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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record 1973/108

VISIT TO GEOPHYSICAL SURVEY VESSEL MV "PETREL", MARCH 1973

by

J.B. Willcox

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SUMMARY

The geophysical survey vessel MV Petrel is operated by Seismograph Service Limited (SSL) for Shell International, The Hague.

Surveying was carried out aboard the Petrel during 1971 off north-west Australia. During 1973 surveying was continued, working eastwards between southwest Australia and offshore Tasmania. Traverses were principally across the continental slope and abyssal plain.

Seismic reflection records were obtained using an air-gun energy source, digital recording, and an on-line display. A proton-precession magnetometer and 'Bell' marine gravity meter were in use. Navigation was carried out by use of a pressure log and an 'ITT' satellite Doppler navigation system.

1. INTRODUCTION

The author travelled aboard the geophysical survey vessel MV Petrel on a cruise between Port Lincoln and Hobart between 9 March and 22 March 1973, and briefly studied the systems and operations. About 1500 kilometres of traversing was carried out, largely on the continental slope and abyssal plain, off South Australia and the west coast of Tasmania.

The MV Petrel was operated by Shell International, The Hague, between 1967 and 1971. The geophysical systems set up by Shell during this period were sold to Seismograph Service Limited (SSL) in 1971. Since then SSL has operated to vessel exclusively for Shell, and has carried out regional geophysical surveys throughout the world.

Navigation, gravity, magnetic, and reflection seismic systems are described, together with the general operations and conditions. For some systems, notably the air-gun energy source, the description is very sketchy, since the company considers the array design as confidential. The work was oriented towards the seismic method, and the gravity data and magnetic data were considered of secondary importance. The 'Bell' gravity meter (BGM-2) is described in fair detail since BMR staff have not had a previous opportunity to see this type of gravity meter in action. Principles of operation and performance figures have been taken mainly from the technical report by Bell (1971).

2. SURVEY VESSEL

The MV Petrel was built in England and launched in 1947. The main deck of the present ship was added in 1967. She operated as an Icelandic trawler before conversion for seismic operations. At the time of this visit the vessel was owned by a Norwegian company and was registered in Thromsø.

Length:	58 metres
Beam:	10 metres
Tonnage:	867 gross; 1600 tons displacement
Draft:	6 metres
Propulsion:	single screw with variable pitch; small thruster located in bow
Crew:	6 officers and 12 seamen.

A sketch giving the layout of the vessel is shown in Figure 1. The instrument room was located on the old main deck near the centre of the vessel. The gravity meter room had been especially installed near the centre of pitch, and this effectively insulated the gravity meter from large vertical accelerations. This room was thermally insulated and air-conditioned. Navigation instruments were located in the chart room behind the bridge. Cabins were positioned towards the stern, and this proved a particular disadvantage owing to the proximity of the air-guns. The loud air-gun shock wave caused considerable noise and vibration throughout the stern. The small lounge room towards the bow provided pleasant relief from this discomfort.

The air-guns were suspended from two booms, one on each side, at the stern of the ship. The drum holding the seismic streamer was mounted on the main deck and was roofed over. The magnetometer reel was on the starboard side.

3. NAVIGATION SYSTEMS AND PROCEDURES

Autopilot:	ANSCHUTZ The heading generally swung by 2-3 degrees in sea-states of about 3-4.
Gyrocompass:	ANSCHUTZ Output from the gyrocompass was sampled each second by the PDP-8 computer (4K) which was interfaced with the Bell gravity meter (BGM-2).
Forward-scan sonar:	SIMRAD This was restricted to three angles of elevation. It was found to be almost essential when working close to reefs.
Fathometers:	SIMRAD EK38B A maximum depth of 3200 metres is obtained with this system. In deeper water, depth values were obtained from the seismic records.
Radar:	JRC and DECCA RM316.

To accompany Record No 1973/108

M.V. "PETREL"

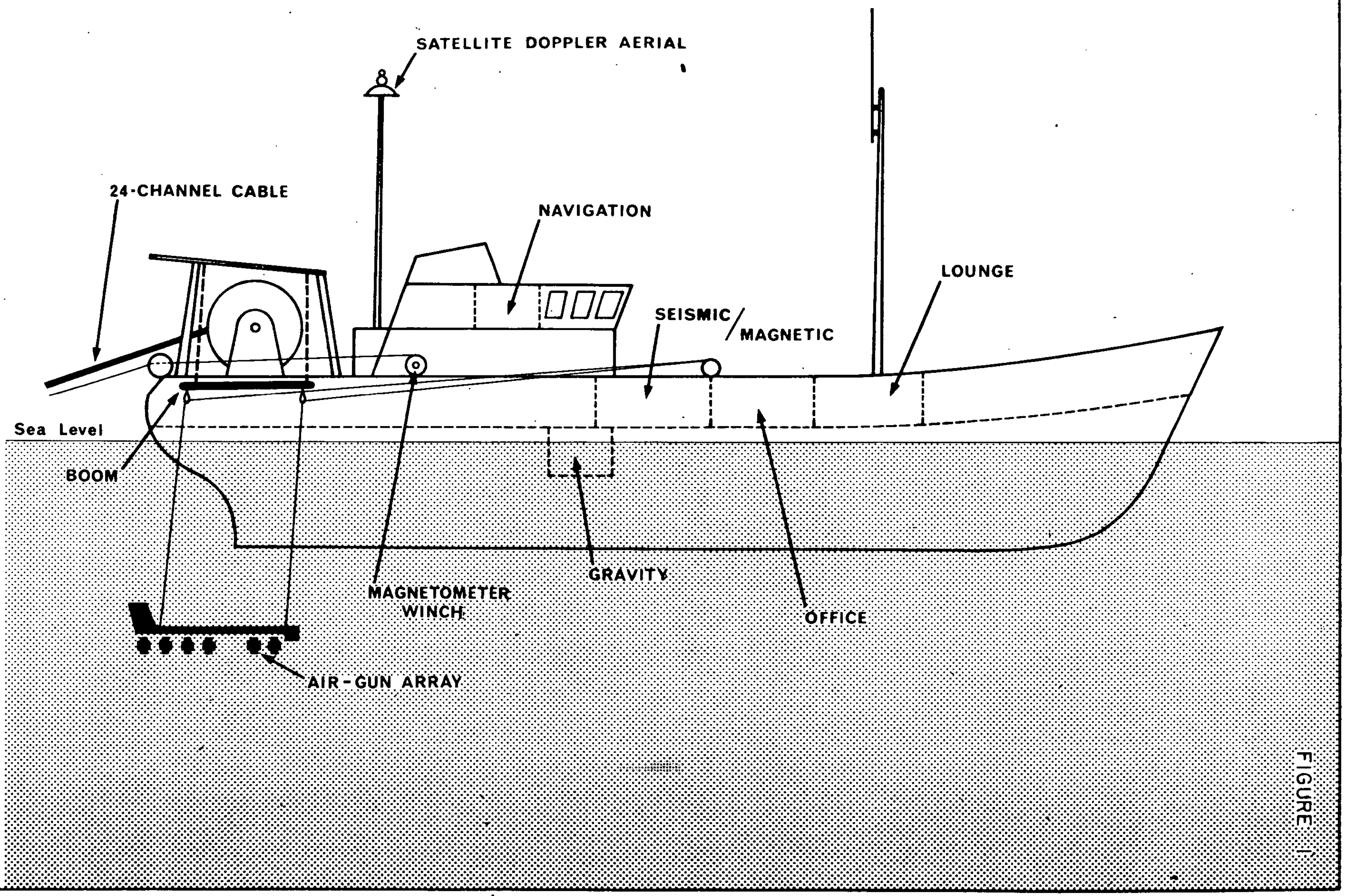


FIGURE 1

G449-72A

Weather map recorder: JRC FAX TYPE JAX - 21, Japan Radio Co. Ltd.

Facsimiles were produced on electrosensitive paper. Weather map transmissions were received once or twice each day, and these were considered important for planning. The maps were of variable quality, but were generally usable.

Ship's log: SAL LOG JUNGNER (pressure log)

The output from the pressure log was sampled at one-second intervals by the PDP-8 computer used with the BGM-2 system.

Sonar Doppler: MARQUARDT

This system was used only on the continental shelf as it was considered unreliable in deep water.

Satellite Doppler: ITT Satellite Doppler Navigator.

This was interfaced with a PDP-8/1 computer which had a 12K core.

The navigation technique was relatively straightforward as Shell's specifications did not require precise navigation for regional traverses. Any adverse effect on the gravity was tolerated. The operation was carried out at about 5 knots but it was slowed down if seismic noise levels exceeded 5 to 7 microbars.

Fixes from satellites with elevations of 15 to 75 degrees were obtained every 2 to 3 hours on average. Hourly positions were plotted by linear interpolation between fixes. It was required that a fix be obtained within 2 hours of the start and end of each line, but extrapolation of positions was permitted beyond the first and last fixes. At the end of each line the turn onto the next line was made in the form of a reversed loop. For example, a left turn was executed by making a clockwise loop to intersect the previous line. Although these reversed turns took about two hours to complete (at 5 knots), they resulted in continuous data between one line and the next, and enabled the line intersections to be located precisely. The ship was held on a straight course well before each intersection, to ensure that the gravity data were free of long-period horizontal accelerations.

After each satellite fix, the distance covered and average speed since the last fix were computed in the PDP-8/1. The shooting interval required to maintain a 24-fold common depth point stack was also computed. The shot interval was then adjusted using the master clock in the navigation room. A check was made between the number of shots, shot intervals, and the distance covered between satellite fixes.

4. GRAVITY MEASUREMENTS

Bell Gravity Meter (BGM-2)

The Bell gravity meter (BGM-2) is a force-balance device mounted on a gyro-stabilized platform. It incorporates a digital recording system.

The platform employs two gimbals, two rate gyros, and two horizontal accelerometers. Each gimbal uses a d.c. torque motor. Pitch has an angular freedom of $\pm 30°$ and roll $\pm 45°$. The platform and sensor are temperature controlled.

The sensor is characterized by high dynamic accuracy stemming from its origin as an inertial navigation sensor. It is essentially a Bell Model VIIIB force balance accelerometer mounted on a stabilized platform. The accelerometer consists of a mass supported on a horizontal beam which is pivoted at one end and kept in its (horizontal) null position by a supporting constant-bias magnetic field. The magnetic balancing force is produced by the interaction between a permanent magnetic field and an electromagnetic field generated by a d.c. current flowing in a coil attached to the pendulum (Talwani, 1970, fig. 17). When the pendulum is displaced, a position detector generates a signal which is fed to a servo amplifier. The current from the servo amplifier is fed to the coil, which is wound such that the electromagnetic force returns the pendulum towards its null position.

Hence, an acceleration force,

$$f = ma$$

is balanced by a constraining force,

$$f = NI_aB$$

where, f = force on pendulum

m = mass of pendulum

a = acceleration

N = number of turns on coil

B = magnetic flux density

I_a = current in coil

Therefore, current ($I_a = ma/NB$) is used as a measure of acceleration.

The force balance gravity meter is used for relative measurements of gravity in the same way as other gravity meters. It is not possible to determine the constants with sufficient accuracy to permit absolute measurements to be made.

Bell claims that the accelerometer has the following advantages:

(i) Identical characteristics for both positive and negative accelerations.

(ii) Protection from external magnetic fields.

(iii) Scale-factor temperature compensation.

(iv) Hermetic sealing of the sensor.

(v) Very low constrainment power (18 μ watts/g^2).

Since the pendulum is constrained close to its null position at all times, cross-coupling errors are negligible.

The data-handling system filters, formats, and stores the gravity data in real time, together with indicators checking status of the system. The system consists of a PDP-8/L computer, and ASR33 teletype, and Digital Data Corporation 7-track 556-bit/inch digital stepping tape recorder. Gravity data, time, and status indicators are recorded every minute on a 2400-foot tape. In normal operations the tape is read back after each write sequence, and a printout is provided. This gives:

DATA VALID CHARACTER	DAY	TIME	GRAVITY	GRAVITY PLOT ON ASR33

Filtering

It is assumed that the vessel remains at zero elevation on average. The gravity data are filtered to eliminate effects of vertical motion, in preference to providing instantaneous altitude and altitude/acceleration corrections, which would be inaccurate. Bell considers that filtering instantaneous gravity values by convolution with a weighted average is more effective than simple long-term averaging or filtering with time-lag filters, which are commonly used for smoothing marine gravity data.

In the BGM-2 system, one-second samples are convolved with a normal curve in which 5 minutes of time is made equal to 5 standard deviations. This filter attenuates vertical accelerations by between 10^6 and 10^7 times, but causes slight smoothing and spreading of 'gravity anomalies'. As an example, if the boat speed were 10 knots, after filtering in this way a 20-milligal anomaly spread over 4000 feet, would appear as a 19.4-milligal anomaly spread over 4120 feet (i.e. 3% distortion).

The plot shown in Figure 2 gives the maximum vertical acceleration, for sinuisoidal waveforms at various frequencies, which can be handled by the BGM-2 filtering system, if errors in gravity are to be kept below one milligal.

Horizontal accelerations and off-level errors

Both the Bell and LaCoste & Romberg gravity meters use a similar technique to minimize the effect of off-level errors in their stabilized platforms.

Stable platforms always exhibit small angular errors due to imperfections in their servo-erection systems and errors in the reference vertical fed to their gyroscopes. If a platform has a small angular error 'd' in one plane and is subjected to a horizontal acceleration 'a' within that plane, the gravity meter will measure

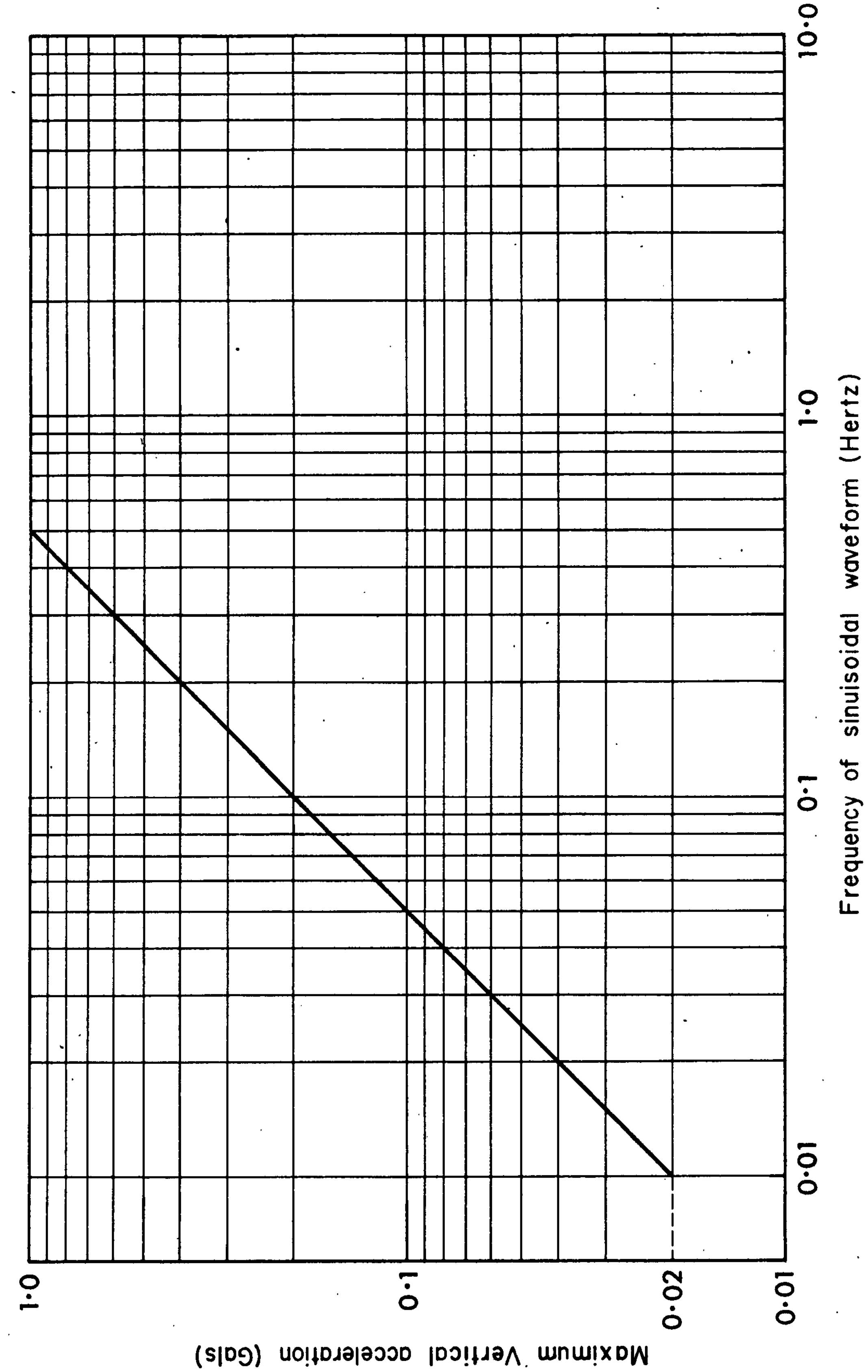
$$a \sin d + (g + z) \cos d$$

instead of $(g + z)$,

where g = acceleration due to gravity,

z = vertical (heave) acceleration

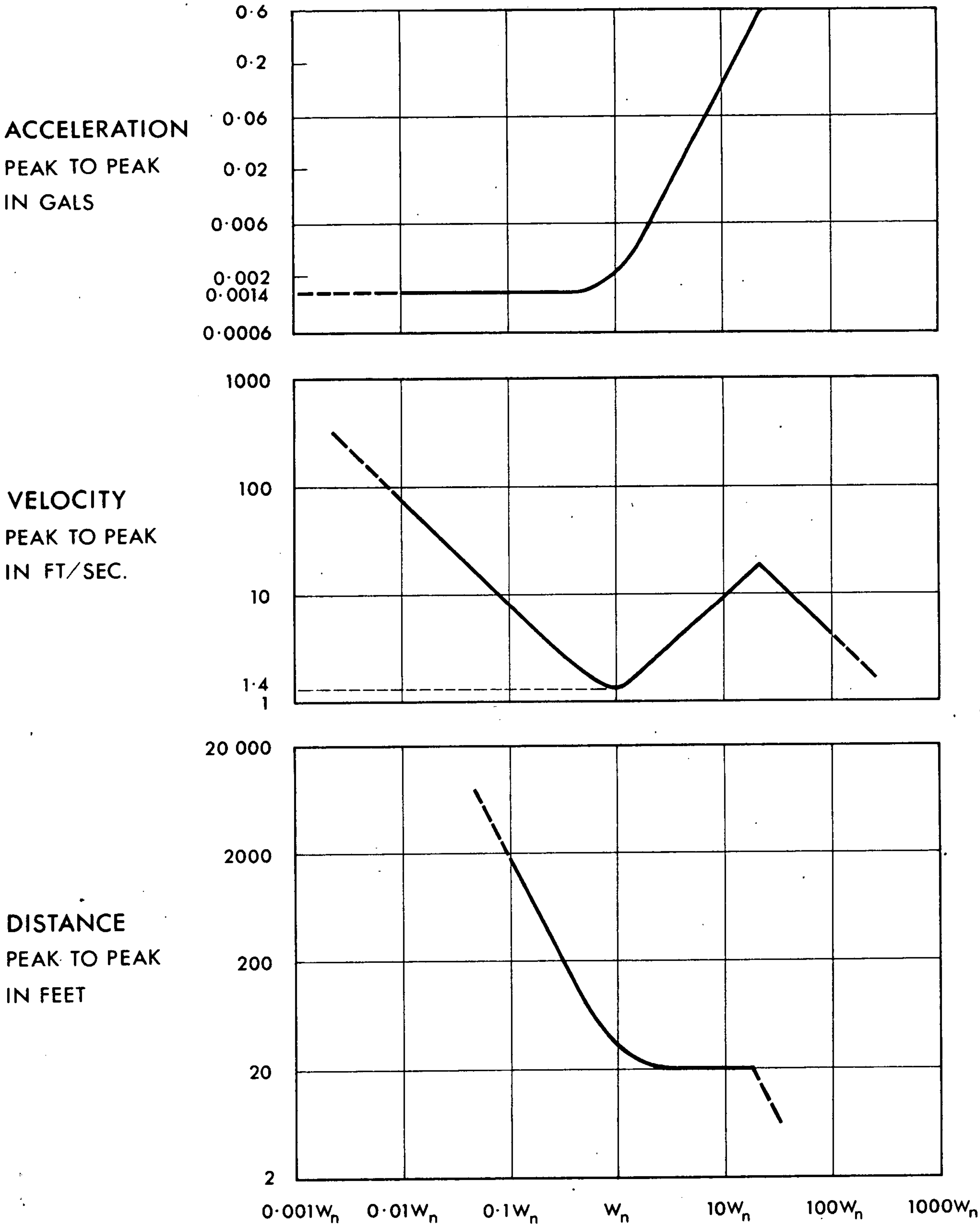
FIGURE 2



MAXIMUM VERTICAL ACCELERATION V. FREQUENCY

Which can be handled by BGM–2 filtering system, for gravity errors of less than one milligal.

FIGURE 3



$W_n = 2{\cdot}83$ rad./min.

ALLOWABLE HORIZONAL MOTION
FOR BGM-2

To accompany Record No 1973/108

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This gives an error of

$$ad - gd^2/2 - zd^2/2$$

It is assumed that 'a' and 'z' are relatively short-period accelerations. Any long-period (several hours) component in the off-level angle will give rise to off-level errors, ad and $zd^2/2$, which will have time averages that vanish. These errors will be effectively removed during filtering. The error term $gd^2/2$ is insignificant.

However, the off-level angle will also include short-period components. If the period of these components is equal to the period of the horizontal accelerations, large off-level errors will result whenever the phase difference is 0 or 180 degrees (Talwani, op. cit., Table 1).

The angular errors in the platform are corrected by precessing the vertical reference gyroscopes with the output from an erection network. In the Bell platform the output of the erection network is the sum of two terms: a signal from the horizontal accelerometers on the platform, and the integral of that signal. These two terms can be adjusted such that the averages of ad and $gd^2/2$ cancel.

Since the sensor is deflected by only 2 seconds of arc for a surge acceleration of g, misalignment of the sensitive axis does not give rise to significant errors.

Figure 3 shows the tolerance of the BGM-2 to horizontal sinusoidal motions for one milligal error in gravity when the natural frequency of the erection loop (W_n) is $2\sqrt{2}$ (2.83) radians per minute.

Specifications

Range	996-944 Gals
Accuracy at sea	1 mGal
Accuracy dockside	0.4 mGal
Scale factor calibration	0.02%
Drift predictability	1.2 mGal/month

The Bell gravity meter has the disadvantage of a large drift rate. It requires continuous power to maintain the oven temperature and to prevent the sensor from collapsing against the stops.

Course and speed variations

Short-period fluctuations in heading of up to 5 degrees and short-period fluctuations in speed of up to 2 knots will not result in inaccuracies greater than 1 milligal, under normal working conditions.

Operation of BGM-2 aboard 'Petrel'

The PDP-8 software supplied with the BGM-2 had been considerably modified by Shell. SSL had little knowledge of these changes, and simply acted as operators of the system as it stood.

The data sampling interval had been changed from one minute to one second. The BGM-2 tape was also used for storing the following parameters:

(i) heading from gyrocompass

(ii) speed from pressure log

(iii) water depth from seismic first-arrival time

(iv) magnetic field from Varian magnetometer

(v) filtered gravity

Shell had provided the facility to apply Eotvos corrections to the gravity values, and hence permit easier assessment of the continuity of data. A printout of (i) to (v), together with the Eotvos correction, and gravity corrected for Eotvos effect, was obtained at 5-minute intervals. The usual 1-minute printout and the gravity plot (on the teletype) had been suppressed.

Shell's system suffered from one serious disadvantage, in that 1-minute values were not read back from tape and printed out for checking. It was possible to spot check the tape only at the end of a cruise. Although the BGM-2 appeared to operate well in seas up to state 5, and was self-checking to some extent, the data quality was difficult to assess.

BGM-2 tapes were sent direct to The Hague for processing by Shell.

5. MAGNETIC MEASUREMENTS

Total magnetic field measurements were recorded with a Varian proton-precession magnetometer. The cylindrical sensor was towed about 250 metres astern. The magnetometer cable reel was mounted on the starboard side to avoid tangling with the seismic streamer. A continuous lead was run between the sensor and the recorder in order to minimize bad connexions caused by water in connecting plugs. There was no provision to prevent the sensor from spinning and it was not streamlined.

The sensor was polarized at 10-second intervals but the instantaneous magnetic values were recorded each second on the BGM-2 tape. Recording was inhibited during polarization. The analogue strip-chart output was operated at 100 gammas full scale.

The noise level was generally about 2-3 gammas peak-to-peak but reached about 5 gammas peak-to-peak in sea state 5. This noise level was considered acceptable.

6. SEISMIC RECORDING

Energy source

The energy source for seismic reflection work was an array of 'Bolt' air-guns. These ranged in capacity from 40 to 120 cubic inches (655 to 1965 cm^3) and were built into an array of about 18 guns, totalling 1090 cubic inches (17 860 cm^3).

The air-guns were mounted on four 'fish' (Fig. 4) which were about 5 metres long. Two 'fish' were suspended from each boom, the booms being mounted at the stern, one boom on the port side and one on the starboard side. Each pair of fish were about 2 metres apart. (Fig. 5). The 'fish' were suspended on cables at a depth of 10 metres. The air-lines and electrical leads were attached along these cables and were covered by streamlined rubber fins. The air-gun array was trailed close to the stern of the vessel.

The array was generally regarded as a point source and the degree of spatial filtering along the line of the streamer was considered negligible. All the air-guns were fired simultaneously. They were arranged such that in the event of failure, additional guns could be switched into the system without upsetting the symmetry to any great extent. SSL had determined the size distribution and spatial distribution of the air-guns by empirical methods and regarded this as confidential. Their method was based on the need to maximize the initial pressure pulse but to reduce the undesirable effect of bubble pulses. For any one air-gun, the separation in time of the primary pulse and the bubble pulse is directly related to the gun's capacity. The frequency spectrum from the 'impulse' of a single gun is a function of capacity, but generally the spectrum contains frequencies up to several hundred Hertz.

Each air-gun was triggered by its own solenoid, and these mechanisms required continual adjustment to maintain synchronized shooting. This was done from the seismic instrument room by monitoring the signal from each gun in turn, on an oscilloscope.

Seismic streamer

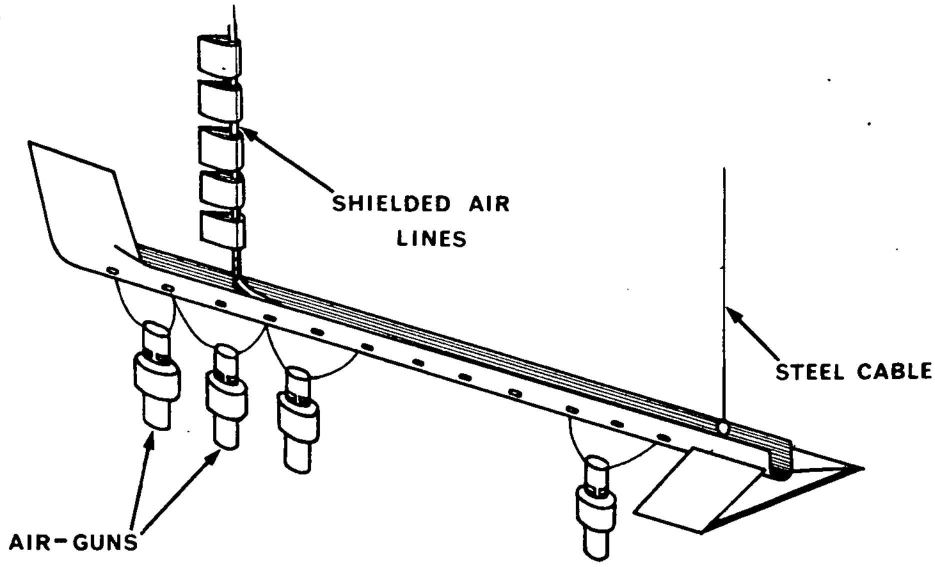
A 2400-metre oil-filled streamer with 24 channels was being used. This was manufactured by Seismic Engineering. The active sections were each 50 metres long and contained 30 hydrophones spread over 45 metres. These active sections were separated by 'dead sections' which were 50 metres long. The first active section was about 380 metres behind the ship and was separated from the winch by an anti-vibration section. This anti-vibration section was covered with soft rubber fins to break up turbulence around the streamer. A tail buoy with a radar reflector and flashing light was used.

The leading part of the streamer was depressed by cylindrical lead weights and the rest was held at depth by pressure-sensitive depth controllers (or birds). The six depth detectors indicated that at speeds of about 5 knots the entire streamer could be accurately maintained at a depth of 25 $\pm$ 2 metres.

Seismic noise

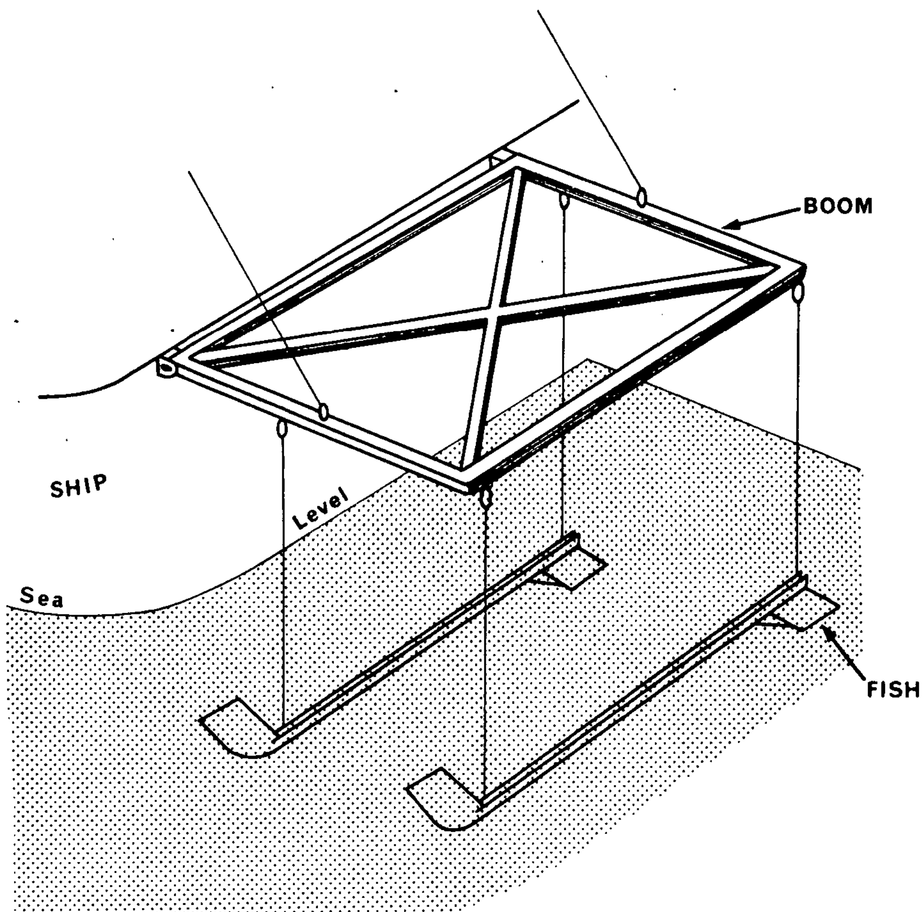
For reconnaissance surveys noise levels of 5-7 microbars were tolerated, but for detailed work the maximum noise level was considered to be 2 microbars. Propeller noise on the near channels presented no problems as it was effectively filtered out by the linear hydrophone array. The noise level varied considerably with the sea state, period of the swell, and its angle of attack. Force 5 sea states and swell up to 5 metres' amplitude presented few problems if the wave crests were parallel to the streamer, but lesser seas running down the cable caused serious noise. This was believed to be caused by the depth controllers riding with the swell.

FIGURE 4



AIR-GUN "FISH"

FIGURE 5



AIR-GUN BOOM

To accompany Record No 1973/108

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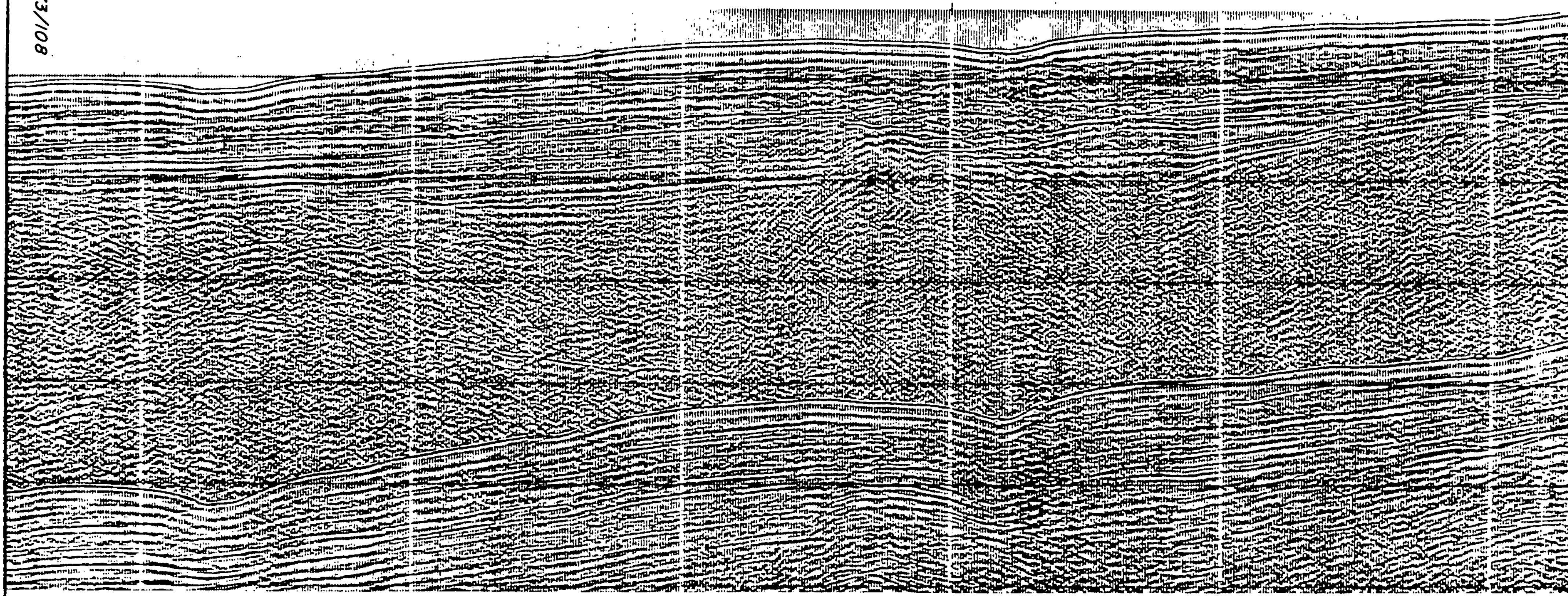

SEISMIC SECTION (VAX) SEISMOGRAPH

SERVICE (MARINE) LTD

G 449-76A

FIGURE 6

Recording system

The seismic system consisted of digital recording and analogue display. The 24-channel input was passed through 0-67.5 Hz anti-aliasing filters, amplified using binary gain ranging amplifiers, and digitized at 4-millisecond intervals. The gain was recorded on the digital tape. Two Texas Instruments digital tape recorders which used one-inch tape were used in tandem to provide continuous recording.

The 24 filtered traces were monitored on a dry-write camera (VRO-6) which allowed a continuous paper record to be kept. A BCD label of shotpoint number was automatically placed on one channel of the camera record and also on the magnetic tape.

The analogue signals from channels one and two were filtered 0-67.5 Hz and amplified to a level suitable for analogue display. The traces for analogue display were also monitored on the VRO-6 camera. Traces one and two were fed to SSL's variable-area display camera (VAX) and recorded on continuous-strip film. Two such cameras were used in tandem to permit continuous recording. The VAX camera was advanced by one trace per shot, such that channel 2 was optically stacked with channel 1 from the preceding shot. The exposure time and high contrast of the film enabled high-quality composite traces to be obtained almost on-line. The records were true common depth point 2-fold stack, but without muting, ramping, or moveout corrections. The film was developed in about 8-hour strips. The shot-points were labelled, and a label showing the recording parameters was spliced onto the film. Very high-quality on-line sections were obtained in this way (Fig. 6).

7. PERSONNEL, CONDITIONS, AND CONTRACT

Personnel

Party Chief	1
Observers	2
Quality control/ observer	1
Operators/clerks	2
Mechanic	1
Navigators	2
Deck hands/cablemen/ occasional operators	6

The navigators, mechanic, and deck hands worked 12 hours on and 12 hours off. Observers and operators worked 4 hours on and 8 hours off.

In general, the observers and navigators held degrees in electrical engineering or similar subjects.

Conditions

The conditions aboard the Petrel were considered to be fair. The cabins were well appointed but somewhat noisy. A high standard of hygiene was maintained, and food was good and quite varied. Provision of the lounge, tape recorder, a small library, and occasional film shows were a great asset. Food was made available for personnel to do their own cooking during the night.

Contract

Shell's contract with SSL was for 3000 kilometres of seismic data per month, as an average. The maximum acceptable level of seismic noise was set at 7 microbars. Gravity and magnetic recording was of secondary importance.

8. REFERENCES

BELL AEROSPACE COMPANY, 1971 - Technical report, marine gravity measuring system, Model 6109, Report No. D6109 - 950003.

TALWANI, M., 1970 - Developments in navigation and measurements of gravity at sea. Geoexploration Vol. 8, No. 3/4, Dec. 1970.