DEPARTMENT OF
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Record 1975/119

REPORT ON VISITS TO GEOPHYSICAL INSTITUTIONS IN USA, CANADA AND UK DURING 27 MARCH - 17 MAY 1974

by

D.M. Finlayson

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SUMMARY

This Record reports on meetings and discussions held by the author at 22 geophysical institutions, conventions, and commercial companies in USA, Canada, and UK during 27 March - 17 May 1974. The visit provided an opportunity for the author to gain a broader understanding of trends in the field of crustal investigations in these countries and enabled him to see at first hand the techniques used overseas for explosion seismic surveys, which will be beneficial to future BMR survey work. Personal contacts were made in these countries which will enable advice to be obtained more easily on interpretational techniques. Access to a number of computer programs was obtained which will save much effort by BMR staff on survey interpretation and improve the quality of interpretations.

1. INTRODUCTION

The Bureau of Mineral Resources, Geology and Geophysics (BMR) has conducted many investigations into the tectonic framework of the Australian region and such investigations are likely to continue to be part of the BMR program for the foreseeable future. The Regional Structural Surveys Group in BMR undertakes seismic, gravity, and magnetic investigations of the Earth's crust and upper mantle to provide information on the tectonic background of near-surface geological features. The continued interest and research into problems of this nature make it essential that BMR keep abreast of modern developments in the fields of survey design, instrumentation, and interpretation; particularly as the BMR has played a major role in explosion seismology in the Australian region. Thus, from 27 March to 17 May 1974 the author visited geophysical institutions in USA, Canada, and UK in order to see at first hand many of the new techniques which are being employed in these countries in the field of explosion seismology.

This Record sets out the scope of discussions undertaken at the various institutions visited and also summarizes impressions gained at the 1974 Annual Meeting of the American Geophysical Union at which the author presented a paper. The topics will generally be considered under three headings; 1) survey motivation and design, 2) survey equipment and operations, and 3) survey data reduction and interpretation.

2. USA

2.1 Hawaii Institute of Geophysics (HIG) 27-29 March 1974

HIG was a participant in the BMR East Papua Crustal Survey conducted in 1973 and the main discussions centred on the results of this survey. HIG operated one land seismic recording station and one shipborne recording station during the survey and all recordings were systematically examined. The land station had a good success rate for the survey but no usable recordings were made on the shipborne recording system.

Instruments examined included an ocean bottom seismograph which telemeters data from a surface buoy to a ship or shore recorder, and a crystal clock for ocean bottom work, which is manufactured commercially (Arias) and fits into a 5-cm cube.

Staff contacted; A.S. Furomoto, M.L. Broyles, R. Mitiguy, E. Murphy, M. Odegard, W. Adams, G.P. Woollard.

2.2 San Francisco Area, 1 - 5 April 1974

National Centre for Earthquake Research, Menlo Park

This office of the US Geological Survey is concerned with all aspects of earthquake research. It conducts explosion seismic investigations of the earth's crust and upper mantle to determine structure across fault zones, variations in seismic velocity etc. In addition it has undertaken seismic surveys in connection with the investigation of potential geothermal energy sources and with the calibration of crustal structure under seismic arrays and nuclear test sites.

Discussions were held on the Californian earthquake recording network of approximately 140 stations and its calibration, the calibration of the Large Aperture Seismic Array (LASA), and the Bear Valley Seismic survey connected with the premonitory effects of earthquakes. The data processing techniques available for such surveys were impressive. Analogue to digital conversion of all field tape recordings is done on a routine basis and computer discrimination of significant seismic events is automatic. The production of record sections in a number of configurations is done as the first step in interpretation of structures.

Field recording equipment used included (a) the 140-station Californian network which is telemetered along the commercial telephone system at audio frequencies into the office, (b) 18 Precision Instrument ½" inch tape recorders, (c) 10 truck mounted arrays each with 8 geophones, photographic recorders and 1 inch Ampex tape recording, (d) 10 Sprengnether smoked paper recorders and (e) a "centipede" array of 40 stations hard wired at 1 km intervals into a computer multiplexing system. Miniaturization of equipment was under way and items inspected included seismometer-amplifer systems and crystal clocks.

Interpretation methods encountered emphasized computer modelling of observed results. Both the kinematic and dynamic characteristics of seismic records were modelled; the kinematic models used ray tracing programs, usually only for simple structures, and the dynamic models used synthetic seismogram programs developed in recent years by Fuchs in Karlsruhe, W. Germany, and Helmberger and Wiggins in Canada/USA.

Discussions were also held with staff compiling and interpreting gravity data in the Californian region.

Staff contacted: J. Eaton, J. Healy, D. Warren, F. Fisher, D. Hill, J. Ellis, S. Stewart, D. Barnes, H. Oliver, A. Griscom.

Department of Geophysics, University of California, Berkley

The main interest of the Department is in earthquake studies of both local and teleseismic events, and in strong motion studies. The crustal investigations are directly related to the potential hazards associated with crustal movements in northern California. The Department has a 15-station seismic network telemetered to the office and this is recorded on a 1 inch Memorex tape recorder. Tapes can be digitized and editted as required. Editted tapes of all events are now available for the past 8 years. An interactive computer system for the analysis of records is being delivered soon.

An unsuccessful search was made of Berkley records ($\Delta = 112^{o}$) for the 10-tonne shot fired by BMR in the Bass Strait in December 1973.

Staff contacted; B.A. Bolt, W.K. Cloud, W.C. Marion, T. McEvilly.

Precision Instruments, Palo Alto

A visit was made to the manufacturers of the PI 5100 series ½ inch tape recorders, of which BMR has 6. These tape recorders are now out of production and spares are no longer made by Precision Instruments. However, the company was trying to transfer the manufacture of spares to a sub-contractor but the long term prospects did not look good. US Geological Survey were manufacturing spares for their PI recorders.

2.3 American Geophysical Union 55th Annual Meeting, Washington, 8-12 April 1974

The annual meeting of the AGU attracted about 2000 delegates and a wide range of geophysical topics was discussed in concurrent sessions. Papers (10 minutes each) were presented covering a number of different aspects of investigations of the Earth's crust and upper mantle and abstracts of these papers are presented in the April 1974 edition of EOS, published by The American Geophysical Union. The author presented a paper entitled "Moho structures in continental Australia from the Trans-Australian Seismic Survey".

No attempt is made here to describe the technical detail in the 91 sessions attended by the author. Only an impression of some aspects of crustal and upper mantle structure investigations will be given. The majority of the papers were, naturally, based on investigations conducted in North America. Much of the motivation for these investigations was derived from the quest for earthquake prediction techniques and the need for investigating potential geothermal energy sources.

The level of activity in North American geophysical institutions on all aspects of problems with direct application to crustal investigations both on land and at sea, is probably the highest anywhere in the world. Many investigations were undertaken in areas of the world other than North America. There was a far greater emphasis on detailed interpretation of data than has been apparent from much of the survey work conducted in Australia. This emphasis, in time, produced a greater enquiry into the theoretical aspects of the geophysical processes and the mathematical methods required for interpretations. Many of the interpretation techniques encountered at the US Geological Survey in Menlo Park were evident at the AGU meeting.

Very few North American seismic crustal surveys described at the Meeting required the detonation of special seismic shots. Most used either earthquakes, quarry blasts, or nuclear explosions as their sources. These "opportunity" surveys were therefore comparatively cheap to organize. Other seismic sources encountered for land surveys were vibroseis techniques, the possible use of railway locomotives as large vibroseis sources, and air guns used in lakes for investigating shallow structures. The single largest set of explosion seismic data presented at the Meeting was contributed by French geoscientists who described a detailed long-range seismic profile of more than 1000 seismograms recorded on 60 profiles across France from Brest to Toulon through the Massif Central. They also described a 450-km marine seismic survey between Madeira and the Canary Islands.

It was evident at the Meeting that emphasis was being placed on the employment of many different geophysical techniques to the same area under investigation. Thus over the period of a few years explosion seismic, surface wave, earthquake, gravity, magnetic, heat flow, and magnetotelluric investigation techniques may be applied to establish a more precise picture of crustal structures.

The overall impression from the Meeting was that crustal structures are undoubtedly more complicated than the plain layered models commonly used, and that the interpretation techniques applied to particular problems in BMR must be improved in order to investigate possible alternative structural pictures.

2.4 Lamont-Doherty Geological Observatory, Palisades, NY; 15 April

The seismology and marine groups at the Observatory were visited.

The main purpose in contacting the marine group was to obtain cruise data from the Papua New Guinea region to use in conjunction with BMR marine data on the interpretation of east Papuan crustal structure. Data from the Vema 24 and Conrad 10 cruises were inspected, and discussions held on the most convenient way of getting this to BMR. Action was taken on this matter on return to Canberra but no response was received from the Lamont-Doherty Observatory.

The main interests in the seismology group were in earthquake prediction, strong motion studies, the use of high-gain long-period seismographs, and micro-earthquake studies both land-based and marine. Many aspects of their work and associated instrumentation were discussed. One aspect of particular relevance to Australia was the idea of intra-plate earthquakes being associated with the continuation of marine fracture zones onto continents. The Adelaide Geosyncline was regarded as an example of this.

The observatory was heavily engaged in earthquake prediction studies using changes in the ratio of the velocities of P and S waves. Micro-earthquake studies were also being made in Pakistan and USSR in association with the construction of large dams. The author attended two lectures on these subjects, one by P. Molnar on a 6-months study conducted at the Garm Centre for Earthquake Prediction, USSR (Tien Shan Mountains) and another by I.N. Gupta on Premonitory Seismic Wave Phenomena before earthquakes in Nevada.

The seismology group laboratories were building tape recording instruments similar to those designed by K. Muirhead of the Australian National University, to replace smoked drum recorders and other tape recorders currently being used. Ocean bottom seismographs were also being used. In common with other Laboratories inspected in USA they had a special purpose interactive computer system with analogue to digital conversion for the processing of seismic records.

Staff contacted; J. Ewing, W. Ludwig, L. Sykes, D. Simpson, M. Shaw, D. Klaus, Y. Aggarwal, W. Lawrie.

3. CANADA

3.1 Toronto Area, 17 - 19 April 1974

Department of Physics, University of Toronto

The Department undertakes many types of small-scale geophysical surveys as part of its graduate and post-graduate training. Interpretation of tectonic structures involving seismic, gravity, and magnetic methods are emphasized. Current surveys were being conducted at the western end of Lake Superior on the Canadian Shield boundary and proposed surveys include work in the St Lawrence graben zone.

The Department had the only laboratory where the author saw portable digital equipment being built for explosion seismic work. The system was designed by G. West. 12 units were being built each weighing 20 lb and fitting into a rucksack frame. Three seismic channels and a time code were recorded digitally and WWV radio time signal recorded directly. Tape cassette recorders were used and these could be programmed to switch on for varying lengths of time (4-40 minutes) at a total of 16 times in an 8-days period. The system endurance was 8 days. The computer compatability of the data enabled processing directly on the university computer system.

The staff had in use a number of seismic interpretation programs developed by R. Wiggins. These included routines for inversion of time-distance data and the computation of synthetic seismograms.

Staff contacted, G.D. Garland, J. Wright.

Department of Geophysics, University of Western Ontario, London

The Department undertakes seismological investigation as part of its teaching and research interests and has its own observatory type instruments. It was in the process of setting up a 70-km triangular array around London and telemetered into the office. Discussions were held on interpretation methods which might be applied to crustal investigations. Professor Mereu has developed a seismic ray tracing program which uses velocity-depth functions of the type $v = ax^b$ and also gives an indication of amplitudes. Unfortunately neither the version of this program he had at London nor the one he left at Australia National University were operating smoothly. In explosion seismic work he was of the opinion that lateral refractions and reflections play a large part in determining the appearance of the seismic wave train and this would certainly apply in the BMR East Papua Crustal Survey. He indicated that deconvolution of the seismic record section with the source wave train was not helpful unless the data were first-class.

Staff contacted; R.F. Mereu.

3.2 Earth Physics Branch, Department of Mines, Energy and Resources, Ottawa, 22-24 April, 1974

The Branch undertakes a wide range of regional geophysical investigation with a far greater staff than their equivalent sections in BMR. There is considerable expertise within the Branch in the fields of earthquake and explosion seismic, gravity, and magnetic methods of crustal study.

Investigations discussed included the British Columbia crustal investigation, calibration of the Yellowknife seismic array, Sverdup Basin seismic surveys in the Arctic, the Grenville Front seismic survey and future plans for investigation in the St Lawrence graben zones. Some of these investigations stem from seismicity studies or teleseismic investigations. The Arctic crustal investigations were being done in conjunction with oil exploration surveys and were usually conducted during the winter by shooting and recording on sea ice.

Deep seismic reflection work had been done in British Columbia using explosive sources in lakes, with expanded recording spreads over a 30-km base line, and by using commercial Vibroseis methods at $3000 per mile. The results obtained were good in both cases with reflections at 10.8 s being prominent.

Calibration of the Yellowknife seismic array had involved shooting several closely spaced profiles. Low-velocity zones in the crust were identified on some of these profiles and not on others, leading to the conclusion that lateral inhomogeneities must exist.

Surface wave dispersion studies were being undertaken using 3 sets of digital tape recording equipment. Baselines were about 50 to 100 km and data sampling was every second. The clock was automatically locked to WWV.

Explosion seismic recording was generally on FM tape recorders with 3 seismic components, 1 clock component, and a radio time signal component. The recording systems were compatible with their earthquake recording system and data processing could be conducted on two special purpose PDP-11/40 computer systems. Miniaturization of the equipment was at the design stage with goals similar to those of BMR. Consideration was also being given to adopting the Toronto digital recording system for explosion work.

Interpretation methods used included the use of synthetic seismogram methods implemented by K. Fuchs when he worked in the Branch. Other methods to improve the interpretation of both the kinematic and dynamic characteristics of seismic records were being tried. In particular, models for teleseismic events were being investigated which enabled structural interpretation near the source and under the recording station.

An interesting method of tapping the expertise available in university and commercial departments was the use of 4 post-doctoral fellowships permanently assigned to the Branch with periods of tenure of up to 2 years.

Gravity and magnetic methods of interpreting crustal structure were also being applied within the Branch. These interpretations were concurrent with the regional gravity survey operations, and regional aeromagnetic coverage of the country which was being done for the second time. Gravity interpretation areas discussed included the Sverdup Basin and British Columbia. Geomagnetic observations and interpretations discussed included iso-magnetic map production, first-order regional magnetic station network, and regional anomaly interpretation in British Columbia and the Arctic.

Staff contacted; M.J. Berry, J.A. Mair, D. Forsyth, A. Green, R.A. Gill, L. Sobezak, R.A. Stacey, E.Dawson, G.V. Haines.

4. UK

4.1 Edinburgh Area, 25 April - 1 May

Global Seismology Unit, Institute of Geological Sciences (IGS)

The Unit is the main section of IGS conducting both earthquake and explosion seismological studies. It runs the World Wide Standard Seismic (WWSS) station at Eskdalemuir and the LOWNET 7 station seismic network round Edinburgh; the routine earthquake data gathered by the installations are passed to the International Seismological Centre.

The Unit also conducts crustal and upper mantle surveys and plays quite a large part in initiating these studies as co-operative projects with universities and other government departments. Current projects include the Lithospheric Seismic Program in Britain (LISPB), development of efficient explosive seismic sources at sea, and the recording of both land and marine shots around the Scottish coastline.

Many of these projects are the result of a Review of Research in the Geological Sciences report sponsored by the National Environment Research Council (NERC Publications Series B, No. 7, Sept. 1973). Reports and recommendations were submitted by eleven NERC geological sciences working parties; the reports of immediate interest to the author were those on Data Processing in Geology and Geophysics, Geophysics (Pure and Applied), Geotectonics and Crustal Studies, and Marine Geology and Geophysics.

Two projects of immediate interest to BMR were the recording of microearthquakes by an IGS seismic network set up round Rabaul, PNG, and the analysis of results from the detonation of 10-tonne seismic shots at sea off Scotland. These shots were used as a model for a similar BMR shot in the Bass Strait. The reduction of the Rabaul records is proceeding very slowly and no analysis of data has been undertaken. The 10-tonne shots were not well detected at the WWSS stations as was originally hoped, but good recordings were made on high-gain tape recording stations in USA and Canada after data processing. It was unlikely that further similar shots would be used for deep mantle interpretation in the immediate future.

An alternative method of shooting at sea was being developed which involved detonating an array of dispersed small charges rather than a single large charge. This technique had been tested in pilot surveys and was going to be implemented on the LISPB survey using Royal Navy depth charges.

The Unit was also engaged in the development of seismic tape recording systems for both permanent installations and field use. This development has been conducted in conjunction with Racal-Thermionic Ltd, an instrumental tape recorder manufacturer. A Mark 1 version of their seven station seismic telemetry system (LOWNET) has been permanently installed in the southern lowlands of Scotland, the central recording station being located at Blackford Hill Observatory in Edinburgh. In routine operation, the tape is changed once per day; the data tape is then played back into an analogue to digital converter and into the Unit's PDP/15 special purpose seismic computer where an earthquake discrimination routine detects and locates events within the network and determines the direction of teleseismic events. The tapes can also be played back through an analogue system, with filter networks, transcription units, and a paper recorder so that a library of tapes and visual records can be assembled.

The Mark 2 version of this equipment (GEOSTORE) has been designed for field work and various recording options are available including telemetry links and land wire links over long or short distances with either seven or 14 channels. GEOSTORE equipment is in commercial production and would be suitable for most of BMR's needs for crustal investigations. The National Environment Research Council (NERC) has purchased a "pool" of ten sets of the equipment for use by either government or university geoscientists in the UK. Various components of it were inspected at the Eskdalemuir Observatory approx. 90 miles south of Edinburgh. The LOWNET system was also inspected at Blackford Hill and Blackhill in the Ochill Hills.

Staff contacted; P.L. Willmore, C.W.A. Browitt, A.W.B. Jacob, D.J. Houliston, C. Fyfe.

Marine Geophysics Unit, Institute of Geological Sciences (IGC)

This Unit of IGS basically investigates the offshore sedimentary section using seismic, gravity, magnetic, coring, and sonar methods. It does not attempt to interpret the whole crustal column nor does it conduct systematic coverage of the continental shelf but rather concentrates on particular areas of economic importance. Eventually it is hoped that the shelf will be surveyed at 5-km line spacing.

Staff contacted; R. McQuillan

Department of Geophysics, University of Edinburgh

A courtesy visit was made to this embrionic department which had no active seismic program. It is located in the same building as the IGS Global Seismology Unit.

Staff contacted; K.M. Creer.

Geophysics Department, British Antarctic Survey (BAS)

This department, in which the author formerly was employed, is located within the Physics Department of the University of Edinburgh. Discussions were held on the basic geophysical observatory program undertaken by BAS. It was interesting to observe the comparatively small departments such as this were equipped with PDP-11 computers for data processing rather than being tied to large computing centres such as the Scottish Regional Computer Centre which is located in Edinburgh.

Staff contacted; J. Farman, M. Sevwright.

4.2 Newcastle/Durham Area, 2 - 7 May

Department of Physics, University of Newcastle-upon-Tyne

Unfortunately all the staff engaged in seismic research were either unavailable or overseas despite prior arrangements to meet them. No useful discussions were held.

Department of Geological Sciences, University of Durham

The Department was engaged in a variety of earthquake and explosion seismic investigations both on land and at sea. Many of the research staff were engaged in projects sponsored by NERC and very often used equipment and ships in co-operation with other universities and government departments.

A seismic processing laboratory had been built up which could handle a number of different seismic tape recording systems (1 inch, ½ inch, and ¼ inch). The department had developed its own long-endurance ¼ inch tape recording system using frequency modulation centred on 80 Hz and a recording speed of 0.05 ips. 6 channels could be recorded and this was being expanded to take 10 channels. The power consumption of the system was about 1 watt. Facilities were available on playback for analogue-to-digital conversion and signal processing on a special purpose Marconi computer.

The research staff were engaged on a number of seismicity studies which included operating a seismic network in the East African Rift system of Kenya, seismic recording in northern England and damsite investigations in Ethiopia and Iran. The department was also cooperating in the LISPB survey and planned to install stations in northern England.

The main interest in explosion seismology seemed to be in the marine environment. Areas under investigation included the Carribean, the area between the Faroe Islands and Shetland Island, the Rockall Bank, and the North Sea between Shetland and Norway (in conjunction with the Norwegian Navy). These areas for investigation were obviously selected for their potential economic importance.

The interpretation methods did not differ greatly from those available in BMR. In marine interpretation, magnetic and gravity interpretations were linked to the seismic work.

Staff contacted; M.H.P. Bott, B. Long, G. Westbrook, C. Bounton, P. Forth, P. Smith, R. Arnold. P. Swinborne.

4.3 Birmingham

Department of Geology and Geophysics, University of Birmingham, 8 May

The Department has a considerable interest in explosion seismology and was currently heavily engaged on the organisation of the LISPB survey. The land recording was being done in co-operation with British, West German, and French universities. The department was also arranging the land shots for the survey in old water-filled quarries or mine shafts.

Discussions were held with D. Bamford and R. King on survey design and data processing. Bamford had done considerable work in Karlsruhe, W. Germany on time-term analysis and was writing a book on the subject in conjunction with P. Willmore. A considerable amount of data is required before a time-term analysis gives a good overall picture. The trend seemed to be away from this approach towards detailed analysis of closely spaced recording stations along profiles. In the LISPB survey all recordings would be on tape, and seismic record sections would be produced as the first step in the interpretation rather than looking at individual records and trying to pick arrivals.

Computer programs were available for using Fuch's synthetic seismogram programs and Wiggins inversion and sythetic seismogram programs.

Other topics discussed included seismicity studies in the Scotia Arc (South Atlantic), W. German refraction work, East African Rift seismic work, and Russian interpretions of seismic data.

Staff contacted; D.H. Griffiths, R.F. King, D. Bamford, R. Adie.

4.4 Southern England, 9-17 May

Department of Geology, University of Oxford

The purpose of the visit to Oxford was to look at the heat flow work being conducted by J. Cull who was on a Commonwealth Post-Graduate Scholarship from BMR. Progress had been made towards the development of a quick and easy method of measuring rock heat conductivities in the field. The miniature probes developed were also small enough to be cemented into small rock samples suitable for placing in high pressure anvils. The technique developed showed promising results; the high pressure work was conducted at the Department of Geology, University of Edinburgh.

Staff contacted; J.P. Cull, M.H. Worthington.

Seismology Division, Department of Defence, Blacknest

This Division is interested in all seismic aspects of nuclear bomb test detection and its main work is concerned with the operation of four seismic arrays (Scotland, Canada, India, and Australia) and the theoretical studies associated with the character of teleseismic events.

Discussions were held on the possibility of the Australian and India arrays having picked up the BMR Bass Strait 10-tonne shot. The opinion was that the low Q values in the upper mantle under eastern Australia would attenuate the signal and make detection difficult. The author requested processed records from the Australia and Indian arrays for examination.

The Division has undertaken a number of seismic ray tracing investigations with various types of source models but generally these are applied at teleseismic distances and the crustal structure at source and recorder are treated as end effects. One computer program which takes into account source and receiver crustal structure in

met in Ottawa) but is not generally available yet.
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teleseismic models has been developed by A.C. Green (author met in Ottawa) but is not generally available yet.

The new Willmore Mk 3 seismometer was inspected and the opinion of the staff was sought. The Division was putting forward proposals for some small modifications to make the period adjusting springs more rugged.

The seismic array processing equipment was inspected and was generally regarded by the staff as becoming out of date. However it still performs very well even though it is about 10 years old. The suggestion was also made that the Australian Government take over the Australian Warramunga array and upgrade it similar to the Canadian Yellow Knife array.

Staff contacted; H.I.S. Thirlaway, A. Douglas, R. Pearce.

<u>Ocean Bottom Seismometer Group, Institute of Geological Sciences (IGS), Blacknest</u>

IGS have a Group working at Blacknest on ocean bottom seismographs because of the availability of technical expertise in the Department of Defence establishment. The instruments have so far been successfully used at two locations on the mid-Atlantic Ridge.

The instrument package consists of a 28-inch sphere (1¼" inches thick) containing a 6-channel FM tape recorder (10½ inch reels, 0.75 ips, FM centre frequency 130 Hz, 0-20 Hz band width, 40 db dynamic range). The system has an endurance of 7 days and the all-up weight of the whole system is ½ tonne. Outputs from three seismometers, a hydrophone, and a time clock are recorded. The instrument package floats to the surface when the time clock fires an explosive bolt to detach the sinker.

This ocean bottom seismometer is a great improvement on that developed by the National Institute of Oceanography which only had a hydrophone detector, did not sit on the bottom and had an endurance of only 6-7 hours (mainly for shallow explosion seismic work).

Staff contacted; T.J.E. Francis.

Racal - Thermionic Ltd, Hythe

This company in conjunction with (IGS) had developed a seismic tape recording system (GEOSTORE) suitable for both permanent installation and field work. The central tape recorder can either be used as a 14-track recorder with tape run in one direction or as a 7-track recorder with tape run through twice automatically. The endurance of the system is 680 hours (4 weeks) and operates with a power consumption of 1.5 watts.

The data recorded on the various tape tracks can be easily changed to suite particular survey requirements. An internal crystal clock time-code is usually recorded on one channel and an external radio time signal on another. The remaining channels can be used for seismic recordings. The seismic stations can either be hard-wired into the recorder for distances up to 10 km, or UHF telemetry links can be used for distances up to 100 km. In both cases the seismic signal is frequency modulated and the centre frequency is 676 Hz. Batteries can be supplied for the seismic amplifier and modulater which will last for approximately 2 years. The amplifier and modulater are located in waterproof cases next to the seismometer. The recorder is run off a 12v car battery with 85 Ah being required to achieve the 680 hours tape endurance. A test box is available for setting up the recording system.

Fully compatible reproducer and transcription units are available for replay of the tapes and the production of library tapes. Recommended filter network and jet pen paper recorders can be supplied but these can be varied to fit individual requirements.

The seismic amplifer and modulator have been designed to use the Willmore Mk 3 seismometer. The Geostore system frequency response is linear in the range .005 to 10 Hz at the slowest recording speed (15/640 ips) and the upper frequency limit increases to about 70 Hz at the highest recording speed (15/160 ips). The sensitivity of the overall system to ground response will depend on the seismometer used.

Discussions were held with the Racal-Thermionic staff on the equipment, and complete operating systems were inspected at the Electronic Industries Exhibition in Olympia Stadium, London.

Staff contacted; E.A. Read.

Fenning Environmental Products, Luton

This small company manufactures the University of Durham seismic tape recording system. However production of the systems was at its initial stage and no definite time scale could be determined for delivery of equipment; no definite prices could be quoted. A playback system had not been finally designed at the time of the visit. The author got the impression that the company would have difficulty fulfilling an order in Australia in the forseeable future.

Staff contacted; P. Fenning.

Department of Geodesy and Geophysics, University of Cambridge

At the time of the visit the Department was heavily engaged in marine geophysical investigations using Royal Research Vessels and many of the senior personnel were at sea. Discussions centred around work being conducted in the Cyprus area of the eastern Mediterranean with particular reference to structures associated with Cyprus ophiolite rocks both offshore and onshore. Discussions were also held on the use of synthetic seismograms and in particular the use of Fuchs computer programs which had been implemented in the Department.

Staff contacted; Sir E. Bullard, M. Purdy, M. Fowler, B. Kennett.

5. COMMENTS

It is difficult to be specific about all the benefits to BMR obtained from the author's overseas visit. However an attempt has been made below to outline the areas where trends in overseas crustal investigations, in particular explosion seismic investigations, can be of benefit to BMR's methods of undertaking and interpreting tectonic structures.

5.1 Crustal seismic survey motivation and design

Many overseas crustal seismic investigations seem to be linked with areas of potential economic importance and are regarded as part of the investigation of the overall tectonic framework of these economically important areas. Examples of this are investigations of geothermal energy sources in USA, continental shelf structures in the North Sea and north Atlantic, graben structures with oil potential in the St. Lawrence area, geosynclinal structures in the Arctic, and earthquake prediction studies in USA. However, in addition, many investigations were undertaken to improve knowledge of basic large-scale geological structures and there was no definite link between pure and applied research. In the countries visited there seemed to be much closer cooperation and interplay between university and government departments, with a freer flow of staff between them, which enabled expertise to be brought to bear on particular problems more easily than in Australia.

The emphasis in the design of surveys was towards shooting along profiles with short recording-station intervals (less than 5 km). These profiles were often contained within one tectonic province. This survey procedure required more recording stations but fewer shots and consequently a much shorter field season. Seismic survey work was very often done in conjunction with gravity and magnetic survey work, and this enabled interpretations to be conducted concurrently in the same area.

5.2 Crustal seismic survey equipment and operations

Many of the institutions visited were designing and building their own seismic tape recording equipment with the same sort of design specifications required by BMR. They were doing this mainly because of the lack of interest by commercial manufacturers in this type of equipment.

However the low-powered telemetry equipment now being manufactured by Racal-Thermionic seems to satisfy many of the needs of BMR seismologists and it is recommended that future equipment requirements be met by purchasing the Geostore system rather than engaging BMR design and development staff in needless competition with commercial expertise.

Considerable savings in expenditure can be achieved by capitalizing on Geostore recording equipment for crustal surveys. In a design study conducted on a proposed survey in Central Australia, Mathur (1974a, b) estimated field man-effort costs at $112 000, explosive costs at $62 000 and operational expenses at $232 000 making a total in these items of $406 000 for a 5-months field season. By putting into the field 40 remote recording stations instead of 20 suggested by Mathur, the number of shots could be reduced by half and the time taken on the survey effectively halved, i.e. field costs would be $203 000. The additional recording capacity could be achieved by buying 4 Geostore recorders, each with 5 telemetry satellite stations, plus a Geostore reproducer, the total cost of which is $126 000. Thus the cost of the equipment is capitalized over less than one field season with an additional saving of $77 000. Proportional savings would be made on other similar surveys.

Another equipment and operations proposal is the trial of the Vibroseis method of obtaining vertical deep seismic soundings. However, research would have to be done to see if this commercial system is available in Australia. The benefits of using the system are that it is a method which is used widely and the data processing can be done by commercial companies.

5.3 Crustal seismic survey data reduction and interpretation

This is one area where BMR should implement many of the techniques which have been tried overseas for many years.

Nearly all the seismic processing laboratories visited had immediate access to their own special-purpose data processing computers for processing seismic recordings from recording tapes to the record section production and interpretation stages. PDP-11 computers seemed to be the most common and many had extensive peripheral equipment such as disc packs, tape drives, interactive screens, etc. This equipment was being acquired despite the availability of large general computing bureau facilities since it was found more convenient and economical to have smaller systems independent of outside control.

It was also evident that specialist professional staff were engaged fulltime on developing, running, and operating the seismic recording systems right from the field recording equipment to the computer processed output. These were generally electronic engineers who did not usually engage in geophysical interpretation.

In the field of interpretation techniques, quite a few computer techniques have been evolved overseas which should be implemented by BMR. The kinematic characteristics of seismic records can be interpreted using a number of least-squares optimisation techniques and by inversion of seismic time-distance data. Contacts have been obtained overseas for both these programs. The dynamic character of seismic records can be modelled using a number of synthetic seismogram programs being used overseas. In particular those developed by Fuchs in W. Germany and Wiggins and Helmberger in Canada/USA seem to be widely used and contacts have been made overseas to enable the introduction of the programs into BMR.

A few comments should be made on the methods used overseas for introducing technical innovations into government departments. In all government geophysical laboratories visited there seemed to be schemes where-by it was attractive for academic or post-doctoral staff to work on interpretational or other problems without taking permanent government staff positions. For example, Earth Physics Branch in Ottawa had 4 post-doctoral fellowships available at any one time (see 3.2). These fellowships were regarded as invaluable for enabling technical innovation at an advanced level and were used by academic staff on sabatical leave and newly-graduated PhD students as positions in which to gain experience. Such schemes exist in Australia in CSIRO and the Department of Urban and Regional Development, and the author believes BMR would benefit by encouraging such a development.

6. RECOMMENDATIONS

The following recommendations are made for future BMR crustal structure investigations on the basis of the experience gained by the author while overseas. The recommendations are not in any order of priority.

1. BMR should initiate moves to obtain copies of computer programs developed overseas for modelling both the kinematic and dynamic properties of seismic waves. These programs should be converted to the CSIRO Cyber 76 computing system.

2. BMR should pursue the development of in-house systems for digitizing seismic tape recordings from crustal investigations and develop the capability for storing the data on library tapes. These tapes should be the basis for plotting seismic record sections and for time series analysis of the seismic signals.

3. BMR should implement a policy of making BMR self-sufficient in many aspects of computing work through the use of more mini-computers, and extend the computing expertise available to handle computing problems at all levels.

4. BMR should implement a scheme for awarding prestigious post-doctoral fellowships for work to be conducted in BMR by acknowledged experts for periods ranging from 6 months to two years. It is suggested that approximately six such fellowships could be current in BMR in any one year.

5. BMR should pursue a long-term systematic approach to crustal investigations in continental Australia, and thus improve our knowledge beyond the reconnaissance level. Such investigations should be largely based on detailed seismic work, but should also include other geophysical disciplines and thus present a unified approach to interpretations.

6. BMR should procure the Racal-Thermionic GEOSTORE seismic recording and replay system to provide it with the capability to achieve the maximum data return from expensive shooting operations. This commercially available system would obviate the necessity of pursuing further lengthy design and development programs in BMR.

7. BMR should investigate the possibility of using the Vibroseis method of obtaining deep vertical reflections.

7. REFERENCES

MATHUR, S.P., 1974a - A proposal for a deep seismic sounding and associated gravity survey in central Australia. *Bur. Miner. Resour. Aust. Rec.* 1974/69.

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