to be laid by Discovery and recovered later by a French naval vessel. They were laid to enable a study of regional seismicity to be made.

The final shot was prepared at first light on Day 039 and fired by 1034. Two further OBS were laid at 1659 and 0005/040. Discovery tied up in Bridgetown's Deep Water Harbour Basin at 1100 the following day.

PRESSURE TESTS OF NERC 28-INCH DIAMETER SPHERES

The OBS operated from Discovery all used 28-inch diameter aluminium alloy

forged spheres (IOS design 4994) for the OBS instrumentation. These spheres were originally designed for depths not exceeding 5000m and had only occassionally been used at slightly greater depths. Since within the working area for LADLE the sea-depth mainly lay in the range 5600 to 6200m a special series of tests was carried out in the IOS high pressure vessel at Wormley to determine whether the spheres could be used at depths down to 6000m.

The results of these tests have been published in IOS Report No. 75. The main conclusion was that only selected and especially tested spheres should be used to depths not exceeding 6000m. The spheres decreased in volume by 1.5 litres at 6000m and the consequent gain in buoyancy (since water is more compressible than aluminium) is 0.63 Kg per 1000m depth increase.

As a result of the above tests all the French OBS and Wormley PUBS spheres were tested in the pressure tank at Wormley before the cruise.

R.B.W.

OCEAN BOTTOM SEISMOGRAPHS

Ocean-bottom seismographs from Institut de Physique du Globe, Paris

These instruments are housed in standard NERC 28-inch diameter spheres. The release of the ballast is effected by firing a miniature detonator, which breaks the vacuum holding the sphere and ballast weight together. The OBS are fitted with an acoustic system (made by Suber, France), which can act both as a transponder and to receive a command to fire the detonator, and with a radio beacon and flashing light. Three independent systems (one acoustic and two activated by clocks) each enable one of the three detonators to be fired. The possible entry of water into the sphere or the vacuum space is detected and causes immediate release of the ballast weight. These instruments contain a vertical L22 Mark Products geophone (fn = 2 Hz). The digitised signals (62 words/sec) pass through a shift register for 15 seconds. An event detector sets in motion the recording of the signal on a Uher cassette tape-recorder modified by an auto-reverse system which can operate during the recording. Ninety minutes of continuous recording are thus available giving 360 windows of 15 seconds. In this system the signals are kept free of the noise caused by the rotation of the tape-recorder which is stopped while the signal is being fed into the shift register memory. After 15 seconds of recording the tape-recorder can be triggered afresh by an S-phase or by a water-wave in the case of a shot. On leaving the

memory the signal is reconverted to an analogue signal with automatic gain control. A dynamic range of 72 dB is thus obtained. Recording on the tape is F.M.

This cruise was the first time the equipment had been used in the Atlantic. Previously satisfactory results had been obtained in the Mediterranean where 34 drops had been carried out in depths of less than 3800 metres. An instrument was lost on the 33rd drop.

Difficulties encountered during the present cruise

One OBS was lost: laid on January 1st in 5800 metres, it was not able to be recalled either acoustically or released by its clocks. On February 6th the transponder was still working. We believe there is a minor fault in the design of the vacuum chamber, which we have since modified in the other five OBS. It should be noted that this sphere, which was the first one purchased by IPG, Paris, was distinctly lighter in weight than the standard sphere tested to 6000 metres. It has withstood a pressure significantly greater than that initially planned.

The settings of the event detectors used in the Mediterranean were found to be too sensitive to transitory noises, probably of biological origin (20 Hz pulses and taps directly on the outside of the instrument) in the Atlantic. The adjustment of this setting was delicate because of concern to maintain sufficient sensitivity to trigger shot recordings. However progress was made. While for the first set of lays the OBS recorded on average for 12 hours this was 5 days for the second and third series.

After just one lay an OBS surfaced without the recorder having operated probably as a result of an incorrect program initialisation.

Data obtained

Out of the 15 lays, 12 gave useful recordings. From January 7th to February 2nd continuous monitoring on the sea-bed was obtained with at least one recorder operating. A total of 115 different (seismic) events was recorded of which eleven were recorded on two OBS, 13 on three OBS and one on four OBS.

It seems, as was expected, that the majority of signals came from the south of the profile but other directions of propagation are also observed. In addition it appears that the seismicity is very variable during the observation period.

The greatest activity seems to have occurred on January 16th.

L.S., C.A-H., F.F.

Pop-up bottom seismographs (PUBS) of IOS Wormley

This was the first cruise that eight-day recording tape-recorders were used in all the PUBS. The instruments were prepared in San Juan and all five laid during the first traverse of the refraction line. Upon recovery of the instruments one of the tape-recorder motors had failed completely and two other tape-recorders had failed to record, one due to a logic fault and the other due to part of the drive mechanism which had become detached inside the tape-recorder. Of the three tapes recovered from the first traverse only one tape was satisfactory whilst the other two tapes exhibited regular noise (data 'drop outs'), in one case upto the point where the motor on one of these failed completely. These 'drop outs' were attributed to periodic slipping of the drive mechanism due to the deposition of aluminium on rubber drive wheels where they were in contact.

As there were no spare motors aboard ship only four PUBS could be deployed for a second time on the refraction line. Replacement motors were requested by telegram from the ship, however these could not be despatched in time to reach the ship before it left San Juan after the mid-cruise port call. The four PUBS were recovered after the San Juan port call and again from the records recovered motor failure and tape drive slippage were evident. One good record was obtained, two records had unacceptable 'wow and flutter' due to sticky motor bearings and the fourth had drop outs which increased as the tape ran due to tape slip.

For the third deployment along the refraction line two of the four PUBS had to be laid with the tape recorders running as the motors would not start without assistance. This proved to be worthwhile as one of these tape-recorders produced the best record of the four although the other motor failed within a few hours. The last two records suffered from wow and flutter, and drop outs.

For the experiment as a whole only twenty-five per cent of the data expected was satisfactory and another fifty per cent was of such poor quality as to be of little use. Another twenty-five per cent of the data was completely lost due to tape-recorder failure. The success rate of recording shots was greater however since most shots were fired near the start of the recording periods.

If a suitably robust and reliable motor can be found, and perhaps the use of harder metal or even a redesign of the drive mechanism can be made to improve these tape-recorders, good PUBS records can be obtained.

Apart from the tape-recorders the instruments functioned well with only one i.c. failure preventing a tape running. All the buoys were recovered acoustically with only one transponder failure, which was noticed just after deployment and did not affect the release circuitry. Once on the surface all the buoys were located with either the flashing light or the PUBS sonobuoy radio beacon, and brought inboard with the minimum of drama.

For this experiment the ship's Watesta clock was used as a local standard for the individual PUBS clocks while the Watesta clock was checked in turn against radio transmitted time signals. This left the PUBS ship clock free for replaying data tapes.

R.E.K.

Ocean-bottom seismographs of IOS, Blacknest

OBS 3A and 6A were to be used to extend the UWI islands-based seismic array out to sea. OBS 5A, 7A and 4A were positioned on the north-south refraction line.

All the instruments had been modified for the LADLE experiment to enable them to record for $30\frac{1}{2}$ days and to be programmeable such that the tape-recorder start delay could be set for up to 96 hours in one-hourly steps. OBS 7A had the IGS type of hydrophone; the other OBS were fitted with USNRL type H58 hydrophones. OBS 3A and 6A were fitted with Sprengnether three-component seismometers with a natural period of 0.1 sec. OBS 1A, 5A, 7A were fitted with 3 component Sprengnether seismometers with 0.5 sec natural period.

On recovery OBS 3A, 6A and 7A were found to have operated successfully and the tape-recorders ran for the expected time. The tape-recorders in 5A and 4A had not started, the fault being tentatively ascribed to the misalignment in its socket of the printed-circuit card that controls the programme. The misalignment is possibly caused by a flexing of the electronics bridge due to hydrostatic pressure (at this depth the RR77 hemispheres and ring shrink by 2.3 mm on the diameter) combined with low temperatures. Both OBS operated perfectly when tested in the lab at 2500 times real time immediately after recovery. Preliminary

replaying of the data ashore suggests that the data is of good quality.

The coded clocks in the OBS all operated satisfactorily, OBS 3A showing a slightly faster drift rate than the others but all are acceptable. The "Jelly-Bottle Compasses" all worked well, all recording negligible tilt on the bottom, with the exception of that on OBS 7A which recorded a tilt angle of 11°. The syntactic foam buoyancy withstood being used at 6000m. Ascent rates of the OBS were 0.8m/sec, descent rates 1.4-1.6m/sec. At the surface the syntactic foam presented a very good visible target. There was no cracking of the foam and no obvious water uptake.

Recoveries of all the OBS were difficult due to problems with the Acoustic Command Systems. OBS 3A had a "dead" beacon board on recovery, OBS 4A would not reply in the transpond mode and was only released after many attempts, OBS 5A could not be reset into transpond mode after release, OBS 6A was recovered on the back-up clock after attempts to release it acoustically had failed, OBS 7A was not "seen" acoustically due to excessive power consumption by the beacon board and consequent draining of the battery pack. These releases had operated well in the Median Valley of the N. Atlantic but in four out of five cases on this cruise the receive electronics were not switching from beacon to transpond mode although the releases had worked.

Getting the OBS inboard was relatively easy with a snap-on hook. None of the OBS was damaged on recovery, despite one recovery in force 6 seas.

This was the first time the Blacknest OBS had been operated to its full potential both as regards duration of recording and depth of deployment. The three OBS that worked indicate that the instrument is viable and when the problem of the failure of the tapes to start up is remedied we hope for a much improved success rate.

I.T.P.

EXPLOSIVE LOADING INTO THE MAIN MAGAZINE

For logistic and economic reasons it was decided to use drums of DuPont Marine Grade Tovex Extra for the large shots to be fired for LADLE. These drums could only be stored in Discovery's Main Magazine. Since each drum weighed 300 Kg and was approximately 60 cm high by 89 cm diameter there was a considerable problem regarding the handling, stowage and unloading of the drums, in particular because

of the low headroom within the magazine. The problem was overcome by designing an external conveyor for the Forward Hold and an overhead rail system for within the Magazine. Handling from the foredeck to the forward hold was accomplished using the ship's crane and a set of drum tongs.

The conveyor system comprises a deck roller-conveyor which runs from under the loading hatch at the forward end of the hold to the entrance of the Main Magazine, and is fixed to the deck. There is a removable section which extends the conveyor through the path of the outward opening magazine door to just over its threshold, and a further removable section which extends a short way into the magazine. A purpose-designed wooden pallet runs on this conveyor to transport the 300 Kg drums of Tovex explosive, which are lowered by crane into the hold, to just inside the magazine.

From here each drum is lifted up with a compact hand-operated hoist, which is attached to the carriage of an overhead track conveyor. This conveyor has three turntables to rotate the carriage through approximately 98° in the horizontal plane and so allow the drums to be loaded into the magazine in three rows and stacked two high. Total capacity of the magazine is 28 drums. The carriage has a fail safe hand-operated brake which is applied automatically, immediately a downward pull is removed, by four strong springs.

The steel RSJ track and turntables, on which the carriage runs, were installed during the refit in South Shields (November 1979), but several hours were spent at sea (Cruise 106 - December 1979) working on improving the alignment of all the tracking, both in the vertical and the horizontal planes; entailing the drilling or elongation of several holes; making, inserting and removing of spacers and the locking of all the nuts and bolts with either locking washers or split pins. Three cylindrical guards were fitted to the turntables to prevent any possibility of the carriage coming off the turntables during rotation. Stops were also added to the turntables to limit their rotation to just the degree required. Provision was made for two bolts to be slipped into each turntable as an additional safety feature for stopping the carriage in event of the brake proving unable to stop the involuntary movement of the carriage when used in other than calm sea conditions.

The carriage was originally designed to have the load attached to the side of it, due to very limited head room, and as a consequence the load was taken out on the track by two nylon wheels running on the underside of the top flange of

the RSJ, whilst the other two nylon wheels ran on the top of the lower flange diametrically opposite.

However, when the carriage was loaded and tested, using a drum filled with water to approximate the load in normal use, the carriage tended to jam. This was partly due to reducing the diameter of the four nylon rollers so that they ran easily in the RSJ track. Small rollers were added to the corners of the carriage to overcome the jamming but with only limited success. These were replaced by two brass guides which ran the length of the carriage and were fixed to it in line with the bottom flange of the RSJ and either side of it. These guides can be adjusted, by means of packing, to increase or reduce the clearance between the RSJ track and the carriage guides.

It was decided to abandon the side loading of the carriage in favour of loading it and the track on the centre line. However, this could only be done if it was possible to save height elsewhere as already there was only about 75 mm clearance between the top of the top drum, when stacked two high, and the underside of the hoist and drum ring when raised to their maximum position.

This nominal 75 mm clearance was maintained by completely re-designing the central cross of the drum ring to reduce its overall height. This drum ring had already been modified by reducing the height of the attachement point and redesigning it to take the chain of the hoist direct, and so gain more clearance by doing away with the hook on the hoist. The lack of height problem was the biggest factor to have to contend with in the design of the overhead conveyor system.

The whole system was tested on 22nd December 1979, again using a simulated load of a drum full of water, and it was found to be very satisfactory.

Finally, the Periscope Valve etc., at the forward end of the hold was boxed in to prevent any possibility of damage from the drums, or any other equipment, etc. when being lowered into the hold.

The drum handling system proved to be practical at sea and survived the rigours of handling 54 drums in and out of the Magazine, sometimes with appreciable ship motion.

N. Timmins, R.B.W.

SHOT FIRING

Twenty tons of explosive type Marine Grade Tovex Extra (Class B) were supplied by DuPont de Nemours & Co., together with primers type HDP1, and were loaded in San Juan in two visits, one at the commencement of the cruise and the other at the mid-cruise break. This was due to stowage limitations in the ship. Also on board were two tons of Geophex transported by Discovery from the UK.

Shot firing was done electrically using two Admiralty-pattern 79 Mk.I electric detonators, one placed in the DuPont primer and the other in the stick of Geophex, this being sandwiched in a vertical position between three drums (1800 lbs net) of Tovex strapped together using steel banding and suspended by means of a net at a predetermined distance of 120m below the surface. The weight was supported by a number of inflatable buoys. For shots larger than 1 ton, additional charges were made up and spaced 30m apart in order to prevent interaction of the gas bubbles. The original programme called for 1 x 1 ton; 2 x 2 ton and 1 x 5 ton on the first leg and 1 x 8 ton, 4 x 1 ton on the second leg (here "1 ton" means 1800 lb).

The first three shots were successful although the time taken to assemble, stream and recover the gear was protracted due to these being the first occasions on which this American explosive had been used by all concerned. As engineering drawings of the drums were not available it had not been possible to construct dummy charges for prototype and drill purposes - a most advisable precaution when working with large suspended bulk and weight of explosive over the heaving deck of a vessel in a seaway.

The first five-ton shot had to be abandoned during the laying of the fourth charge. It was noticed that one of the group of three buoys supporting the first charge had broken loose. The two remaining buoys and their associated charge eventually sank dragging the two remaining buoyed charges and dan buoy with them. These were cut loose when almost vertically under the stern of the ship and allowed to sink. Shortly afterwards a submerged explosion was experienced. It seems likely that one or more of the 12 jettisoned drums of Tovex imploded at great depth. The remaining 1 ton charge was streamed and fired successfully one hour later.

After the mid-cruise port-call, when the remaining 10 tons of Tovex were loaded, it was decided that the Tovex shots would comprise 1 x 5 tons, 1 x 4 tons and 1 x 1 ton and this schedule was successfully completed apart from a partial misfire on

the 4 ton shot of 1 ton, probably due to the detonator being pulled out of the charge due to surge and rope elasticity. This unfired package was cut loose on recovery and the ship steamed immediately to a safe distance prior to completing gear recovery. The time taken to prepare lay and fire the charges became progressively less as everyone became more familiar with procedures.

The two tons of Geophex, were fired as two 900 Kg shots at the end of the cruise, each shot consisting of two packages of boxes strapped directly onto wooden pallets and suspended as described above.

During the preparation of the initial 1 ton Tovex shot it became apparent that the charge suspension rope from the buoy was inadequate in that it had an insufficient safety factor to cope with hydraulic dynamic forces of "dunking" the charge and buoys in the considerable sea and swell at that time, and whilst on deck or hoisted over the stern. Recourse was made to ship's stores for a stronger dropper rope and a further 1200 ft was purchased in San Juan to replace the cordage jettisoned with the aborted 5-ton shot mentioned above. Replacement of the lost inflatable buoys and provision of reserve buoyancy for each one-ton charge was achieved by the purchase of oil drums in Puerto Rico. Buoys and drums were thereafter clustered in nets of four per ton charge, the nets being made on board.

The shot instant in nearly all cases was obtained by firing a detonator + $\frac{1}{4}$ oz of Geophex positioned 20m deep over the ship's side as near as possible to the echo sounder fish and fired in series with the main detonator circuit. The audio output of the PES fish was recorded onboard alongside time marks from the ship's Watesta clock.

C.C.M., D.B., I.T.

WATESTA CLOCK TIME CHECKS

The reference clock for all OBS, PUBS, airgun shot times on this cruise was the Watesta master clock system. In order to calculate the drift rates of the internal clocks of the OBS during the laid periods and to provide accurate shot instants the drift rate of the Watesta clock had to be known and this was achieved by comparing the clock one minute mark with a known minute mark from a radio time signal, either WWV (5, 10, 15 MHz) or BBC (5.91 MHz). The two marks played out simultaneously on the Oscillomink jet pen recorder with a paper speed of 100 mm/sec; times could be read to $\pm$ 5 msecs. The clock was monitored daily for the period

361/1979 to 038/1980. Over this period the clock drift rate was found to be + 10.2 msec/day and to be consistent. The graph in Figure 5 gives the value of the time correction to be applied versus day number.

I.T.P., R.C.L.

RADIO COMMUNICATIONS

The work at sea required a frequent flow of information between the scientists on CSS Dawson (CGBV) and those on RRS Discovery (GLNE). This was achieved using an intership assigned frequency of 8292.5 kHz twice a day. The morning schedule was at 0830 and the evening schedule at 1830. The evening period was sometimes curtailed due to static. Generally the frequency was workable but it was also quite heavily used by other ships.

Ship-to-shore communication was less vital but an attempt was made to keep in daily contact with the centre of the island network on Montserrat (VP2MI). Discovery again transmitted on the intership frequency 8292.5 kHz (and listened on the Bridge receiver) and Montserrat transmitted on 7200 kHz. Initially communication was impossible because of a fault in the receiver at Montserrat. Once this had been repaired communication was possible but at ranges not exceeding about 500 kms. Discovery could also monitor conversations between Montserrat and Trinidad again on 7200 kHz. This system, although imperfect, allowed the exchange of very useful information between Montserrat and the two ships.

R.B.W.

NAVIGATION

The prime navigational aid throughout the cruise was the Transit Satellite system with dead-reckoning between fixes provided by the gyro and two-component electromagnetic log.

The satellite navigator performed well with the exception of two occasions (one at the turn of the year) when the program required reloading. The Magnavox MX1107, temporarily installed as a standby system also behaved well. Speed and heading were entered manually on the MX1107. The fixes from the two systems usually agreed to within 1/6 mile and rarely differed by more than 1/3 mile.

The frequency of passes was usually adequate, despite there being only four satellites operational. However, on a few occasions there were gaps of up to

10 hours between acceptable fixes.

The starboard electromagnetic log was used throughout the cruise for navigation. During the cruise the fore-aft calibration factor was adjusted by 11.5% (Day 022) and the signs of the athwartship velocities, which were inverted, were changed.

J.S., C.P.

PRECISION ECHO-SOUNDER

The echo-sounder fish and Mufax were used continuously during the cruise not only for echo-sounding but also for acoustic monitoring of the IOS OBS and PUBS transponders. The "single element" in the fish was used to transmit the various command frequencies generated by an IOS Deck Unit. No problems were experienced with the Mufax. PES fish No. 2 was used throughout. On the approach to San Juan (Day 018) some fairing was damaged by a piece of fishing net but this was repaired.

R.B.W.

MAGNETOMETER

The magnetometer system did not function correctly when first streamed and showed the large variation in total magnetic field values reported from Discovery 106. The Pre-Amp and Relay Board was replaced and the system operated well for the rest of the cruise. The new IOS outboard cable with sensor 'B' and a new RVS outboard cable and sensor were used on different occasions.

Consistent negative anomaly values were investigated and revealed that the field readings were being reduced using the 1965 IGRF. 1975 IGRF coefficients were sent to San Juan and implemented during the second leg. All the cruise magnetic anomaly values were then recomputed. It appears that since 1975 all Discovery magnetic anomalies may have been computed using the 1965 IGRF.

P.R.M.

GRAVIMETER

The LaCoste and Romberg gravity meter (S84) had been used on M.V. Starella during the autumn and had been "off heat" while kept in store in San Juan. The meter was installed, run up and the usual checks made a week before the first leg out of San Juan. The meter operated without any apparent problems during the first leg, except for half a dozen 60 Hz mains failures to the console box from the ship's DC rotary convertor. Each power failure caused loss of up to two hours

data while the system was run up and settled.

During Leg 1, in the absence of a computer interface to the IBM 1800, analogue records were hand digitised every ten minutes and fed into the computer via paper tape. On return to San Juan the meter was shown to have an exceptionally high mistie of 12 milligals. There being no evidence of a tear during the first leg the meter appears to have had a high drift rate possibly due to being "off heat" for a month before its use.

During the first week of the second leg several interface problems were encountered with both the shaft encoder interface and the TTL-to-computer interface sent from Barry. After construction of a new TTL-to-computer interface digital gravity data was successfully logged without problems for the remainder of the cruise.

The main chart drive motor on the analogue recorder failed during the latter part of the second leg and the chart was run on slow speed for some time until its eventual repair before the ship's arrival in Barbados. There were no power failures on the second leg.

The mistie at Bridgetown, Barbados was 6.3 mgals, corresponding to almost half the drift rate, but with the same sign, experienced during leg 1, thereby supporting the contention that the drift was due to the meter having been 'off-heat' for most of December.

Ties to land stations were carried out using a Worden Educator gravimeter kindly loaned by the Institute of Geological Sciences.

C.P.

SEISMIC REFLECTION PROFILING

During Leg 1 two 161 (1000 ins^3) airguns were fired every two minutes at about 2000 psi for 77 hours. At the same time a 0.641 (40 ins^3) gun was fired every ten seconds. Later on in the cruise some short lines were run using either a 0.641 or a 4.81 (300 ins^3) gun. The compressors gave little trouble provided the throughput demanded was not too great or too small. The IOS guns kept extruding chamber 'O' seals due to wear on clamp and mating surfaces and top housings had to be remachined and skimmed because of wear. Initially the hydrophone capstan was completely seized up and had to be disassembled so that the roller bearings

could be freed. Both analogue and digital recording was trouble free and it was possible to further develop the digital logging routine to make it more flexible and to remove some jitter on playback.

C.F.

DISPOSABLE SONOBUOYS

Six sonobuoys stations were successfully occupied but in addition two buoys failed to operate on deployment. During Leg 1, the buoys of stations 1 to 4 monitored the 0.641 gun at 5 kts producing adequate signals for at least $2\frac{1}{2}$ hours and good trace to trace correlation records but poor refracted arrivals. The 161 gun source was fired every two minutes during these stations. During Leg 2 the 4.81 gun was used for the sonobuoy stations. The PUBS aerial positioned on the Monkey Island port lighting stantion and facing aft was used for reception. This was satisfactory. The only console malfunction was the band selector not operating on the Eddystone receiver.

P.R.M.

QUANTITATIVE UNDERWAY GEOPHYSICAL OBSERVATIONS

Depths were measured using an IOS Mk III Precision Echo-Sounder using an assumed sounding velocity of 1500 m/sec and a fish depth of 5m. These depths were corrected according to Carter's tables (unpublished).

The total magnetic field was measured by a Varian V75 proton magnetometer towed 750 feet astern. Magnetic anomalies during Leg 1 were initially calculated relative to the now outdated International Geomagnetic Reference Field (IGRF) 1965. However this error was discovered during Leg 1 and rectified on receipt of the IGRF 1975 coefficients at the mid-cruise port call. All magnetic anomalies now held in computer data files for this cruise were calculated relative to IGRF 1975. It appears that contrary to the view held on earlier cruises the IGRF 1975 may never have been previously implemented on the Discovery IBM 1800 system.

Gravity was measured by the LaCoste Romberg marine gravimeter S84. Free-air anomalies were calculated with respect to the 1967 International Gravity Formula and to tie-ins to land base stations at San Juan, Puerto Rico and Bridgetown, Barbados linked to the International Gravity Standardisation Network, but have not yet been corrected for drift of the LaCoste Romberg meter.

R.B.W.

SHIPBOARD COMPUTING AND DATA LOGGING

The IBM 1800 ran throughout the cruise recording navigational, geophysical and meteorological data and was used extensively for data editing, plotting, listing, display of live track in the plotting office, and for program development.

Data processing was performed largely on a daily basis, and the following plots and listings were produced:-

Mercator track plots, scale 1:1,000,000 for track annotated with fixes, soundings (corrected metres), free-air gravity anomaly (F.A.A.) and magnetic anomaly.

Profile plots, versus time, of gravity F.A.A. and magnetic anomaly profile plots, along annotated track, of gravity F.A.A.

A series of A4 size track plots, scale 1:1,000,000 for the whole cruise.

A series of 75 track plots, annotated with depth for each pass over the buoy positions, scale 1" to 1 n.m.

Listings of all edited navigation, gravity, magnetic, and depth sounding data.

A program to enter gravimeter readings from paper tape was written and used until the gravimeter interface was connected during the second leg.. The program (GRVEN) interpolated linearly for values entered at intervals of ten minutes or less to produce two minute values for storage in File CDAT. Program GRAVY was then run to calculate the Eotvos correction and F.A.A. GRVEN has been included in the ship program library.

It was found that subroutine RGMAG had not been updated to include the 1975 International Geomagnetic Reference Field coefficients. These were installed for the second leg. Magnetic anomalies for the first leg were re-calculated using a specially written program (MAGGO).

Echo-soundings were corrected according to the (yet unpublished) tables compiled by D.J. Carter. New software to do this was installed for the previous cruise.

The port electromagnetic log was unservicable at the start of the cruise, so the starboard log was used throughout. After a few days it was estimated that

the fore-aft component gave readings 11.5 percent high, so the computer calibration was adjusted accordingly. On 22nd January, it was noticed that the athwarthsips components of both logs were inverted on the displays and on the computer inputs. The computer inputs were reversed to give the correct values. A series of comparison runs were made at 4, 7.5 and 10.5 knots in calm conditions with no wind. Using program EMMS the port log, which had by now been repaired, fore-aft calibration was adjusted to give correspondence with the starboard log. An estimate of the misalignment angles was also made.

The IBM 1800 performed very reliably throughout the cruise with no major hardware or software problems. However during the first few days the air-conditioning system gave severe problems and the computer was run continuously at a temperature close to its safe operating limit (95 deg. F.) After one of the Voyager units was replaced satisfactory operation was attained though on occasions the temperature subsequently rose to 75 deg. F. The efforts of the ship's engineers are gratefully acknowledged.

Because the cruise spanned the turn of the year it was necessary to start an 'artificial leg' on January 1st. The data files are therefore divided into three legs. Leg 1 29-31 December 1979, Leg 2 1-18 January, Leg 3 22 January-9th February.

J.S.

METEOROLOGICAL OBSERVATIONS

Meteorological observations were carried out daily at sea throughout the cruise as near to midday as watchkeeping duties allowed. 1200 local time (1600 GMT) was used as it was more practical than 12.00 GMT and middle of the day temperatures were in general more indicative of overall weather patterns. The officers on the bridge kept the main ship's weather log at 0600, 1200, 1800, 0000 GMT which was sent to Washington D.C. This log compares favourably with the computer print out on the IBM 1053 terminal. An edited part of this log is in the scientific log.

Weather in general was good for scientific purposes with calm seas and skies. On the first leg the collection of the first lay of buoys was affected by a storm, and several buoys were passed over to be collected later. At the end of the collection of the LADLE buoys, the ship was caught in the edge of a storm (centre 66 °W, 30 °N). Very little rain fell throughout the cruise, only occasional

showers late at night. Humidity in general fair though noticeably changed south of 20° latitude.

Events noted during the cruise,

16th January, heavy rainclouds showed up on ship's radar
2nd February, strong squall with low visability at 17.40
4th February, storm clouds throughout day. Electric storm in evening.
7th February, very high humidity (Rel.100%) throughout morning accompanied by 5 minutes of lashing rain.

S. O'F.

SEDIMENT TRAP MOORING

An IOS sediment trap was deployed during the cruise for Dr. W. Simpson at position 23°43.5'N, 61°29.7'W for subsequent recovery during cruise 108. Due to the ship's schedule there was not sufficient time to deploy a full mooring in the area requested. Therefore a shorter mooring consisting of a release, a sediment trap, and deep water buoyancy were laid in a water depth of 5800m. Prior to deployment the acoustic release/beacon were wire tested, using the electric winch, at a depth of 5000 metres.

R.E.K.

SCIENTIFIC PERSONNEL

R.B. Whitmarsh	Principal Scientist	IOS, Wormley	Legs 1, 2
R.N. Bonner	Airguns, compressors	IOS, Wormley	Legs 1, 2
M. Donegan	PUBS, geophysics	IOS, Wormley	Legs 1, 2
C.G. Flewellen	SRP	IOS, Wormley	Legs 1, 2
Miss R. Glosby	Geophysics	IOS, Wormley	Legs 1, 2
R.E. Kirk	PUBS	IOS, Wormley	Legs 1, 2
P.R. Miles	Geophysics	IOS, Wormley	Leg 1
Miss S. O'Farrell	Geophysics	IOS, Wormley	Legs 1, 2
R. Lilwall	OBS, geophysics	IOS, Blacknest	Leg 1
I.T. Porter	OBS, PUBS	IOS, Blacknest	Legs 1, 2
C. Tew	OBS	IOS, Blacknest	Legs 1, 2
C. Paulson	Gravimeter	RVS, Barry	Legs 1, 2
J. Sherwood	Computer	RVS, Barry	Legs 1, 2
C. Antenor-Habazac	OBS	IPG, Paris	Legs 1, 2
L. Steinmetz	OBS	IPG, Paris	Legs 1, 2
F. Ferucci	OBS	IUN, Naples	Legs 1, 2
D. Baty	Shot firing team	Unaffiliated	Legs 1, 2
C.C. Moore	Shot firing team	Unaffiliated	Legs 1, 2
I. Thomas	Shot firing team	Unaffiliated	Legs 1, 2
R. McNab	Computer/observer	BIO, Dartmouth Nova Scotia	Leg 2

IOS = Institute of Oceanographic Sciences

RVS = Research Vessel Services

IPG = Institut de Physique du Globe

IUN = Istituto Universitario Navale

BIO = Bedford Institute of Oceanography

SHIP'S OFFICERS

P. Maw	Master
K. Avery	First Officer
S. Sykes	Second Officer
T. Harrison	Third Officer
C. Latter	Chief Engineer
T. Rees	Second Engineer
J. Richardson	Third Engineer
R. Whitton	Fourth Engineer
G. Gimber	Fifth Engineer
G. Greene	Electrical Engineer
D. Taylor	Radio Officer
R. Morris	Catering Officer
S. Carrs	Doctor

ACKNOWLEDGEMENTS

In a long cruise involving a considerable amount of over the side work on station efficient execution of the work depends on a good working relationship between the officers, crew and scientists. The assistance of the whole ship's company is gratefully acknowledged, particularly with the sometimes protracted shooting operations, and this contributed considerably to the success of the cruise.

TABLE I OCEAN BOTTOM SEISMOGRAPH (OBS) LAY POSITIONS

LAY I					LAY II				LAY III			
BUOY POSITION	BUOY	LATITUDE °N	LONGITUDE °W	DEPTH u.c.m.	BUOY	LATITUDE °N	LONGITUDE °W	DEPTH u.c.m.	BUOY	LATITUDE °N	LONGITUDE °W	DEPTH u.c.m.
B13	OBS 4A	27°42.0'	61°28.9'	5830								
B12	OBS 7A	27°4.0'	61°30.9'	5985								
B11	OBS E	26°35.3'	61°27.8'	5900	PUBS 4	26°34.5'	61°28.0'	5910	OBS D	26°34.1'	61°27.8'	5905
B10	OBS D	26°03.6'	61°29.9'	5912	OBS D	26°03.9'	61°29.7'	5912	PUBS 2	26°04.7'	61°29.1'	5912
B9	PUBS 4	25°31.2'	61°30.5'	5870	PUBS 5	25°31.6'	61°30.0'	5870	OBC C	25°31.7'	61°29.8'	5865
B8	PUBS 6	24°58.5'	61°30.3'	5807	OBS C	24°59.8'	61°29.4'	5785	OBS B	24°59.8'	61°29.0'	5775
B7	OBS C	24°25.7'	61°30.8'	5808	OBS B	24°26.5'	61°30.5'	5790	PUBS 6	24°27.2'	61°31.2'	5785
B6	OBS B	23°54.8'	61°30.9'	5770	PUBS 2	23°54.8'	61°31.9'	5795	PUBS 5	23°55.9'	61°32.4'	5815
B5	PUBS 5	23°19.5'	61°26.1'	5825	OBS E	23°20.4'	61°28.6'	5825				
B4	PUBS 3	22°47.8'	61°29.3'	5820	PUBS 6	22°48.3'	61°29.6'	5790	PUBS 3	22°47.9'	61°29.5'	5825
B3	OBS A	22°16.3'	61°29.7'	5725	OBS F	22°14.9'	61°30.0'	5792	OBS F	22°15.4'	61°29.7'	5792
B2	PUBS 2	21°45.0'	61°27.5'	5760	OBS F	21°45.1'	61°27.5'	5750				
B1	OBS 5A	21°06.4'	61°31.2'	5765								
A2	OBS 6A	17°47.5'	61°01.3'	4957								
A1	OBS 3A	16°31.0'	60°17.0'	5115								

NOTES

OBS 4A = IOS Blacknest OBS

OBS E = Institut de Physique du Globe OBS

PUBS 4 = IOS Wormley OBS

TABLE II LARGE SHOTS FIRED DURING LADLE

SHOT NO.	SIZE Kg	LATITUDE °N	LONGITUDE °W	TIME (G.M.T.)	DATE	WATER DEPTH m sec (1 way)	SHOT DEPTH m sec (1 way)	SEDIMENT THICKNESS m sec (2 way)	FIRING SHIP
10	818	18°32.5'	61°59.1'	1124 37.997	365/1979	4033	100		DISCOVERY
4	1636	20°37.9'	61°32.0'	1436 21.921	010/1980	3589	80	250	DISCOVERY
8	1800	25°35.89'	61°30.2'	1718 15.137	010	3875	72	200	DAWSON
2	1636	20°19.3'	61°30.6'	2051 38.589	010	3650	80	250	DISCOVERY
7	5400	23°42.82'	61°29.25'	1419 20.317	016	3886	72	300	DAWSON
* 3A	2455	22°09.7'	61°21.6'	1711 01.286	016	3847	600	200	DISCOVERY
3B	818	22°12.4'	61°23.8'	1839 15.269	016	3820	80	220	DISCOVERY
6	3600	23°37.52'	61°29.41'	2058 24.732	016	3840	72	200	DAWSON
5	1800	23°32.52'	61°28.71'	1508 33.042	017	3890	72	320	DAWSON
9	2700	23°46.32'	61°30.12'	2101 29.321	017	3844	72	250	DAWSON
1A	2455	23°34.3'	61°27.2'	1746 31.955	027	3885	80	450	DISCOVERY
1B	1091	23°44.6'	61°29.6'	1857 20.320	028	3885	80	280	DISCOVERY
11	818	17°30.8'	61°22.1'	1710 55.665	030	2673	80		DISCOVERY
14	900	17°31.1'	60°31.3'	1918 57.541	033	3540	80		DISCOVERY
12	850	15°39.6'	60°15.0'	1134 18.921	039	3340	80		DISCOVERY

* Shot 3A exploded at depth after being cut free from the stern

All shots were of Dupont Marine Grade Tovex Extra or of Canadian Hydromex except shots 12 and 14 (ICI Geophex)

TABLE III DISPOSABLE SONOBUOY DEPLOYMENTS

SONOBUOY NUMBER	TIME DEPLOYED (G.M.T.)	LATITUDE °N	LONGITUDE °W	AIRGUN SOURCE (litres)	RESULTS
1	1824/006	27°15.7'	61°28.1'	0.624	Fairly noisy
2	0823/007	26°01.1'	61°29.7'	0.624	Good data
3	0808/008	24°16.6'	61°31.1'	0.624	Good data at second attempt
4	1733/008	23°33.1'	61°27.9'	0.624	Good data
5	-	-	-	-	Dummy deployment
6	1800/029	20°46.8'	60°04.9'	4.680	Good first hour, moderate second hour
7	2034/029	20°27.7'	60°13.9'	4.680	Noisy towards end; 20 mins missing in middle
8	0007/030	-	-	-	Buoy failed

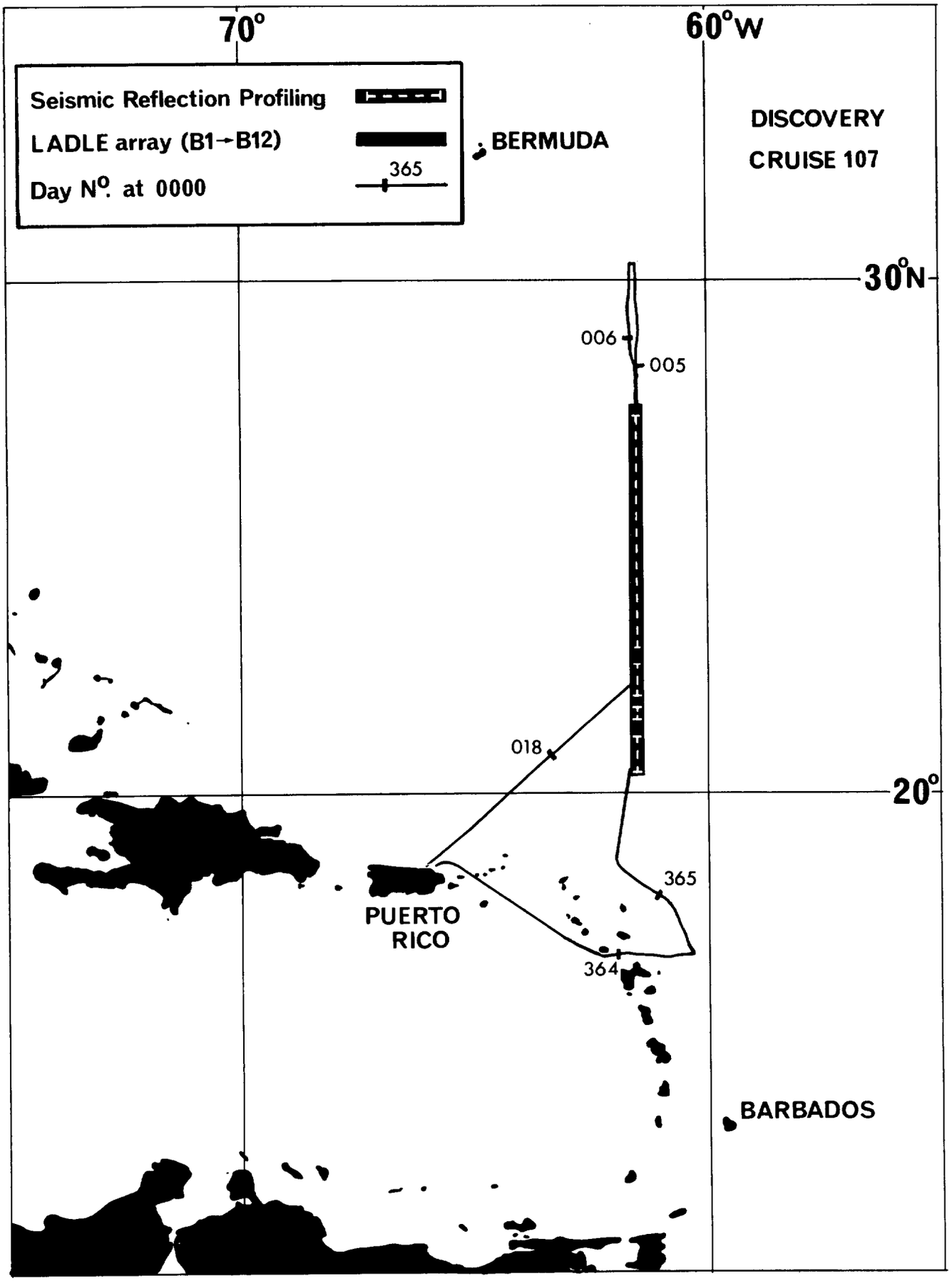
Figure 1. Ship's track during Leg 1. The thick line denotes an area of tracks along the OBS array too complex to show at the above scale.

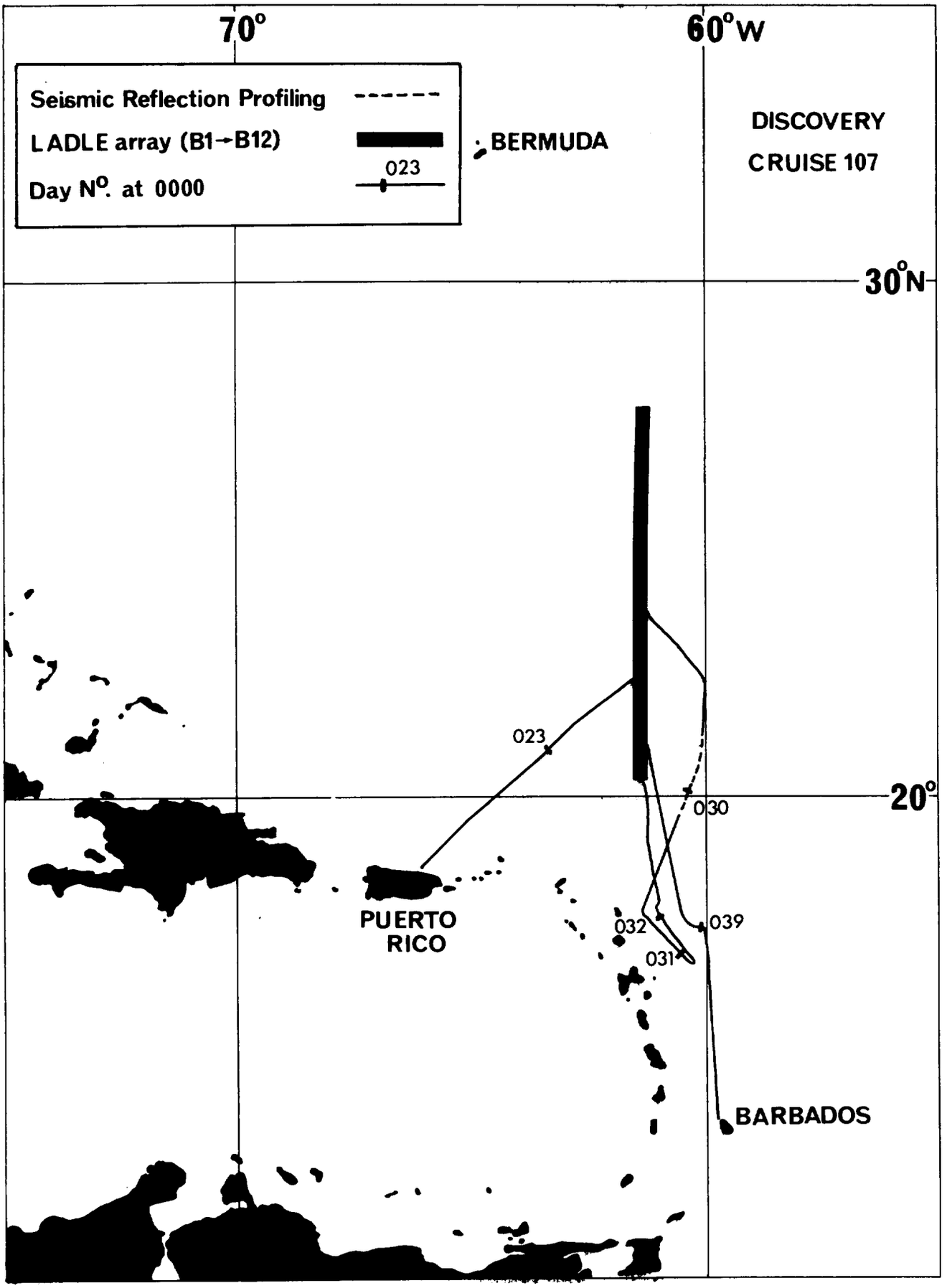
Figure 2. Ship's track during Leg 2. The thick line denotes an area of tracks along the OBS array too complex to show at the above scale.

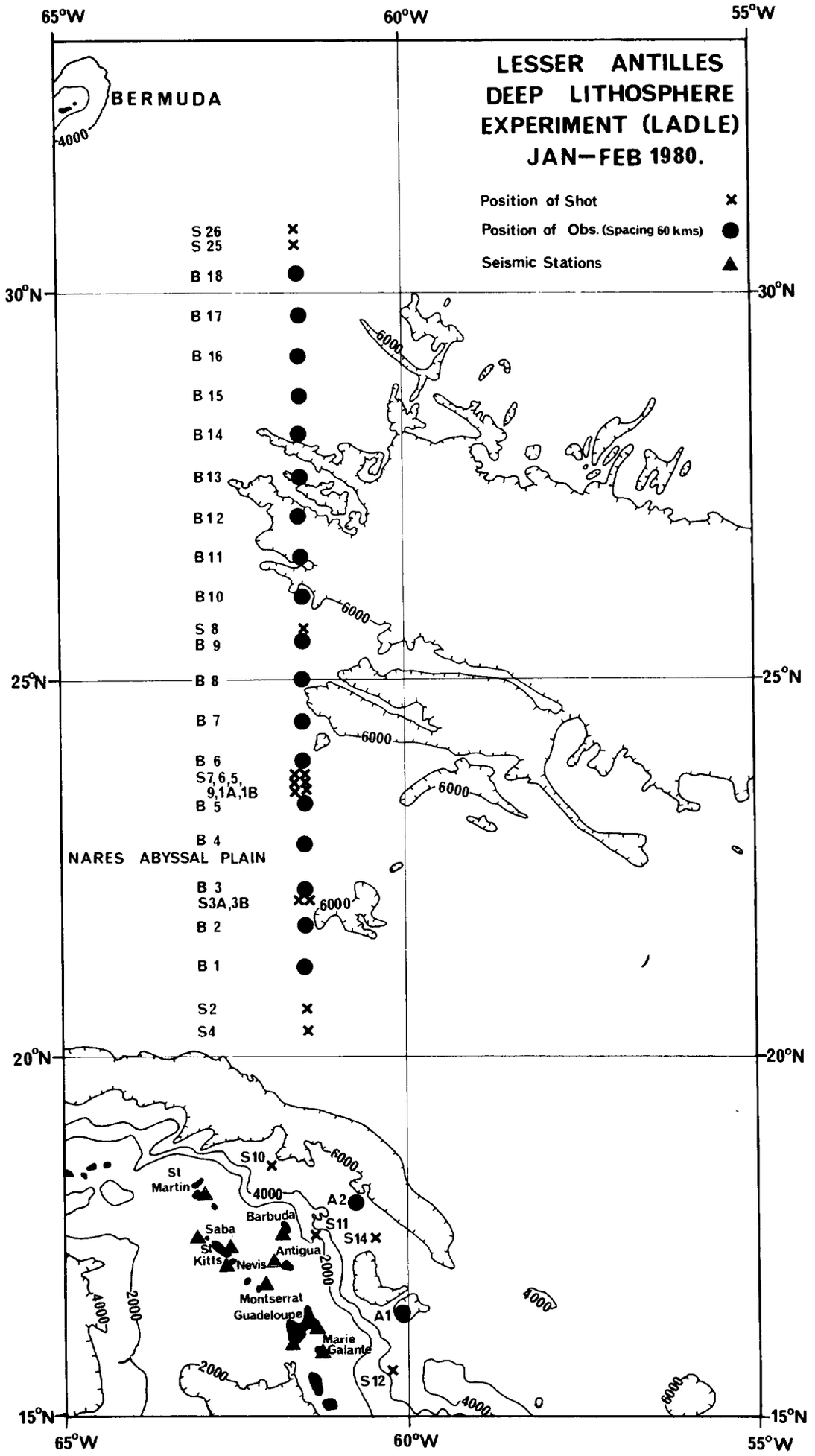
Figure 3. Positions of the OBS and of shots of 1 ton or more laid by RRS Discovery and CSS Dawson. OBS positions (B1, B2 etc.) and shot numbers (S1, S2 etc.) are referred to in the text. See Tables I and II for precise co-ordinates of these positions. The figure also shows island recording stations operating during LADLE.

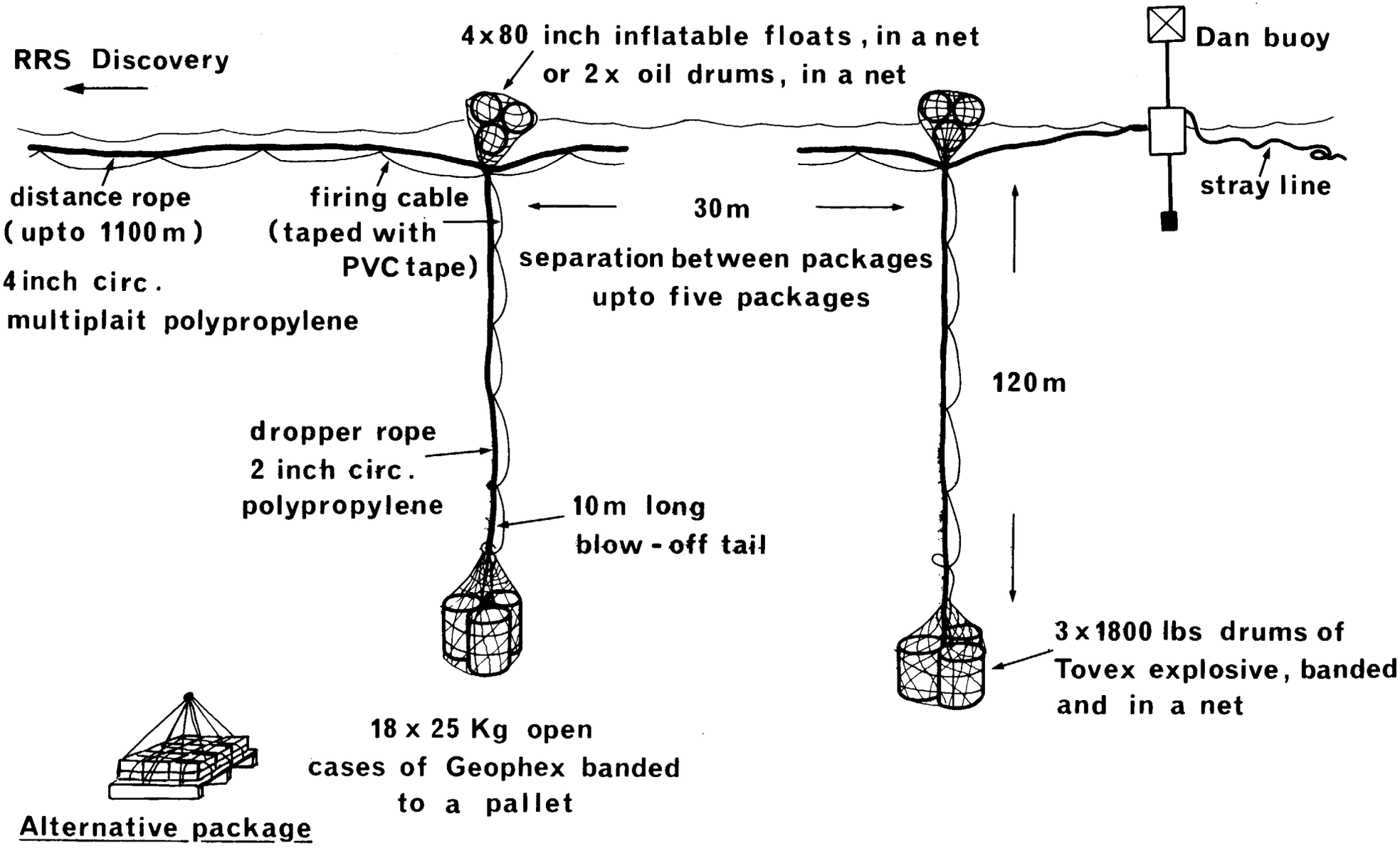
Figure 4. A sketch to illustrate the shooting technique used for most of the shots fired from RRS Discovery during Cruise 107

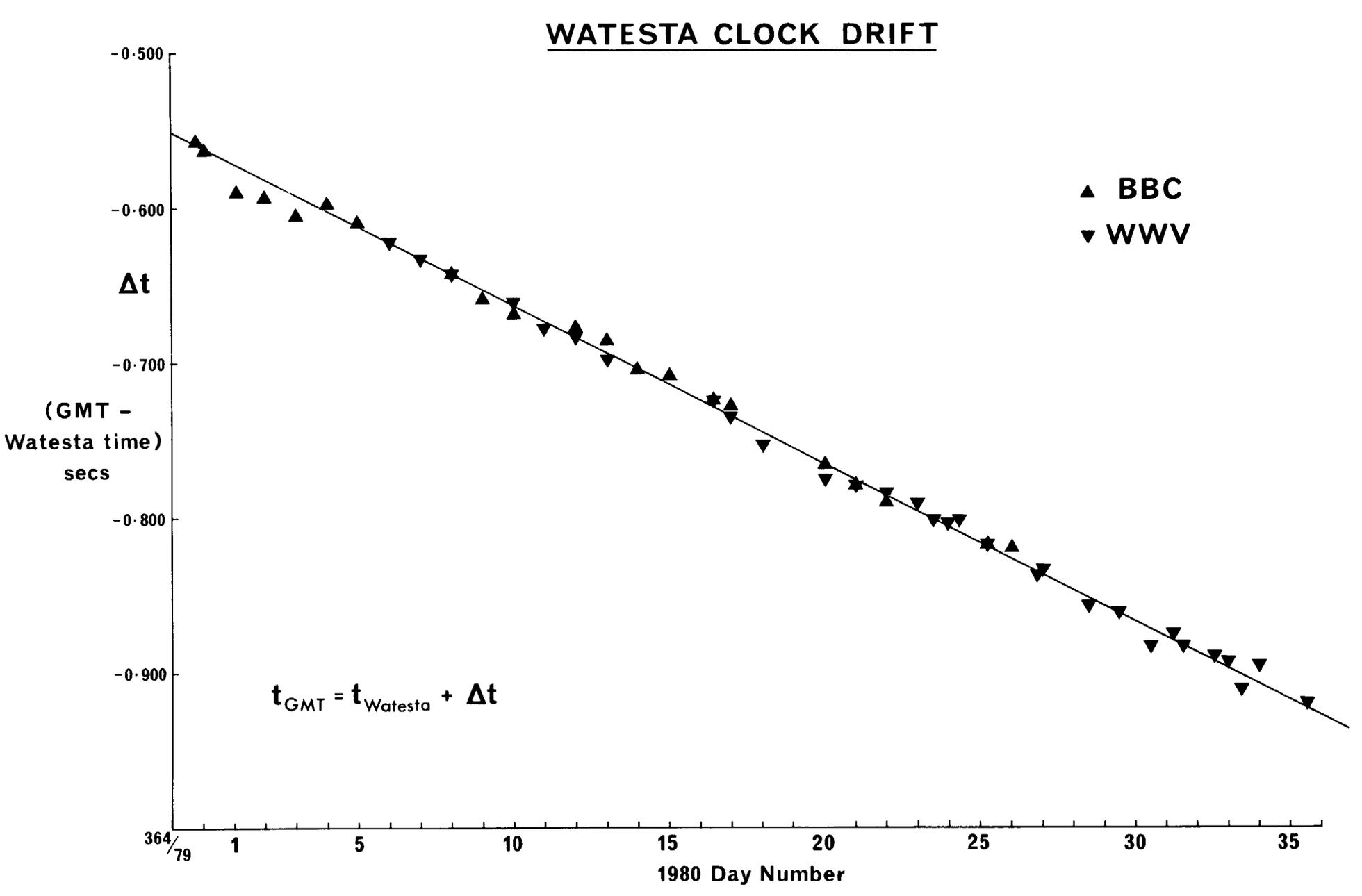
Figure 5. A plot of the drift of the shipboard Watesta clock against radio time signals during part of Cruise 107.


70°
60°W
Seismic Reflection Profiling
LADLE array (B1→B12)
Day N°. at 0000
365
BERMUDA
DISCOVERY
CRUISE 107
30°N
006
005
018
20°
365
PUERTO
RICO
364
BARBADOS


70°
60°W
Seismic Reflection Profiling
LADLE array (B1→B12)
Day N°. at 0000
023
BERMUDA
DISCOVERY
CRUISE 107
30°N
20°
023
030
PUERTO
RICO
032
039
031
BARBADOS


LESSER ANTILLES
DEEP LITHOSPHERE
EXPERIMENT (LADLE)
JAN–FEB 1980.
Position of Shot
Position of Obs. (Spacing 60 kms)
Seismic Stations
65°W
60°W
55°W
30°N
25°N
20°N
15°N
BERMUDA
4000
S 26
S 25
B 18
B 17
B 16
B 15
B 14
B 13
B 12
B 11
B 10
S 8
B 9
B 8
B 7
B 6
S7,6,5,
9,1A,1B
B 5
B 4
NARES ABYSSAL PLAIN
B 3
S3A,3B
B 2
B 1
S2
S4
6000
S10
St
Martin
4000
A2
Barbuda
S11
S14
Saba
St
Kitts
Nevis
Antigua
2000
Montserrat
Guadeloupe
A1
Marie
Galante
S12
0


RRS Discovery
4x80 inch inflatable floats, in a net
or 2x oil drums, in a net
Dan buoy
distance rope
(upto 1100m)
4inch circ.
multiplait polypropylene
firing cable
(taped with
PVC tape)
30m
separation between packages
upto five packages
stray line
120m
dropper rope
2 inch circ.
polypropylene
10m long
blow-off tail
3x1800 lbs drums of
Tovex explosive, banded
and in a net
18 x 25 Kg open
cases of Geophex banded
to a pallet
Alternative package


WATESTA CLOCK DRIFT
-0·500
-0·600
-0·700
-0·800
-0·900
Δt
(GMT - Watesta time) secs
▲ BBC
▼ WWV
$t_{GMT} = t_{Watesta} + \Delta t$
364/79
1
5
10
15
20
25
30
35
1980 Day Number