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APPLICATION OF ELECTRONICS TO OFFSHORE OIL EXPLORATION

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1. INTRODUCTION

The search for minerals in general, and in particular the search for oil, depend very largely on the application of electronics to the measurement of physical properties of the earth's crust. This paper is intended to be an introduction to the methods of geophysical exploration as applied to offshore oil exploration, and the way in which electronic equipment is used to determine the subsurface structure of the earth. The descriptions of equipment will be confined to equipment used by the Bureau of Mineral Resources, Geology & Geophysics (BMR) in two recent surveys off the northwest coast of Australia.

The primary objective of geophysical exploration in the search for oil is to map geological structures which may be potential oil traps. Other than by geophysical methods, the only way to determine these structures is to drill a large number of exploration wells, the cost of which is prohibitively high. In the earlier stages of exploration of an area, geophysics supplements the geological mapping of the boundaries of sedimentary basins in which the oil traps necessarily occur.

In offshore areas, geological mapping by means of shallow core samples must be minimal, and geophysical exploration is the only method of finding prospective areas without the prohibitive cost of drilling deep wells. The magnetic and gravity methods described later are essentially used to define the sedimentary basin boundaries and to give a preliminary estimate of the thickness of sediments. The seismic method is normally used then to delineate the potential oil structures within the sedimentary basin.

In the final stage, wells must be drilled anyway to determine whether the sediments contain oil or gas. Even after this, electronics still plays an important part in correlating sedimentary structures. Electronic probes are used which measure the electrical conductivity, self-potential, natural radioactivity, porosity, etc., of the rocks through which the drill passes.

This paper describes briefly the three techniques mentioned earlier - gravity, magnetic, and seismic - together with navigation and data acquisition equipment used in offshore exploration.

In the gravity and magnetic methods, small local variation in the earth's gravitational and magnetic fields are caused by the distribution of rock types of different density and magnetic susceptibility within the crust. By measurement of these variations at the surface, the larger subsurface structural features can be inferred from the surface field map. A rough depth estimate can often be made from the observed gradients of the surface field. The seismic technique, on the other hand, directly maps subsurface structures by locating reflections of sonic pulses from velocity contrasts between sedimentary layers. Some knowledge of the physical properties of the rock layers can also be gained from the speed of sound waves within the rock, determined by refraction seismic techniques.

2. GRAVITY MEASURING EQUIPMENT

The gravity equipment is described very briefly. The ordinary land gravity meter is essentially an extremely sensitive spring balance whose extension is proportional to the pull of gravity. The anomalous gravitational fields which we wish to detect are of the order of 1 to 10 milligals in a total earth field of 980 gals (a gal being 1 cm/s^2). Thus a reading sensitivity of about 0.1 milligal, or one part in 10^7 of the earth's field, is required.

At sea, the difficulties in measuring to these sensitivities are increased greatly by the accelerations due to the motion of the ship. These disturbing accelerations can be up to 0.5g or 500,000 milligals so that significant variations in reading must be distinguished from "noise" up to half a million times the required signal. In practice, although 0.1 milligal can be read, accuracies of only about two milligals can be achieved; but this is adequate, at least for reconnaissance-type surveys.

Fortunately, the largest source of interfering acceleration is the vertical motion of the ship, and this is of relatively high frequency compared with the rate of change of gravitational field being measured. Low-pass filtering with a period of the order of 10 minutes eliminates most of the error due to this cause. The effect of accelerations due to the pitch and roll of the ship are reduced by mounting the meter on a gyro-stabilized platform (or, on earlier models, in gimbals). Other corrections which must be made include the variation with latitude and the Eotvos effect, which is an acceleration component caused by the rotation of the earth on a body moving in an east-west direction. Corrections for these effects put quite stringent requirements on the navigation system. There is also an interaction of vertical and horizontal accelerations, called cross-coupling errors, which must be calculated and allowed for. Figure 1 shows a block diagram of the sea gravity meter. Most of the corrections are computed by special analogue computers intergrated with the equipment.

3. THE PROTON PRECESSION MAGNETOMETER

Local variations in the earth's magnetic field are measured usually with a sensitivity of 1 gamma (10^{-5} gauss). Recent trends are to increase this resolution to 0.1 gamma. The total earth's field near Australia is roughly 60,000 gammas, so that there is an analogous requirement to the gravity equipment in that small variations in a large total field must be measured, and "noise" is also present. Disturbing fields are those due to the magnetic field of the vehicle, in this case the ship, and variations in the earth's field due to normal diurnal variations and erratic magnetic storms. The effect of the vehicle is removed by towing the magnetometer detector several hundred feet behind the ship; stationary magnetic field monitor provides data from which corrections can be made for the other variations.

Two main types of magnetometer are used: one is the fluxgate, in which the field is measured by the effect of the field on a saturable permalloy core; the other, the proton precession type, depends on the effect of a magnetic field on the spin angular momentum of hydrogen atoms. Because of severe requirements on the orientation of a fluxgate element in the earth's field, the proton precession type is normally used at sea.

In the proton precession magnetometer, the detector is a sample of a liquid rich in hydrogen atoms and a coil of wire wound around it. The nucleus of the hydrogen (the proton) possesses a magnetic moment and an angular momentum as it spins, and may be regarded as magnets spinning on its magnetic axis. When a large current is passed through the coil, producing a field of a few hundred gauss, the protons will tend to align themselves in the direction of this field. Sudden removal of this field leaves only the earth's field acting on these protons. The resultant torque causes the protons to precess about the direction of the earth's field with a frequency which is proportional to the magnitude of the earth's field. The frequency is given by $f = BC$ where B is the intensity of the earth's field and C is an accurately determined atomic constant; f is typically about 2500 Hz. The precessing protons induce an alternating E.M.F. of this frequency in the coil. This signal is initially a few microvolts, and decays exponentially with a time constant of up to one second depending on the type of liquid and other conditions.

The electronics of the magnetometer are shown in simplified block diagram form in Figure 2. The main functions are to amplify the small signal and to obtain an accurate measurement of frequency by means of frequency multipliers, narrow-band filters, and gating and counting circuits. Digital and analogue outputs are provided.

4. SEISMIC REFLECTION TECHNIQUE

The seismic technique provides the most detailed information on the subsurface structures. The information is recorded in a form which directly shows the structures in pictorial form. Figure 3 shows a typical seismic section.

Basically the equipment comprises a source of pulses of sonic energy, hydrophone detectors which receive reflections from different rock strata below the surface, and a display system. The principle is identical to that of the familiar echo sounder but differs essentially in the power and frequency content of the sonic pulse.

To provide the large amount of power required for the energy source, several forms of transducers are used. These include compressed air guns, sparkers, gas guns, or small explosive charges. Current BMR surveys use the sparker system; although of lower power than the others, this system offers some advantages in pulse shape and operating convenience. The spark apparatus comprises a set of underwater electrodes, energy storage capacitors, and power supplies. The existing system uses a 21,000-joule capacitor bank, which is charged to about 4000 volts and discharged every few seconds through a triggered spark gap to the underwater electrodes. The duration of this discharge pulse is roughly a few milliseconds. The discharge from the electrodes creates a large plasma bubble, the formation of which produces the required sonic pulse. Because of the low sonic efficiency of this system, considerably larger energy storage capacity is desirable, but an economic limit using capacitor banks appears to be about 100,000 joules. For this reason, BMR is co-operating with the Australian National University in an investigation of the feasibility of using a homopolar generator as a source of electrical energy.

The detecting and recording equipment is shown in Figure 4 in block diagram form. The hydrophone detector may be either a single group or in multi-channel groups. The section of Figure 3 was recorded from a single-channel detector, but considerable signal-to-noise improvement can be obtained by adding in-phase signals from separate channels. The channel separation is calculated to offer the best noise rejection from wave fronts along the length of the cable. For reflections from below the surface, a correction must be applied to allow for the horizontal path component of the transmitted pulse. Figure 5 illustrates the geometry of the reflection paths.

As this configuration is not suitable for very shallow data, a second single-channel detector is also used with the record displayed on an expanded scale. The deep reflection detector is capable of receiving reflections for strata of depths to about 3700 metres below the ocean floor, representing a two-way travel time of about three seconds. The shallow reflection detector is used to detail reflections down to about one second.

All detector channels are amplified and filtered through special-purpose seismic amplifiers. These amplifiers are capable of amplifying, with low distortion, signals from less than one microvolt to about 100 millivolts, an input dynamic range of about 100 dB. This is achieved with a rather complex automatic gain control (AGC) technique or other time-varied gain systems. Filters are normally bandpass with lower cutoff frequencies from 2 to 40 Hertz and upper cutoff 30 to 300 Hertz.

An idealized signal trace after amplification and AGC is shown in Figure 6. The data are recorded on a standard 14-channel instrumentation recorder, with a tape speed of 15/16 inch per second for further processing later if necessary. Single channels are also recorded in analogue form on facsimile recorders, as in the sections shown in Figure 3.

Because of the large amount of data obtained on a survey of this type, subsequent processing of those data becomes nearly impracticable. For this reason, it is intended as far as possible to carry out all processing on line, and it is proposed to integrate a small general-purpose computer to correct and stack (add) the six-channel detector outputs. The signals from each channel must be corrected for the horizontal component of the travel time. This is represented by a variable delay from the beginning to the end of each 4-second record. This process can be conveniently done digitally. Each of the six channels is sampled every 2 milliseconds by a high-speed analogue-to-digital converter and held in core for the required delay interval. After this correction has been applied, the corrected traces are transferred to the disc store and are recalled at appropriate times to add signals corresponding to the same subsurface reflecting points.

The corrected and stacked records are then put out through a digital-to-analogue converter to the facsimile recorder.

Modifications were made to the facsimile recorders to enable them to stop and start on command and single sweep to an accuracy of one millisecond. The problem was solved by the installation of a high-speed stepping motor (500 steps per second). Considerable difficulty was encountered when using sweep speeds of less than one second, owing to the high starting torque required. This problem was overcome by controlled acceleration, using a programmed pulse train while accelerating and stopping.

5. SEISMIC REFRACTION EQUIPMENT

The system described above can depict only relative depths to rock strata by measuring times for reflection. In order to correct to absolute depths, the velocities of propagation must also be known. These velocities can be computed by measuring the travel times of refracted paths.

For deep structures, this requires a much larger distance between shot pulse and detector. A telemetry sonabuoy system is used to record these data without interrupting normal geophysical recording.

6. NAVIGATION

Because of the very high capital cost of the ship and its equipment, economical operation can be achieved only by working 24 hours per day wherever possible. This consideration places very stringent requirements on the ship's navigation systems. The more usual forms cannot be used: phase systems such as Decca or Raydist have a limited range, particularly at night, and dead reckoning systems are much too inaccurate.

These requirements have led BMR to investigate and adopt sophisticated methods that are not yet in common use. The navigation used has depended primarily on the Satellite Doppler and VLF-Omega systems with supplementary information from Sonar Doppler, compass, electromagnetic logs, and radar.

These systems and equipment are not described in detail, as they have been adequately described elsewhere. However, there are some points of interest in the way they have been used in BMR surveys.

The Satellite Doppler was not commercially available in time for BMR's 1967 survey, so VLF-Omega was the primary system used. Because of the lack of Omega stations within usable range, the normal Omega mode of operation was not possible. Instead of using the phase differences between stations, which define hyperbolic lanes as in the Decca system, the phase differences between the stations and an atomic frequency standard are measured. These phase differences define circular lanes about the transmitting station, the width of the lane being 15 to 30 kilometres according to frequency. This method has the added advantage that stabilized VLF communication and time-standard stations are also usable. Figure 7 shows the stations typically used during these surveys.

Because of the great distances over which the signal is transmitted, a monitoring station on shore must be used to measure and correct for diurnal and other phase changes due to the long signal path. Position accuracies within about 3 kilometres were achieved, with an average error about one 1.5 kilometres.

In BMR's 1968 survey, the Satellite Doppler became the primary navigation system. However, fixes from this system are obtained only each 2 hours or so, and the other systems are used to plot the ship's course and velocity between fixes.

The Sonar Doppler equipment is a relatively new navigation system. In principle, it is similar to the aircraft doppler system in that speed and drift of the ship can be determined relative to the sea bottom (at depths to 180 metres). The difference is the use of sonic pulse instead of radio signal transmission and reception. The equipment is available in both pulse and CW system, but the pulse system appears to be the better at the present stage of development.

7. DIGITAL DATA ACQUISITION

Apart from the on-line seismic data processor, it has become essential that as far as possible all data should be recorded in digital form suitable for immediate computer processing. In the 1968 survey, a special-purpose data acquisition system was used, but this was designed before the complete ship's system was clearly defined, and was unable to cope with all data produced on the ship.

It is intended in future surveys to utilize a second general-purpose computer together with multiplexed analogue-to-digital converter to obtain flexibility in data recording.

The satellite doppler equipment normally incorporates a small digital computer for acquisition and processing of satellite data, and it is expected that there will be sufficient time to acquire all other data and process the various navigational inputs to give accurate position fixes in real time.

It is also intended that the computer will automatically check as far as possible all data recorded. This will be achieved by read after write of the data recorded on tape and the read data will be compared with redundant data input channels. In some cases it will be possible to input the same data in both digital and analogue form, thus including virtually the complete digital acquisition system in the check loop.

8. CONCLUSION

The equipment and method described above give a reasonable picture of the state of the art in reconnaissance-type offshore surveys. As with most technologies, however, further improvement is desirable and will undoubtedly be achieved. The most pressing problems are in the field of navigation. Here, the systems used at present are barely adequate and far too complex. Improvements may be possible by use of inertial systems, but at present these appear to be too expensive, and they also suffer from the lack of unclassified information. Satellite systems that use synchronous satellites, and so allow continuous fixing, may also eventuate.

Another problem in the seismic field is the efficient production of sonic pulses from standard energy sources. The various methods available are inefficient both in terms of overall energy conversion and in their ability to produce a suitable pulse shape.

9. REFERENCES

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STANSELL, T.A. Jr, 1969 - An integrated geophysical navigation system using satellite-derived position fixes. Offshore Technology Conference, Dallas, Texas, 1969. Paper No. OTC 1102.

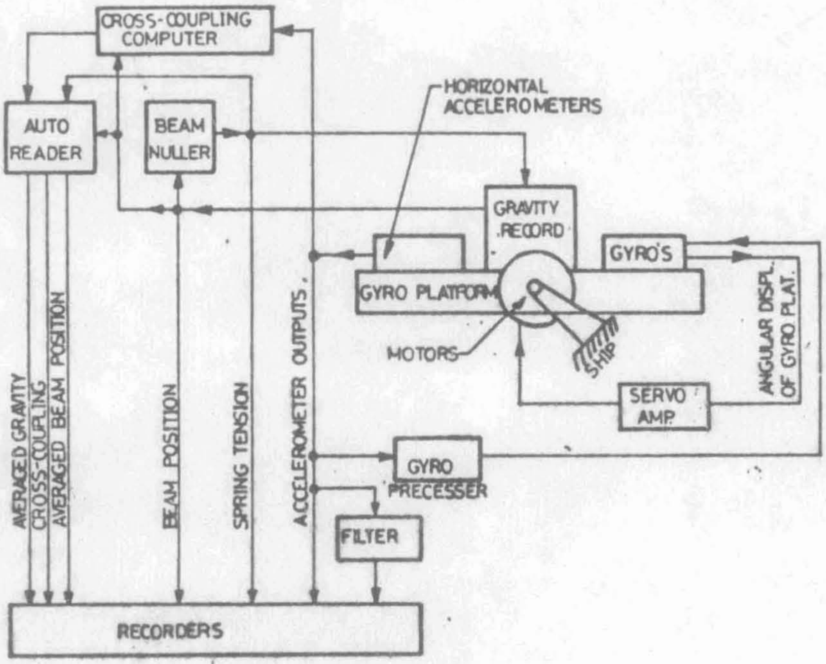
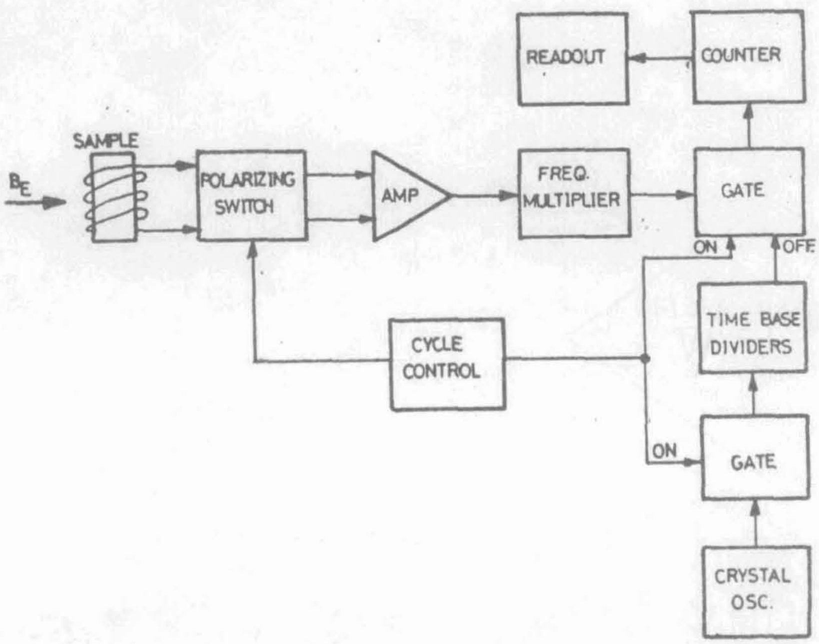


Figure 1. Block diagram of surface gravity meter

Figure 2. Simplified block diagram of proton precession magnetometer



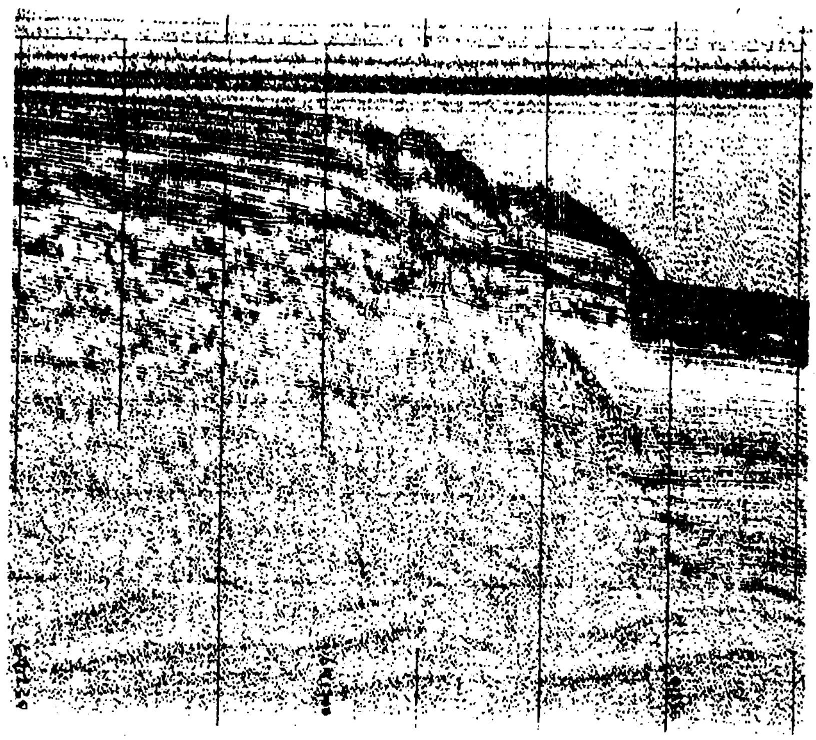


Figure 3. Marine seismic section

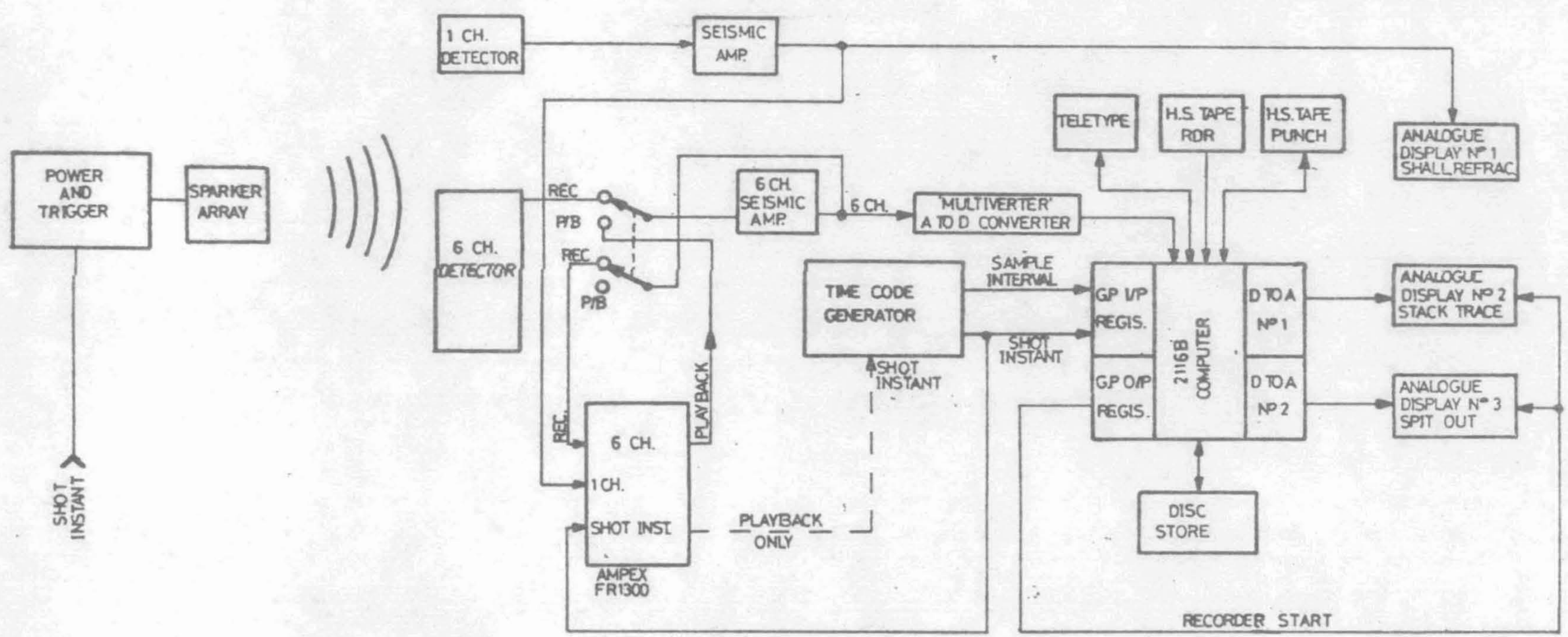
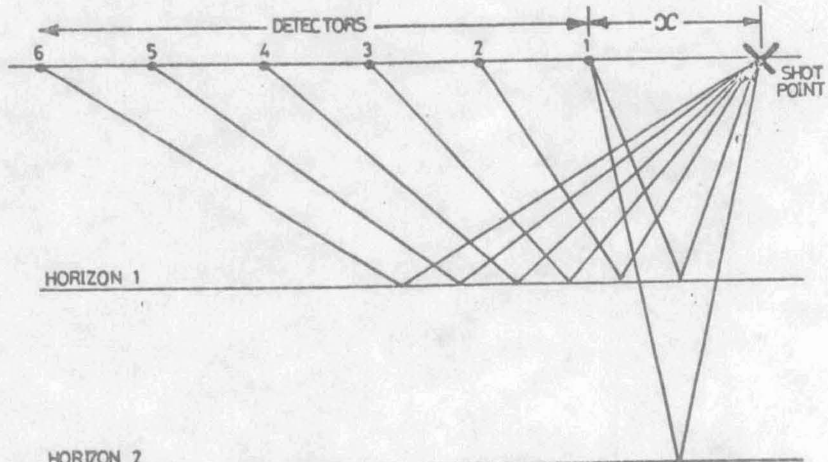


Figure 4. Block diagram of marine seismic data acquisition system

Figure 5. Seismic reflection ray paths - illustrating time corrections



TIME CORRECTION: $\Delta t = \sqrt{\frac{X^2}{V^2} + t_o^2} - t_o$

V = AVERAGE VERTICAL VELOCITY

X = HORIZONTAL DISTANCE TO DETECTOR.

t_o = CORRECTED VERTICAL TRAVEL TIME.

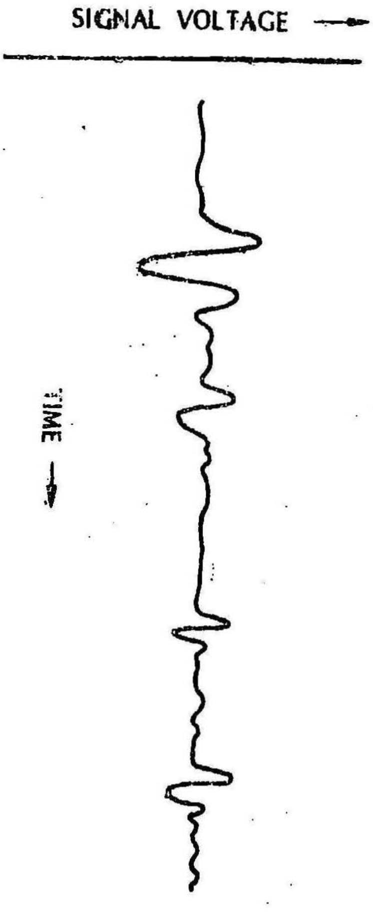


Figure 6. Idealized seismic signal trace
after amplification and AGC

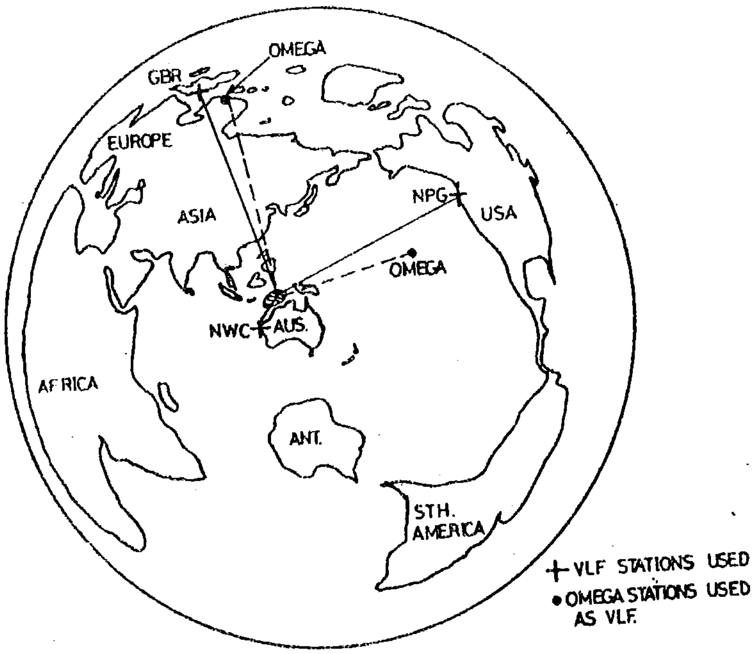


Figure 7. OMEGA and VLF stations usable in Australia.