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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1976/87

VEMA CRUISE 33 LEG 3 OVER THE MAGNETIC QUIET ZONE SOUTH OF AUSTRALIA, 20 JANUARY TO 19 FEBRUARY 1976: OBSERVER's REPORT

by

H.M.J. Stagg

Survey 1036

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SUMMARY

In leg 3 of cruise 33 of the Lamont-Doherty Geological Observatory research vessel Vema, seismic refraction, seismic reflection, magnetic, gravity, bathymetric, and heat flow data and piston core samples were collected along traverses over the magnetic quiet zone south of Australia. The primary objective of the leg was to investigate the nature and origin of the quiet zone and, in so doing, to learn about the processes operating during the first stages of separation of Australia and Antarctica. The main technique of investigation was the seismic refraction method. To acquire information of possible use in future BMR refraction surveys at sea, the author made a close study of the system and procedures used by Lamont on this leg.

Lamont used three different types of refraction detector - short-range 'Military SSQ-41' sonobuoys, long-range 'Aquatronics' sonobuoys, and ocean-bottom seismometers. Sources used were the air-gun for small offsets of the ship from the sonobuoy, and explosive charges of various sizes for longer offsets. Short-range sonobuoy signals were recorded on fixed styli drumrecorders which were also used in vertical reflection profiling; long-range sonobuoy signals from explosive shots were recorded on an camera-oscillograph.

It was concluded that the refraction system and procedures used by Lamont would be suitable for application by BMR, although the system could be improved by recording data on magnetic tape. The long-range sonobuoys are preferable to short-range buoys, particularly in areas of thick crust. The ocean-bottom seismometers appeared to perform well, but the long-range sonobuoy data alone were sufficient to achieve most of the survey objectives. In view of the high cost of ocean-bottom seismometers and the inconvenience caused by having to recover them, there would seem to be little advantage for BMR to consider using them in geophysical reconnaissance surveys at this stage.

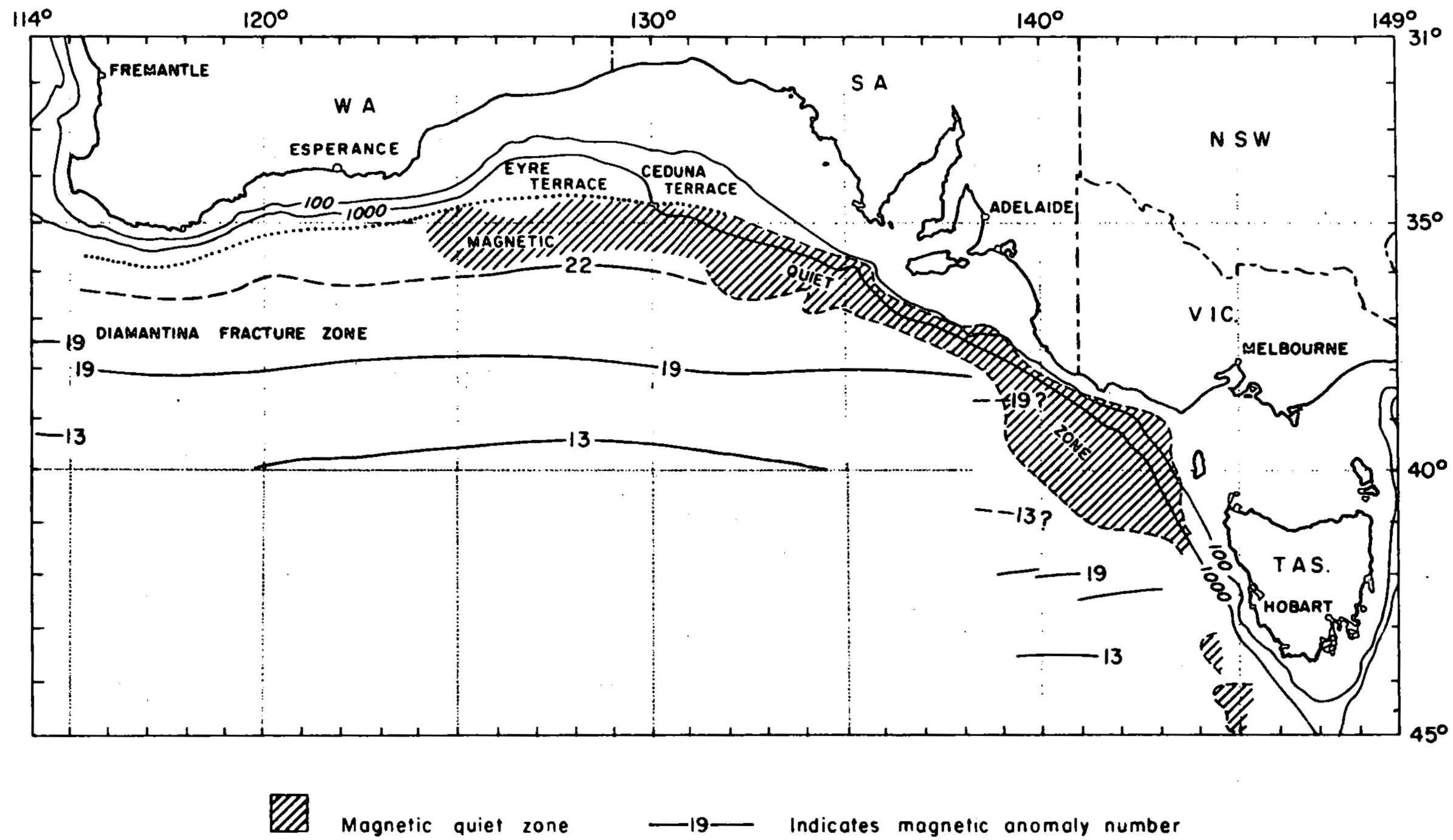
Other techniques learned and observations made, which may be relevant to future BMR refraction work, include:

(1) The performance of long-range sonobuoys can be improved by replacing some of the weights on the hydrophone string with enough paraffin wax to give the string almost neutral buoyancy. This is effective in reducing noise, by decoupling the hydrophone from sonobuoy motion on the surface.

(2) Primacord and booster caps should be used in the firing of large charges.

(3) If refraction shooting is done while a long hydrophone cable is streamed, some method should be found to avoid the sonobuoy strings and the hydrophone streamer cable becoming entangled.

As this report was going to press (October 1976), data from the leg were still being processed and interpreted at Lamont's headquarters in New York. J.C. Mutter, one of the two BMR participants on the leg, is co-operating with Lamont geoscientists in the interpretative work, and will be a joint author of proposed papers on the seismic results from the leg, on the general geophysical interpretation of the survey area, and on a theoretical model for the formation of magnetic quiet zones.



LOCATION OF MAGNETIC QUIET ZONE SOUTH OF AUSTRALIA

FIG. 1

1. INTRODUCTION

Aims

The basic objective of leg 3 of cruise 33 of the Lamont-Doherty Geological Observatory (L-DGO) research vessel *Vema* was to investigate the nature and origin of the marginal magnetic quiet zone south of Australia (Mutter, 1975; Houtz & Talwani, 1975). The magnetic quiet zone is an area of low-magnitude magnetic anomalies over the continental slope and rise in the Great Australian Bight (Fig. 1), which is probably associated with the breakup of the Australia/Antarctic landmass. By studying the quiet zone, it was hoped to learn about the processes operating during the first stages of spreading.

The principal geophysical technique to be applied was seismic refraction. In addition, seismic reflection, magnetic, bathymetric, and gravity data were to be collected and an extensive program of heat flow measurements and piston-coring was to be carried out.

Co-operation between BMR and L-DGO

The BMR has had an interest in geophysical surveying of the Australian continental margin since its Continental Margins Survey, 1970-73. As much of the surveying in L-DGO cruise 33 was to be carried out over the continental margin, BMR took a strong interest in the project. As a result of this interest, L-DGO in late 1975 invited BMR to participate in the survey by supplying explosives and sonobuoys for refraction shots, minor logistic support, and observers with special knowledge of the survey area of each leg of the cruise. The other three legs of cruise 33 are discussed by Jongsma (1976), Petkovic (1976), and Tilbury (1976).

Equipment on Vema

Geophysical equipment carried aboard the *Vema* included:

- single-channel continuous seismic reflection profiling system with a 50 in^3. air gun source and two fixed-styli, rotating drum recorders.
- Short-range 'Military SSQ-41' and long-range 'Aquatronics' sonobuoys with 'Watkins Johnson' and 'Aquatronics' receivers and a DRESSER-SIE camera-oscillograph. The long-range sonobuoys were not available until the first port call at Experance on 31 January 1976.

- Graf-Askania GSS-2 gravity meter. This could not be operated until after the first port call at Esperance because of a breakdown in the gyrostabilizers on leg 1 of cruise 33.

- 3.5 and 12 kHz precision analogue depth recorders (PDR).

- Proton precession magnetometer.

- Two ocean-bottom seismometers (OBS).

- Satellite navigation system.

- Computer system consisting of two ruggedized PDP-11 computers, a BUS switch, three moving-head discs, two teletypes, a visual display unit, and an on-line drum plotter.

Scientific Staff

The following scientific personnel were aboard Vema for leg 3:

- M. Talwani, co-chief scientist and Director of L-DGO.

- R.E. Houtz, co-chief scientist.

- B. Hermann, heat-flow PhD student

- M. Sundvik, geologist/core describer

- A. Rock, computer programmer and technician

- J.C. Mutter, BMR observer

- H.M.J. Stagg, BMR observer

In addition, there were three electronics technicians, one gravity meter technician and one air-gun technician.

All scientific personnel, excluding the co-chief scientists, stood a 6-hour lab. watch. Duties were:

(i) Checking that instruments performed satisfactorily and adjusting them as necessary,

(ii) Annotating the strip chart records every 30 minutes and at course and speed changes, and hand-digitizing the data at six-minute intervals,

(iii) Operating the satellite navigation system and obtaining satellite fixes with the aid of a computer.

In addition, the personnel on watch assisted other available hands with streaming cables, launching and retrieving equipment, firing explosives on refraction lines, and with other occasional tasks requiring basic man-power.

2. CRUISE REPORT

R/V Vema sailed from Fremantle at 1000 hrs* on 20.1.76 and arrived at the Woodman's Point Explosives Wharf at 1130 to load six tonnes of 'Nitramon' explosives for refraction shooting. The explosives came in 2, 7, 15, 35, and 67-lb canisters which were stored in bins on the deck behind the upper laboratory and on the forecastle.

Vema departed Woodman's Point at 1600, proceeded north around Rottnest Island, and steamed southwest across the continental shelf towards deep water. The seismic cable and the magnetic sensor were streamed at 2300 hrs in approximately 100 fm of water with the ship on a southerly course.

At 0600 on the 22nd the ship was positioned on longitude 115°30'E to begin a north-south traverse, the first of several traverses across the Diamantina Fracture Zone. This line was made primarily to set up the refraction procedure that would be used on the remainder of the leg. Three refraction profiles were recorded on the analog profilers using short-range military SSQ-41 sonobuoys and the air-gun. Another short-range sonobuoy refraction profile was shot using explosives and recorded on photographic paper on the camera-oscillograph. Preliminary picking of first arrivals gave velocities of 2.75 and 4.8 km s^{-1} for the two refracting horizons identified. This activity served to acquaint the scientific staff with the procedure to be adopted for handling sonobuoys and explosives.

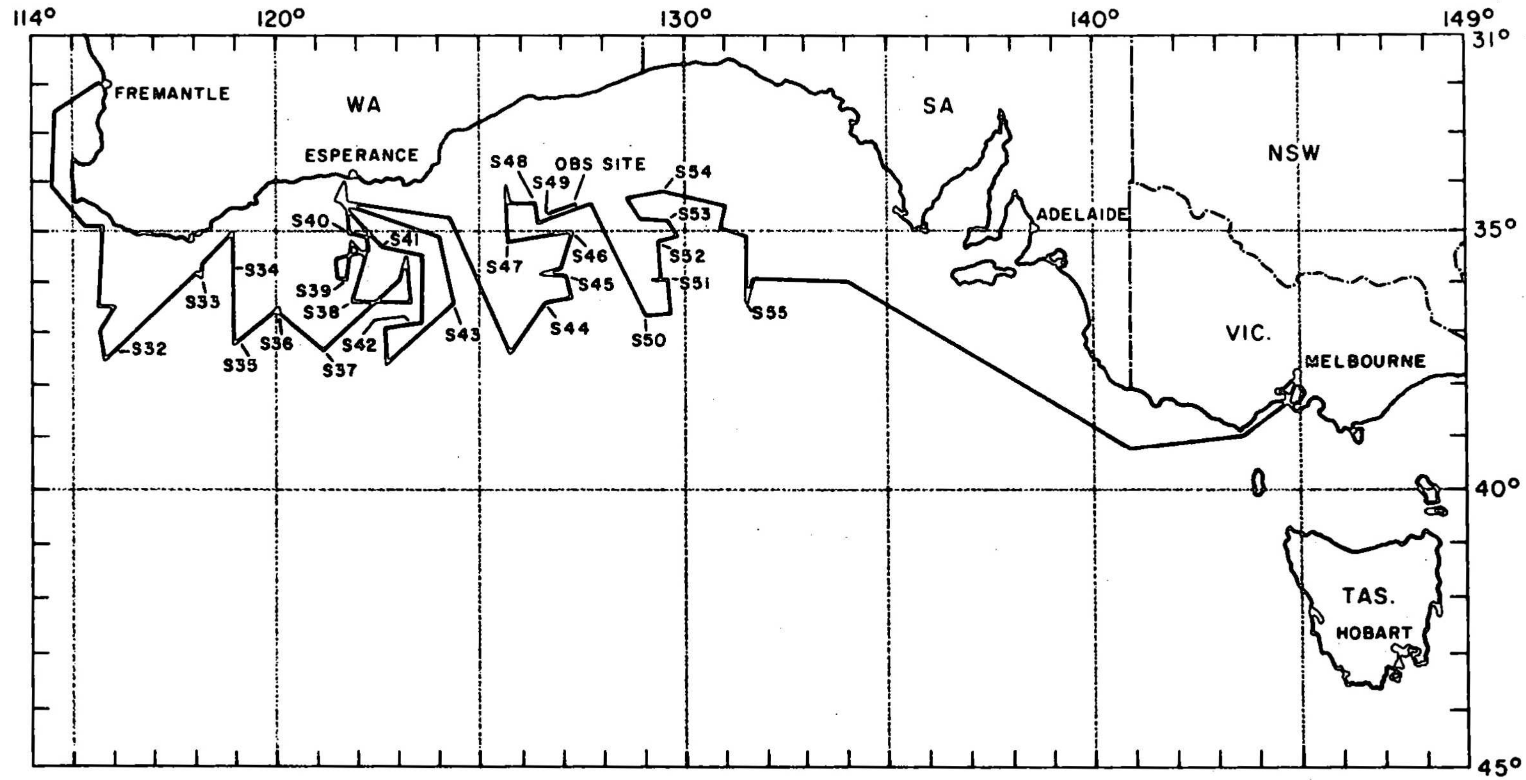
* All times given in this report are local. Time zones -8, -9 and -10 hours with respect to G.M.T. were passed through during the cruise.

After this southerly line, profiling was continued on a north-easterly course. On this line, heat flow measurements were taken at two stations (S32 and S33 in Fig. 2) to the north of the Diamantina Fracture Zone. At the first station, the BMR Geometrics magnetometer was rigged and tested. L-DGO scientists were unhappy with the idea of towing the BMR magnetometer because of the possibility of its becoming entangled with the Vema's air-gun trip-eel, hydrophone streamer, or magnetometer. Consequently it was decided to use the BMR magnetometer only if the L-DGO magnetometer broke down. Between S32 and S33 a refraction probe was made using the airgun. The first sonobuoy failed almost immediately but the second, a military sonobuoy, performed satisfactorily.

During this part of the leg, the computer system was consistently giving trouble. Lengthy down-periods were resulting in considerable delay in the computing of satellite fixes. The hardware problems could not be solved by the on-board operator, so arrangements were made to meet a representative of the Digital Equipment Corporation at the port of Esperance on 31 January.

Work continued despite the computer problems. On the next southerly traverse a heat-flow station was occupied in the magnetic trough to the north of the Magnetic Quiet Zone (S34 in Fig. 2). Sediments here and at most other coring stations on the continental slope and rise were hard enough to make coring difficult, and at this station only 53 cm of core was taken. A serious problem caused by the hard sediments was the consistent bending of core pipes on penetration of the sea-floor, especially when two core pipes were used.

After this station, a refraction profile was recorded across the quiet zone and sea-floor spreading anomaly 22 using explosives and short-range sonobuoys. For this and for most other refraction probes, Lamont simultaneously deployed two sonobuoys with different transmission channels to increase the likelihood of success. Both sonobuoy signals were recorded on the oscillograph and events were picked from the better record. Both refraction probes were satisfactory, with 25-30 shots being fired to each sonobuoy out to a distance of more than 30 km, equivalent to 20 seconds of direct wave or D-wave travel time. In both cases preliminary picking of first arrivals indicated a mantle velocity of about 8.3 km s^{-1}. The profile across anomaly 22 showed a step-down in the travel-time plot, indicating a possible topographic rise in the high velocity layer.



TRACK MAP FOR VEMA CRUISE 33 LEG 3

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FIG. 2

On 27 January, heat-flow station S37 was occupied. Some surveying time was lost owing to a faulty connection in the leading section of the hydrophone streamer and after this fault was corrected, more time was lost because of problems with a seal in the air-gun. A further 1½ hours was lost on the 28th owing to engine trouble.

From 27 to 31 January, profiling was carried out on a series of closed loops south of Esperance. During this time, three heat-flow stations were occupied (S37-S39) and five sonobuoy refraction probes were made successfully, two with explosives and three with air-gun. A new practice introduced at this time was to extend refraction lines surveyed with the short-range sonobuoys and the air-gun by firing 2-lb explosives at one-minute intervals when the air-gun refraction events on the profilers began petering out. By using this method, the line could be extended for another 40-50 minutes, with refractions still clearly evident on the profiler records.

Recording ceased at 0500 on the 31st and Vema arrived in Esperance at 1000. Two additional Lamont representatives were taken on board and 24 long-range sonobuoys, a replacement satellite mast group (the one in use was giving a very weak signal), gravity meter spares, and more magnetic tapes for the BMR Ampex tape recorder were loaded. Difficulties arose in obtaining a Digital Equipment Corporation (DEC) representative to sail aboard the Vema for Melbourne; the only solution was to take aboard a DEC representative temporarily, and return to Esperance on 4th February to pick up a replacement technician who could stay on board until Melbourne was reached.

Vema left Esperance at 2300 on 31 January and surveying commenced at 0500 the following morning. For the next three days detailed surveying was carried out southeast of Esperance between the magnetic trough to the north of the quiet zone and the Diamantina Fracture Zone. During this period, three heat-flow stations were occupied (S41 - S43), two long-range sonobuoys probes were recorded using explosives, and one short-range sonobuoy probe was recorded using both the air-gun and explosives. Aquatronics long-range sonobuoys were used and these proved to be very successful - refractions were detected at offsets of up to 34 and 43 seconds D-wave time by the two sonobuoys.

The malfunctioning gravity gyrostabilizers were replaced in Esperance, and gravity data were recorded for the remainder of the leg. From Esperance to the end of the leg, all magnetic, gravity, and bathymetric data were hand-plotted hourly by the duty lab-watch so that the vessel could be more accurately positioned on particular geophysical features.

Recording ceased again at 1400 on 4 February and Vema entered Esperance at 1600. During the port call, a replacement DEC representative was taken on board and the defective satellite mast group was replaced. Vema departed Esperance at 0000 on 5 February and commenced surveying at 0930, although the satellite mast group was still not working because of a faulty cable connection. This problem was not rectified until 1400, and until this time Vema steamed slowly eastwards parallel to the coast.

Once the mast group was repaired, Vema set course for the southern-most of a series of east-west lines to be run south of the Eyre Terrace. It was planned to take refraction and heat flow measurements along lines in the following positions: between seafloor spreading anomalies 20 and 21; between anomalies 21 and 22; in the quiet zone along the inferred anomaly 23 (Mutter, 1975); centrally over the quiet zone where it was proposed to deploy two ocean-bottom seismometers (OBSs); and on the gravity high overlying the magnetic trough to the north of the quiet zone. All profiles were to be made parallel to the structural strike. East-west lines, similarly positioned with respect to the magnetic features, were also planned to the south of the Ceduna Terrace, but it was doubtful if all the lines could be surveyed because of the time lost during the Esperance port calls.

Shooting along the first of these lines began at 0700 on 7 February. The refraction probes in the first two positions were both shot successfully, giving mantle velocities of 8.0 - 8.2 km s^{-1}. Heat-flow values were low (about 1 HFU) and largely typical of ocean basins of this age. The other heat-flow values obtained on this leg were also low with the exception of anomalously high values obtained on the gravity high/magnetic trough to the north of the quiet zone. On the line between anomalies 21 and 22, a BMR Aquatronics short-range sonobuoy was deployed at the same time as a Lamont sonobuoy. Signals could not be recorded from either buoy after about 30 minutes shooting but a long-range sonobuoy was more successfully deployed.

Two long-range sonobuoy refraction lines were shot near the inferred anomaly 23. Both were shot parallel to the magnetic strike, one on the anomaly and one just to the south of it. Both refraction probes were successful and indicated a thicker-than-normal oceanic crust (14 km as against 10 km).

Considerable care was taken in positioning the Vema accurately on the gravity high to the north of the quiet zone. This was done by overshooting the anomaly to the north and calculating the position of the peak of the high from the hand-plotted data. The course was then reversed and the refraction probe was shot when gravity, magnetic, and bathymetric data indicated that the ship was in the correct position. The probe was successful and on-board plotting indicated that the crust was thinner than expected, being approximately 2 km thinner than the crust to the south.

The combined OBS/sonobuoy line was shot in the quiet zone over the following 1½ days. The procedure adopted is illustrated in Figure 3 and described below. The first OBS drop was made at 22 00 on 9 February. The OBS took about 90 minutes to reach the sea-floor. A sonobuoy probe using the air-gun and explosives was then shot on an easterly course to determine sediment velocities. The second OBS was dropped at 03 00 on 10 February about 20 miles to the east of the first OBS. Vema steamed a further 20 miles to the east, dropped a long-range sonobuoy and then steamed westwards back along the line, firing explosives at five-minute intervals. Charge sizes used were 15 lb, with a 35-lb charge every 15 minutes. Shooting was continued to 20 miles west of the first OBS where a second long-range sonobuoy was deployed. Signals from this sonobuoy were recorded while steaming on an easterly course to pick up the first OBS.

A heat-flow station (S49) was occupied while waiting for the OBS to release. Satellite fixes were also taken while on station to check that the Vema was close to the known position of the OBS. The OBS was released at 19 56 (4 minutes earlier than planned) and arrived at the surface at 21 32 (2 minutes late), less than 0.5 mile from the ship. The second OBS was released successfully at 04 00 on the 11 February, and was picked up at 06 30. A second air gun/explosives sonobuoy probe was shot from this site, also to obtain sediment velocities, although this buoy was not very successful.

After the completion of this line, a southeasterly course was steered to begin the second set of lines southwest of the Ceduna Plateau. It was apparent at this stage that lack of time would prevent doing a second OBS/sonobuoy probe. On this long southeast traverse, two long-range sonobuoys were deployed successfully along track. The first 10-12 km of the refraction lines were shot within the air-gun and recorded on the drum profilers to obtain better sub-buttom reflections. This practise was successful and was continued for all subsequent long-range refraction lines.

The first of the next set of east-west lines was shot between anomalies 19 and 20. Two long-range sonobuoys were deployed but signals from neither could be recorded after 1-1½ hours because of excessive instrument noise. No attempt was made to shoot another buoy on this line. Refractions were recorded more successfully along a line near anomaly 21.

Two refraction probes and a heat-flow measurement were again taken in the quiet zone. The first refraction probe was moderately successful - the signal was sometimes very noisy and it eventually failed at 35 seconds D-Time. The signal from the second buoy was likewise intermittently noisy, but results were good in the quiet periods. The 6.2 km s^{-1} layer appeared to be quiet thick and in an effort to get mantle refractions, two attempts were made to fire 134 lb charges (2 x 67 lb). However, neither multiple charge could be detonated.

The next heat-flow measurement and sonobuoy probe were made on the gravity high west of the Ceduna Plateau. Because of lack of time the vessel could not be positioned accurately on the anomaly, but was probably fairly close to it. Signals from the long-range sonobuoy were recorded for about 4 hours, but intermittent noise made accurate picking of events difficult. Consequently the travel time curve could not be plotted accurately and it was difficult to identify a mantle break.

After this line, two long-range sonobuoy probes were shot on the Ceduna Plateau. The first was shot on a southerly course across the plateau. The signal was weak and noisy and recording was abandoned after shooting for one hour with explosives. A second long-range sonobuoy was deployed on a course parallel to the southern margin of the plateau. Signals from this buoy lasted for four hours, and indicated a thick layer of sediments, of velocity 3.6 km s^{-1}, overlying basement of velocity 5.8 km s^{-1}, with a third layer beneath of velocity 7.0 km s^{-1}.

After this line, Vema steamed southwards and took a heat-flow measurement (S55) on a magnetic feature tentatively identified as anomaly 21. Subsequently two long-range sonobuoys probes were shot in southerly and easterly courses. Both were shot to about 40 seconds D-time, but refractions from the mantle were not apparent on either line. The second probe indicated a layer of 3.8 km s^{-1} velocity sediments underlain by a layer of 7.5 km s^{-1} velocity, seemingly with little or no 5.8 km s^{-1} material between.

The Vema steamed directly for Melbourne on 16 February and all remaining sonobuoys were deployed along the track. Of three long-range sonobuoys probes, one failed after 8 shots but the second and third were successful and indicated what appeared to be continental type crust. Finally a Lamont military sonobuoy and a BMR Aquatronics buoy were deployed and both failed prematurely.

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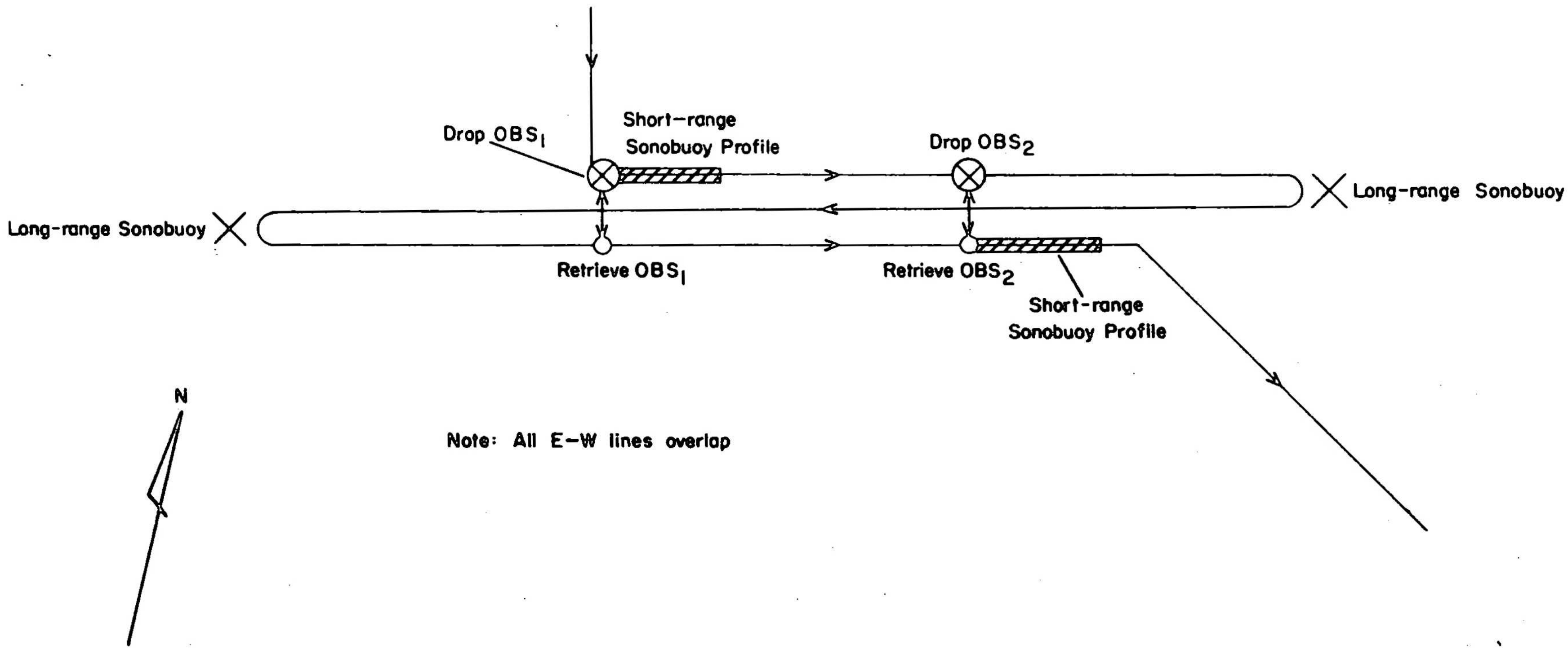

METHOD OF SHOOTING AN OBS/SONOBUOY REFRACTION LINE

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FIG. 3

The hydrophone streamer and air-gun were hauled in and stowed away at 1400 on 18 February, in 80 fm of water in Bass Strait. The magnetometer was hauled in at 0300 on the 19th, outside Port Phillip Bay when picking up the harbour pilot. Vema tied up at Princes Pier, Port Melbourne, at 0620 on 19 February.

3. REFRACTION SYSTEM AND PROCEDURES USED ON VEMA

The most important geophysical technique applied on leg 3 of the Vema cruise 33 was seismic refraction shooting. By studying the operating procedures, equipment, and reduction methods used by Lamont in this leg, I hoped to acquire information which would be relevant to future BMR marine refraction projects.

Lamont used three different types of refraction detector - short-range 'Military SSQ-41' sonobuoys, long-range 'Aquatronics' sonobuoys, and ocean-bottom seismometers. Acoustic sources used were the air-gun for small offsets of the ship from the sonobuoy, and explosive changes of various sizes for longer offsets. Short-range sonobuoy signals were recorded on drum recorders which were also used for vertical reflection profiling; long-range sonobuoy signals from explosive shots were recorded on camera-oscillograph.

Lamont's refraction system and methods can be described comprehensively by referring separately to short and long-range sonobuoy probes, the use of explosives, plotting and reduction of sonobuoy refraction data, and ocean bottom seismometers.

Short-range sonobuoy probes

The air-gun was mostly used as the source and the hydrophone cable left streaming so that vertical reflection profiling could continue while refractions were being recorded. The sonobuoy signals were received on a Watkins-Johnson receiver and recorded alongside the vertical profiler data on two drum recorders.

On one drum recorder, the refraction data were recorded through a 100-400 Hz passband filter and with zero sweep delay time. The filtering was done to enhance the D-wave arrival, and the sweep delay time was made zero so that the D-wave travel time could be read from the record. The D-wave travel time gives a direct measure of the ship/sonobuoy separation which allows the effects of drift of the sonobuoy or non-uniformity of the ships speed to be corrected for when the refraction data are finally reduced. In practice, these effects were reduced by stabilizing the ship's speed at between 4 and 6 knots in the 5 to 10 minutes before each sonobuoy was deployed.

On the other drum plotter, the refraction data were recorded through a 5-35 Hz passband filter to enhance the quality of sub-bottom refractions, and the sweep delay time was made sufficient (about 5 seconds) to ensure that all useful reflection and refraction data were recorded in one drum sweep (10 seconds).

When the ship/sonobuoy separation exceeded 6 or 7 seconds D-wave time, the refraction signal began to wane and the amplifier gain was increased. Further improvement was obtained at larger separations if small explosive charges were used instead of the air-gun. By firing 2-lb explosive charges at intervals of 30 to 60 seconds, the refraction line could be extended sufficiently to obtain mantle refractions in some areas.

Long-range sonobuoy probes

Long-range Aquatronics sonobuoys were deployed with considerable success on the survey. Explosives were generally used as the energy source, but on some lines the air-gun was used out to 6 to 7 seconds of D-wave time so that vertical reflections as well as refraction data could be recorded.

Signals from the long-range sonobuoys were received and amplified by a Telseis STR-74 receiver which has housings for two receiver modules. The crystal oscillators within these modules are interchangeable enabling different sonobuoy channels to be received. From the appropriate module, the signal passes to a DRESSER - SIE Model RA - 44 recording amplifier equipped with 24 channels in two groups: group A with channels 1 - 12, and group B with channels 13 - 24. Only channels 1-6 and 13-18 were used in the Lamont recorder. Filter passband settings were:-

Channels 1 & 13, 2 - 150 Hz
Channels 2 & 14, 2 - 75 Hz
Channels 3 & 15, 2 - 35 Hz
Channels 4 & 16, 2 - 16 Hz
Channels 5 & 17 and 6 & 18 (water break) 400 Hz - 3.5 KHz

After this stage of amplification, the signal is passed to a DRESSER-SIE Model R-6 oscillograph which uses pencil-type galvanometers (one per channel) to reflect light beams on to light-sensitive paper. The shot instant is received from the trip eel through a special input on the RA-44 and recorded as a single trace on the oscillograph.

A marked improvement in the performance of the long-range sonobuoys was brought about by replacing some of the weights in the hydrophone string with enough paraffin wax to give the string almost neutral buoyancy. This effectively reduced noise by decoupling the hydrophone from sonobuoy motion at the surface.

Use of explosives

The table in Appendix 2(a) indicates fuse lengths, burn times, firing intervals, and sink rates for charges of various sizes; it was used as a general guide in refraction shooting. However the shot size and firing interval were normally increased above that shown when first arrivals were expected from the next layer in the sub-surface. Charge sizes were also increased if there was any doubt about whether the charge was large enough to give pickable refractions. Difficulty was experienced in detonating two or more charges simultaneously and or several occasions lumped charges failed to detonate at critical points on refraction lines. Use of primacord or larger booster caps would have overcome the problem, but no primacord was available on the ship.

Details of the shot-logging procedure used on the Vema and the regulations concerning the storage and use of explosives on board American research vessels are given in Appendix 2.

Plotting and reduction of sonobuoy refraction data

Lamont's practice on this leg was to plot the results of all explosive shots immediately after they were fired. Although the time interval between shots was too short to enable the plotter to pick all arrivals accurately, the procedure helped to ensure that optimum charge sizes and firing intervals were being used. Two curves were plotted concurrently (Fig. 4). The first was a refraction travel time plot with D-time as the horizontal axis. The second was a plot of survey time versus D-time which was used to determine D-times when the direct arrival on the water break trace could not be picked because of high-frequency noise. At constant ship speeds this plot was a straight line.

Early in the cruise attempts were made to pick second and third arrivals. This was discontinued when it was found that the time interval between the firing of shots was too short to enable more than the first arrival to be picked and plotted with acceptable accuracy.

Immediately after every refraction traverse, the co-chief scientist, R.E. Houtz, re-examined the records and made corrections to the plots as necessary. The revised plots were used to plan subsequent refraction traverses. On several occasions, significant changes were made to the preliminary interpretation of the data on re-picking the arrivals and applying minor corrections. The details of Hourz's procedure are as follows:-

(1) All shot-instant and arrival times were checked from the records and corrected as necessary. If the picking of a first arrival was of doubtful accuracy, it was generally deleted from the plot.

(2) Shot-depth and shot-instant corrections were made (Fig. 5). The shot depth correction is negligible for all except 35 and 67-lb charges, for which it can be as large as 0.1 s. Application of this correction adjusts the shot point to the surface. The shot-instant correction is more significant as there is a considerable time lapse between the shot instant as recorded by the trip eel and the actual firing time. Houtz compiled graphs of shot-instant correction versus fuse burn time for ship speeds from one to ten knots (Fig. 6) so that the shot-instant correction could be determined graphically.

(3) Houtz avoided having to carry out the tedious procedure of applying terrain corrections, by not attempting refraction shooting where the reflection profiles showed side echoes. On some lines, the topography became rugged after a refraction profile had commenced but its effects were never large enough to necessitate making onboard corrections to the data. Houtz believes that the topographic effects of seafloor relief of less than 100 fathoms can be ignored.

A notable feature of the refraction records was the presence of strong later arrivals, probably S-waves. Lamont scientists only make use of S-wave arrivals when the first refractions are hard to pick, although useful information could probably be gained by studying them in detail. One of the major difficulties is in identifying layers corresponding to particular S-wave arrivals.

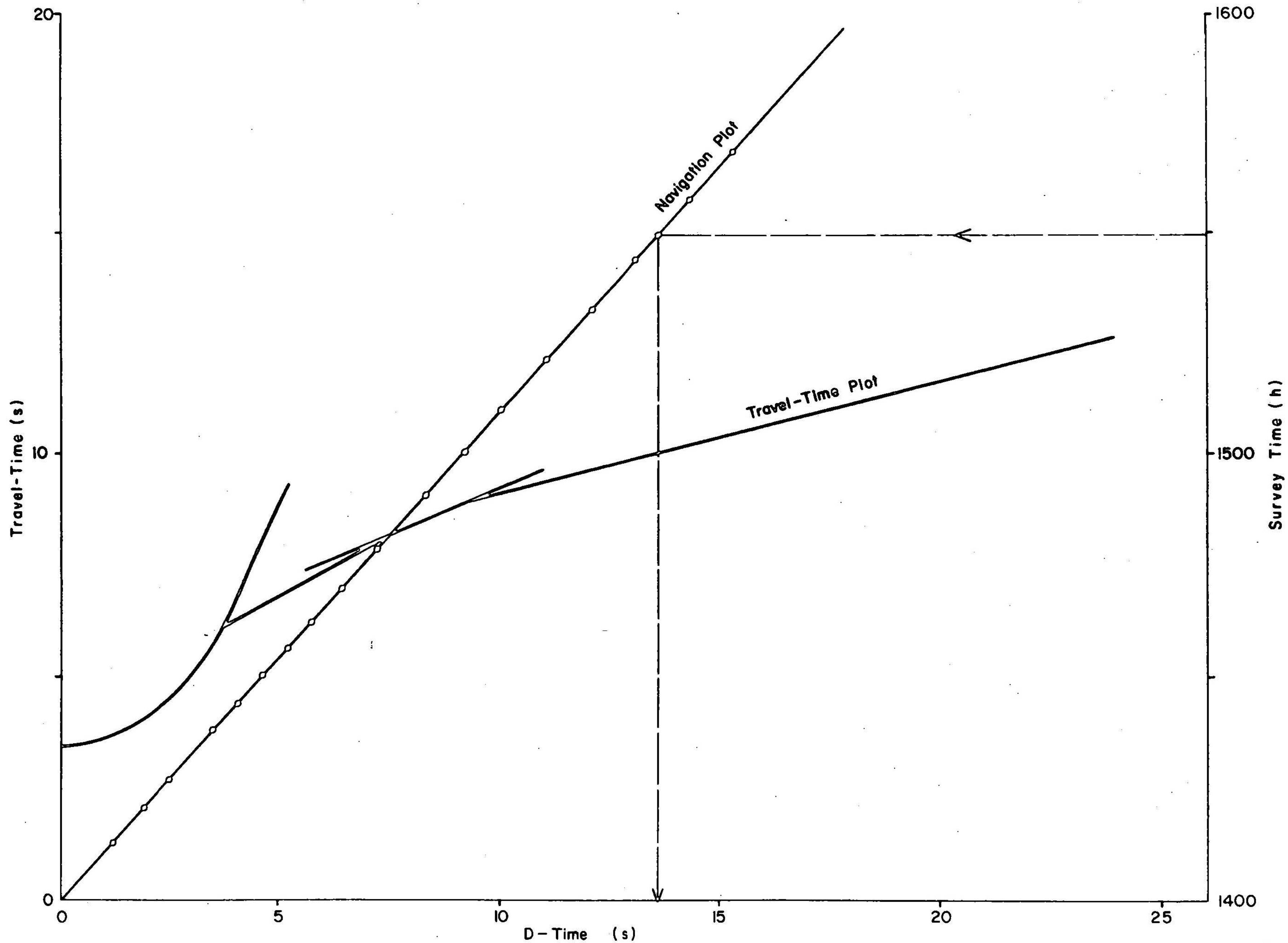
Ocean Bottom Seismometers (OBS)

Tilbury (1976) gives a detailed account of OBSs and their use in refraction studies. Briefly, the main advantages of OBSs over long-range sonobuoys are:-

(1) OBS recordings are not affected by noise due to wave action.

(2) The range of operation of the OBS is not limited by the range of radio transmission.

(3) The vertical and horizontal seismometers in the OBS are more sensitive than sonobuoy hydrophones.



SAMPLE TRAVEL TIME AND NAVIGATION PLOT

FIG. 4

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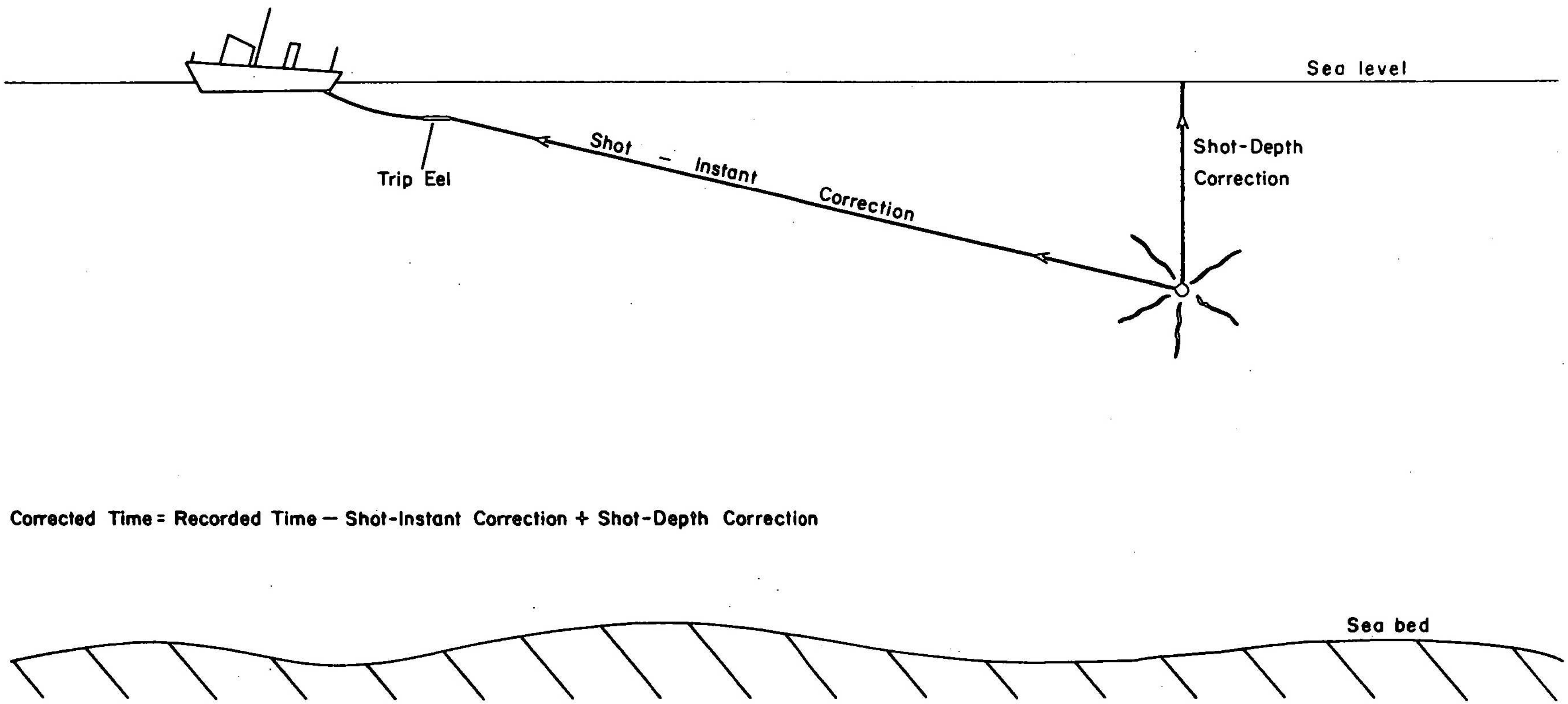

ILLUSTRATION OF SHOT–INSTANT AND SHOT–DEPTH CORRECTIONS

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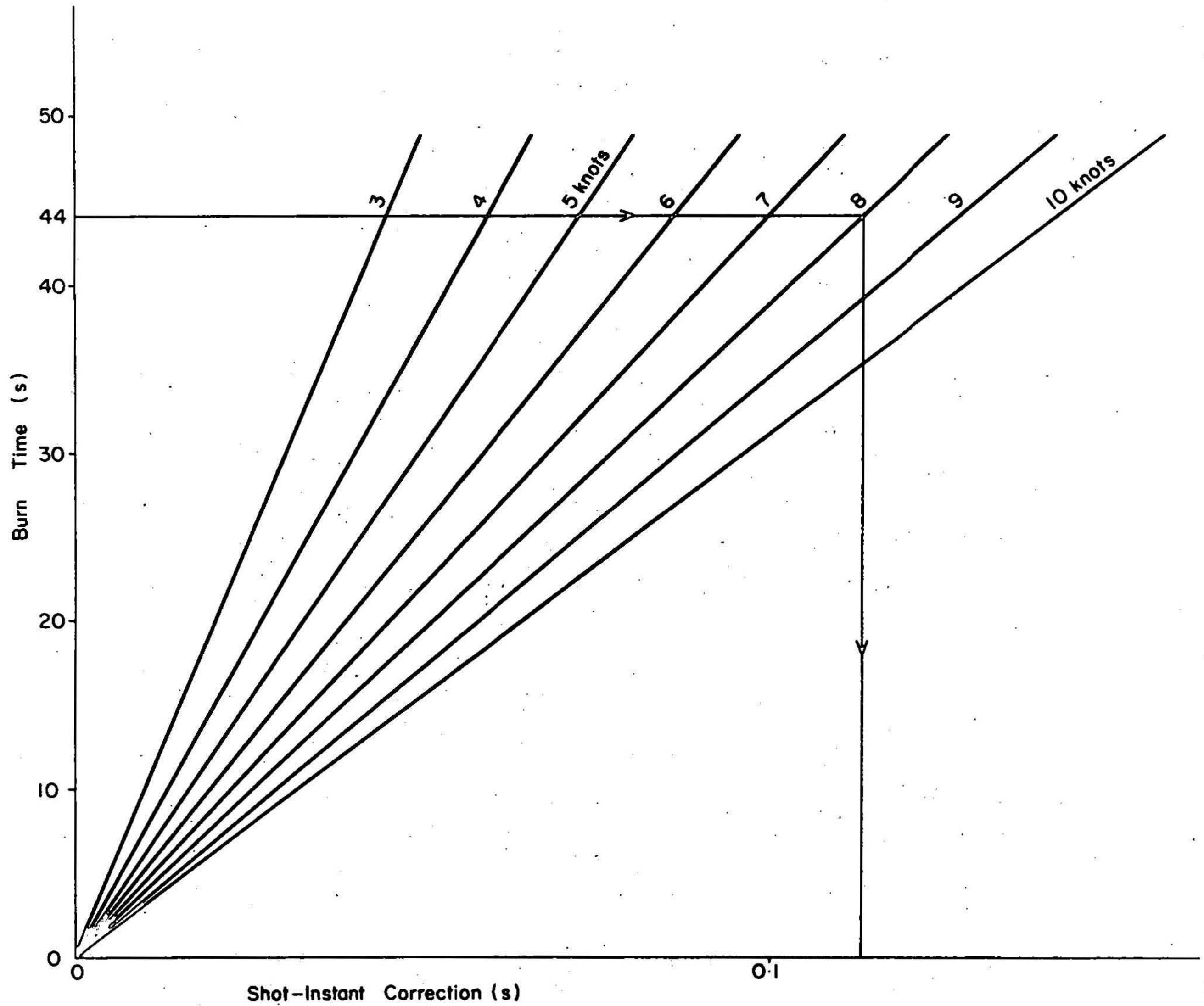
FIG. 5

FIG. 6



BURN TIME VERSUS SHOT-INSTANT CORRECTION

(4) As OBS recordings are made on magnetic tape, more can be done with the data in terms of filtering and phase and amplitude analysis.

(5) The OBS recording life is 10 to 12 days compared with about 4 hours for sonobuoys.

Against these advantages are the following disadvantages:-

(1) At stations in deep water, about 4 hours are lost in deploying and retrieving an OBS.

(2) Time is also lost in steaming back over a previously surveyed track to retrieve an OBS.

(3) Losing one OBS is equivalent in monetary terms to losing 40 to 50 long-range sonobuoys.

(4) The performance of an OBS cannot be monitored.

(5) Whereas the interpretation of sonobuoy refraction data can normally be regarded as a two-dimensional problem, the interpretation of OBS refraction data may require consideration of a third (lateral) dimension if the ship does not pass directly over the OBS on a return traverse.

Houtz feels that at present, the advantages of using OBSs are not sufficient to outweigh the disadvantages. Lamont handled the instrument impressively well and useful data were probably recorded, but the long-range sonobuoy data alone were sufficiently good to achieve most of the objectives of the refraction surveying. At this atage, there would seem to be little advantage for BMR to use them in geophysical reconnaissance surveys.

4. CONCLUSIONS

Several conslusions are drawn which maybe pertinent to the operation of future BMR refraction surveys at sea. These are:-

(1) The operating system and procedures used by Lamont on this leg and described in this report would be quite suitable for application by BMR. BMR could improve on the system by recording data on magnetic tape.

(2) In surveys to study the crust, long-range sonobuoys are preferable to short-range sonobuoys in spite of their considerably greater cost. It is more valuable to have refraction velocities down to the mantle along one line, than to have refraction velocities for upper crustal layers only along several lines. The military SSQ-41 short-range sonobuoys may be useful in areas of deep water and thin crust, but for work in areas of thick crust, long-range sonobuoys are essential.

(3) The performance of long-range sonobuoys can be improved by replacing some of the weights on the hydrophone string with enough paraffin wax to give the string almost neutral buoyancy. This is effective in reducing noise by decoupling the hydrophone from sonobuoy motion on the surface.

(4) The explosive bolts on BMR short-range Aquatronics sonobuoys are defective, and the buoys should be deployed manually using the procedure described in Appendix 1.

(5) If a sonobuoy is launched while vertical reflections are being recorded, there is a danger of the buoy becoming entangled with the hydrophone streamer cable, particularly if the cable is long. The BMR should investigate methods of overcoming this problem. Two possibilities are to use delayed deployment sonobuoys (eg. 8-minute delay for ship speed of 8 knots), or to devise a system for launching a sonobuoy at a safe distance to one side of the streamer cable.

(6) Primacord and booster caps should be used in firing large charges. On the Vema cruise, primacord was not used and several large charges failed to detonate at a critical point on a refraction line.

(7) When there is doubt about whether a particular charge is sufficiently large to give pickable refractions, a larger charge should be used.

(8) Refraction shooting should preferably not be attempted where reflection profiles show rugged seafloor topography or the effects of same (eg. side echoes). By this means, the need to make topographic corrections to the refraction data will be largely avoided.

5. REFERENCES

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APPENDIX 1. Use of BMR equipment on the Vema

At the beginning of leg 3 of Vema Cruise 33, BMR had the equipment aboard:

- two Ampex 14-channel analogue tape recorders.
- two E.P.C. continuous paper chart recorders.
- one set of PT-100 seismic amplifiers with power supply.
- one Geometrics magnetometer with power supply, cable, and sensor.
- one Krohn-Hite filter.
- Aquatronics short-range sonobuoys and Telseis STR-74 receiver.

Because of lack of rack space in the upper lab and Lamont's fear of a second magnetometer becoming entangled with their equipment, the seismic amplifiers and magnetometer were not used on the cruise. The final arrangement for the AMPEX/E.P.C. recording system was that five channels would be recorded as follows: (Fig. 7).

Channel 1 - unfiltered trip-eel signal

Channel 2 - trigger for E.P.C. recorder. This was taken from a logic circuit at the back of Lamont Profiler B. An inverter circuit built by R. Dulski of BMR converted this signal to a sharp positive spike which was sufficient to trigger the E.P.C. The trigger pulse occurred about 260 ms after the trip-eel pulse because of delays in the logic circuit elements.

Channel 3 - 30-minute event marker taken from the E.P.C.

Channel 4 - wide-band seismic signal filtered through a 10-300 Hz passband.

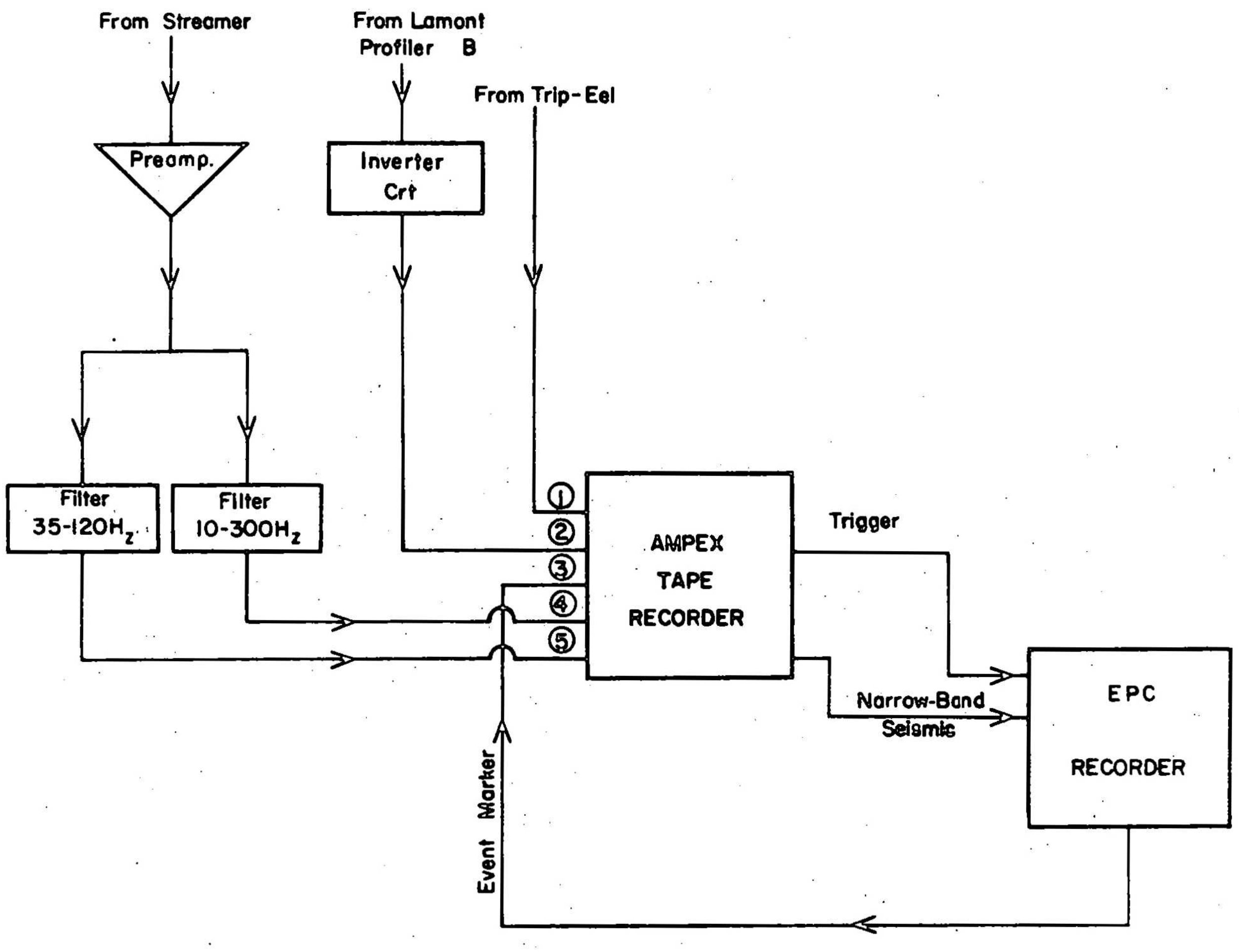
Channel 5 - narrow-band seismic signal. This was passed through a Krohn-Hite variable filter with low and high frequency cut-offs at 35 and 120 Hz. The narrow-band seismic signal was played back on the E.P.C. recorder to be used as a monitor of record quality.

When refraction shooting was done with the air-gun, channel 5 was used to record signals taken direct from the Watkins-Johnson sonobuoy receiver. When refraction shooting was done with explosives, signals were recorded as indicated in Figure 8: channel 1 recorded one-second time marks from a Monsanto digital clock supplied by Lamont; channel 2 recorded the shot-instant signal direct from the trip-eel; and channel 3 recorded the sonobuoy signal via the TELSEIS STR-74 receiver. No attempt was made to filter either of the sonobuoy signals. Early in the leg signals were monitored on an oscilloscope to determine the signal levels going on to tape. Once these were found to be acceptable, the system was left almost entirely alone.

The explosive bolts on the BMR short-range Aquatronics sonobuoys were found to be defective. The buoys had to be deployed manually using the following procedure:

- removing the central plastic shield
- cutting the two wires leading to the explosive bolt
- unscrewing the bolt holding down the U-shaped plate and removing this plate
- sliding loose the basal section of the sonobuoy containing the hydrophone. This basal section is held against the buoy to contain the hydrophone and prevent it tangling before the buoy is dropped into the sea.

FIG. 7

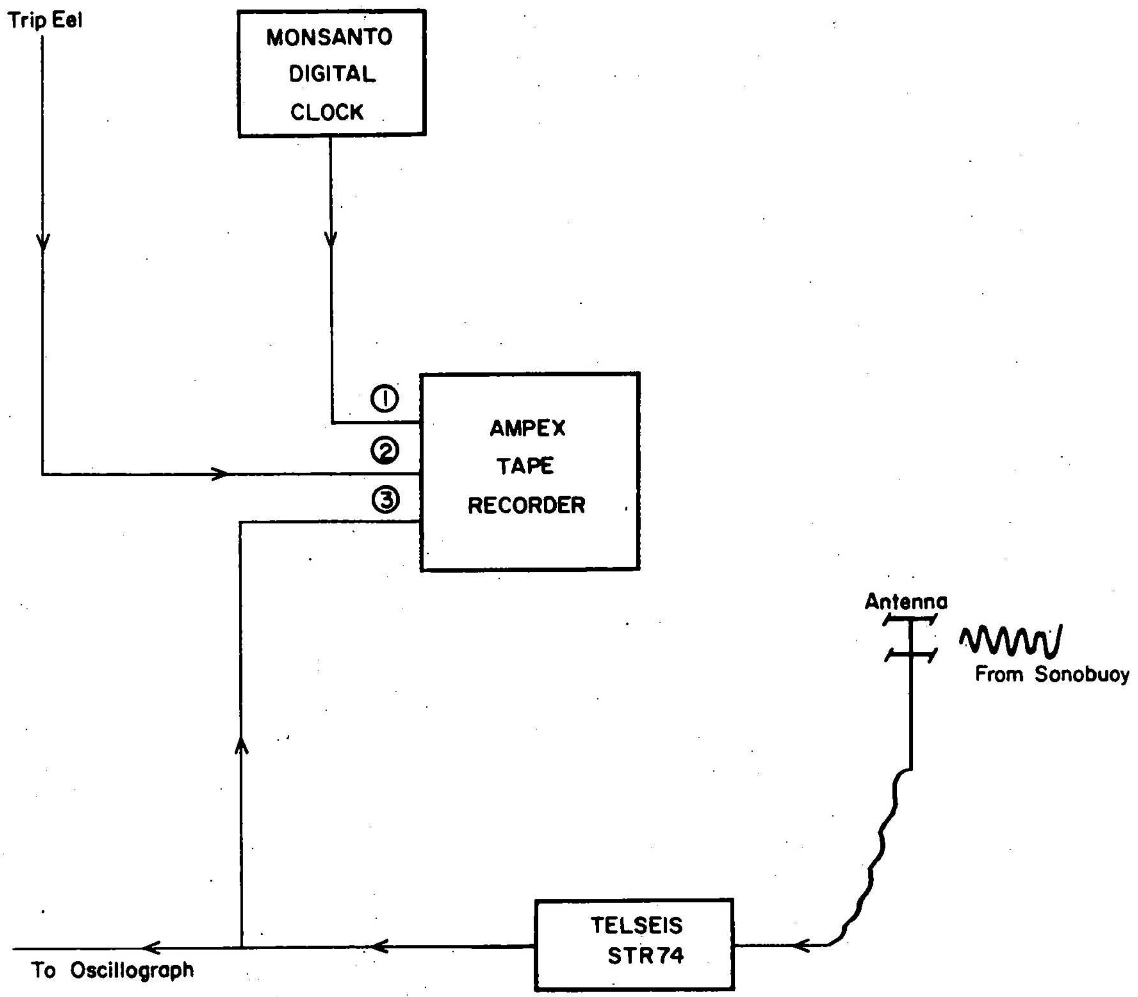


BMR SEISMIC RECORDING SYSTEM

Record No. 1976/87

A/B8-158A

FIG. 8



SYSTEM FOR RECORDING LONG-RANGE SONOBUOY SIGNALS

APPENDIX 2. Procedures and safety regulations for handling explosives on the Vema

(a) The following table indicates fuse lengths burn times, firing intervals, and sink rates for charges of various sizes:

Shot Size (lb)	Fuse Length (inches)	Burn Time (s)	Firing Interval (minutes)	Sink Rate m/s
2	8	24	3	0.85
4	8	24	3	0.90
7	12	32	3	1.0
15	18	44	5 or 7	1.1
35	36	72	7 or 10	1.7
67	36	72	10, 15 or 20	1.6

This table was used as a general guide in refraction shooting, but the shot size and firing interval were normally increased when first arrivals were expected from the next layer in the sub-surface.

(b) Safety regulations

The regulations concerning the storage and use of explosives on board American research vessels are contained in NAVORD OP 3696 (Explosives Safety Precautions for Research Vessels.). The principal regulations are:

(1) Blasting caps must always be kept separate from explosives and fuse lighters.

(2) The quantity of explosives stored on the fantail for immediate use should not be more than is likely to be used.

(3) Preferably use explosives cannisters with deep cap wells; if not, extreme care should be exercised in making up the charge.

(4) Fuse lengths should be cut so that the charge detonates at a safe distance from the ship. Graphs of the 'shock factor' versus depth and distance from the ship are contained in NAVORD OP 3696. Minimum fuse length in any circumstances is 8 inches.

(5) Charges should be assembled only shortly before they are due to be used.

(6) Fuse lighters should not be attached to fuses until the 10-second firing warning has been given. This is to guard against the dangers of pre-ignition.

(c) Shot logging

A shot logger on the Vema recorded each shot number, charge size, fuse length, time of charge over the side, time of firing, burn time of the fuse, water depth, and any pertinent remarks. Shot numbers started at No. 1 for the first shot of the leg, and were numbered sequentially thereafter, whether or not the shots were successful. The table below is an example of a shot logging sheet. In addition, the shot logger timed the operation, giving the shooter on the fantail one minute and ten seconds warnings and the fire order at the appropriate time. On a three-minute shooting schedule the shot logger was quite heavily occupied and minor tasks such as taking PDR readings were handled by the duty lab. watch.

TABLE. Example of a shot logging sheet

Buoy over at 1541 10/2/76
Hydrophone depth 180 ft

Course 090°
Sea Temp. 18.5°C
Channel C

Shot number	Shot size (lb)	Fuse length (inches)	Time Over	Time Fire	Burn Time (s)	PDR (fathoms)	Remarks
382	2	8	15 4102	15 4126	24	2608	3-minute firing interval
383			4402	4425	23	2604	
384			4703	4726	23	2602	
385			5002	5026	24	2607	
386			5301	5325	24	2600	
387			5602	5625	23	2595	
388			5902	5927	25	2595	
389			16 0203	16 0227	24	2592	
390	7	12	0503	0535	32	2596	
391			0803	0834	31	2588	
392			1102	1135	33	2576	
393			1403	1435	32	2578	
394			1704	1736	32	2580	
395	15	18	2003	2047	44	2580	

TABLE (Cont'd)

Shot number	Shot size (lb)	Fuse length (inches)	Time Over	Time Fire	Burn Time (s)	PDR (fathoms)	Remarks
396			2503	2547	44	2581	5-minute interval
397			3004	3047	43	2584	
398			3504	3548	44	2584	
399			4003	4048	45	2585	7-minute interval
400	35	36	4704	4816	72	2587	
401			5404	5515	71	2590	
402			17 0105	17 0216	71	2590	
403			0805	0916	71	2588	10-minute interval
404			1805	1917	72	2587	
405	67	36	2805	2916	71	2586	
406			3806	3917	71	2501	15-minute interval
407			5305	5417	72	2575	
408			18 0806	18 0917	71	2574	
409			2307	-	-	2574	Dud
410			2806	2818	72	2570	