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DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1964/132

VISIT TO EUROPE AND THE USA

1963

by

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CONTENTS

SUMMARY

The author spent five months in the USA and Europe studying recent developments in geophysical methods and instrumentation for oil exploration. The study was concentrated on the seismic and well-logging methods. The main interest was with seismic playback systems, particularly the system that at that time was being purchased by the Bureau of Mineral Resources.

Visits were made to 40 separate geophysical organisations and manufacturers of geophysical equipment.

1. INTRODUCTION

In March 1963, the Overseas Travel Committee approved an overseas tour by A.J. Barlow to study recent developments in oil exploration by seismic and related geophysical equipment and techniques.

The search for oil in Australia has been stimulated by the Petroleum Search Subsidy Act, and the use of geophysical methods has increased substantially during the last few years. To enable the Bureau of Mineral Resources, Geology and Geophysics to extend its studies of oil exploration in Australia, Cabinet approved in 1959 an additional expenditure of £1 million per year by the Commonwealth Government and provision was included for officers of the Bureau to be sent overseas to study oil exploration techniques.

The most important geophysical method used in oil search is that of seismic prospecting in which potential oil reservoirs can be delineated by means of reflection and refraction of elastic energy waves from underground strata. The waves are usually generated by explosive charges detonated in drill holes below the ground surface, but more recently surface impactors and vibrators have been used successfully. The reflected or refracted waves are detected at the surface by a pattern of geophones which convert the received energy to electrical signals, which are amplified and recorded on magnetic tape and photographic paper.

Many oil companies and geophysical contracting companies are now using seismic and other geophysical methods in Australia for both detailed and regional oil surveys. The Bureau which operates two seismic field crews and also employs a contract crew is concentrating its field activities on reconnaissance surveys in new and perhaps less-encouraging areas, and also on the development of field techniques to be used in difficult areas. Much of the increased activity by private industry has resulted from the payment of the Government subsidy for oil exploration. The Bureau, in addition to its field activities, has the technical responsibility for ensuring that the work carried out by companies qualifying for subsidy attains the standard required for payment.

The Bureau also incorporates a Sedimentary Basin Study Group whose function is to correlate and interpret geological and geophysical information obtained both by Bureau field parties and by exploration companies. Under the Petroleum Search Subsidy Act the Bureau makes public the records and reports compiled by companies receiving subsidies. In many cases it may be possible for this group to obtain further useful information from re-interpretation of original records and maps after additional related data is studied. This is particularly true in the case of seismic data where the use of new computing and display techniques can improve the interpretation of seismic records.

For these reasons the Bureau has purchased a seismic playback system which is essentially an analogue computer for correcting and enhancing data recorded on magnetic tape in the field. The system displays the corrected data in the form of a subsurface cross-section. The machine will be used for presentation of results of the Bureau field and contract parties, evaluation of experimental techniques, and re-interpretation of records of important areas.

2. PURPOSE OF TOUR

The object of the tour was to study recent developments in geophysical methods and instrumentation used in oil exploration. The subjects of study were almost entirely confined to seismic and well-logging equipment and techniques. The most important phase of the tour was concerned with seismic playback systems. It was essential to be thoroughly familiar with operation and maintenance of playback equipment and particularly that system purchased by the Bureau. The schedule of the tour was timed for the author to be present at the factory while the equipment was assembled and checked out. This enabled a close study of operation and maintenance to be made before delivery and installation in Australia.

Visits to many other operators and manufacturers of similar equipment were made to become familiar with operation of, and available facilities on, machines of different types.

Another important aspect of the tour was for the author to become acquainted with new developments in field techniques with a view to assessing their value under Australian conditions. These fall into four categories.

(a) Recent improvements in field recording techniques with particular reference to improvements in signal-to-noise ratios,

(b) Application of surface impactor methods such as the Weight Dropper and 'Vibroseis',

(c) The development of digital methods of computing seismic data, both field recording and office handling of such data,

(d) Equipment used for Marine Profiling surveys such as the sparker, gas gun, and 'Sonar Boomer' systems.

The study of well-logging equipment was generally confined to locating suitable equipment for immediate needs and to the detailed study of the Continuous Velocity Logging equipment purchased from the Shell Development Company.

Opportunity was also taken to visit manufacturers of geophysical equipment used by the Geophysical Branch of the Bureau. These visits included detailed discussion of the specifications of equipment which the Bureau expects to order in the 1963/64 financial year. The most important of these items included a field frequency-modulated magnetic recorder and a portable seismic system for use in Antarctica.

It was not possible to include a study of seismic interpretation theory on which the playback system procedures are based. Much of this theory will have been studied by E.R. Smith and C.S. Robertson (Geophysical Branch) who made overseas tours in 1961 and 1962 respectively.

3. ITINERARY

The itinerary of the tour was scheduled for a period of five months from 31st March to 3rd September 1963. This period was made up of three weeks in Europe, one week in the north-eastern states of the USA, 17 weeks in Texas and Oklahoma, and one week in California. Most of the period in Texas was spent at the SIE Division of Dresser Industries, Houston which manufactured the playback system purchased by the Bureau. However, during this time visits were made to numerous geophysical companies in Houston and two trips were made to other cities in Texas and Oklahoma. The first of these was a three-week tour to visit geophysical equipment manufacturers and oil companies in Dallas, Texas, and in Tulsa and Ponca City, Oklahoma. The other was made to the Midland-Odessa area of West Texas to visit field crews and regional offices of seismic contractors.

Details of the actual itinerary are listed below:

Date	Place	Company	Items of interest
31st March - 1st April	Melbourne - Milan		
2nd-3rd April	Milan	AGIP Mineraria	Playback system (Western) Digital techniques
		Levici Foundation	Playback system (Techno) Field seismic units Seismic models tests
3rd-7th April	Hanover	Prakla GmbH	Digital techniques (SIE) (Prakla) Playback systems Airborne magnetometer
7th - 17th April	Paris	Institut Francais du Petrole (IFP)	Playback systems (seismic) (IFP) Seismic computing techniques Transistor field seismic equipment
		Compagnie Generale Geophysique (CGG)	Playback systems MTD field corrector Miscellaneous geophysical equipment.
18th-21st April	London	British Petroleum	Playback system (Carter) Synthetic seismograms Model tests Basic seismic pulse theory
		Seismograph Service Ltd	Playback systems (Techno) VAX and VAP recorders 'Vibroseis'

Date	Place	Company	Items of interest
21st-23rd April	New York	Australian Consulate General	
		Mobil Petroleum	
		Pan American Oil Corp.	
24th-25th April	Boston	Edgerton Germeshauser and Grier	'Sonar Boomer' equipment
25th-27th April	Pittsburgh	Gulf Research and Development Co.	Playback system (Gulf) Airborne magnetometer Seismic interpretation
27th April - 23rd August (excluding periods listed below)	Houston	SIE division of Dresser Industries	Playback system Field recording equipment
		Marine Geophysical Co.	Marine profiling-equipment Portable field seismic equipment
		Shell Development Co.	C.V.L. logging equipment Field seismic equipment
		Robert H. Ray Co.	Seismic playback system (Geograph) Field playback equipment Weight dropping techniques Discrete vibrator frequency techniques
		Texas Instruments	Time varied gain Seismic amplifiers
		Electrodynamic Inst. Co.	Playback systems Field seismic systems
		Hall Sears	Geophones (velocity and pressure)
		Geospace Corp.	Playback systems Sudip system FM field recorder Transistor seismic amplifiers Programmed gain
		Independent Exploration Co.	Sudip
		Electro Technical Labs.	Widco well-logging equipment Portable field seismic equipment Geophones

Date	Place	Company	Items of interest
	Houston (cont.)	Vector Manufacturing Co.	Seismic cables and repair
		Pan American Oil Co.	Playback system
		Hale Instrument	Omnitape 400-c/s motors
		Geophysical Associates	
21st-27th May	Tulsa	Seismograph Service Corporation	Well-logging equipment (Birdwell) Playback system (SSC) Synthetic seismograms Analogue-to-digital converter
		Pan American Oil	Playback system (SIE, EIC) Maintenance of playback
		Davis	New magnetic tapes Magnetic recording theory
		Sinclair Research	Playback systems (EIC) Synthetic seismograms (digital)
28th-29th May	Ponca City	Continental Oil Co.	Geophone cable repairs Programmed gain 'Vibroseis' Playback equipment (SIE and Continental)
30th, May	Blanco	Shell Development	CVL well test
31st May - 7th July	Dallas	Dresser Industries	
		Well Reconnaissance	Portable well-logging equipment
		Mobil Geophysical Services	Playback systems (SIE, Mobil) Digital techniques Programmed gain
		Mobil Research Labs.	Well logging - new techniques Seismic model tests Playback equipment Analogue digital converter Synthetic seismograms Marine profiling equipment
		Delhi Taylor	Impactor

Date	Place	Company	Items of interest
	Dallas (cont.)	Geotronics	Delay line (digital)
		Geophysical Services Inc.	Programmed gain Playback system
8th-11th July	Midland	Robert H. Ray Co.	Playback system (Geograph) Weight dropping party Conventional seismic party
		Empire Exploration	Playback system
		National-Continental Geophysical	'Vibroseis' field crew
26-30th August	Los Angeles	California Research Corporation	Digital equipment Theoretical seismograms Playback techniques
		United Geophysical	Digital techniques Impacting method Playback equipment
		United Electro-dynamics	Field seismic equipment Refraction pre-amplifiers
		Techno Instrument Co.	A.M. field recorders Wave analysers
30th August	San Francisco	Australian Consulate General	
30th August - 1st September	San Francisco-Melbourne		

4. SEISMIC FIELD EQUIPMENT

Field recording equipment

There appears to have been no outstanding developments in seismic field recording equipment over the last few years apart from the investigations into digital recording. However, there has been a steady improvement in the performance and quality of both amplifiers and magnetic recorders.

Solid-state amplifiers have now been developed to the stage where their performance is equal to or better than the best vacuum-tube types. In 1963 almost all production of amplifiers was confined to solid-state types. Vacuum-tube amplifiers were not being replaced by transistor amplifiers simply because of slightly better characteristics of the latter, but many contractors are re-equipping because of obsolescence of some of their systems and demands of oil companies for specific modern equipment. Apart from the improvement in performance, specifications, and reliability, recent developments are concerned with gain control and efforts to increase the dynamic range of amplifers to cope with wide-range digital or frequency-modulation (FM) recorders. Methods of improved gain control have been confined to more-efficient programmed gain units or development of very slow AGC circuits. There is little to choose between the types of transistor amplifiers now commercially available.

There has also been a steady improvement in the performance of field magnetic recorders. Improved techniques both in the mechanical drive of the tape transport and in magnetic tape manufacture have resulted in an increased dynamic recording range. The differences of opinion on the relative merits of direct and FM recording still remain. It is generally conceded, however, that FM is capable of the better results particularly with regard to frequency response and distortion. There seems to be little difference in attainable signal to noise ratios, both types exceeding 60 db under laboratory conditions. It is doubtful whether this figure can be maintained under field conditions. This figure has been achieved by improved drum drive control and in the case of direct recording by the use of thick oxide tapes.

Some development of flux-sensitive heads has been attempted to give improved low-frequency characteristics to direct-recording systems. The response of these heads is ideally proportional to the actual flux density recorded on the tape rather than proportional to the rate of change of flux as the head moves over the tape. Two systems have been tried, one depending on the magnetic modulator principle and the other on Hall effect. So far these heads have not been as good in performance as other playback heads. The chief limitation appears to have been an excessive noise level at low frequencies.

The French organisations (CGG and IFP) still favour pulse-width-modulation systems but it is believed that Esso is the only United States company employing this method. It is claimed that the performance approaches that of frequency-modulation recording but that it is easier to maintain in good condition in the field.

New developments in field recording systems have been confined to the design of more-versatile and complex systems which can be used both for weight-dropping techniques and the more-sophisticated shooting techniques such as the common depth-point methods. Two examples of this type of equipment are the 'Sudip' of Geospace and a similar unit designed by the Robert H. Ray Company.

These systems comprise basically two or more recording drums together with transfer and compositing facilities. 'Sudip' which has been specifically designed for use with surface impacting methods also features a 'quick start' device that allows the dropping weight to trigger the record cycle rather than the reverse method. This has the advantage of allowing the weight to be dropped as soon as the truck is in position and obviates the necessity of static corrections to compensate for differing drop times.

Another development being carried out by SIE is a large dynamic-range recording system. The aim is to enable signals with a 90-db-or-more dynamic-range to be recorded without distortion, for subsequent conversion to digital form, enabling full advantage to be taken of digital computing methods. The system is based on the standard PMR 20 transport but uses two recording heads on each channel. The received signal is channelled into two separate amplifiers whose gains differ by 40 db. The high-level and low-level portions of the signal are thus recorded on separate heads and can be remixed on playback. The standard transport used this way provides only twelve recording channels.

<u>Weight dropping and surface impacting systems</u>

A considerable effort has been made over the last few years in the United States towards the replacement of shot-hole and explosives by surface impacting methods. The methods can be conveniently divided into three types, <u>viz</u>. weight dropping, mechanical impacting, and mechanical vibration transducer equipment.

In general, the surface methods have considerable economic advantages over conventional shooting particularly where drilling conditions are not good and in remote areas where cost of transporting explosives is high. Many who use these systems are enthusiastic about them and claim superior results to conventional methods. However, careful comparison between the methods has indicated that there is little significant difference in quality of records and if anything the surface methods are slightly inferior.

Weight-dropping techniques were developed first and remain the most popular. The mechanical-impacting devices have been developed to overcome some disadvantages of weight dropping. At least three types of mechanical impactors are now in use, <u>viz</u>. a gas exploder, a compressed air hammer, and a coiled-spring-operated impactor. These types have the advantage over the weight dropper in better control and also generally produce a seismic pulse with a higher frequency spectrum. They have the disadvantages of less mobility and increased complexity.

Although a conventional geophone layout can be used with these energy sources, a technique using two or four geophone patches is more generally employed. A pattern of drops or impacts between the two geophone patches provides both coverage and diversity of sources. In all cases the energy from individual impacts is relatively small and compositing facilities are necessary to obtain a useful signal-to-noise ratio. Also a relatively large surface wave is generated and some offset is required.

Recording techniques are less simple than for conventional shooting as radio control of the energy source must be maintained. In the case of the weight-dropping system a microswitch on the recording drum initiates the weight drop, and the actual time of impact must be transmitted back to the recording truck. The actual impact time must then be applied as a static correction before the records are transferred to the microtrack heads for compositing. Newer recording systems such as 'Sudip' feature a quick-start drum-drive which initiates the record cycle from impact time. This allows the signal to be laid down immediately on to the microtracks. Synchronisation of other impact methods is simpler because of zero or fixed time-delay between trigger and actual impact.

Vibrator transducer systems

The vibrator technique, 'Vibroseis', is a more-recent development and differs from other surface methods in that a suite of frequencies of vibration energy is coupled to the ground instead of a single pulse of seismic energy. In order to obtain synchronisation of the received signals a programme of the swept frequency is pre-recorded on magnetic tape and is used to directly control the transducer. The transducers may be either hydraulic or electro-magnetic. The hydraulic units are capable of more power output; however, better reliability and better waveform and control are claimed for the electromagnetic units. To obtain more seismic energy two or more transducers are often operated in synchronism.

The suite of frequencies can theoretically be synchronised into a seismic pulse. Correlation processes carried out on the seismic record produce a final record that is similar in character to that obtained by shooting or impacting. So far results obtained appear to be just slightly inferior to those of other methods but the system does have a considerable potential for further development.

Recording techniques are similar to those employed in other surface impacting methods. A two-patch geophone layout with a linear pattern of sources is most generally used. Because of direct control of the source transducer from the recording cab, received signals can be recorded immediately on microtracks for compositing. As the correlation process is complex, the tapes are processed in a field office at the end of the day's work. The field records are meaningless until correlation has been applied and therefore no field monitor record can be obtained.

A new technique using a vibrator transducer as an energy source is now being tested. In this system a series of discrete frequencies is generated rather than a single-frequency sweep. The received signal is allowed to reach a steady state before being recorded. Two parameters only, viz. amplitude and phase, are required to be measured for each generated frequency. This method could simplify recording equipment and is obviously amenable to digital recording and digital computation. However, there may be other practical difficulties that may limit its usefulness.

Field correction systems

A study was made of several types of field systems able to make some correction and compositing functions in the field. The study was stimulated by a Bureau proposal to replace one of its present magnetic-tape recorders and by the fact that its experimental survey party will need corrected records as soon as possible to assess the value of its experimental techniques. It is important for any seismic field party to have results as quickly as possible so that variations in technique may be made as the survey progresses. Ideally an office playback system should be able to process records in time to plan the following days work. In many areas this is impracticable due to communication difficulties; therefore some correcting, compositing, and cross-section plotting must be done in the field.

The amount of work of this type that must be done in the field depends on circumstances such as locality and on the difficulty experienced in obtaining good usable results. A number of different systems have been designed to cope with these problems, and range in complexity from simple playback with static corrections to what is essentially a portable office playback system. Recent developments in field techniques such as common-depth-point procedures have also demanded compositing and mixing facilities to obtain completed cross-sections.

Several of the field recording systems now in use employ two or more drums so that corrections can be made sequentially while transferring from one drum to the other. Methods of introducing the dynamic correction vary considerably. Most of them depend on a cam and proportion control to generate the normal move-out curve. A new cam must be cut for each different normal move-out curve required.

The cam output may be used in several different ways to produce a corrected record. In the 'Sudip' system the output and proportion are applied to a differential between field-tape drum and transfer-tape drum. Another common method is for the cam to generate the NMO curve as a varying voltage to operate a servo-driven head. A separate complete servo-operated delay line could also be used but would be bulky and difficult to maintain under field conditions. The Techno system is also cam-operated but in this case the cam is directly mechanically-coupled through 24 separate proportion controls to the magnetic heads allowing 24 traces to be corrected simultaneously.

A novel method is employed in the Electro Tech and C.G.G. 'MTD Corrector'. In this system the move-out curve is programmed on magnetic tape in the form of pulses corresponding in time to a given Δt correction. The pulses are counted, converted to an analogue voltage, proportioned, and added to pre-set voltage representing the static correction. The output voltage is then applied to a second galvanometer in a special drum oscillograph. This galvanometer has its mirror in the optical path and is at right angles to the normal signal galvanometer. This allows the trace to be moved around the circumference of the drum corresponding to the desired correction.

Another possible method for introducing field corrections is to programme a lumped parameter delay line such as that of Geotronics or CGG. A convenient method of programming would be to use a magnetic tape as in the MTD corrector.

Specifications of proposed BMR seismic equipment

The tour offered a unique opportunity to discuss with possible suppliers detailed specifications of seismic equipment that is expected to be purchased in the 1963-64 financial year. The most important of these items were the portable seismic system for use in ice thickness determinations in Antarctica, the FM magnetic-tape recording system, and equipment for improving the low-frequency response of existing seismic amplifiers for the refraction surveys.

Three quotes were obtained for the ice-thickness equipment. Through discussions with the suppliers quotes that closely met requirements were obtained with the minimum difficulty. Only some minor points remain to be cleared before a final choice can be made and the equipment ordered.

The Bureau also intends to purchase an FM recording system to take advantage of improved record quality afforded by this equipment. As it is almost essential that some provision be made for field corrections and compositing, a two-drum system becomes mandatory. As there is an almost endless variety of possibilities to meet Bureau requirements, discussions with suppliers enabled a firm idea of the best methods of meeting these requirements to be obtained. The system was narrowed down to four possibilities and approximate prices were obtained for each. A final choice can now be made after discussion with officers of the seismic group. The choice lies between the following offers:

Electro Technical Laboratories offers only its standard FM system but it would be possible to synchronise a second transport at a later date.

SIE recommend its standard FM system but will carry out any engineering necessary to direct-couple a second drum at a later date. The second drum would probably be of a Techno type to allow the use of microheads for compositing purposes.

Geospace Corp. have offered a simplified version of their 'Sudip' equipment omitting the cross-section plotter and some specialised controls for conducting weight-dropping surveys at maximum speed. Features such as their quick-start and dynamic and static correctors would be retained. AM - FM heads could be supplied on one drum together with FM modulators and demodulators but it is considered that the signal to noise ratio of the system used in this way would not exceed about 50 db, or 10 db less than that obtainable on the standard FM recorders.

Geospace Corp. could also offer a two-drum FM system but this would probably not be flexible enough to cope with some requirements.

An effort was made to determine the best method of improving the low-frequency response of the type 8000 seismic amplifiers for use in refraction surveys. As the Bureau seismic parties are committed to a considerable amount of refraction shooting, satisfactory response is important. The limitation in the type 8000 amplifiers is largely caused by the relatively low input impedance of the amplifiers and the high effective impedance of the long cables necessary in refraction work. Discussions indicated that the best method of improvement would be to design and build a suitable high-input-impedance pre-amplifier to use ahead of the main amplifiers. Quotes for suitable pre-amplifiers were obtained from Texas Instruments and United Electrodynamics.

Programmed gain

There is a definite trend in seismic prospecting towards the use of pre-programmed gain of field seismic amplifiers. However, as with many techniques, it was not possible to obtain a unanimous opinion of the value of programmed gain and on the extent to which it should be applied in normal seismic surveys.

Two reasons for the use of the technique are (a) to eliminate distortion inherent in an automatic gain control and (b) to obtain a measure of the relative energy of reflections. The latter requirement is generally required only over a limited section of the record but newer methods will allow the absolute value of any part of the record to be obtained. This statement is subject to the limitations imposed by a limited dynamic range of the early stages of the amplifier and also that the pre-programming is sufficiently close to keep the output level within a specified dynamic range.

The programmed-gain unit introduces into the amplifier a high-frequency rider signal identical with a normal pre-suppression signal. The amplitude of the high-frequency signal is controlled in accordance with a pre-set curve. The gain of the amplifier is normally inversely proportional to the amplitude of this signal so that a suitable gain/time curve can be pre-programmed.

The curve is generated either by a number of single-point controls and a function potentiometer or by a single-point control with exponential decay times of different time constants. The number of control points varies with different types of equipment. Also in some systems the programmed gain is used in conjunction with an extremely slow AGC to trim overall trace levels. This method does not allow the absolute energy levels to be recovered. The most sophisticated system is that of CGG which controls each step by means of a signal sampled from the integrated level of the input channels.

Investigation has shown that for any given area the form of the signal-attenuation curve does not appreciably alter but the general level of the received signal can vary considerably depending on the amount of energy transmitted by the explosion. Therefore, it is difficult to predict the initial level at which the gain should be set. For this reason several companies are designing or have completed a system whereby the initial level is set from the sampled energy from a particular geophone. This has the effect of raising or lowering the gain curve for the complete record.

In general, the requirements for magnetic recording are not too stringent because of the relatively large dynamic range of magnetic recorders, but it will be nearly impossible to obtain a uniform monitor record. This is the reason that some oil companies have been reluctant to accept the technique. For magnetic recording, an expected curve is chosen e.g. 20 db above the tape noise level allowing for 30 db to cope with reflection energy above the general background level.

Brief details of systems inspected include :

(a) Texas Instruments unit is specifically engineered for the type - 7000B amplifier system and allows an initial level to be set with a choice of five exponential decay time constants.

(b) SIE produces a 30-point control system using a function potentiometer driven by a synchronous motor. SIE is also designing an auxiliary unit to set the initial level automatically.

(c) Compagnie Generale Geophysique has designed a unit that sets not only the initial level from sampled signals but controls and records the gain curve for the whole record.

(d) Institut Francais du Petrole favours a much-simpler system using a nine-point function, six points of which are normally not adjusted. This system is used in conjunction with very slow AGC.

(e) Dynatronics produces a system similar to that of SIE but has already completed a design of automatic initial gain setting.

(f) Geospace equipment is also similar but has fewer control points.

(g) Geophysical Services Incorporated uses a relatively simple system but has included a switched test oscillator by which the gain can be regularly and quickly calibrated.

(h) Continental Oil Co. is also working on a system that is mainly directed at integration with its own (Continental) amplifiers.

One requirement for integration of units with amplifiers is that the amplifier gain be linear with the level of rider signal introduced. Otherwise calibration of amplifier gain would be difficult. It is also desirable that the rider signal should be part of a closed-loop gain control, otherwise stability may be inadequate and frequent recalibration would be necessary.

Seismic detectors and cables

Two companies, viz. Hall Sears Inc. and Electro Tech between them now manufacture almost all the geophones commercially available to the industry. Visits were made to their plants to discuss new developments and particularly Bureau requirements for 1963. In addition, a few oil companies and contractors still manufacture geophones for their own use and also produce some special types.

Recent developments appear to have been limited to improvement in manufacturing techniques with regard to both reliability and reduced cost. For instance Electro Tech has recently announced a new subminiature geophone that is completely manufactured by automatic machines. Hall Sears has also recently announced a new type of pressure-sensitive geophone that is made up of a pair of subminiature velocity movements coupled in opposition for velocity motion but adding for pressure detection. This type is becoming popular for marsh work and is suitable for water work to a shallow depth (about 50 ft). Some effort is also being directed to the design of a more-compact and stable very-low-frequency detector. The frequency of these detectors (0.562 c/s) is normally below that required in oil exploration and the detectors are mainly being developed for detection of underground atomic explosions.

Enquiries were made to obtain suitable pressure geophones for both shot-hole and deep-well logging. The manufacture of the only deep-well pressure geophone commercially available is the Birdwell Division of Seismograph Service Corporation. Its use was recommended by engineers of Hall Sears but they have not manufactured a similar model because of limited demand. The most-suitable type for shot-hole work appears to be the Hall Sears type Mp3. This is a reluctance-type geophone and has neither the flat frequency response nor the sensitivity of the crystal type made by Electro Tech. However this latter type is not made in a form suitable for stringing at intervals along the well cable.

The relative damping of random noise (wind noise) in a group of geophones connected in series or parallel and using a single damping resistance for the group was discussed with Mr E.M. Hall of Hall Sears. A simplified calculation showed that in the case of the series-connected type-HSJ geophones recently purchased by the Bureau, the noise level could be expected to increase by about 1 db consequent on using a single damping resistor rather than individual damping resistors. Theoretically, there is some advantage in using parallel-connected geophones where damping of noise is increased by the parallel impedance of the other geophones in the string. In this case there is no difference whether the external damping resistances are connected across individual geophones or a single resistance is connected across the string. However, the improvement in practice is not significant.

A visit was also made to the Vector Cable Co. which specialises in the manufacture of geophysical cables. The range includes all types of seismic and well logging cables and special connectors for use with seismic cables.

Two geophone test set-ups were noted that are of practical interest. British Petroleum have recently completed the design and construction of a field geophone tester. This instrument is based on the familiar ellipse test and does not basically provide any additional information but has been designed to simplify measuring procedures and also provides the data more accurately than the usual test set-up. The other item of interest was a small motor-and-cam-driven shaking table used by AGIP Mineraria. Geophones are compared with a standard geophone at 1 c/s. The low frequency is used to avoid undesirable noise and resonance effects.

With the low cost of geophones and their present methods of construction it is now no longer economical to repair them. Very few companies now make any attempt to repair their geophones.

Cable repairs were discussed with Continental Oil Co, which manufacture its own geophones and cables, and with the Vector Cable Co. In particular, methods of moulding rubber-covered cables were discussed. It appears practicable to use our existing vulcaniser for the process but a slight change in the form of the mould may be necessary. A local source of supply of uncured rubber is also required as the uncured rubber will not keep longer than a few weeks.

Continuous profiling equipment

The techniques and construction of three types of continuous profiling equipment were investigated. As the Bureau is purchasing a system of this kind, it was important to ascertain which would be best suited to the Bureau requirements. The three types are known as the Sparker, Gas Gun, and Sonar Boomer.

The Sparker is essentially a lower power type used for high resolution at relatively shallow depths. Elastic energy waves are produced by generating a large spark below the water surface. The Gas Gun consists of a chamber of a mixture of oxygen and propane which is exploded below the surface. It generates considerably more energy than the sparker and is capable of moderate to deep penetration.

The Sonar Boomer is intermediate between the other two and its energy is generated by a pulsed-eddy-current transducer. The eddy currents induced in two aluminium plates force the plates apart generating the energy wave.

In use, the transducers are towed behind a boat and pulsed every few seconds. Reflections are received by a hydrophone unit and amplified and recorded in a similar manner to seismic procedures. It differs from ordinary seismic techniques in that only a single detection unit is used and therefore only one trace is recorded at one time. Corrections therefore do not need to be applied to obtain the completed record. A recorder of the facsimile type is most often used, but more recently the signal has been recorded on a single-channel magnetic tape, transcribed, and presented on a conventional seismic playback plotter.

Because of limited depth penetration the Sparker system was not considered for use by the Bureau and the choice was between the Gas Gun and the Sonar Boomer equipment. The gun offered by Marine Geophysical Co. is believed to be inferior to that used by other companies. Owing to various patent rights it was the only system of this kind that we were able to buy. It was also felt that the Sonar Boomer offered more flexibility and a decision was made to purchase this unit rather than the Gas Gun. Some disadvantages of the Sonar Boomer include lower power and less depth penetration, heavy AC power-supply required, and dangerously-high voltages. Advantages include suitability for both engineering and limited off-shore oil exploration, more-reliable pulse generation, and no requirement for handling and plumbing of the gas supply.

The unit to be purchased will comprise power supplies, storage capacitor banks, detector, amplifier filter and recorder, and both 1000 watt-second and 5000 watt-second transducers. Consideration will be given to the addition of a magnetic-tape recorder at a later date.

Gas Gun and Sonar Boomer equipment is now being used extensively in off-shore oil exploration particularly in the Gulf of Mexico and the North Sea. Geophysical Services Inc. use both systems and Mobil Oil Co. use a gas gun of their own design. It was not possible to obtain information on the relative merits of the system from GSI as the geophysicists and engineers concerned were not available at the time of the visit.

5. SEISMIC COMPUTING TECHNIQUES AND EQUIPMENT

Seismic playback systems

To gain a good working knowledge of the operation and maintenance of the Bureau's playback system, visits were made to many central playback offices operated by oil companies and geophysical contractors. Although widely differing in design, the systems perform essentially similar functions. Most of them were designed primarily for routine processing of seismic records, their functions being limited to time corrections, relatively simple mixing and compositing facilities, and cross-section plotting.

Owing to the wide differences in design it is not possible to conveniently classify the systems into groups. Differences include the type of time correction system used, whether the machine operates simultaneously or sequentially, and whether frequency modulation or direct playback and recording are used. In addition many machines may have any combination of these characteristics.

In a sequential system magnetic tracks are processed one at a time and in the simultaneous system up to 24 traces at a time. Some machines carry out some operations, such as time correction, sequentially and other operations, such as compositing and section plotting, simultaneously. Unless the correction settings and controls can be set into the system automatically, e.g. from punched cards, the time saved by the use of the simultaneous systems is not as great as may be expected. A dual-channel system appears to be the best compromise between production rate and initial cost.

The various methods of incorporating dynamic time corrections include:

Servo-driven drum delay lines,
Servo-driven optical heads in the cross-section plotter,
Cam-operated movable heads on the playback or record drum, and
Servo-driven heads on the magnetic drums.

Static corrections may be introduced either by movable heads on the drums or by introducing a fixed correction into the delay lines.

Playback systems are also characterised by the number of drums which may be used for compositing and other processes. The simpler machines use only two drums and are capable of only simple compositing processes. Most compositing can be done using three drums but the process is often slow. To facilitate the more-complex compositing operations, machines of up to 14 drums have been constructed. The use of microtracks on direct-recording machines also facilitates many compositing processes.

Cross-section plotters also vary considerably in design. Most modern plotters are photographic and are able to produce cross-sections in variable density, variable area, wiggle trace, and combinations. Most cross-section plotters are of the drum type with a length of up to 48 in. and surface speeds ranging from 3-12 in/sec. In some cases, 24-channel oscillographs are used and each record is reprinted side by side on to the master cross-section. Some older units produce pen and ink wiggle cross-sections directly on a recording drum.

Monitoring of field records is important and two methods are widely used. In many systems a pen and ink or electrostylus drum is included on the machine-drum transport. Other operators prefer to do their monitoring on a special 24-channel oscilloscope that is manufactured by several firms.

Two auxiliary units that are in common use are the 'Omnitape' for transcribing field tapes of differing standards to the standard tape used on the particular playback machine, and the Transcorder, which is used to transcribe old photographic records to magnetic tape. Although some of the original data may be lost on these records, it has been found profitable to re-record and process the records on the seismic playback machines.

Bureau of Mineral Resources playback system

The seismic playback system purchased from SIE by the Bureau was designed to afford maximum flexibility in compositing and filtering procedures but was not designed for a high production rate on the more-sophisticated techniques. The system was designated type MS 42 by SIE and includes all the features normally supplied in the SIE MS 40 series. Additional flexibility is achieved by the incorporation of comprehensive signal-patching facilities and the addition of extra units such as micro-heads, long tape composition, programmed gain, 28-channel record and amplifiers, 28-channel demodulators, and interchangeable field tape drums.

One of the main aims of the overseas tour was to ensure that the equipment supplied was capable of carrying out its envisaged functions and that a thorough knowledge of operational and maintenance details was obtained. A total of about 10-weeks was spent at SIE studying circuits and checking out the system after assembly. One of the first duties on arriving in Houston was to check SIE's proposed system against our specification and to clear up minor details on some of the specifications. Only two major departures from the Bureau's requirements were noted and required negotiation. Provision for reversal of the output of the demodulators was not originally specified and it was necessary to make considerable modifications to the demodulator unit to accomplish phase reversal. An additional order was raised to meet this requirement. There was also some misunderstanding of the specification for three-drum compositing but SIE agreed to instal this facility at no additional cost. Minor changes, particularly in the signal-patching facilities were also made at no further cost to the Bureau.

Construction of the system was well-advanced by April and at that stage check-out was scheduled to commence by the middle of June and be completed early in August. Check-out actually commenced early in July and was completed except for a few minor alterations by the third week in August when it was necessary to leave Houston. Most of the time, up until check-out commenced, was taken up with a study of the circuits of the system and the sketching of signal paths and block diagrams. Participation in the actual check-out of the unit provided an excellent insight into the operation and maintenance of the system.

Seismic computing techniques

Although the tour was concerned primarily with the study of instrumentation, some effort was made to become familiar with various techniques of seismic computing, particularly those which can be applied by the seismic playback system. Unfortunately in the limited time available during most visits it was not possible to understand fully the mathematical basis of many of the procedures.

However, it was evident that the various processes applied to seismic records can be conveniently divided into three groups that are realisable on the Bureau's playback system. They are record stacking, mixing processes, and filtering techniques such as time domain and velocity filtering. Few of these processes are in common use as it is considered by many geophysicists that improvement in record quality is generally only marginal. Rarely are previously-unrecognisable reflections made evident, but doubtful reflections can often be accentuated into good quality.

There is an almost endless number of mixing techniques employed depending on the number of traces and percentage of mix. Skip mixing and reverse skip mixing are special techniques used where it is desired to accentuate or limit reflections from dipping strata.

Record stacking is used where multiple shooting has been used to improve signal-to-noise ratios. Common-depth-point shooting has recently become popular and record stacking is essential in the computation of this type of survey. Surface impacting methods also inherently require record stacking but much of this is actually carried out on the special field recorders used.

Filtering techniques such as 'Brick Wall Filters' and high-frequency enhancement, which depend on a correlation process, can be realised by delay lines and remixing procedures. Velocity filtering, fan filtering, and 'Pie Slice' techniques also utilise similar procedures.

Digital techniques in seismic prospecting

Digital methods have been applied to seismic equipment in limited form for a number of years. Until recently this has been restricted to the use of punched paper tape, key punch, and digital magnetic tape for introducing corrections to conventional analogue playback systems. One of the first was the use of punched tape in the 'Seismac' playback system.

More recently, however, there has been considerable activity directed towards complete reduction of seismic records by digital computors. There are two methods of achieving this end, one being to record data in digital form in the field and the other to utilise existing analogue-recording equipment and carry out analogue-to-digital conversion with office equipment. However, to utilise the full value of digital computation it will be necessary to improve the fidelity and dynamic range of recording equipment. SIE in particular is presently designing both wide-range amplifiers and magnetic recorders.

In the USA a group of oil companies and a manufacturer and contractor have co-operated in producing a full-scale digital field recorder and a special-purpose computer for the job. The field equipment is being proved under field conditions but it is understood that the computer is not yet ready. Details of the system are expected to be announced soon.

The choice of computer for the reduction will depend largely on economic factors. There is little doubt that present large general purpose computers will be suitable but will probably require special input facilities. A large storage capacity is required and this may limit the use of smaller computers. It will be possible to use a small computer for a limited volume of work but it may be necessary to input the data more than once thus tying up the computer for excessive periods. If the computer is to be used exclusively for seismic data processing then a special computer would no doubt be more economical.

A number of organisations, notably Prakla GmbH, are considering office analogue-to-digital conversion. Their approach is to convert from their analogue magnetic tape to punched tape for use with their own Elliot type-803 computer. This method obviates the need for special input facilities for their computer but is suitable only for initial assessment of the method as the recording and reading of paper tape is far too slow for production work.

Basically the field recording equipment comprises a normal set of analogue equipment together with a multiplexer, analogue-to-digital converter, and digital tape transport. Each of the 24 traces is sampled at intervals of about one millisecond and recorded sequentially in binary form on a 12-track tape. The number of binary bits recorded is a present limitation to the dynamic range of the system.

No details of computer programme in the USA are yet available but it is known that one of the aims is to compute and eliminate multiple and ghost reflections in order to detect weak primary reflections. Prakla has used digital-computation methods to determine depths, but in this programme reflections are measured in the usual way and manually fed into their computer. AGIP Mineraria also has a research project to grade and record reflections using a mechanical plotter with a digital input.

Generally the oil industry is cautious of predicting the outcome of the trend to digital methods and most oil companies are content to study developments. Many believe that office analogue-to-digital conversion will be the course that they should eventually follow. However, it is significant that the contracter using field digital equipment is winning some contracts from those who are not equipped for digital computation.

Seismic pulse studies, model tests, and synthetic seismograms

A number of organisations visited were carrying out theoretical studies and model tests to improve their basic understanding of seismic problems and for application to seismic interpretation procedures. British Petroleum Ltd in particular has done a good deal of research into frequency components of a seismic pulse and the Earth's response to its transmission. BP believes the study will enable it to take maximum advantage of new digital computing techniques.

A considerable amount of related work has also been undertaken in the USA. One research group has devoted much of its time to analysing sections of a field seismic record into its frequency components. Both analogue and digital computing methods may be used in this analysis. Results emphasise just how efficiently the Earth itself behaves as a seismic filter. The average seismic record contains only a relatively narrow band of frequencies some 10 to 20-c/s wide. The centre frequency is usually around 30 to 50 c/s. A practical application of this work is to determine to what extent high (or low)-frequency enhancement techniques can profitably be applied.

Seismic model tests are an important phase of research work of several organisations notably British Petroleum, Levici Foundation, and Mobil Research. Most model tests are confined to two-dimension structures simulated by thin sheets, but there have been attempts to use flat slabs as models. Considerable care must be taken in the construction of models. Inaccurate results can be caused by glued joints representing velocity or density contrasts, the joint, if thick, acting as a double interface. Complications from reflections from the boundaries of the flat slabs limit the usefulness of models of this type. The techniques and results of model tests have been described in various journals.

Synthetic seismograms are now proving a useful practical aid in the interpretation of seismic records. The seismograms are constructed from continuous velocity well-log data. Most calculations are now performed on digital computors but several companies still retain comprehensive analogue systems. In practice, the velocity logs are measured at 2-ft or 10-ft intervals depending on well depth. Standard programmes are available for computation of seismograms based on data representing up to 2000 'layers'.

Seismograms comprising primary reflections only or including multiple and ghosts may be produced. A simplified programme is also available based only on major velocity changes that can be manually picked from a continuous velocity log. This method is capable of good results but it is possible to miss significant reflections. The value of synthetic seismograms will greatly increase as digital methods of multiple elimination become more-widely used.

6. WELL-LOGGING EQUIPMENT

Shell Continuous Velocity Logging equipment

Several days were spent with engineers of the Shell Development Co. studying and working with a continuous velocity well-logger unit similar to that supplied to the Bureau. During this period several modifications to their equipment were made and checked. Most important of the modifications was a re-design of the receiver amplifer pulse-shaping circuit to prevent premature triggering by noise caused by the source transducer. Modifications were also made to the stop delay circuit in the control unit to improve timing accuracy. Details of these modifications were forwarded to Melbourne for installation in the Bureau's equipment.

Shell were also acquainted with several problems experienced on the Bureau's unit. The most serious of these was pre-triggering of the receiver amplifier by the source pulse. The modification mentioned above was designed to overcome this problem but it was also found that the trouble was aggravated by the use of unsuitable wire used in winding the transducers. Recommendations for replacement were forwarded to Melbourne. Another serious problem encountered on the Bureau's unit was the binding of threads where sections of the downhole tool were joined. It was established by the Bureau's officers that nickel plating on the threads was flaking off to cause the binding. Shell admitted that a new nickel-plating process had been tried and was not successful. For this reason they supplied free replacement parts in stainless steel to obviate the trouble. A modification in design also enabled easier dismantling of the tool.

After modifications and bench-testing of the Shell unit were completed, a full-scale field test was made in a Schlumberger test well near Blanco in Texas. The test showed that the new equipment was capable of more-consistent results than that used previously. 'Drop-outs' from weak signals were less evident and an excellent log was obtained. One minor additional fault was made evident during the test. Small spikes were produced on the analogue record by relay transients but a simple modification was devised to eliminate the fault.

In general, a good appreciation of the maintenance and handling of the equipment was obtained in the few days spent with Shell. Incorporation of the modifications in the Bureau's equipment should be made with the minimum of trouble and it is hoped that the equipment can now be quickly placed in service and will operate reliably.

Other logging equipment

Some time was taken to inspect and discuss standard logging equipment that is commercially available. Some of the Bureau logging instruments are obsolete and are due for replacement, and some new types of tools will be required. Three of the four main suppliers of well-logging equipment were visited.

The Widco Division of Mandrell Industries is now producing an excellent range of winches, up-hole electronics, and tools for the common logging methods, both for deep wells and shallow wells. Well Reconnaissance has confined its production to portable equipment suitable to depths of 6000 ft. Its equipment is also of high quality. The Birdwell Division of Seismograph Service Corporation produces mainly deep-well instruments and do not normally sell equipment inside the USA. It was not possible to fit in a visit to the fourth supplier, the Failing Company. Other large logging contractors such as Schlumberger, Shell, and Lane Wells produce their own logging instruments, but do not offer them for sale commercially.

Items specifically discussed and for which quotes are being obtained are a high-temperature gamma-probe, a logging cab complete with hydraulic drive for the existing Birdwell winch, and replacement electric, gamma, and temperature tools and up-hole electronics for obsolete equipment now held by the Bureau.

Some logging equipment manufactured and used by the European organisation was also seen but as the equipment was not for sale few details were obtained.

New developments in logging techniques and instrumentation

Considerable effort has been devoted recently to improvements in reliability and performance of standard logging instruments particularly gamma and caliper tools. New developments have been generally confined to more-sophisticated use of neutron logging and continuous velocity logging techniques. Many of these new techniques have been applied to specific problems in producing wells rather than for stratigraphic correlation in which the Bureau is most interested.

In the case of neutron logs effort is being concentrated in developing suitable pulsed neutron sources. The rate of decay of the neutrons can then be measured, and forms an important parameter in the determination of oil-bearing strata.

Additional data are also being obtained from continuous velocity logs that can yield important information on porosity and bulk elastic properties of rock strata. This may have application in engineering work where it has been found that the elastic properties determined from core samples differ from the bulk constants. Two distinct techniques are being applied to determine these properties. In the first, the amplitude of the received energy pulse at the receiver is measured and this parameter can yield useful information for identification of cavities and fissures in producing wells. In the other system, the complete waveform of each received pulse is recorded in a density-modulated display. This enables time of arrival and character of shear waves and tube waves as well as pressure waves to be identified. From these data the bulk elastic constants of the rock strata may be determined.

Papers have been published on some of these new developments.

7. AIRBORNE MAGNETIC AND OTHER GEOPHYSICAL METHODS

Airborne magnetometer equipment

It was not possible during this tour to spend appreciable time on geophysical equipment other than seismic or well-logging. However, the airborne magnetometer operated by Prakla GmbH in Hanover, Germany, was inspected and is worth a brief description. Prakla had recently re-installed its magnetometer and ancillary equipment in a type-B26 bomber and was carrying out final check-outs before doing surveys in Africa.

The basic equipment is a nuclear-resonance magnetometer designed for direct reading, and for punched-paper-tape recording. A readout and automatic check system for the digital record is included. The magnetometer head is installed in a towed bird. It was found necessary to include a pre-amplifier in the bird as it was not possible to obtain a towing cable sufficiently free from noise at the B26 operating speeds.

Navigation depended largely on a Doppler system, a modified General Precision Inc. radar type being used in conjunction with a Kearfott Gyro with the low drift rate of $\frac{1}{4}$-degree per hour. Navigational data from the Doppler unit are also recorded digitally on the punched paper tape. Type APN-1 radio altimeter has been found adequate for aircraft height measurements.

Discrimination scintillation counters are also carried on the aircraft. These units were designed and manufactured by CGG in France.

Gulf Research and Development is still building a few airborne magnetometers for licensed geophysical contractors. It has not found it necessary to modify appreciably its standard design and no new developments are contemplated.

8. CONCLUSIONS

This tour afforded a valuable insight into recent developments and standard practices employed in seismic and well-logging instrumentation. No attempt was made to study instrumentation for other geophysical methods but some information was gained in passing. Unfortunately, the time available was insufficient to gain more than a superficial background into seismic field and computing techniques. The most-important aspect of the tour was the detailed knowledge gained of the circuit details, maintenance, and operation of the seismic playback system purchased by the Bureau. However, a better-balanced tour may have resulted from spending a little less time on this equipment and more on seismic field and computing techniques.

Opportunity to discuss projected Bureau purchases with manufacturers was another important aspect of the tour. Discussion of detailed specifications in this way can save a considerable amount of time and correspondence, and should result in a more-satisfactory purchase.

Discussions with geophysical contractors and oil companies have emphasised the need for closer control of maintenance and calibration of field geophysical equipment. It was also evident that the provision of trained staff within the Bureau to cope with proper maintenance of geophysical instruments compares unfavourably with other geophysical organisations. The increase in amount and complexity of electronic equipment used by the Bureau has outstripped the capacity to handle it and it will be necessary to expand training and staff in this division to maintain equipment in top condition and achieve maximum efficiency on field surveys.