DEPARTMENT OF NATIONAL RESOURCES

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VEMA CRUISE 33 LEG 2, IN THE SOUTHEAST INDIAN OCEAN, 21 DECEMBER, 1975 TO 17 JANUARY, 1976: OBSERVER'S REPORT

by

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SUMMARY

During leg 2 of *Vema* cruise 33, geological and geophysical data were collected along the Southeast Indian Ocean Ridge crest, and on either side of the ridge along isochrons corresponding to seafloor spreading Anomaly 6. The data collected include seismic refraction, seismic reflection, magnetic, bathymetric, and heat flow data, rock dredge hauls, and piston cores. In addition, geophysical data were obtained along two traverses over the Australian continental margin, one across the Great Australian Bight, and one across the Naturaliste Plateau.

Short accounts of the theory and method of measuring heat flow, and the method of dredging on the ridge crest are given in this report. On the *Vema* a piston corer with outrigger probes was used to measure the thermal gradient in the bottom sediments. The thermal conductivity of the sediments was measured by inserting a needle probe with an internal heater wire and a thermistor into the core sample, and measuring the rate of rise of temperature when a known amount of heat was applied to the wire.

Dredging of basalt from the ridge was accomplished by lowering a chain bag and allowing it to scrape along the bottom for a period of between one and three hours.

1. INTRODUCTION

Geophysical and geological data were collected in the Southeast Indian Ocean between 132°E and 115°E during the second leg of cruise 33 of the Lamont-Doherty Geological Observatory research vessel *Vema*. Chief scientist on this leg was Dr D.E. Hayes. The complete track of the leg is shown in Figure 1. *Vema* covered a distance of about 8000 km and completed her millionth mile since becoming a research vessel. The leg consisted mainly of three east-west lines, one along the Southeast Indian Ocean Ridge crest, and two on either side of the ridge along an isochron corresponding to seafloor spreading Anomaly 6. The data collected consist of seismic refraction, seismic reflection, magnetic, water depth, and heat flow data, rock dredge hauls, and a number of piston cores. Owing to a fault in the gravimeter caused by a severe roll on the previous leg, gravity data were not collected.

The other three legs of cruise 33 of the *Vema* are discussed by Petkovic (1976), Stagg (1976) and Tilbury (1976).

2. CRUISE SUMMARY

The *Vema* left Port Adelaide at 1000 hrs on Sunday 21 December and, after taking on explosives from a barge at the entrance to the port, commenced surveying at 1500 hrs. The continental shelf was traversed in a southwesterly direction after which the *Vema* steamed due south towards the Southeast Indian Ocean Ridge. Two BMR sonobuoys were launched while crossing the continental rise, but owing to failure of the hydrophone deployment system, no useful information was obtained. A heat flow measurement was taken on the 24 December (S14) using a multigrad instrument. Unfortunately this instrument was lost as it was being raised, when the winch cable broke.

The Southeast Indian Ocean Ridge was reached on the 27 December and a long-range sonobuoy profile was shot in the early afternoon. Preliminary plotting of arrival times indicated a layer with a velocity of 5.65 km/s overlying material with a velocity of 6.85 km/s. Later that day, fresh tholeitic basalts were recovered at a dredge station (S15). An ocean bottom seismometer (OBS) was launched at station S16 on the evening of 27 December and the next day profiles of about 35 n miles length were shot on either side of the OBS.

From 29 December until 3 January, the *Vema* surveyed on and near the ridge crest. Six dredge stations (S17 and S22) were occupied along the ridge during this period. At all but one station large amounts of fine-grained pillow basalt were recovered. After working west along the ridge crest the vessel steamed south to latitude 54°30'S and from 4 January worked its way eastward along an isochron corresponding to Anomaly 6 (21 m.y. B.P.) south of the spreading centre. A long-range sonobuoy probe was shot at the beginning of this line and three heat flow and piston core stations (S23 to S25) were occupied. The preliminary results indicate heat flow values of 0.3 to 0.4 HFU (S23), 1.1 to 1.2 HFU (S24), and 0.8 HFU (S25) which are lower than the average value of 1.45 HFU for oceanic crust. Short-range sonobuoy probes were made between the stations. The end of the line was reached on 5 January, and the Vema headed north towards the site where the OBS had been launched. The OBS was recovered on the night of 7 January after it had been on the sea-bottom for 11 days.

The ship then steamed north to survey a line along an isochron corresponding to Anomaly 6 north of the spreading centre. From 13 January, five heat flow and piston core stations were occupied along this east-west line. Preliminary heat flow values of 0.9, 0.8, 0.8, 0.8, and 0.9 HFU were measured at stations S26-S30 respectively. Two long-range sonobuoys and four short-range sonobuoys were deployed along this line. The westernmost probe, near S30, indicated a layer with velocity 3.5 km/s over one with a velocity of 7 km/s.

Upon completion of the line the ship steamed towards the Naturaliste Plateau. Sonobuoy probes were made along lines intersecting Deep Sea Drilling Sites 264 and 258. A heat flow measurement at station S31 on the plateau gave a preliminary result of 1.4 HFU. The track across the Naturaliste Plateau ties to several lines from the BMR continental margins survey. The Vema arrived at Fremantle at 1200 hrs on Saturday 17 January.

3. SEISMIC RECORDING

BMR continuous seismic profile recording

The BMR seismic recording system, consisting essentially of a 14-channel Ampex tape recorder and an E.P.C. monitor recorder, had been installed in the Vema for the first leg of cruise 33. In Adelaide, before the second leg commenced, a preamplifier was added to the system. Recording commenced at the start of the leg on 21 December and continued until 4 January. Several gaps in the data are due to failure of the power supply and the lack of a trigger pulse. Recording was discontinued between 4 January and the morning of the 17th, because ocean bottom sediments were too thin to make recording worthwhile.

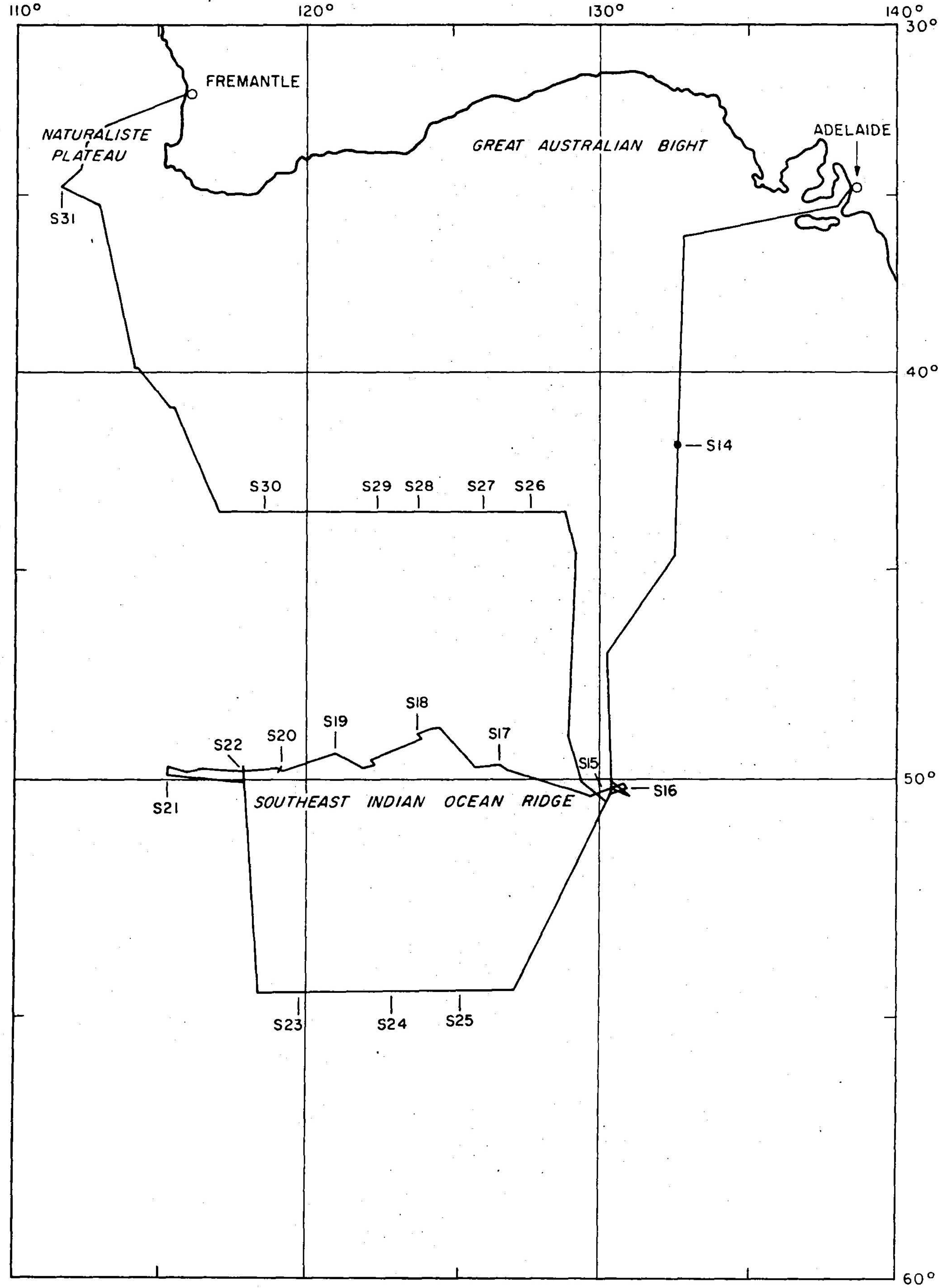

FIG. 1 TRACK OF THE VEMA CRUISE 33-02

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Difficulties experienced with the system were mainly due to interference of the BMR recording gear with the Lamont instruments. For instance, when the trigger signal was taken direct from the trip eel, the Lamont profiling recorders functioned erratically. The trigger was eventually taken from the logic circuit of one of the Lamont profilers but this gave rise to noise in the signals recorded by the BMR tape recorder. This noise was later identified as being caused by too large a D.C. voltage level on the trigger signal.

The E.P.C. recorder triggered on spurious noise and since there are no delay facilities built into the recorder it had to run on a very long sweep of 8 seconds. It was of little help in monitoring the signal going onto tape. For this reason the E.P.C. recorder was switched off and instead the signal was monitored using an oscilloscope. Filter settings on the Krohnite filter were kept at 50 and 500 Hz for the low and the high cut-off frequencies.

Sonobuoy recording

Signals from six short-range sonobuoys were recorded on a spare channel of the 14-track tape during the leg. Recording of reflection and trigger signals on two tracks continued while the refraction signals were being recorded. The Ampex tape recorder was also used to record the results of seismic refraction experiments with four long-range sonobuoys. Three signals were recorded on separate channels during these experiments: a 1-s pulse, a shot-break signal, and a seismic signal. Both the shot-break and the seismic signal were amplified to 1 volt peak-to-peak before recording on tape.

BMR Aquatronics sonobuoys

During this leg, ten Aquatronics short-range sonobuoys owned by BMR were used. Of these, four gave good results after several problems with the buoys, the receiver, and the ship's high frequency antenna were overcome. The major findings concerning the state of the buoys, which probably apply to the other Aquatronic sonobuoys held by BMR, are as follows:

(i) The batteries inside the buoys and the audio electronics were still working.

(ii) The hydrophones did not generally deploy automatically when the buoy was launched probably because of a failure in the firing circuit.

Because of the failure of many of the sonobuoys to release their hydrophone automatically, it was necessary to release the hydrophone before launching a sonobuoy. This was done as follows. The middle shroud of the buoy was removed and the two wires to the firing pin were cut and a U-shaped plate covering the firing pin was removed by unscrewing the bolt which fastens it. Another U-shaped plate which holds the firing pin was then removed allowing the hydrophone to drop out of the sonobuoy's bottom section. In launching the buoy, care was taken to ensure that the hydrophone was let go a few seconds before the buoys.

4. DATA OBTAINED FROM THE LEG

I obtained the following data records at the end of the leg: four tapes of seismic reflection data, one tape of long-range sonobuoy refraction data, one box of satellite navigation computer output, one set of copies of the chief scientist's log, one set of copies of the ship's track maps showing fixes and depth values at six-minute intervals (total of 14 maps), one copy of the track map with station positions. The rest of the data, including magnetic and bathymetric data at 6-minute intervals and copies of the seismic profiler records, will be sent to BMR by Lamont when the data records have been digitized and copied.

5. MEASUREMENT OF HEAT FLOW

This section briefly describes how heat flow is measured from the RV Vema. The basic equation in determining the heat flow towards the Earth's surface is relatively simple and consists of:

$$q = K\ (\partial T/\partial Z)$$

where q is the geothermal flux, K is the thermal conductivity, T is the temperature and Z is the depth. The quantity $\partial T/\partial Z$ is referred to as the geothermal gradient (g) and is the rate of increase of temperature with depth. K is related to the specific heat c, the density ρ, and the diffusivity κ, in the following way:

$$K = \rho c \kappa$$

a

In practice the main object of heat flow measurements at sea is to determine the geothermal gradient g, since the thermal conductivity K does not vary by large amounts. For most deep sea sediments K varies between 1.8 and 2.5 μcal cm^{-1} sec^{-1} $^{o}C^{-1}$.

Equipment

To measure the thermal gradient in the ocean, the method devised by Bullard (1954) is used. This method requires a probe or corer with two or more temperature sensing devices spaced along the instrument, together with a recorder (Fig. 2). Onboard Vema, a Ewing piston corer with a length of about 10 m is employed. Attached to the corer are five outrigger probes spaced 2 m apart which contain thermistors. The recorder is housed in a pressure vessel which sits in the core weights. A schematic circuit diagram of the recorder is shown in Figure 3A. The recorder is of the 'Ewing thermograd' type. The thermistors in the temperature sensing probes are sequentially placed in one arm of a simple Wheatstone bridge by an automatic 16-position rotating selector switch. Any imbalance in the bridge is detected by a sensitive 30-cps galvanometer. Deflections of the mirror are recorded photographically on a 70-mm film placed about 23 cm from the galvanometer. The bridge and the galvanometer are repeatedly calibrated by placing a standard resistor in the bridge instead of the thermistor on every half-minute cycle of the rotary switch. The standard resistors are selected to cover the range of expected thermistor resistance in the ocean bottom sediments. A typical film record is shown in Figure 3B.

Procedure before station

Before the Vema came on a station the piston corer was rigged with the probes. The recorder was loaded with new film and the batteries were renewed. During the approach to a heat flow station, a 3.5 kHz echosounder was watched to ensure that sufficient sediment was present on the bottom to allow full penetration of the corer. Seismic profiles and sonobuoy probes were made along the approach track to the heat flow station, and where possible the station was situated on the intersection of two seismic profiling lines. This seismic profiler and sonobuoy data are later used to obtain several corrections to the measured heat flow.

Procedure on station

Once the Vema came on station, the corer with the heat flow equipment attached to it was lowered over the side. The tripping arm on the triggering device (Fig. 1) was set in the cocked position and the corer was lowered to the sea-bottom. In several instances a pinger was attached to the wire above the corer so that its distance from the bottom could be read from the precision depth recorder. Wire was paid out until the trigger weight had reached the bottom and the corer had been released. The corer was then left in the sediment for about ten minutes to allow the effect of frictional heating of the probes to die down and for the temperature of the probes to come to equilibrium with that of the bottom sediments. Because of the small mass of the outrigger probes, the effect of friction on them caused by penetration died out within a few minutes. During the period of measurement, wire was paid out spasmodically to prevent pull out of the corer. After the required time for a reliable temperature measurement had expired, the corer was hauled onboard.

Procedure after station

When the corer had been hoisted aboard, the recorder was disconnected and taken into the laboratory and the film was developed. The piston core was extracted and described and measurements of thermal conductivity were made at 10-cm intervals along its entire length. Cores of up to 9.5 m were taken during this leg.

The conductivity measurements done onboard Vema use the needle probe technique. This consists of inserting a very thin cylinder containing an internal heater wire into the core, and applying a known amount of heat to the wire. A small thermistor which is inside the needle and midway along its length measures the rate of rise of temperature. The value of the conductivity (K) is obtained from the following formula:

$$T = (Q/4\pi K)\ \ln(t) + C$$

where Q is the heat applied per unit length per unit time, T is the temperature at the thermistor is a function of time t, and C is a constant. Readings of T for each conductivity measurement were usually taken over a four-minute period.

Calculation and correction of the heat flow measurement at a station

The heat flow value obtained from the measured thermal gradient and conductivity requires several corrections before it is close to the true thermal flow through the ocean floor. To make these corrections, it is necessary to know the sedimentation rate, the thickness of the sediment, and the topography of both the sea-floor and the basement. The corrections are applied to the thermal gradient data and are known as environmental corrections. They correct for:

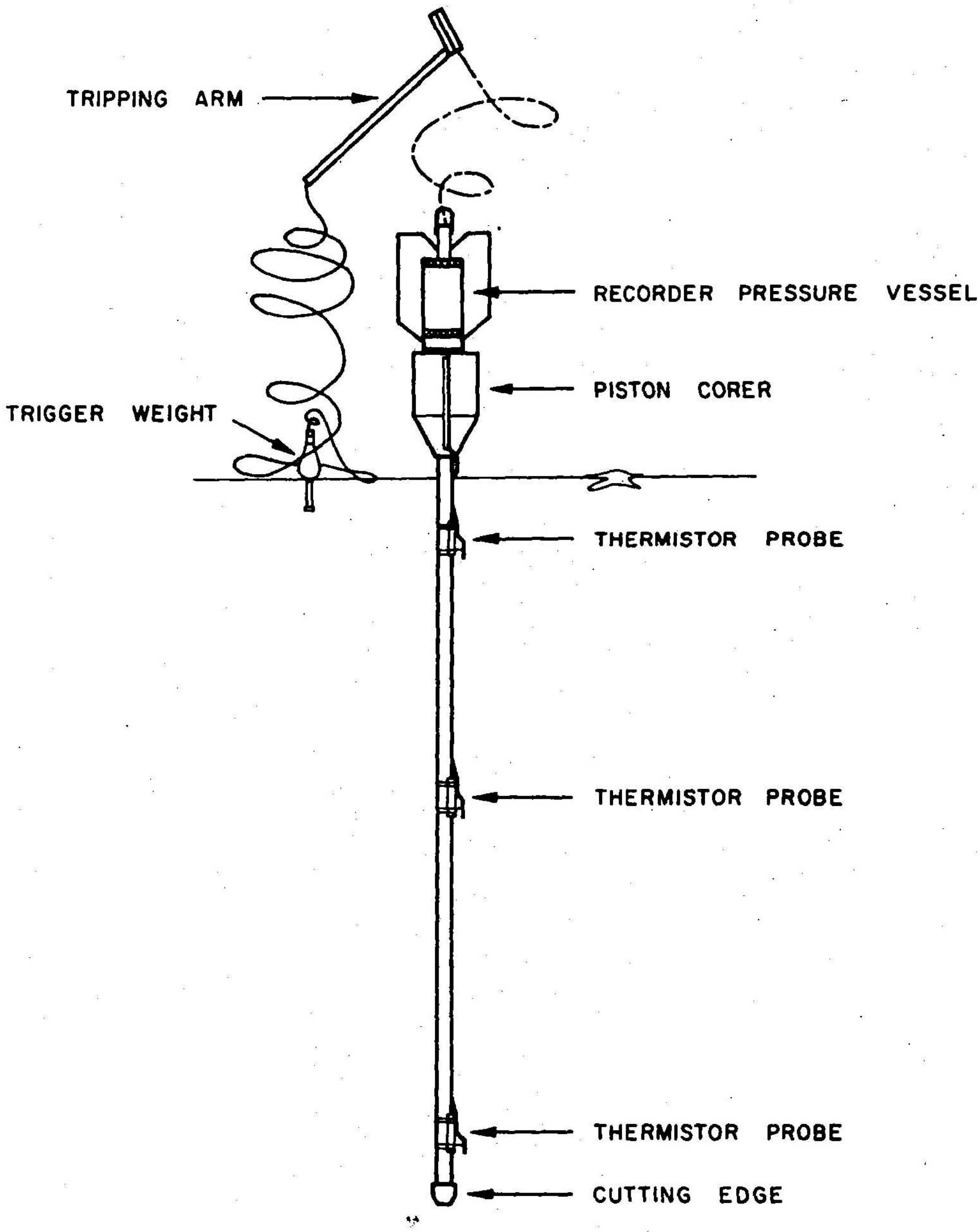

FIG. 2 OUTRIGGED TEMPERATURE GRADIENT PROBE
ATTACHED TO A EWING PISTON CORER

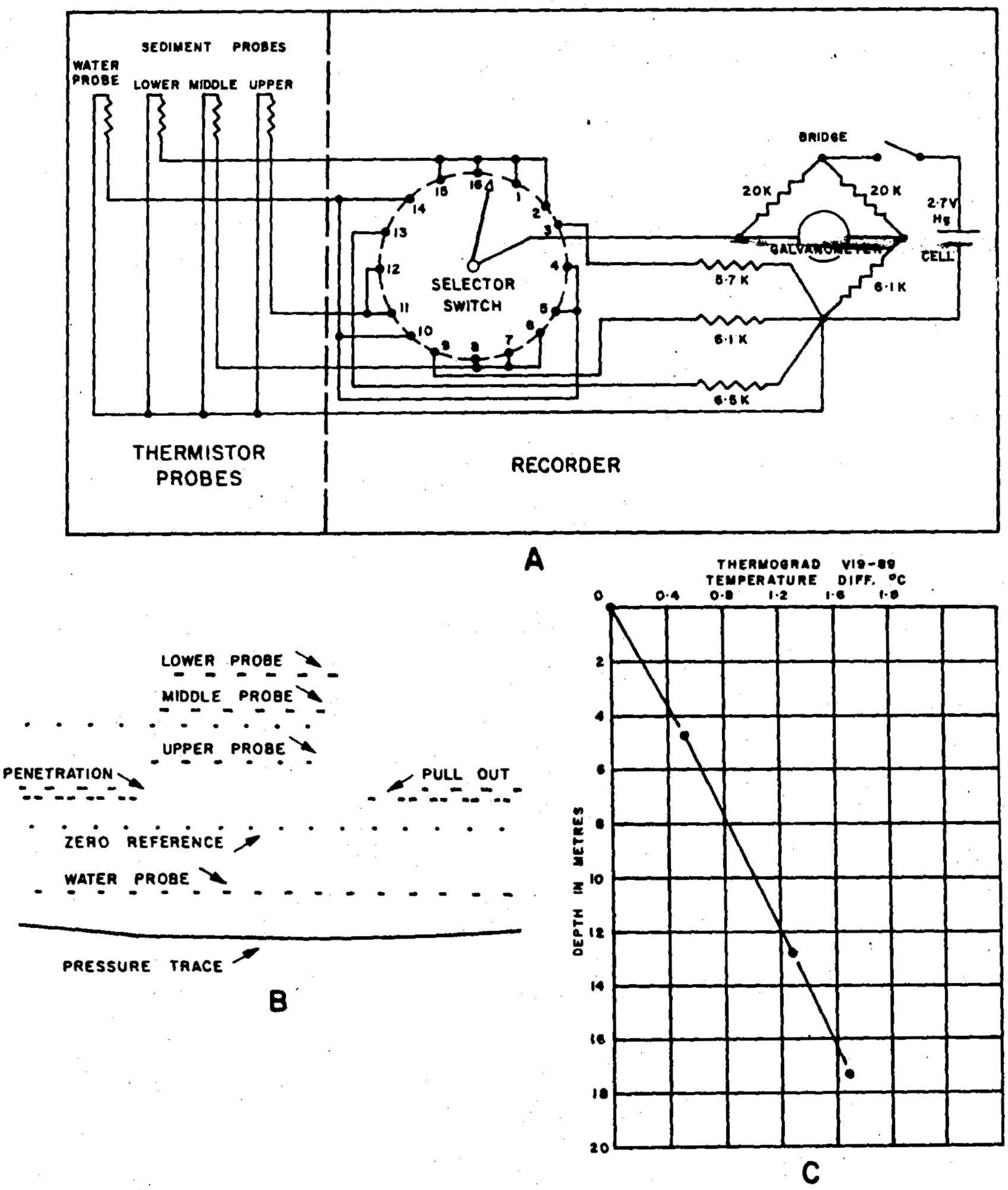

FIG. 3

A SCHEMATIC DIAGRAM OF SENSOR AND DETECTING CIRCUIT OF THE EWING THERMOGRAD.

B TYPICAL RECORD OF THE OUTRIGGED PROBE APPARATUS.

C TEMPERATURE VERSUS DEPTH IN THE BOTTOM SEDIMENT RELATIVE TO THE BOTTOM WATER TEMPERATURE DERIVED FROM THE RECORD SHOWN IN B.

a) the effects of deposition and erosion. Freshly deposited sediments tend to have a lower thermal gradient than sediments which are being eroded.

b) local topography and irregular sediment cover. These effects can be estimated using the results of calculations performed by Von Herzen & Uyeda (1963) and Sclater et al. (1970).

c) bottom water temperature variations. These appear to be negligible in the deep oceans.

d) biogenic activity or water movement within the sediment. If either of these have taken place, the effects will be evident in the core sample taken at the heat flow station.

The theory of the method used to estimate these environmental corrections is treated in a volume edited by Lee (1965). Once the corrections are applied to the measured thermal gradient, the heat flow through the ocean floor can be calculated from the expression given in the introduction.

6. DREDGING OPERATIONS

The *Vema* occupied seven dredge stations on or near the crest of the Southeast Indian Ocean Ridge during leg 2. At six of these stations, large amounts of fine-grained pillow basalts were recovered. The following is a general description of the equipment used and the procedure adopted.

Equipment

The dredging equipment on the *Vema* consists of a winch driven by a converted tractor engine, and an A-frame. The winch is situated on the deck slightly aft of midships and the A-frame is on the starboard side of midships. The wire from the winch's drum goes over the side via blocks mounted on the top of the A-frame and on the deck immediately below the A-frame. The amount of tension on the wire is indicated on an arbitrarily graduated scale situated near the side of the drum. The dredge consists of a conventional rectangular frame to which a chain net is attached.

Procedure

Dredging on the *Vema* was a hard task in the rough cold weather experienced at the latitude of the Southeast Indian Ocean Ridge. The winch and its controls are exposed and a large amount of discomfort for the operator was caused by bad weather or sea-state. However the arrangement does allow the winch operator to observe the operation at all times.

Dredging on the ridge crest proved to be a relatively simple operation. The Vema would come on station with the starboard side to windward and the dredge was lowered over the side. A length of wire, in excess of the water depth by about 1000 m, was paid out and the dredge was then left on the bottom. After several solid pulls on the dredge had been observed on the tension measuring device, the dredge would be hauled in again. The period for which the dredge was left to drag along the bottom varied from 1 to 3 hours. While the dredge was being hauled in the Vema would be manoeuvred clear of any snags.

The amount of rock recovered at different stations varied from 100 to 1500 lb; some boulders were as large as 0.15 m^3. In the water-depths of about 2 km over the ridge crest, the time taken for a dredging was between 3 and 5 hours.

7. DISCUSSION AND RECOMMENDATIONS

At present there is no organization or institution in Australia engaged in making heat flow measurements at sea. This is largely because of the high cost and the specialized nature of heat flow surveying. It is worth reflecting on the possibility of BMR becoming involved in making heat flow measurements at sea. Heat flow measurements have been made in all the world's major oceans since the 1950s and they have contributed greatly to knowledge of the evolution of the ocean basins. One of the earlier discoveries was that the mean heat flow at sea was equal to that on land. Later work has shown that the amount of heat flow and the depth of the sea-floor are related to the age of the oceanic crust. Of particular importance was the discovery of high heat flow in the marginal basins of the northwest Pacific such as the Sea of Japan.

If BMR were to do heat flow work, it should concentrate its efforts on the marginal plateaux and ridges around Australia where the small amount of work done hitherto indicates the presence of anomalous heat flow regimes. For instance, the Naturaliste Plateau and the Lord Howe Rise both have higher than normal heat flows judging from the one measurement taken on each of the structures. Such information is necessary in determining whether the temperature of the sub-bottom is conducive to the formation of hydrocarbons in an area.

The equipment onboard the Vema described in this section is by no means the most sophisticated. There was an instrument called a multigrad on board at the start of the cruise but this was unfortunately lost during the first attempt at using it. This instrument is much smaller and can be lowered on hydrographic wire. It also has an advantage in that it takes several measurements of the thermal gradient during the one lowering. This type of instrument would be the sort that BMR should consider using if it is going to start a heat flow program. Oceanic heat flow recorders are not 'off-the-shelf' items and they are usually built by the organization which uses them. It is therefore difficult to estimate the cost which BMR would incur in acquiring heat flow measuring apparatus.

Whether a heat flow program could be conveniently fitted into the BMR normal multi-sensor type geophysical surveys remains to be seen. The time for a measurement to be made is of the order of an hour, and while the ship is on station there could be a certain amount of drift from the line. In addition a considerable amount of time is lost in pulling in and letting out the geophysical gear used to do the underway measurements.

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