BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD

Limited Distribution

Record 1981/54

Report on a visit to USA and Canada,
July/August 1981

by

D. Denham

Limited Distribution

Record 1981/54

Report on a visit to USA and Canada,
July/August 1981

by

D. Denham

Contents

Summary

From 16 July through 10 August 1981 I visited geophysical institutions at Menlo Park, California; Cornell University, New York; Lamont-Doherty Observatory, New York; California Institute of Technology, Pasadena; and the Earth Physics Branch of the Canadian Department of Energy, Mines and Resources at Ottawa. I also attended the 21st Assembly of the International Association of Seismology and Physics of the Earth's Interior, where a paper on the stress field in the Australian continent was presented; and represented Australia on the Governing Council of the International Seismological Centre.

During these visits I was able to obtain computer programs for analysing earthquake source mechanisms; discuss co-operative projects with workers in other institutions; and compare the geophysical programs carried out in the US and Canada, with those undertaken in Australia by BMR.

The US programs appeared to be too lavish in terms of money and manpower for them to be realistically compared with the Australian situation. However, Canada is of similar size, wealth and population to Australia, so comparisons are valuable.

In fields of geophysics that are directly comparable to BMR programs, the Earth Physics Branch of the Energy, Mines and Resources Department spends about ten times as much, and employs about 4 times as many people as does BMR. I believe that BMR should: (1) take steps to try and improve our capabilities in large earth geophysics - perhaps not necessarily to the levels reached by the Canadians, but certainly in that direction; (2) purchase more word processors that are accessible to scientists as well as typists; (3) look at the possibility of purchasing a colour jet plotter or equivalent; (4) take the lead in developing an Australian deep seismic reflection program; (5) publish the deep seismic reflection results obtained to date in an international journal; and (6) publish values of seismic moment for Australian earthquakes wherever possible.

INTRODUCTION

The purpose of this oversea visit was to attend the meetings of the International Association of Seismology and Physics of the Earth's Interior and the Governing Council of the International Seismological Centre at London, Ontario, Canada; and to visit geoscience institutes at Ottawa, Canada, Ithaca (NY), Lamont-Doherty, Palisades (NY), California Institute of Technology, Pasadena, and USGS (Menlo Park, California).

The following is an account of my impressions and observations. It is not intended to be a comprehensive account, because time and space preclude such an effort. However, it is hoped that this Record will provide some important ideas which can be profitably applied to BMR for the benefit of Australia.

The account that follows is in chronological order, and the six recommendations are listed in the Conclusions.

Menlo Park - California (16-17 July)

A wide variety of earth science activities are carried out at the Menlo Park offices of the US Geological Survey. During my two-day stay I visited only the Office of Earthquake Studies, where most of the programs being undertaken are under the auspices of the Earthquake Hazards Reduction Act of 1977.

Under this Act the responsibilities of the Geological Survey are to:

Conduct research on the nature of earthquakes, earthquake prediction, hazards evaluation and delineation, and induced seismicity.

Evaluate, with the advice of the National Earthquake Prediction Council, earthquake predictions.

Prepare national seismic risk maps.

Provide data and information on earthquake occurrences and hazards.

The USGS earthquake hazards program is divided into four major elements as follows:

Earthquake Hazard and Risk Assessment - to identify the earthquake hazard potential on a national and regional basis and to evaluate the risk due to this hazard.

Earthquake Prediction - to forecast the time, place, and magnitude of damaging earthquakes.

Global Seismology - to conduct fundamental studies of seismological phenomena and to provide a sound data base for studies in observational seismology and public earthquake information services.

Induced Seismicity - to prevent and mitigate the effects of earthquakes induced by the activities of man.

At present, the level of funding for the USGS Earthquake Program runs at about US$32 million per year.

During my stay at Menlo Park, the second joint meeting of the US-Japan Conferences on Natural Resources Panel on Earthquake Prediction Technology was taking place. I was invited to attend the panel meetings, and while the papers presented gave a good account of the state of the art of earthquake prediction studies in Japan and the US, my attendance limited the time I was able to spend discussing, in-depth, specific research programs with officers at Menlo Park.

In California, the main thrust of the earthquake prediction program concentrates on the San Andreas Fault System. Many techniques are being used to attempt to forecast earthquake occurrences, but the well-tried methods of examining crustal deformation by geodetic observation and seismicity-pattern fluctuations by studying earthquake occurrences are proving to be the most rewarding.

The famous Palmdale Bulge in Southern California has come back into favour, and data from both VLBI (using quasars), and more conventional laser geodetic techniques are now giving consistent results. The accuracy of the laser distance measuring techniques is now about 1 part in 10^6 and atmospheric effects are the limiting factors. For the most accurate measurements, aeroplanes and helicopters are used to measure temperatures and humidities along the lines of sight.

Changes in seismicity patterns in both space and time have now provided an improved understanding of the behaviour of the San Andreas Fault System. When these results are combined with the geodetic data it is possible to identify the faults which are creeping, and those which are locked and likely to be associated with large, potentially damaging earthquakes. On this basis it appears that the 1857 fault trace in Southern California is not likely to be reactivated until about the year 2000, and that the aseismic gap between the 1857 and 1906 fault traces should not be associated with a large earthquake because it appears to be actively creeping.

My discussions at Menlo Park outside the Earthquake Prediction Technology Panel meetings were mainly with the following people:

Barry Raleigh. He is shortly to move to Lamont to take up the position of Director there. At Menlo Park he has been in charge of the earthquake prediction program and has been involved with *in-situ* stress measurements close to the San Andreas Fault. His position at Menlo Park will be filled by Jim Deiterich.

Thomas Hanks. He has been studying the character of high-frequency strong ground motion, and found that accelerograms can be used to determine stress drops for at least moderate-to-large earthquakes. He uses the relation

$$a_{rms} = 0.85 \frac{(2\pi)^2}{106} \frac{\Delta\sigma}{R} \frac{f\,max}{f_o}$$

where a_{rms} is the root-mean-square acceleration over the faulting duration, $\Delta\sigma$ the stress drop in bars, the density, R the distance in kilometres, $f\,max$ the highest frequency passed by the accelerograph, and f_o the spectral corner frequency. This result should be applied to the Meckering and Dalton/Gunning accelerograms.

Jerry Eaton. Jerry Eaton is in charge of the network operations. The main California seismograph network comprises some 350 stations telemetered into Menlo Park and about 250 stations telemetered into Caltech. He estimates the coverage is complete down to ML ~1.5, and they are aiming for a coverage of ML 1. If an earthquake takes place within the network it can automatically be treated by the on-line computer, but if it occurs outside the network or close to the edge, the computer has to be manually driven.

Data are transmitted in real time using FM techniques, and are recorded on magnetic tape recorders and develocorders. Fifteen develocorders with 18 stations on each provide the main analysis medium. In addition 12 key stations are monitored on helicorders so that when a large earthquake takes place its approximate location can be determined rapidly.

HYPO-71 is used for routine hypocentral locations with HYPO-ELLIPSE being used for special studies. M_D is used to determine quick ML magnitudes but the results show considerable scatter. As would be expected, the costs of operating the network are large. In 1980, $4.25 million was spent to operate the networks - this includes support functions, routine analysis and some research. However, the average cost per station to get the data into the office is a modest $3500 per station. I was surprised to learn that there are no plans at present to change to digital recording and processing, and many seismologists in the US outside Menlo Park regard the present recording and analysis procedures there as rather antiquated.

Jack Healey. Jack Healey, who aims to be the complete 'synergist', is in charge of the explosion seismology program at Menlo Park. The objective is to study the crustal structure around the San Andreas Fault to help in earthquake prediction studies. However, his group seems easily distracted to nuclear waste disposal problems and the study of the crust in Saudi Arabia.

The instruments are standard FM recorders, very similar in design to those at BMR. They have 100 of them, paid for by Saudi Arabia. They are controlled by a clock but they can operate for a maximum time of only 13 minutes. 2 Hz Mark Products Seismometers (which they find to be more robust than the 1Hz variety) are used as detectors and power is provided by dry cells and solar panels. The complete station (including seismometer) fits into a box smaller than 0.02 m^3 and the total power is 1 watt per station. 20 sets are neatly stacked in each of 5 trucks of similar size to a combi-van and off they go - one technician per truck. They have no plans to go digital and are firmly of the opinion that since explosives are the greatest cost in explosion seismology, one should have as many recorders as possible.

Walter Mooney. Most of the interpretation programs are done by Walter Mooney. He has developed - with George McMechan - a technique for producing synthetic seismograms for laterally varying structures and has promised to send a tape of the program to BMR. Most of his work in recent months has been involved with the interpretation of the Saudi Arabian work.

Word Processors. Throughout Menlo Park - and in fact North America in general, Word Processors are extremely commonplace. At the USGS it seemed that in the equivalent of every Section at BMR a word processor is available to secretarial and professional staff. Access is not restricted to specialised personnel and they are not hidden away in hard-to-find rooms. The general system seems to be for the stenographer to type up the first draft and then hand over to the author.

The flexibility and power of word processors has also advanced in recent years, and some will check the spelling and grammatical construction of the manuscript. I am convinced that a more widespread use of word processors in BMR would significantly enhance the efficiency of the organisation.

IASPEI - London, Ontario (19-30 July)

General Assemblies of the International Association of Seismology and Physics of the Earth's Interior are comparatively large conferences. About 600 delegates attend the London meeting, and over 400 papers were presented during the nine days devoted to technical sessions. It is therefore impossible to report fully, or even listen to all the papers - one tends to move from session to session trying to optimise one's time by attending the more significant presentations. I shall therefore briefly report only on those matters which I found interesting or significant in terms of major advances, and in terms of geophysical programs in Australia.

UNESCO/IASPEI Working Group on Historical Seismogram Records

Arising from meetings convened by Unesco in 1977, and held by IASPEI's Commission on Practice at Strasbourg later that year, some progress has been made - particularly by WDC-A and the US Geological Survey - in a program to copy historical seismograms. To date, the USGS has spent about $0.5 million on the project. The aim is to copy all available records (recorded before 1960) from a selection of a few well-distributed stations, and to copy selected events at all available stations. In this way valuable historical data will be preserved and be available to research workers throughout the world.

Copies would be made on microfiche with 24 records on one sheet. A master copy would be stored at Boulder, and another at the station. Present arrangements call for the cameras to be shipped from station to station, and for the host country to carry out the copying.

I sat in on the first session of this Working Group, which is chaired by Willie Lee at Menlo Park, and will endeavour to provide information on the availability, dimensions and type of records available in the Australian/SW Pacific region. At this stage no timetable has been set for the copying of records from this area. Unesco was brought into the discussions in the hope that some funds could be provided by them to assist in the project. Although USGS has bought the camea, it has funding problems in sending technicians outside the U.S. to carry out the copying.

I believe this to be a most worthy project, and after our experience in Australia where early records from both Brisbane and Adelaide have been destroyed, and where storage problems are becoming acute for currently obtained records, we should support the project, and if the camera comes to Australia examine the feasibility of copying more than those records required by the WDC-A.

Standard Earth Model (PREM)

Anderson and Dziewonski's Standard Earth Model was formally presented to the Standard Earth Model Workshop. It was derived to fit body-wave travel-times, and surface-wave and free-oscillation observations. The inversion procedures have worked very well and the fit to the data is extremely good; however, there was considerable discussion on what use the model should be put to, now that it has finally been completed. Many people felt that the sharp discontinuities in the upper mantle do not represent well the real earth, and it was also felt by some that it should not be used for earthquake locations.

The model represents several years of dedicated work by Dziewonski and Anderson, and the results are published in a 1981 issue of Physics of the Earth & Planetary Interiors.

Digital Seismometry and the Use of Digital Seismic Data

Rapid progress in digital seismometry was evidenced by the very strong symposium on digital seismometry and the use of digital seismic data. Of the 26 papers presented in this session more than half originated from the USA, and considerable resources are now being devoted in this field. There are at present several US-operated world-wide digital systems in operation. These comprise the IDA project of 17 low-frequency accelerometers (25 mHz and below), the SRO system (such as that at Narrogin in Western Australia), the 15 new WWSSN stations (such as the one at Hobart), and the RSTN system which will operate only in North America.

The RSTN or Regional Seismic Test Network is the most advanced. It will comprise six stations, of which five (at Tennesse, Albuquerque, South Dakota, New York and Red Lake) should be operating by the end of 1981. Essentially each station uses modified Geotech KS36000 seismometers down boreholes with Geotech S-750s used as back-ups. Gain ranging is used to provide an overall dynamic range of 120 dB, and three overlapping passbands of long, medium and short period data are transmitted via satellite with a 3 meter dish to a central receiving and processing centre.

Discussions with Bob Engdahl on reading the SRO tapes revealed that all the software is contained on the Day-Tapes, and really one is not supposed to read the tapes before they have been massaged in the U.S. He promised to send all the software and a data tape so that we should not have any problems in using the Narrogin records in future.

The new ANU digital tape recording seismograph was described, and it seems to be more advanced in concept than any other if one system for both earthquake and explosion seismology is required. For special earthquake studies, the Meyer system from Madison seemed very effective. It uses event detectors, digital cassettes, and, most impressively, the Omega world-wide navigation system for positioning and timing. The positioning accuracy is to $\pm$ 100 m and it may be useful in the Antarctic.

Several papers on automatic seismic analysing procedures were presented. The Lawrence Livermore and MIT Laboratories appear to be the leaders in this field, and a prototype working system has been developed at MIT.

Earthquake Prediction and Risk

This was one of the most strongly supported symposia with 47 papers being presented. In quantitative terms it appears, at first sight, that earthquake prediction techniques have advanced very little in the last ten years. People are still looking at seismicity gaps, migration of earthquake patterns before earthquakes, and deformation of the ground surface. Progress here is very slow and although the data set from workers in many countries has grown considerably, no definitive usable patterns seem to have emerged.

What has been realized however, is that the signal-to-noise levels for changes in seismic velocity, stress, or any other physical parameter are often very small, and specially designed experiments are necessary to accurately monitor crucial parameters.

Perhaps the best example is the experiment of McEvilly using Vibroseis along the San Andreas Fault. He has developed a weekly program of measuring travel-times to the Moho to a timing precision of $\pm$ 0.1 ms. The main difficulty is correcting for the effect of water table changes. However, an overall accuracy of a few parts in 10^5 for Moho reflections is now achievable. The Piñon Strain observatory in southern California, where deformations of 1 part in 10^7 are being claimed, is another example where high precision is being achieved.

In eastern Canada, the Earth Physics Branch of the DEMR have set up a network to monitor seismic velocities, electrical conductivities, tilt, and gravity. Timing accuracies of the order of 10 ms over 50 km are obtained every 6 months, and while not as precise as the Californian work they provide reliable control.

Feasibility studies should be carried out on the situation in Western Australia to see if similar parameters can be cheaply and accurately measured.

New risk maps were presented for Canada, New Zealand, and Spain, based on data accumulated in the last fifteen or so years to improve the data sets. It seems that we may be approaching the realistic limits in seismic zoning techniques because of the inhomogeniety of the earth, and earthquake distribution patterns.

One unusual method of estimating seismic hazard for the eastern United States was that used by TERA Corporation at a cost of $1.5 million. They selected ten 'experts' (who were nameless), gave them a questionnaire on zonation, seismicity and ground motion and presented the suite of answers. As the answers were all provided subjectively it seemed a good deal for TERA Corp but not for the taxpayer.

For me, the most important paper in this session was that presented by Ian Gough on oil-well break-outs and stresses in the crust. He suggested that systematically aligned elongations of many oil wells in Alberta are caused by spalling of the walls (break-outs) under strongly unequal horizontal compressions. The data were provided from routine well logs using four-arm dipmeters, and showed that the stress field (σ_1) in Alberta is consistently NE-SW.

This technique is not only valuable in determining regional stresses but should provide oil companies with valuable information on stress fields likely to be encountered in any hydrofracturing undertaken to boost production. The method should be looked at in Australia.

<u>Probing the Earth's Lithosphere by Controlled Source Seismology</u>

The IASPEI Commission for controlled source seismology held a successful series of meetings including a vigorous poster session. Results were presented from many parts of the world including the American COCORP effort and the BMR's data from the Eromanga Basin. From both Canada and Great Britain, data were presented which showed evidence of reflections associated with the base of granites. If these results can be repeated in other locations it should put very tight constraints on the formation of granites in the crust. Discussion was lively on the shingling effect at the top of the upper mantle, whether Mereu's random earth model was valid, and why BMR has not published its results from the SEG Mexico City meeting.

The shingling effect is evident on many refraction profiles in the 300-500 km range, in which subparallel sets of first arrival curves come in en-echelon. Prodehl interprets these as evidence for discrete layers (including as many as three low-velocity layers) beneath the Moho, while other authors look to heterogeneities in the upper mantle as an explanation.

Mereu proposed a model where the velocities in the crust and upper mantle are represented by a function of the form

$$v_{ij} = u_j + \Delta V_{ij}$$

where v_{ij} is a two-dimensional array of velocities used in the model, and where

$$\Delta V_{ij} = K(F_{ij} * A_{ij})$$

K is the range of velocities, j corresponds to the depth, A_{ij} is an array of random numbers, and F_{ij} a smoothing filter. In other words the velocity-depth function in the lithosphere is represented as a set of smoothed random numbers inside some specified upper and lower bounds.

John Moss's paper at the SEG meeting at Mexico City must have created quite an impression because I was bombarded with questions inquiring where the data had been published. I believe a special effort should be made to publish the BMR deep seismic reflection records in an international journal. They are probably still some of the best in the world, and should be published while they still fall into that category.

Similarly the 1980 Eromanga Basin records are superior to much of the COCORP data and should be released in an international journal as soon as possible.

Earthquake ground motions and their effects on critical structures

A joint symposium between IASPEI and the International Association of Earthquake Engineers was most successful, and 49 papers were presented during the three-day session. Although accelerographs are being installed at a seemingly ever increasing rate, there is still a need to 'catch' a really big earthquake. An International Strong Motion Array Council (ISMAC) has been formed to try and set up a full-scale array in a likely place. Some countries already have excellent networks. There are national networks of about 200 accelerographs in Italy, 40 in Taiwan, 100 in Mexico, and 60 in Turkey, so many of the most vulnerable countries are reasonably well instrumented.

There has been an increasing use of strong-motion records to study faulting processes, and the 1980 Imperial Valley earthquake was well enough recorded for displacement contours on the fault surface to be derived.

Engineers are still correlating peak ground acceleration and velocity with distances from earthquake hypocentres. However, the relations derived are more complicated than the early attempts - for example Campbell of TERA Corporation suggests:

$$PGA(g) = 0.0159 \exp (0.868 M) [R+0.0606 \exp (0.700 M)]^{-1.09}$$

where PGA is the peak ground acceleration in the nearfield (<50 km), M the moment magnitude, and R is the distance from the earthquake (km).

Boore suggested:

$$\text{Log } A = -1.23 + 0.280 M - \text{Log } R - 0.00255R + 0.27P$$

where $R = (d^2+7.3^2)^{\frac{1}{2}}$ and A is the peak horizontal acceleration in units of g, M the moment magnitude, d the closest distance to the surface projection of the fault rupture in km, and P is zero for 50 percent exceedance probability, and one for 84 percent.

Moment magnitude is becoming more commonly used. This is a worthwhile trend and should be adopted at BMR wherever possible. Furthermore, more accelerographs should be installed in Western Australia to study the southwest seismic zone.

<u>Quantification of Earthquakes</u>

The workshop on the quantification of earthquakes proved very successful, with Hiroo Kanamori giving a convincing display to support the implementation of the moment magnitude M_w. However, the East Europeans were not at all in favour of its adoption and consequently the Commission on Practice would not accept a resolution supporting its implementation. The use of seismic moment was formally adopted but is unlikely to be calculated by the Eastern Block. USGS aims to routinely compile M_o and M_w wherever possible, and I believe BMR should do the same.

Earthquake Algorithms

The symposium on earthquake algorithms considered earthquake location, focal mechanisms, source parameters and moment tensors - which are all the rage. The trick seems to be to invert the seismograms or accelerograms using the appropriate Green's function to determine the moment tensor, and hence the faulting parameters. Kanamori uses 250 s Rayleigh waves from the IDA stations, and 5 min after the tapes have been received is able to determine the fault geometry. Thus with satellite links he could easily be able to make real-time tsunami warnings.

Mechanics of Earthquake Sources

An excellent symposium on the mechanics of earthquake sources produced a wide variety of papers ranging from theoretical models, through induced seismicity, stress in the crust, and the mechanics of rock fracture, to slow earthquakes.

Slow earthquakes have been observed in Japan usually following large normal earthquakes. Their faulting velocities are in the range of km/min or km/hour rather than km/sec but they can account for a significant part of the strain release. For example, the slow earthquake associated with the Izu-Oshima earthquake had a seismic moment of about 5×10^{18} N-m, about a quarter of the main earthquake.

Unesco Working Group on earthquake prediction research areas

A three-day working group on international experimental sites for earthquake prediction was held during the Assembly. This meeting followed the UNESCO panel of experts meeting in 1979 and the International Advisory Committee on Earthquake Risk in 1980. The purpose of the London meeting was to look for possible sites for international experimental work, and to discuss preferred ways of undertaking geophysical observations. These activities would be to further earthquake prediction research by developing advanced theories of earthquake occurrence and techniques of experimental work - mainly geophysical.

The group prepared lists of suitable sites in three tectonic environments: (1) subduction zones, (2) transcurrent faults, and (3) intraplate regions.

The Meckering area of SW Australia was proposed under (3), and although rated behind the Beijing region of China, was ranked as an important site for experimental studies on earthquake prediction.

Resolutions and other Miscellania

Nineteen resolutions were passed at the final plenary session. These are contained in Appendix I. Those most affecting BMR are the ones on the Directory of World Seismograph stations, and the use of Seismic Moment.

Planning for the August 1983 Hamburg IUGG meeting is advancing well, and titles of symposia sponsored by more than one Association have been finalized and will be circulated shortly.

The 1985 IASPEI meeting will be in Japan, at a city yet to be determined.

ISC Governing Council Meeting, 31 July

Two days were set aside for the meeting of the Governing Council, but it turned out that one day was sufficient to deal with all matters on the agenda.

In previous years Council Meetings were dominated by four main issues: (1) the legal status of the organisation, (2) where it should operate, i.e. U.K., Austria or U.S., (3) its mode of operation, i.e. within WMO, UNESCO or as an independent organisation, and (4) its financial viability.

Items 1-3 have now been settled and the ISC will continue - at least for the foreseeable future - to operate as an independent organisation in the U.K. Thus most of the deliberations at London were centred on trying to make ISC a more effective and financially sound organisation.

ISC's annual budget is about 200 000 pounds sterling, which is maintained by subscriptions from 42 member countries, 16 companies (Associate Members), and sales of publications.

The main decisions at the Council Meeting were as follows:

1. To purchase an RM80/TS11 based VAX-11/750 computer system with a 124 M Byte disc. The total cost will be about 90 000 pounds sterling, and is necessary because of the steep increases in charges at the Rutherford Laboratory, Reading University.
2. A free-field telegraphic format has been devised by ISC. This is currently being tested by NEIS and if found to be satisfactory it will be adopted, and an appropriate fixed-field format will be derived.
3. It was agreed that earthquakes unsupported by phase data should not be listed in the Bulletin but should be included in the Regional Catalogue. Canada removes all earthquakes with a magnitude smaller than three before transmitting hypocentres to ISC but only ISC knew of this.
4. To save money the computing assistant will not be replaced but the junior seismologist will be.
5. Dr M. Berry will replace Dr O. Dahlman on the Executive of the ISC.
6. The level of unit subscriptions will be as follows.

Calendar year	US$
1982	1 050
1983	1 150
1984	1 250

7. The next meeting of the Council will be in Hamburg in August 1983.

Department of Geological Sciences, Cornell University, 3 August

The Department of Geological Sciences at Cornell University is the operating agency for the COCORP project. The team is led by Professors Jack Oliver, Sid Kaufman and Larry Brown, and contains 18 other workers. Twelve of these 18 are M.Sc. and Ph.D. students and the other six are post-doctorate students. They are either geophysicists, geologists or physicists, and no-one is working on the software or processing aspects of the COCORP operation.

Since 1975 when COCORP started they have recorded deep reflections from over 20 sites in the USA and have covered over 3000 km of profiles. Most of the important results to-date relate to the upper crust, where it is possible to make some sort of correlation between the reflections and the geology.

I was surprised that no-one in the group was carrying out research on the processing side of the operation. They tend to use the MEGASEIS standard computer packages which are treated essentially as black boxes. They also do not seem to have effective quality control over the field operations in that the signal-to-noise ratios down the record are not monitored and they do not know how far down the record the seismic signals persist.

I suspect that the main problem is that they are geared into a $3.3 million per annum field program which involves a commercial contractor, and that to stop too much and experiment would jeopardise the km/month output.

From what I saw it seemed to me that the BMR's deep seismic reflection effort is more effective than theirs - probably because we use explosives and have a more flexible field operating procedure.

The big drawback with the BMR operation at present is its lack of processing capability.

While at Cornell I also visited the earthquake seismology group headed by Bryan Isacks - they have a field program in the New Hebrides to study the regional tectonics, and also earthquake precursors; and the theoretical geophysics group headed by Don Turcotte, which is looking at rheological behaviour of the lithosphere.

Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, 5 August

The Earth Physics Branch (EPB) carries out equivalent functions to the Geomagnetism, Seismology and Regional Geophysics Section at BMR. However, the program undertaken by the EPB is much larger than that carried out by BMR. They appear to be adequately staffed, and do not have problems with funding - once the program has been approved. Programming is tightly controlled and essentially mission oriented. The objective of the branch is:

'To ensure the availability of geophysical information concerning the configuration, structure, evolution and dynamical processes of the solid earth and the hazards associated with natural and induced geophysical phenomena, with special reference to the Canadian landmass'.

To fulfil this objective, the Branch, which is organised in three scientific divisions and one administrative division, conducts geophysical studies of the crust and interior of the earth under five Sub-Activities: the Seismological, Geothermal, Geomagnetic, Gravity, and Geodynamics Services of Canada. Each Sub-Activity has its own Objective and set of Sub-Sub-Activities, each with its own objectives.

Thus for Sub-Activity : Seismology, we have as an objective 'To operate the Canadian National Seismograph Networks to accepted international standards; to operate a national data centre for analogue and digital seismic records and data; to operate the requisite data-processing facilities; to detect, locate and report all significant Canadian earthquakes; to provide a national information service on Canadian seismicity and Canadian earthquakes including strong motion information; to conduct theoretical and field studies into earthquake processes both on- and off-shore and on earthquake precursory phenomena; to conduct research on the methodology of seismic risk assessment and seismotectonics, to complete new seismic risk maps of Canada in 1981, and to revise these maps as appropriate as significant new information comes from siesmotectonic studies of various regions of the country; to delineate the structure and physical properties of key geological structures of fundamental significance both on- and off-shore; to operate seismological facilities appropriate for identification of underground nuclear explosions, and to provide advice on this as required.

As a Sub-Sub-Activity : Monitoring of Seismic Ground Motion, with its objective : To ensure the availability of Canadian seismological ground motion data and information'.

An approximate comparison between the EPB and the BMR's Seismology, Geomagnetism and Regional Geophysics Section is shown below.

EPB (Ottawa)	BMR (Canberra)

Seismology Division 50 officers

- Monitor seismic ground motion
- Maintain and disseminate seismological data
- Study Earth dynamics
- Study structure of the Earth
- Geoscience of nuclear explosions

(The budget for seismology is about C$3 million, 18 standard stations and 22 regional stations plus 52 accelerographs at 44 sites are operated).

Geomagnetism Division 40 officers

- Operate magnetic observatories
- Carry out magnetic surveys
- Operate and maintain geomagnetic data base
- Geomagnetic Studies of Earth structure (including palaeomagnetism)
- Geomagnetic disturbances

(13 magnetic observatories are operated at a cost of about C$35,000 each per year).

Gravity Division 32 officers

- Gravity mapping
- Gravity standards and gravity data base
- Gravity studies of Earth structure

Geothermal Division 7 officers

- Geothermal energy resource studies
- Geothermal studies of Canadian landmass
- Permafrost studies

Geodynamics Division 15 officers

- Generation and management of geodynamic data including recent crustal movement, earth tides and polar motion.

Total Ottawa staff 145
Staff at British Columbia 24

Total budget C$10 million from government plus C$2 million from energy and geothermal contracts.

Geomagnetism and Seismology 16 officers

- Operate geomagnetic observatories
- Carry out magnetic surveys
- Maintain and disseminate seismological magnetic data
- Monitor seismic ground motion
- Investigate detection of nuclear explosions

(Operates 4 magnetic and 19 seismograph observatories - total budget is $A0.5 million).

Regional Gravity 5 officers

- Gravity mapping
- Gravity standards and gravity data base
- Gravity studies of Earth structure
- Recent crustal movements
- Antarctic regional geophysics.

Regional Geophysics 10 officers

- Study Earth structure by explosion seismology and magnetotelluric studies.
- Carry out palaeomagnetic studies
- Geothermal studies of Australian landmass and energy resources.

Total Canberra staff 32
Staff at Mundaring & Darwin 7

Total budget $A1 million - solely from government sources.

The $2 million program from energy and geothermal contacts is spent on surveys for safe nuclear waste repositories and on geothermal energy programs.

Comparative statistics between Australia and Canada are shown below.

	Population (millions)	GNP (1979) (millions of dollars	Surface area km^2
Australia	15	130 000	8×10^6
Canada	25	230 000	10×10^6

The seismic coverage in Canada is complete down to magnitude 3, and in the eastern states where the detecting capacility is enhanced it is down to magnitude 2. A 16-station telemetry array is operating in eastern Canada with plans to increase the number of stations to 24. All data are transmitted in real time analogue format (for a phone bill of ~$100 000 for 1981). The data are converted to digital form of 60 samples per second and processed by two PDP 11 computers. Selected stations are recorded on helicorders, but there is also an event detection algorithm whereby all the network data are recorded on a 5-minute ring buffer and preserved if one station is triggered. On average about 120 triggerings a day are processed. A day file lists all the triggerings of interest and the traces are plotted on the computer for picking.

The present system is very reliable with a down time of about 0.4 percent. The dynamic range is about 100 db with a 1-bit sensitivity of 10 nm/s on all stations. It is a very impressive system.

They have 4-5 people analysing the seismograms and two engineers responsible for the hardware side of the operation.

In the Geomagnetic Division, the 13 permanent magnetic stations have all been converted to digital format with fluxgates and protons. These are based on the AMOS Mark III, in which each component is sampled at 1-second intervals and running means are derived in the microprocessors.

Absolute measurements of D, I and F are made twice a week with a fluxgate magnetometer on a theodolite, and a proton magnetometer. Local contractors are trained to do this work. It costs about C$5000 per year and takes about 15 minutes per set.

Magnetic tapes are mailed from the stations every month and some stations have dial-up facilities for output checks.

The secular change program operates so that every station (36) is visited every 4 years and 4 key stations are occupied every 2 years.

Reports on an independent inquiry into the Canadian geomagnetic facilities and various other operational material were collected and are deposited with the Observatory group.

The gravity section carries out a similar program to that undertaken by BMR except they have still a large area of the country not yet covered by regional observations. A new map of the Canadian field will be produced in 1981 and it is based on the format of the BMR's 1:5 million Gravity Map.

The Canadians have, over the years, developed a large program to reduce gravity observations and obtain 'best values' at key stations. Recently they have analysed the Italian and Latin American networks and will be prepared to reduce the recent Australian data.

The Canadians are using automated computer techniques to plot geophysical parameters. Examples produced on an Applicon colour jet plotter were displayed. I recommend that BMR acquire a comparable facility.

The Canadian program on large-earth geophysics is very impressive, particularly in the geomagnetic and earthquake seismology fields. It appears to be well designed at an appropriate level to meet the Canadian requirements and makes our efforts in these fields appear piecemeal and inadequate.

Lamont-Doherty Geological Observatory, 6-7 August

I gave my talk on the stress regime in the Australian crust at the Lamont-Doherty seminar series, and visited several research groups at the Observatory. Gary Karner is making good progress on his study of basin development and lithospheric flexure, and I was able to discuss his present and future work programs.

There is a strong group on earthquake prediction which includes Bill McCann and Claus Jacob. They are studying seismic gaps in active subduction zones, and also intra-plate earthquake activity in New York State. The total budget for seismology is about $2 million per year.

In New York State some 30 seismographs are telemetered into Lamont, and the system used to record and analyse the data is very similar to that at Ottawa, with a line analogue signal being fed into a PDP11 computer for data massage and pre-analysis rearrangement.

I discussed with Larry Birdeck the problems of obtaining seismic source mechanisms, and I learned that Charles Langston had already looked at the 1968 Meckering earthquake but had not published the results.

California Institute of Technology, 10 August

My visit to Caltech was primarily to discuss the problems we have been having with the body-wave synthetic programs written at Lamont by either Kanamori or Helmberger. This was sorted out with Kanamori, and it was proposed that we co-operate with one of his research students, Terry Wallace, to do the detailed modelling.

Caltech operates one of the most advanced siesmograph networks in the world. About 160 stations are telemetered in to the Laboratory in real-time analogue mode. 21 monitors display key stations on a conventional pen and ink format for rapid analysis of large earthquakes. The routine analysis is carried out using computer interaction with a system that displays the seismograms on a VDU so that the phases can be picked automatically with a cursor. They locate about 15,000 earthquakes a year, and coverage is complete in southern California down to about magnitude 2.5 ML.

CONCLUSIONS AND RECOMMENDATIONS

In attempting to pick out a few significant factors resulting from my visit I recommend the following:

(1) BMR should work towards the adoption and implementation of an improved national program in geomagnetism and seismology designed to meet Australian requirements.

(2) Because of the significant new geological information that can be gained from deep seismic sounding, as witnessed by the results of CO-CORP, BMR should take the lead in developing an Australian DSS facility.

(3) To enable BMR to provide better and faster products it should purchase more word processors, and these should be available to the scientists as well as the typists.

(4) BMR should investigate the possibilities of purchasing an Applicon-type colour jet plotter to improve our display capabilities for geophysical parameters.

(5) BMR should publish the deep seismic reflection results that have been obtained so far, in an international journal.

(6) BMR should publish values of seismic moment for Australian earthquakes whenever possible.

APPENDIX I
RESOLUTIONS OF THE INTERNATIONAL ASSOCIATION OF SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

(1) Recognising the valuable services rendered over the past five years by the EUROPEAN-MEDITERRANEAN SEISMOLOGICAL CENTRE (E.M.S.C.) in Strasbourg to the scientific community and the general public in the form of a rapid epicentre determination of strong earthquakes, the regular dissemination of epicentral data, the cataloging of earthquakes and the transmission of European earthquake data to seismological world data centres,

Noting that the demand for such services, in particular the rapid information for civil protection authorities and news media, will increase in importance during the years to come,

Being aware of the imminent danger that these services will have to be terminated at the end of 1981 due to financial difficulties,

Urges all national and international organisations concerned to provide the necessary support for assuring the continuation of the E.M.S.C. services beyond 1981.

(2) Noting the valuable past contributions of UNESCO, UNEP and UNDRO towards the development of multidisciplinary studies of earthquake prediction and its social implications,

Recognising the need for the world seismological community to develop a code of practice on the formulation, assessment and communication of earthquake predictions, especially when the crossing of international boundaries is involved,

Recommends that ICSU be invited to encourage these United Nations Agencies to address this need in implementing their work programmes related to seismology and the mitigation of earthquake risk.

(3) Noting that the International Seismological Centre (ISC) and International Seismological Summary (ISS) data archives for the years prior to 1971 are not in forms that can be readily utilised by the scientific community,

Recognising the importance of the data sources and the possibility of their irrevocable loss,

Recommends that fixed format ISC Bulletin and Catalogue data tapes be prepared from Bulletin and Catalogue image tapes for the period 1964-70, and that fixed format ISS data tapes be prepared from ISS card image tapes for the period 1918-42.

(4) Recognising the importance of the work of the regional compilers of the Directory of World Seismograph Stations in preparing comprehensive information on the location, operation and instrumentation of, and availability of records and data from the world seismograph stations past and present,

Urges national seismological agencies and observatories to co-operate with this effort when contacted by the regional compilers.

(5) Recognising the continuing need to make available more readings of amplitude and period of seismic waves,

Recommends that the international agencies extend their existing formats in such a way as to permit the acceptance of measurements of amplitude and period, as adopted at the Canberra Assembly in 1979.

(6) Noting that rapid publication by seismological observatories around the world of basic observations such as arrival times and maximum amplitudes of seismic waves recorded from earthquakes is essential in providing basic data for seismological research,

Urges that continuing national and international support be given to observatories in preparing and publishing their station bulletins.

(7) Recognising the need to extend the magnitude scale to large earthquakes,

Recommends that wherever possible seismic moment be estimated and that institutions include this value in earthquake catalogues.

(8) Recognising the value of the Homogeneous Magnitude System developed for the Eurasian continent,

Recommends that consideration be given to development of comparable Homogeneous Magnitude Systems for the North American, South American and Australasian regions.

(9) Considering that accelerograms provide invaluable data for near field studies in seismology,

Recognising that these data are of limited use without absolute timing and a knowledge of the crustal structure and details of the source geometry,

Urges that absolute time be recorded with ground motion and that regional and site characteristics be determined for strong motion sites,

Further, urges that when a significant number of strong motion records are obtained in an earthquake, field investigations be made to endeavour to determine the location and geometry of the source.

(10) Considering the detailed processing which is necessary for strong motion data,

Recognising the variety of new procedures being developed,

Resolves to investigate the possibility of active co-operation with the International Association of Earthquake Engineering and other concerned organisations for the purpose of setting standards for data processing techniques,

Further, urges that, pending the development of such standards, the raw data, together with the unprocessed digitised data where possible, be preserved and made available for distribution.

(11) Considering the lack of data obtained from the near field of large earthquakes,

Urges that every attempt be made to obtain near field data, for example by installing strong motion instruments in recognised seismic gaps or in regions of predicted earthquakes, and by moving portable arrays of strong motion stations into the epicentral region as soon as possible following a major earthquake.

(12) Noting that the UNDP-Japan joint project, established in 1963 by the International Institute of Seismology and Earthquake Engineering (IISEE), Tokyo, and operated from 1972 by the Japanese Government, contributed much to the training of seismologists and earthquake engineers in the developing countries, especially with the help of UNESCO experts before 1972.

Recommends that the IISEE endeavour to resume its former practice of inviting professors from abroad, seeking national or international funds to achieve this.

(13) Recognising the importance of retaining old seismograms, bulletins, unpublished readings, clock correction and calibration records and other seismological information,

Noting the danger that these data may be lost due to lack of space or facilities, or for other reasons,

Encourages all stations and institutes to take appropriate measures to improve storage conditions in order to preserve these invaluable data, if necessary seeking financial and technical help from national or international sources.

(14) Recognising the usefulness of regional seminars which have been devoted to specific seismological topics, such as that held by CERESIS/OAS on microzonation in Lima in November, 1978, and that held by the IISEE on engineering seismology in Japan in April 1980,

Noting that these seminars have particular value for scientists from developing countries,

Resolves to encourage national and international bodies to organise similar regional seminars and symposia in and/or for the developing countries.

(15) Noting the continuing development of new digital seismograph stations by many countries,

Urges that directories of digital recording stations be updated at least annually, and that these directories be made available in computer accessible format.

(16) Noting the variety of data formats currently in use for digital data,

Recommends that the global digital seismograph network day tape format be adopted as the initial standard for international data exchange, and that data sets in this format be made available for arbitrary (user defined) event time windows,

Further, recommends that one or more demonstration data tapes be developed to help users.

(17) Recognising that digital waveform analysis is a detailed procedure,

Urges that software for simple types of analysis be made available to seismologists who are relatively inexperienced in digital seismometry.

(18) Recommends that digital seismograms in an internationally accepted format be included in the International Data Exchange data sets.

(19) Considering the success of the 1981 Assembly,

Recognising that much work and time were involved in preparation,

Expresses its thanks to the University of Western Ontario, the Department of Geophysics and the local organising committee for the fine facilities which were made available and for all the preparation which contributed to an excellent Assembly.

APPENDIX II

ITINERARY FOR DR D. DENHAM

Depart Canberra Arrive Sydney	5:10 p.m. 5:45 p.m.	Wednesday 15 July Wednesday 15 July	TAA TN 426
Depart Sydney Arrive San Francisco	8:05 p.m. 6:20 p.m.	Wednesday 15 July Wednesday 15 July	Qantas QF 3
Depart San Francisco Arrive Toronto	8:30 a.m. 4:00 p.m.	Saturday 18 July Saturday 18 July	American Airlines AA 44
Depart Toronto Arrive London (Ontario)	5:10 p.m. 5:45 p.m.	Saturday 18 July Saturday 18 July	Great Lakes Air GX 815
Depart London (Ontario) Arrive Toronto	8:05 a.m. 8:35 a.m.	Sunday 2 August Sunday 2 August	Great Lakes Air GX 806
Depart Toronto Arrive Buffalo	12:32 p.m. 1:05 p.m.	Sunday 2 August Sunday 2 August	Allegheny Airlines AL 479
Depart Buffalo Arrive Syracuse	2:20 p.m. 2:55 p.m.	Sunday 2 August Sunday 2 August	Allegheny Airlines AL 294
Depart Ithaca Arrive New York (LGA)	7:45 a.m. 8:30 a.m.	Tuesday 4 August Tuesday 4 August	Allegheny Airlines AL 418
Depart New York (LGA) Arrive Toronto	9:05 a.m. 10:32 a.m.	Tuesday 4 August Tuesday 4 August	American Airlines AA 245
Depart Toronto Arrive Ottawa	11:05 a.m. 11:54 p.m.	Tuesday 4 August Tuesday 4 August	Air Canada AC 448
Depart Ottawa Arrive Toronto	8:50 a.m. 9:43 a.m.	Thursday 6 August Thursday 6 August	Air Canada AC 543
Depart Toronto Arrive New York (LGA)	11:10 a.m. 12:23 p.m.	Thursday 6 August Thursday 6 August	Air Canada AC 190
Depart New York (JFK) Arrive Los Angeles	12;00 p.m. 2:25 p.m.	Sunday 9 August Sunday 9 August	United Airlines UA 5
Depart Los Angeles Arrive Sydney	10:30 p.m. 9:05 a.m.	Monday 10 August Wednesday 12 August	Pan American PA 815
Depart Sydney Arrive Canberra	11:35 a.m. 12:15 p.m.	Wednesday 12 August Wednesday 12 August	TAA TN 449