BMR Report 275

Australian Geoscience 1985

AGC

Department of Resources & Energy

BUREAU OF MINERAL RESOURCES, GEOLOGY & GEOPHYSICS

REPORT 275

Australian Geoscience 1985

Annual Report of the Australian Geoscience Council Inc. The Council of Earth Science Societies in Australia

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AGC

ABBREVIATIONS

ADAB	Australian Development Assistance Bureau
AMDEL	Australian Mineral Development Laboratories
AMIRA	Australian Mineral Industries Research Association
AMSTAC	Australian Marine Sciences and Technologies Advisory Committee
ASTEC	Australian Science and Technology Council
BMR	Bureau of Mineral Resources, Geology and Geophysics
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTEC	Commonwealth Tertiary Education Commission
FASTS	Federation of Australian Scientific and Technological Societies
IGCP	International Geological Correlation Program
NERDDC	National Energy Research, Development and Demonstration Committee
NERDDP	National Energy Research, Development and Demonstration Program

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PRESIDENT'S REPORT

By the time this report is published the Australian Geoscience Council will have reached its fifth birthday and it's time to stand back and frankly assess the success (or otherwise) of its activities.

Let's hear the good news first. I believe the Council has achieved its goal of providing a forum in which the major geoscientitic societies and organisations, together representing over 6000 professional members of the geoscientific community, can exchange views on the many problems facing professional geoscientists in Australia today. My evidence for this belief is the wide and active membership of the Council which now has nine full-member societies and eleven associate and three observer organisations which represent all geoscientific disciplines including geology, geophysics, geochemistry, palaeontology, soil science, physical geography, geomechanics, hydrogeology, geoscience information, and resource law.

The most visible Council activity has been the publication of its innovative Annual Reports for 1982, 1983, 1984 and now 1985 which have provided highly informative status reports of the geosciences in Australia and discussed in detail major issues affecting the geosciences nationally.

A particularly successful initiative was the commissioning of Dr Morgan Sant's Australian Geoscience Human Resources Survey which was published in two volumes—'Employment Patterns in Government and Industry' and 'The Human Resource'. The project was completed with his article 'Women and Children First? Geoscience Careers and Family Life' in the 1984 Annual Report. Viewed together these three contributions provide a unique database for a more effective understanding of the strengths and weaknesses of the massive human resources deployed to meet Australia's need for non-renewable resource exploration and development.

There is also evidence that the Commonwealth Government is now recognising that the Council provides a central source of advice on matters concerning the geosciences in Australia and, on several occasions, it has asked Council to provide names of appropriate geoscientists to act on government committees and enquiries.

These are all very positive results which would justify the faith of those geoscientists who worked so hard to see the Council established—but what about the bad news?

The worst news has been the continued depression of world demand for metals and, more recently, for petroleum. Of course neither of these problems can be blamed on the Council but there is no doubt that they have caused great instability in the resource industries which, in turn, has had drastic effects on the well being of the geoscience professions. The major concern is the uncertainty for the future of our resource industries—is the present situation just another one of the many dips in the cycle we have all experienced in the past or is it the beginning of a new phase in which the importance of metals and fuels are to be relegated to a relatively minor role in our economy in the future? Unless the economists get answers to these questions 'quick smart' our industry will continue to wallow in its slough of despondency and uncertainty.

There have been other problems which have directly affected Council activities and one example was the nearly zero response from politicians and media and conservationist representatives to the symposium *Radioactive waste management: a geoscientific assessment* which was held in November 1983 in co-operation with the Australian Academy of Science. It was a well organised and very well presented symposium on a topic which, if you believe the media, relates to a burning public issue which is badly in need of informed comment and ongoing responsible dialogue. Despite some 300 letters sent personally to the public opinion makers on this issue, the 117 attendees were nearly all geoscientists concerned in one way or another with the uranium mining industry and our attempt to make a significant public contribution to this important issue largely failed.

It is too early yet to make a judgement on the latest Council initiative—the symposium on 'Tertiary Geoscience Education in Australia' held in Sydney on 29 November 1985. Certainly the record of the proceedings has stirred up a massive interest in the way forward for tertiary geoscience education but little consensus on the path to be chosen. Provided we do not allow the issues identified to insulate our educators from their clients (i.e. the non-renewable resource industries), the results of the workshop should now be used to develop an appropriate and effective strategy for the future development of national geoscience education policies. To achieve this we will need the leaders in our profession to raise themselves above petty concerns of self-interest and preservation of entrenched organisational structures which are no longer tenable options to take a broad view of innovative new structures and options. Just a little sensitivity and understanding should go a long way to ensure that any changes proposed would have a relatively insignificant effect on legitimate career expectations of individuals concerned in such changes. Whatever eventuates must be significantly better for the geoscience professions than would have occurred if we, the members of the geoscience professions, had simply left it to others to impose solutions on us.

In completing my term as your President I would like to pay a high tribute to all those members of Council and its Executive who participated so willingly and effectively in Council activities. It would be impossible to record all those who made major contributions to the work of Council but I would like to make a special point of thanking Dr C. D. Branch, our Immediate Past President, who has provided me with massive personal support.

The Australian Geoscience Council is now established as the national voice of the geoscience professions in Australia. May it continue its vigorous development for the benefit of both the geosciences and our nation.

J. F. Lovering
President

SECRETARY'S REPORT

The Council and the Executive

The Council elected a new seven member Executive at the Annual meeting held in Canberra on 31 May 1985. The Secretary-elect, Dr R. W. Young, was unable to take up the position and was replaced by Dr D. B. Waghorn. Executive meetings were held on 16 August 1985 (Melbourne), 10 October 1985 (Canberra) and 14 March 1986 (Melbourne).

Meetings of the full Council were held in Canberra on 31 May and 11 October 1985.

Associate Professor John Roberts was re-appointed as Editor for the Council's Annual Report. During the year the Executive Member, Mr R. J. Henderson, was appointed Publicity Officer. This important role has resulted in a more effective dissemination of information on Council activities and a better public image for geoscience.

The member societies continued to contribute financial support to assist with the running expenses of the Council. Significant contributions were also made by the employers of Council and Executive Members by way of time, travel expenses and services. The CSIRO assisted the Council greatly by providing continued use of the CSIRO Conference Centre in Limestone Avenue, Canberra, and Dr A. F. Reid, Director of the CSIRO Institute of Energy and Earth Resources, is especially thanked for arranging the use of this facility. During the year the Geological Society of Australia allowed the Council use of their secretariat in Sydney as a permanent mail drop.

It is obvious that Council could not have functioned throughout the year without the assistance from the above sources. This generous support is acknowledged gratefully.

Membership

The membership list reads as follows:

Members

Association of Exploration Geochemists (AEG)
Australasian Institute of Mining and Metallurgy (AusIMM)
Australian Geomechanics Society (AGS)
Australian Institute of Geoscientists (AIG)
Australian Society of Exploration Geophysicists (ASEG)
Australian Society of Soil Science Inc. (ASSS)
Geological Society of Australia Inc. (GSA)
Institute of Australian Geographers (IAG)
Petroleum Exploration Society of Australia (PESA)

Associate Members

Australian Council of Chairman of Earth Science Departments (ACCESD)
Australian Geoscience Information Association (AGIA)
Australian Mineral Foundation Inc. (AMF)
Australian Mining and Petroleum Law Association Ltd. (AMPLA)
Bureau of Mineral Resources, Geology and Geophysics (BMR)
CSIRO
Consortium for Ocean Geosciences (COGS)
Government Geologists' Conference (GGC)
*International Association of Hydrogeologists
Soil Conservation Service of N.S.W.
Statistical Society of Australia

Observers

Australian Academy of Science
Australian Academy of Technological Sciences
*Australian Mineral Industries Research Association

Activities

Membership of the Council continued to grow with the addition of one associate member and one observer. During the year invitations to be associated with Council were issued to the Australian Marine Science and Technology Council, Australian Marine Sciences and Technologies Advisory Committee and the Australian Quaternary Association. All three associations declined although each expressed a strong desire to maintain a close association with Council.

The principal ongoing activity of the Council is the production of the Annual Report entitled 'Australian Geoscience 1985'. The content of this year's report has changed. The *Status of the Geosciences in Australia* will now be published every three years. During intervening years this review will be replaced by a topic or topics of importance to Australian geoscience. This year's topic—Teritary Geoscience Education—is based on a Council organised workshop held in Sydney in November 1985 (see below).

The Annual Report is published by the Bureau of Mineral Resources as part of its report series. This is a significant contribution towards Council as the principal cost of the Report is met by the Bureau and wide circulation is achieved through their distribution lists. The Bureau and the Federal Minister responsible are thanked for their generous support. Editorial control and circulation remain, however, with the Council and its constituent organisations.

Council realised an important function and constitutional objective when it made a submission to the Australian Science and Technology Council's review of public investment in research and development in Australia. The submission prepared by the Executive included comment from representatives of member organisations and reflected the Council's broad-ranging interests which include research funding, the geoscience workforce and tertiary geoscience education. Preparation is currently underway for a submission towards the next stage of the ASTEC review, that of higher education research funding.

A highlight of the continuing commitment by the Council to Geoscience Education occurred through a one day workshop on 'Tertiary Geoscience Education in Australia' held on 29 November in Sydney. There were over eighty delegates and representatives from industry, universities, colleges of advanced education and government who put forward views—some controversial and conflicting—for the reorganisation and rationalisation of geoscience education in Australia.

An important outcome was the suggestion for the introduction of a small number of key centres to cater both for particular teaching and research requirements and the often-specialised needs of industry.

The formation late last year of the Federation of Australian Scientific and Technological Societies (FASTS) fulfilled an important function in the structure and representation of earth science organisations throughout Australia. The 56 societies which comprise the founding members of FASTS constitute a diverse range of interests and represent almost 60 000 scientists and technologists throughout Australia.

The Council played an important role in the formation of the Federation. The Past President, Dr. C. D. Branch, represented the geoscience sector on the interim committee and much of the structure and constitution of the Federation was based on that of the Council. The initial high profile of the geoscience sector will be maintained as the Past President was elected as Secretary to the Federation for its first term.

*Admitted in 1985

Many geoscience organisations elected to seek representation on FASTS through the Council, and Council will play a key role in presenting the interests of the geoscience community in this important body. In particular the Council will be able to contribute towards the annual review of the federal science and technology budget allocations, a duty requested of the Federation in conjunction with the Academy of Science, the Academy of Technological Sciences and the Institution of Engineers, by the Department of Science.

Other matters of concern considered by Council and Executive during the year included the low level of support from Government in funding the Ocean Drilling Program, the declining international support for the IGCP and the lack of geoscience representation on the recently formed Australian Water Research Advisory Council. The Council participated in planning a proposal for renewed co-operation and exchange with the USSR in earth sciences and continued to seek support for regular geoscience employment surveys of the mining and petroleum industries.

David B. Waghorn
Secretary

TREASURER'S REPORT

The 1985 financial year (calendar year) is described in this report. The finances of the Council have changed marginally during the year as a result of the Bureau of Mineral Resources publishing the Australian Geoscience report. As in previous years, the Council is greatly indebted to the continuing financial support provided by the State Geological Surveys and by the subscriptions from member societies. The final cash balance of $7089 represents the first instance since inauguration that funds have accumulated sufficiently for Council to plan its activities and budget for the year ahead. Transfer of accumulated funds amounting to $1288, surplus to the requirements of producing the two-volume report of the manpower survey, has contributed to the cash balance on hand.

The Council continues to operate on a very frugal budget with member delegates meeting all their own expenses associated with travel and accommodation when attending Council or Executive meetings. Expenditure of Council funds during 1985 has been restricted to meeting the cost of $867 to print an additional 1000 copies of the 1984 Report and $128 to obtain microfiche copies of the two-volume manpower survey report[1] for distribution to meet a continuing demand for these publications. Other costs associated with lobbying politicians and senior public service and industry executives have been minimal and primarily borne by the Council delegates attending these occasions. A very successful one-day workshop at the University of New South Wales was organised by Professor J. Roberts and Dr R. E. Wass on 29 November 1985. The workshop was wholly financed from registration fees paid by delegates. A submission arising from this workshop and a separate submission from Council to ASTEC on Commonwealth-funded research in Australia represent significant efforts made by member delegates on Council and constitute examples of the important functions now performed by the Australian Geoscience Council.

Thus far these functions have been achieved with little or no cost to the Council. Nevertheless the heightened activity of Council in the sphere of influencing research and training in the geosciences in Australia must be expected to place increasing strain on the Council's financial resources. Furthermore, the inauguration of the Federation of Scientific and Technological Societies (FASTS) is now adding to the level of financial commitment faced by Council, particularly with the request by member societies for Council to corporately represent geoscientists on the Board of the Federation. This bold new initiative in forming a Federation, actually modelled on the objectives and constitution of our own Council, is vital for the health and vigour of Australian scientific and technology endeavour into the next century. Therefore, I commend the initiatives taken by the Australian Geoscience Council during 1985 and I thank all member societies and associated organisations for their generous financial and moral support during the 1985 financial year. Auditors for the Council are Price Waterhouse, Chartered Accountants, and appreciation is expressed for the services given free-of-charge by their Canberra Office.

Financial Statement

Receipts		$
Subscriptions		1300
Donations		2000
Balance of Manpower Fund		1228
Bank Interest		421
		4949
Expenses		$
Meetings		75
Annual Report 1984		867
Miscellaneous		131
		1073
Balance brought forward	(31.12.84)	$3213
Cash balance	(31.12.84)	$7089

Gordon J. Burch
Treasurer

STATUS OF GEOLOGICAL SURVEYS, AMF, BMR, AND CSIRO

Information contained in this section of the report summarises the main geoscientific activities carried out in major Government organisations and one non-profit servicing organisation during 1984. It is not intended to replace reports issued by each of the institutions. Council gratefully acknowledges the information supplied by each organisation.

Australian Mineral Foundation

The Australian Mineral Foundation has just passed through the most testing period in its history. The volatile nature of the mineral and petroleum industry continues to make course

[1] Microfiche edition of the two volumes of the Human Resources Survey is available for $5.00 from the Geological Society of Australia, Challis House, 10 Martin Place, Sydney, NSW 2000.

programming difficult. The first half of 1985 was very difficult financially, due mainly to the effect of the Australian dollar/US dollar relationship. (Most overseas AMF courses are contracted in US dollars.) The situation improved significantly in the second half of the year due to increased demand for petroleum courses. As anticipated in the previous report the mineral industry continued in a depressed state and this affected continuing education demand.

The development of a bookshop, heralded in the last report, has continued and at the end of December 1985 17 institutional publishers had granted us agency rights. Further additions are expected early in the New Year. Aside from Australian publications, significant overseas agencies include:

- American Association of Petroleum Geologists
- Society of Mining Engineers
- Centre for Resource Studies, Queens University
- Geological Association of Canada
- Institution of Mining and Metallurgy
- International Union of Geological Sciences
- Mining Journal Books

As at December 1985 the AESIS data base contained almost 45 000 records, with 5150 records added during 1985. Thirteen lists have now been produced against the Retrospective Project, the last in September 1985. Eleven of these lists had been released for open availability as at December 1985. More volumes in the *AESIS Special List* series were produced with List 13A *Geostatistics* being updated, and supplements issued for the *Gold* and *Petroleum* lists. A change from the commodities emphasis in the *Special Lists* was approached by producing indexes or bibliographies to theses, Bureau of Mineral Resources, Geology and Geophysics Publications, and the Western Australian and Victorian Geological Surveys' Open File Reports. Along the same lines a prototype list was produced for The Australasian Institute of Mining and Metallurgy publications. A ten-year index (1976-1985) of the Institute's publications will be produced in the *Special List* series in 1986.

Early in the year the AMF Library established connection with the Australian Bibliographic Network (ABN). This has enhanced our inter-library loan service as well as cataloguing operations.

The course, 'Middle management for the mineral industry', with its associated spouses program, (a first in mineral circles in Australia), was successfully presented by the AMF Director in March 1985 in association with The Australian Administrative Staff College. As a result of reports from the course, a paper based on the course is being presented at the CMMI Conference in Singapore in May 1986. Co-authors of the paper with Dean Crowe are Ken Davis (Staff College), and Valerie Pratt (CSR Oil & Gas Division).

Early in 1985 the Founder and Chairman of AMF, Professor Rudd, retired. In recognition of his services to AMF, he was made a life member of Council. The current Chairman and Deputy Chairman are Sir Russel Madigan and Mr Norton Jackson respectively.

Following his recognition (Robert Williamson Award) for contributions to the development of information science in Australia, Mr D. A. Tellis, AMF's Information Services Manager, was made a Fellow of the Institute of Information Sciences in London in recognition of his international standing in the field of geoscience information.

Bureau of Mineral Resources, Geology & Geophysics

BMR undertakes geoscience research into the geological framework of Australia and its territories, and petroleum and minerals resource assessment, and is the primary national source of geoscience data. BMR has a total staff of about 600 including some 250 scientific staff.

BMR's projects are now grouped into eight programs: Fossil Fuels, Minerals, Groundwater, National Geophysical Observatories, National and International maps, Overseas Operations, Petroleum and Minerals Resource Assessment, and Geoscience Databases. Many of BMR's projects are of a multidisciplinary and interdivisional nature, and there is active co-operation with State Geological Surveys, universities, other geoscience research organisations and exploration companies.

During 1985, a BMR Advisory Council was established by the Minister for Resources and Energy. The role of the Council is to advise the Minister and the Director, BMR, on BMR's research program. The inaugural Council consists of Mr B. P. Webb (Chairman), Professor K. Lambeck, Professor D. H. Green, Mr R. J. Allen, Dr J. R. Ross, Mr V. G. Swindon, Mr B. Hill, Professor R. W. R. Rutland, and Dr H. L. Davies.

The emphasis in BMR's scientific program continues to be on energy research. During 1985, BMR commenced a new program of marine research cruises using the research vessel *Rig Seismic*. Successful cruises were carried out on the southern Lord Howe Rise, the Heard-Kerguelen Plateau, the Otway Basin, and the Queensland Plateau-Western Coral Sea Region.

One of the highlights of 1985 was the discovery of 'live oil' in the Velkerri Formation of the McArthur Basin. This oil is about 1500 million years old and is probably the oldest oil show yet discovered anywhere in the world.

BMR's national geoscience database function was further developed with the calling of tenders for a new computer system. The computer is due to be installed in the first half of 1986 and will join the new seismic processing system in BMR's newly established Computer Centre. It will serve both database and specific data processing needs.

In the geophysical area, an important achievement in 1985 was the development of a pixel-map technique for displaying aeromagnetic data. This technique shows considerable improvements over the traditional contour-map presentation and enhances the interpretation of low-amplitude and regional features.

Brief reports of the Divisions follow.

Division of Geophysics

This Division carries out research within four discipline-based sections:

- Explosion Seismology
- Potential Fields
- Seismic Monitoring
- Geomagnetism

The Explosion Seismology group contributes mainly to research in BMR's Fossil Fuels program using reflection and refraction seismology. Current projects include studies of the Surat and Clarence-Moreton Basins where a traverse was completed during 1984. During 1985 approximately 500 km of seismic reflection profiling was undertaken across the Arunta Block and Amadeus Basin in central Australia. Data are currently being processed on BMR's new seismic processing system.

The Potential Fields group carries out aeromagnetic and gamma spectrometric surveys of the continent. To date about 80% of the continent has been flown at reconnaissance level. It is expected that the whole continent will be covered by 1992. A program of digitising old analogue aeromagnetic data is currently underway so that the entire database will be in digital form by 1992. A new series of 1:1 000 000 aeromagnetic pixel maps is being produced. This involves the merging of 16 standard 1:250 000 sheets into one map. This is not a trivial task as sheets were flown at different times, and have different base levels and IGRF. These maps have generated particular interest because of the large-scale features visible at this scale. Currently maps for Albany and the Riper River sheets and the Murray Basin have been developed.

The Seismic Monitoring and Geomagnetism groups form part of BMR's National Geophysical Observatory function. Seismic Monitoring records and investigates earthquake occurrences in Australia through a network of 24 seismic observatories. Studies are carried out into earthquake risk, notably in the SW Seismic zone and in the Dalton-Gunning region of NSW. A new group has been set up for the Department of Foreign Affairs to monitor nuclear explosions in the region and to set up an International Data Centre to monitor any nuclear test ban treaty that may be entered into at the Geneva disarmament talks.

The Geomagnetism group monitors the Earth's magnetic field in the Australasian region covering one-eighth of the Earth's surface. It runs five observatories on continental Australia, one on Macquarie Island and one at Mawson, Antarctica. A program of reoccupation of about 80 first-order stations occurs over a five-year cycle to measure the secular variation. These data are to be modelled into a new Australian Geomagnetic Reference Field for use in aeromagnetic surveying and in the production of magnetic charts for the region at five-yearly intervals.

Division of Petrology and Geochemistry

The Division of Petrology and Geochemistry has the primary responsibility for metallogenic research and associated 'hard-rock' geological studies within BMR. As such, it has the main carriage of the Mineral Deposits and Metallogenic Provinces sub-programs. Within the Mineral Deposits sub-program, it is carrying out research into aspects of hydrothermal gold, tin-tungsten, diamond, platinum-group element and a range of base-metal mineralisation. The Metallogenic Provinces sub-program is concentrated on the Early to Middle Proterozoic mobile belts, with specific attention to the Mount Isa province. In addition, the structural geology group within the Division is involved in a range of onshore and offshore basin studies.

Research into gold mineralisation concentrated on metamorphic hydrothermal (Leonora, WA; Starra, Qld) and high-level magmatic (Red Dome, Qld; Braidwood, NSW) styles, with emphasis on structural and hydrothermal geochemical control on mineralisation. Similar integration of geochemical and structural investigations is being applied to a range of tin-tungsten deposits and sub-provinces. Research into magmatic hydrothermal and epithermal types of mineralisation will be largely consolidated into a single province study in the Permo-Carboniferous of north Queensland from 1986.

A major collaborative study with industry and the Geological Survey of Western Australia (GSWA) on diamonds and their host rocks in northwestern Australia is nearing completion, and the results will be reported at the 4th International Kimberlite Conference in Perth in August 1986. Following the recognition of lamproites as an important diamond source, a major review of alkaline igneous activity throughout Australia has been carried out. A reconnaissance study of layered mafic/ultramafic intrusions in northwestern Australia has resulted in selection of targets (Munni Munni, Andover, Soansville sills) for detailed studies related to platinum-group element prospectivity. A major geochemical study of Archaean volcanic rocks in the Pilbara region in collaboration with GSWA has been completed, and release of the data and interpretation is imminent.

The Division organised and co-sponsored an international meeting on the 'The tectonics and geochemistry of early to middle Proterozoic fold belts' in Darwin in August 1985. Field trips to the Capricorn, Halls Creek, Pine Creek, Arunta and Mount Isa provinces were held in conjunction with the meeting. Processing of the Division's extensive geochemical and geochronological database for the Early to Middle Proterozoic is proceeding and has already provided the basis for remarkably precise correlation between provinces. The Division's main province study at Mount Isa has concentrated on structural, geochemical and geochronological research which has led to significant advances in understanding the tectonic evolution of the province from basin formation through orogenesis to late rifting. In addition, the Division will carry out intensive ground studies and image processing related to the NASA Scanner project flown south and east of Mount Isa in late 1985.

The structural geology group within the Division is involved in a number of sedimentary basin and crustal geodynamic studies in collaboration with the other research Divisions. In particular, it has been applying the concepts of extensional tectonics that have recently evolved from the Basin and Range province, USA, and the North Sea, to passive continental margins and their basins. Specific structural research is being carried out in the Amadeus and Eromanga Basins, and on the northeastern and southeastern continental margins.

Division of Continental Geology

Emphasis in the Division's research program is on fossil fuels and groundwater. These topics are pursued in co-operation with other BMR Divisions, CSIRO Divisions, State government bodies and university departments. Close links have also been established with a large number of exploration companies.

The Division's efforts in fossil fuels are two-fold—broad scale Australia-wide projects and more detailed basin analysis projects. The Australia-wide projects include a major project (supported by AMIRA) to produce a series of time-slice palaeogeographic maps and to place Australian petroleum source rocks in their palaeogeographic context. Production of some 60 maps is planned each showing the distribution of major environments through a relatively narrow time slice. The maps are based on continent-wide, biostratigraphic correlation charts which in themselves are a valuable data resource. The Cambrian maps, the first of the series, will be published shortly; the Ordovician, Permian, Triassic and Jurassic Periods are either finished or approaching completion. Study of the composition of fossil fuels within the Divisional and Baas Becking Geobiological Laboratory (BBGL) programs has been directed at unravelling the detailed geochemistry of Australian oils and organic-rich sediments. Not only has this provided further evidence of the importance of non-marine source rocks, but it has also demonstrated the importance of bacterial activity in the formation of oil-prone source rocks in terrestrial sequences. Biomarker studies of Proterozoic and Phanerozoic sediments have led to the identification of specific precursor bacteria. Associated biochemical studies of Holocene environments (by the Baas Becking Geobiological Laboratory) particularly at Shark Bay have been undertaken to show the role of major groups of organisms in hydrocarbon accumulation.

BMR has had a longstanding national role in palaeontology and has a large body of palaeobiological expertise. The role of the palaeontological group within the Division is twofold: first, it provides a biostratigraphic framework against which the evolution of selected basins can be studied, and second, it undertakes research designed to improve the resolution of the biochronological framework of Australia as a whole. Palaeoenvironmental and palaeoclimatic studies are an integral part of palaeontological research.

The major effort in basin analysis is directed at the Amadeus Basin with particular emphasis on parts of the section which are known to be or may be important petroleum source or reservoir rocks. Seismic stratigraphic studies are helping to unravel the structural, depositional and sea-level history of the Late Proterozoic and Early Palaeozoic. Detailed sedimentological studies on individual protential source rock units such as the Bitter Springs Formation (with BBGL) and the Chandler Limestone and on potential reservoir rocks such as the Mereenie, Arumbera and Pacoota Sandstones are providing a better understanding of the depositional environments. Related palaeontological studies have necessitated modifications of parts of the biostratigraphic framework of the Basin.

Two years ago BMR's longstanding research in the McArthur Basin was re-orientated towards evaluaton of the petroleum potential of this Proterozoic basin. The 'live oil' in the Velkerri Formation, which is about 1500 Ma old, is probably the oldest oil show yet discovered anywhere in the world. Detailed studies of the Velkerri oil and other potential source rock studies are now underway.

A third basin analysis project is presently underway in the Clarence-Moreton Basin. This project is at an early stage but new seismic information coupled with various other lines of evidence such as fission track dating (with Melbourne University), organic geochemistry, and detailed sedimentology should lead to major advances of our understanding of this poorly-explored basin.

The study of Cainozoic onshore basins helps in establishing environmental conditions through the development of depositional models. During the year small projects were completed in the Lake Eyre and Lake George basins. A major aspect of the study of these continental basins is in establishing the recent climatic history of the southeastern corner of the continent.

The mineral program of the Division is mainly directed towards the weathered zone. During 1985, a highlight of the remote sensing project was the support by BMR-CSIRO and industry of a combined remote sensing exercise with NASA using a C-130 aircraft and a wide range of advanced technology. A large amount of data was acquired through this experiment and will be analysed during the coming year. The related work on the regolith project had the aim of producing regolith maps at various scales. A first draft of an Australia-wide regolith map was compiled at a scale of 1:2 500 000 for publication at 1:5 000 000. Experimental maps were also produced for several 1:1 000 000 sheets.

Also included in the mineral program of the Division is the study of sedimentary minerals with emphasis on research on phosphorites and black shales. The role of oceanic anoxic events in the formation of black shales and phosphorites and the possible link between phosphogenesis and boundary events were investigated during the year. The role of the biota in the formation of phosphorites will receive more detailed consideration during 1986-87.

BMR's role in groundwater research is to study major groundwater resources in large sedimentary basins. During 1985 research was undertaken in the Amadeus, Great Artesian and Murray Basins in conjunction with the relevant State water authorities and Geological Surveys. Emphasis was placed on the Murray Basin because of major environmental problems being experienced in that basin. A 1:1 000 000 Cainozoic geology map of the basin was completed during the year and a new understanding of the geology of the basin was developed through the production of a 1:1 000 000-scale aeromagnetic pixel map by the Geophysics Division. A major hydrogeological database has also been prepared for much of the basin.

As part of its Australia-wide responsibilities, the Division produced a 1:5 000 000 computer-based hydrogeological map of the continent and further computer-based hydrogeological maps are planned for the coming year.

Division of Marine Geosciences and Petroleum Geology

This Division carries out resource-related and basic research in BMR's Fossil Fuels Program, including studies in:

- the origin and distribution in space and time of fossil fuels
- development of continental margins
- modern marine processes
- research and development of computer-based systems and marine instrumentation

The Division also carries out some reconnaissance studies of offshore metallic resources, and is involved in overseas marine geoscience programs in the southwest Pacific. Petrologists, sedimentologists and structural geologists from other Divisions are involved in these studies.

BMR's geoscience vessel *Rig Seismic* acquires new geological and geophysical data on six cruises per year over the Australian continental margin and in offshore territories. The major techniques applied are multichannel seismic reflection profiling, sampling of seismic sequences by dredging and coring, and the measurement of the flow of heat through the seabed. Other techniques used include echosounder profiling, the acquisition of sidescan sonar images, and continuous reading of the Earth's gravity and magnetic fields. The data obtained by these techniques are of direct importance to the assessment of offshore petroleum resources, as well as to the study of more basic scientific problems. The multichannel seismic data are processed at BMR's Seismic Processing Centre; geological samples are also processed at BMR.

In 1985 four topics were addressed by the first five *Rig Seismic* cruises:

- Structure, stratigraphy and petroleum potential of the Lord Howe Rise. A *Rig Seismic* cruise was complemented by two joint cruises with the West German research vessel *Sonne*.

- Structure, stratigraphy and petroleum potential of the Heard-Kerguelen Plateau.
- Structure, stratigraphy and petroleum potential of the Otway Basin, the west Tasmanian margin, and the South Tasman Rise. Both *Rig Seismic* and *Sonne* cruises were carried out.
- Structure, stratigraphy and modern geological processes of the Queensland Plateau and nearby areas (two *Rig Seismic* cruises).

All *Rig Seismic* cruises were successful in obtaining excellent geophysical data, and the last three also carried out worthwhile sampling programs. The data from the cruises are being processed and evaluated, and it is clear that they will lead to major re-evaluations of the geological framework and history, and the resource potential of the area studied. A cruise report for the Lord Howe Rise work (BMR Report 266) is available, and the seismic data package is due for release in June 1986. Reports for the other four cruises will be available in 1986.

Baas Becking Geobiological Research Laboratory

The Laboratory undertakes research into interaction between biological and geological processes that have a bearing on the genesis of ore deposits and hydrocarbon accumulations. The Laboratory is administered and staffed jointly by BMR and CSIRO.

In 1985 financial and other support for the Laboratory programs from exploration companies, acting through AMIRA, continued through its twentieth year. Research on the microbial enhancement of oil recovery also attracted substantial financial support from the NERDDP, while some of that on microbial ecology was supported by a grant from the Marine Sciences and Technology scheme.

Five years ago the Laboratory commenced a research program on Proterozoic and Cambrian petroleum (co-ordinated with projects in the Division of Continental Geology, BMR). From the beginning it was recognised that the processes and ecosystems being studied were significant not only in Cambrian and older times, but also were operative throughout the Phanerozoic, particularly in hypersaline environments. The significance of the research, therefore, is not limited to the interpretation of Proterozoic and Cambrian sequences. Concurrent with this program has been another on the Mississippi Valley type lead-zinc deposits in Devonian reefs of the Lennard Shelf, Western Australia. This has included experimental work on processes of sulphate reduction, including the possibility of bacterial reduction as part of ore deposition, as well as a wide range of petrographic, geochemical and fluid inclusion studies of the deposits and their host rocks. Research on the microbial enhancement of oil recovery draws on experience gained in both our other programs, and contributes to them, in that it is concerned with the microbiology, geochemistry and fluid mechanics of basinal fluids. All three research programs are planned for completion in 1987. All three involved extensive co-operation with industry and are supported by industry funding.

Some of the highlights of the 1985 research are:

- The discovery of an extensive sulphidic, relatively organic-rich sediment in southern Hamelin Pool. This has yet to be mapped, but seems to cover some 100 km^2.
- Elucidation of the effect of salinity and other factors on the preservation of organic matter in sediments. High salinities affect some bacterial processes, including sulphate reduction, retarding the degradation of organic matter in anaerobic environments.
- No thermal alteration haloes can be detected around the lead-zinc deposits on the Lennard Shelf, apparently indicating that there were multiple brief episodes of mineralisation. This will significantly constrain the interpretation of possible depositional mechanisms.
- Bacteria that produce surfactants under anaerobic conditions have been discovered. In laboratory experiments these have increased the recovery of oil from a simulated reservoir by up to 20% of oil-in-place.

Resource Assessment Division

The Resource Assessment Division is responsible for assessing Australia's petroleum and mineral resources, developing and maintaining the national geoscience database, and providing scientific and technical advice to the Australian Government about the exploration for and development of mineral resources in Australia and its territories. The Division also provides expertise to assist in the administration of mineral exploration activities in other countries in the southwest Pacific such as Papua New Guinea, Fiji and Tonga.

The staff are largely engaged in studies and activities designed to provide information on some 65 mineral commodities considered likely to be of economic or strategic importance to Australia. Greater emphasis is given to the study of energy minerals—in particular petroleum—because of their economic and strategic importance. However, considerable effort is also directed towards studies of other important commodities such as aluminium, copper, fertiliser minerals, gemstones, gold, iron, lead, manganese, nickel, tin, titanium, tungsten, zinc, and zircon.

Most of the effort in resource assessment is directed towards the study of known mineral deposits because information about the quality, quantity, and availability of these resources is of prime importance to the Government and of major interest to industry and the public. Nevertheless there is a growing demand for information about the petroleum and mineral potential of Australia and its territories as a basis for Government policy formulation and land-use planning.

Although most of the staff are engaged in database development and resource assessment, the Division is also engaged in research relevant to its major functions. Research programs are planned or in-progress with a view to improving the methodology of resource assessment, understanding formation damage in petroleum reservoirs as a contribution towards improving oil recovery, and investigating the possibility of improving utilisation and interaction between the various geoscience databases in BMR. Resource Assessment Division staff work closely with staff from the research divisions in BMR and a number are involved in collaborative research programs directed by research staff in other divisions.

The Resource Assessment Division was established in 1982 by the amalgamation of various units in BMR at the time and the addition of the Uranium Resource Evaluation Unit from the Australian Atomic Energy Commission. The Division has a structure comprising four branches which reflect its major functions. The branches are:

- Petroleum Branch
- Mineral Commodites Branch
- Mineral Project Evaluation Branch
- Geoscience Computing and Database Branch.

The Division has a well-established series of regular publications and information releases including:

- The *Australian Mineral Industry Review* (AMIAR)
- The *Australian Mineral Industry Quarterly* (AMIQ)
- *AMIAR* Preprint Chapters and Annual Preliminary Summaries for major mineral commodities.

In addition the Division produces an annual publication on *Petroleum Exploration and Development in Australia*, and detailed reports on 'Australian Uranium Resources' and 'Coal Resources in Antarctica' are currently in preparation for publication. A series of reports summarising information on oil accumulations in sedimentary basins or regions of Australia has also been commenced and it is hoped that the first six reports in this series will be published in the next year.

Special Projects & Geoscience Services Branch

The Branch undertakes national and international geoscientific map projects where map production is the main end-product for a summary of resources and information; it undertakes foreign aid projects and is responsible for geoscientific work in Antarctica. It produces maps and other publications and maintains the Library, Museum, and the Cartography Group as services to BMR. As well, it provides liaison with the State and Northern Territory geological surveys.

The main national geoscience map projects cover the preparation of regional or Australia-wide maps. The *BMR Earth Science Atlas of Australia*, at 1:10 000 000 scale, is popular and so far 15 maps and their commentaries have been published in the series. During 1985 *Metamorphism, Cainozoic geology and minerals,* and *Palaeomagnetism* were published. The Branch also assists the Division of National Mapping in the *Atlas of Australian Resources* project by providing input for several geoscience-related maps and their commentaries.

The Branch is working on the design of a proposed 1:1 000 000-scale geological map series, including the use of computer graphics. State geological survey support will be important for this project. Trial areas covering Tasmania, Victoria, Bass Strait and Kalgoorlie are being assessed.

In conjunction with the Specialist Group for Tectonics and Structural Geology of the Geological Society of Australia, the compilation of a Tectonic map of the Tasman Fold Belt System at a scale of 1:2 500 000 continues. Contributions prepared by BMR, State geological surveys, and universities are being integrated and compiled.

The first draft of a regolith map of Australia co-ordinated by the Division of Continental Geology is complete. It will be published at 1:5 000 000. Preparation of a regolith map of the Kalgoorlie 1:1 000 000 sheet, based on Landsat imagery and published geology and soil maps, is nearly complete.

A bicentennial project that aims to publish several volumes on Australian geoscience for 1988 is being co-ordinated with scientists from BMR and other organisations. The four volumes planned are geophysics, biostratigraphy, the coals and coal basins of Australia, and the tectonics of the Tasman Fold Belt System (as a companion to the 1:2 500 000 map).

The main international map project was on the Southwest Quadrant of the Circum-Pacific Map Project. The 1:10 000 000-scale Geological map of the quadrant will be published in 1986 and compilation of the 1:10 000 000 Mineral resources map and Energy resources map continues. Compilation of the 1:10 000 000 Tectonic map has been completed (by Dr Erwin Scheibner, NSWDMR). A Geodynamics map of the Southwest Quadrant (at 1:10 000 000 scale) and of the Pacific Basin (at 1:17 000 000 scale), and a Manganese nodule/seafloor sediment map of the Pacific Basin (1:17 000 000 scale), were published by the Project headquarters (in USGS, Menlo Park, California).

For the Commission for the Geological Map of the World, a first-draft map of Australia for inclusion in a 1:25 000 000 geological (wall) map of the world was submitted.

The main BMR overseas project is the geological and geophysical mapping and training program by BMR personnel in Indonesia. This program is being carried out in co-operation with the Geological Research and Development Centre of the Indonesia Department of Mines & Energy and funded by the Australian Development Assistance Bureau. Eleven Australian staff members in Bandung work in co-operation with Indonesian geologists and geophysicists in a helicopter-supported mapping project in West Kalimantan. The area covered constitutes part of an extensive east-trending Cretaceous magmatic arc intruded by a tonalite-grandiorite suite of plutons; widespread volcanic and associated ?Triassic sediments in the southwest of the arc are intruded by I-type granites. The prospective non-marine Late Cretaceous to Early Tertiary Melawi Basin overlaps the northern margin of the arc and deepens to the north. The northern margin of the Melawi Basin comprises deformed Middle Cretaceous sedimentary rocks and melange; the combined geological and geophysical results suggest that this east-trending melange belt represents a steep southerly dipping crustal suture.

The lack of logistic facilities has continued to restrict onshore geoscientific Antarctic investigations, but a major field program in 1985-86 is underway in the Bunger Hills-Denman Glacier area. The preparation of geological maps (Enderby Land 1:500 000 in colour, and Northern Prince Charles Mountains 1:500 000 preliminary) is proceeding.

Under the Memorandum of Understanding for the exchange of geoscientific information between Australia and China, a five-person mission visited China between 23 May and 14 June 1985, to study research into natural gas and oil formation in coal-bearing sedimentary basins.

NSW Department of Mineral Resources

During 1985 reorganisation of the Department's geological work continued with further regionalisation of branch activities. Branch offices of the Geological Survey of New South Wales continue to operate at Broken Hill and Armidale, a Coal Geology office has been established at Singleton in the Hunter Valley and it is expected that a Geological Survey office will be established at Orange late in 1986. A staff geophysicist has been located at Armidale with the geological team.

In the Geological Survey Branch, regional geological studies continued in the Cobar, Broken Hill, New England, Southern, Lachlan and Sydney Basin areas. At Cobar,

PRELIMINARY EDITION

1:100 000
1 Yeuralba Region (BMR)
1:250 000
2 Alligator Rivers Uranium Field (BMR)
3 Brisbane (QLD) reprint
4 Maryborough (QLD) reprint
1:1 000 000
5 Murray Basin Geology (BMR)

COLOUR EDITION

1:10 000
6 Boulder–Hope Islands Reef (BMR)
7 Ribbon No 5 Reef (BMR)
1:25 000
8 Pinnacles (NSW)
9 Silverton (NSW)
1:50 000
10 Cairns–Trinity Bay (QLD)
11 Keep River National Park (NT) release date 30/5/85
12 Pedder (TAS)
13 Rockingham (WA)
14 St. Marys (TAS)
15 Yanchep (WA)
1:75 000
16 South Alligator Valley Uranium Field (BMR)
1:100 000
17 Anson (NT), (1)
18 Arltunga–Harts Range Region (BMR)
19 Batchelor–Hayes Creek Region (BMR)
20 Beenleigh (QLD) reprint
21 Canbelego (NSW)
22 Coolullah (BMR)
23 Fog Bay (NT) release date 30/5/85
24 Forsayth (QLD) reprint
25 Georgetown (QLD) reprint
26 Hatches Creek Region (BMR)
27 Koolpinyah (NT) release date 12/12/85
28 Mount Allen (NSW)
29 Mount Oxide Region (BMR)
30 Murwillumbah (QLD) reprint
31 Myally (BMR)
32 Rockhampton Region (QLD)
33 Wollongong — Port Hacking (NSW)
34 Wrightville (NSW)
1:250 000
35 Abminga (SA)
36 Canberra Metallogenic (NSW) reprint
37 Cargelligo — Narrandera Metallogenic (NSW) reprint
38 Coober Pedy (SA) reprint
39 Corrigin (WA)
40 Dalhousie (SA)
41 Dixon Range (WA) reprint
42 Dumbleyung (WA)
43 Edmund (WA) reprint
44 Georgetown Region — Geological Special (BMR)
45 Georgetown Region — Mineral Deposits (BMR)
46 Goulburn Metallogenic (NSW) reprint
47 Hyden (WA)
48 Huckitta (NT), (1)
49 Kellerberrin (WA)
50 Kennedy Range (WA)
51 Mount Isa Landsat Map, approx 1:250 000, jointly with DMS, (NSW)
52 St Lawrence (QLD) reprint
53 Tarcoola (SA)
54 Townsville (QLD) reprint
55 Turee Creek (WA) reprint
56 Urandangi (QLD) reprint
57 Winning Pool — Minilya (WA) reprint
58 Wooramel (WA) reprint
1:1 000 000
59 Tasman Orogenic Profile Wagga Wagga–Batemans Bay (NSW)

*(1) in press at 31/12/85

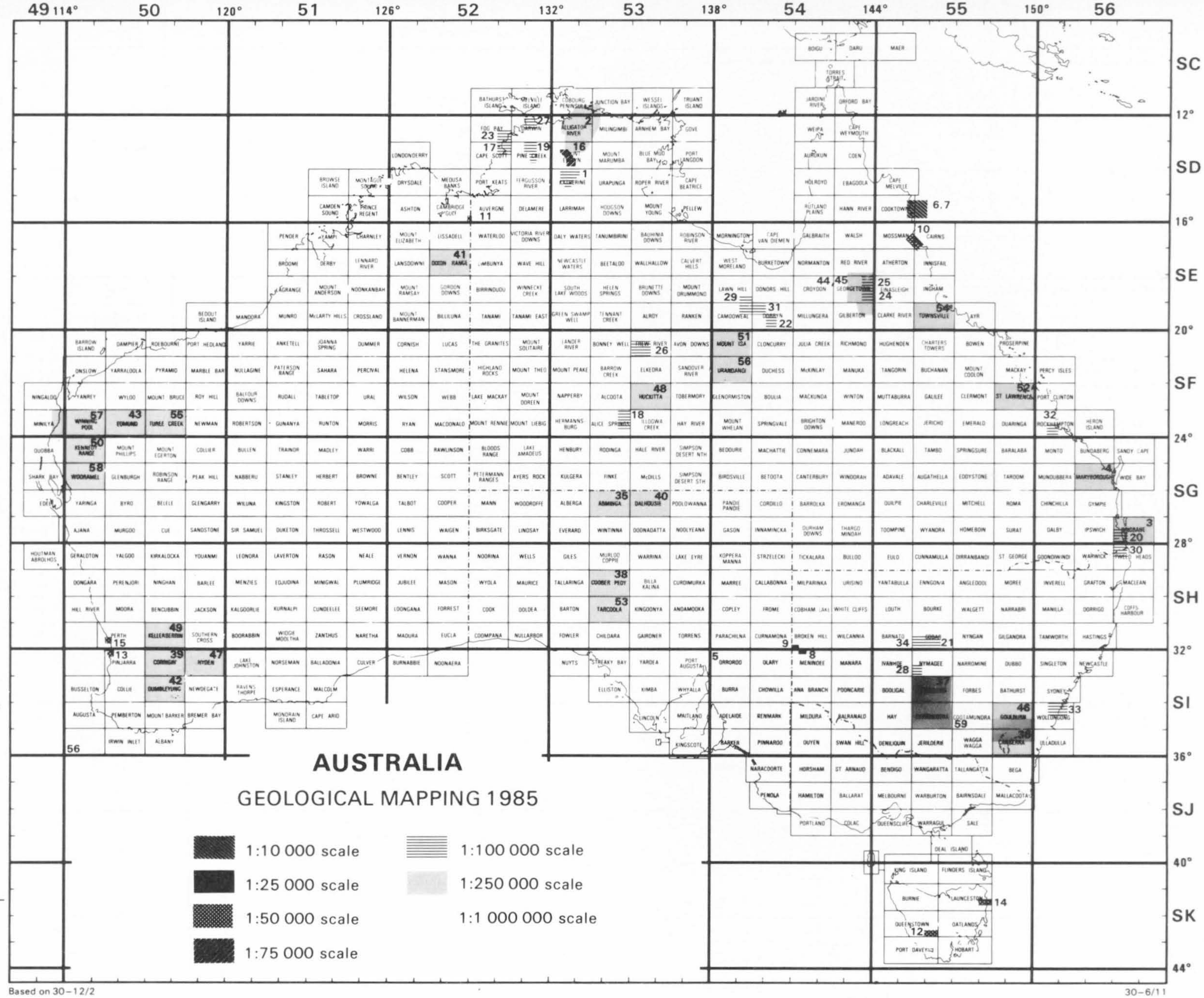

Fig. 1. Geological mapping in Australia, 1985.

RADIOMETRIC

1:250 000

1 Atherton (BMR)
2 Ayr (BMR)
3 Dorrigo – Coffs Harbour (NSW)
4 Maurice (BMR)
5 Noorina (BMR)
6 Queenscliff (BMR)
7 Red River (BMR)
8 Townsville (BMR)
9 Wells (BMR)
10 Wyola (BMR)

MAGNETIC

1:250 000

11 Atherton (BMR)
12 Ayr (BMR)
13 Bathurst (NSW)
14 Birksgate (BMR)
15 Bourke (NSW)
16 Clarke River (BMR)
17 Cootamundra (NSW)
18 Eucla (BMR)
19 Everard (BMR)
20 Gilberton (BMR)
21 Goulburn (NSW)
22 Innisfail (BMR)
23 Lindsay (BMR)
24 Maurice (BMR)
25 Mount Egerton (BMR)
26 Mount Phillips (BMR)
27 Noorina (BMR)
28 Nymagee (BMR)
29 Queenscliff (BMR)
30 Red River (BMR)
31 Townsville (BMR)
32 Wells (BMR)
33 Wyola (BMR)

1:1 000 000

34 Albany (BMR)

GRAVITY

1:250 000

35 Cobar (NSW)
36 Forbes (NSW)
37 Narromine (NSW)

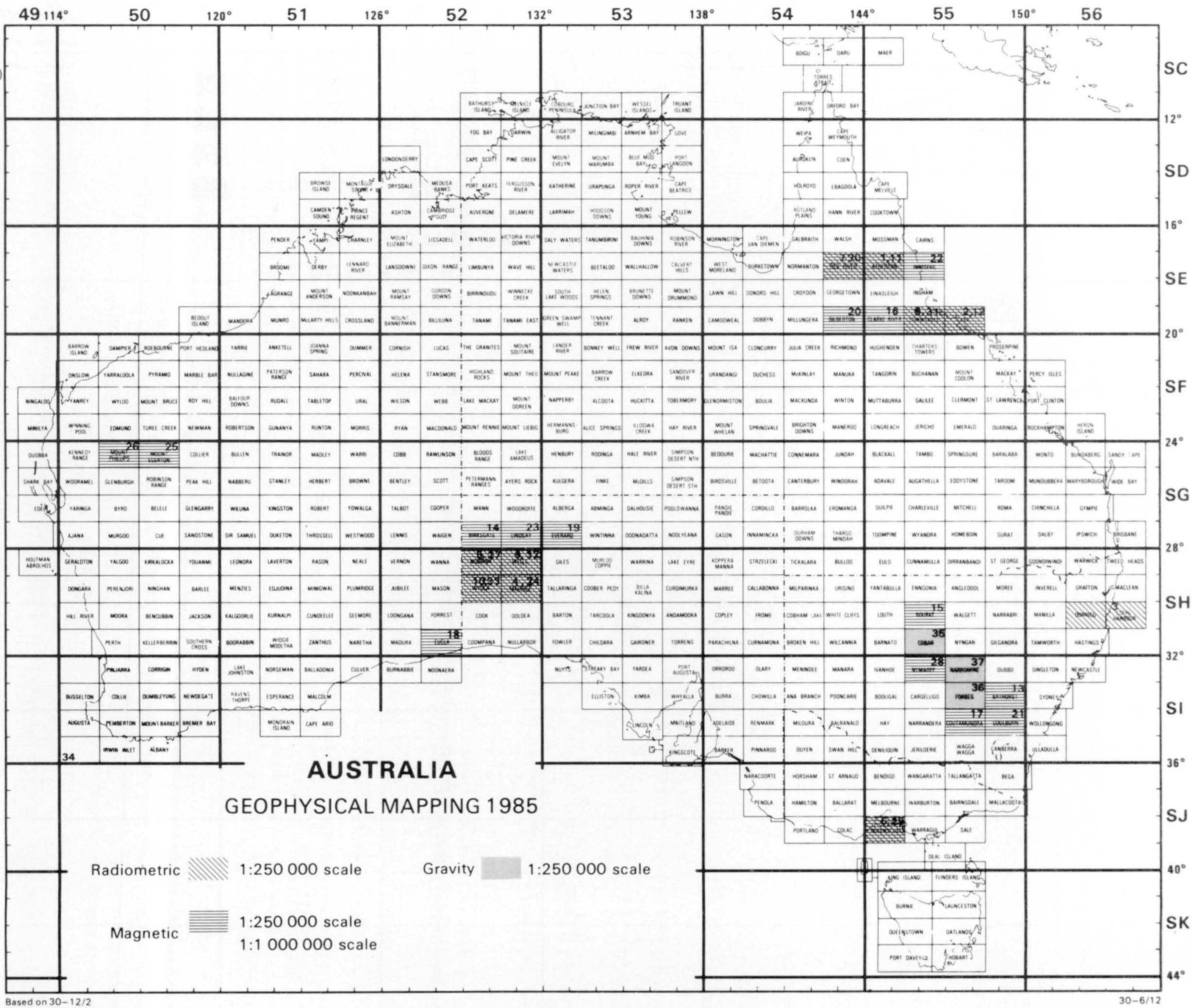

Fig. 2. Geophysical mapping in Australia, 1985.

mapping has been completed on six 1:100 000 sheets and synthesis of the data obtained is in preparation. The preliminary results of this synthesis were presented at a field conference in November 1985. Work at Broken Hill continued towards completion of the geologic and metallogenic mapping programs covering the Willyama Block. In the New England region compilation and field checking have been completed for the Manilla 1:250 000 sheet and have commenced for the Grafton/McLean 1:250 000 sheet. The Tamworth/Hastings metallogenic map and notes are nearing completion as is compilation of the Dorrigo/Coffs Harbour sheet. In the Sydney Basin compilation of the Penrith and Gosford/Lake Macquarie 1:100 000 sheets and notes continued. The Penrith sheet is in the final stages of editing.

Major mineral assessments were completed for construction and glass sand resources of Botany Bay and the Newnes Plateau. A study of future opal potential at Lightning Ridge was also published. Clay/shale assessment of the southern Sydney area continued. Major work also commenced on New South Wales sapphires and zeolites. The sapphire studies indicate pyroclastic relationships and have led to the formulation of new concepts in the origin of such gem deposits. Work continued on gold mineralisation in the Parkes and West Wyalong-Temora-Adelong areas. 1:100 000 mapping and reports are being finalised for the Parkes area and a preliminary report will shortly be available on gold mineralisation associated with the Gilmore Suture Zone near Temora.

During 1985 wide-ranging incentives to encourage petroleum exploration in New South Wales were announced by the Minister. Part of the incentives was the production of petroleum information packages consisting of compilations of basic data for the major sedimentary basins of NSW—the Sydney, Gunnedah, Clarence-Moreton, Eromanga, Surat, Darling and Murray Basins. As part of this program, a further fully-cored stratigraphic drillhole was completed in the Eromanga Basin, and two seismic traverses were completed, one in the Eromanga Basin and the other in the Gunnedah Basin near Narrabri.

Regional geophysical investigations continued in close association with mapping and resource assessments carried out by regional groups. Reprocessing of aeromagnetic and radiometric data to produce 1:250 000 sheets continued, and the continuous down-the-hole IP logging system was developed under an AMIRA grant. A NERDCC-supported study examining the use of geophysical logs in determining coal quality parameters has been completed.

As part of the State's marine resource assessment a program of co-operative studies of the NSW Coastal Zone has been developed in association with the Department of Geography, University of Sydney. Studies have been completed in the Ulladulla and Sydney areas and are in progress at Wooli and Eden.

During the year definitive geological and mineral resource data was provided for many major land use and planning studies throughout the State. The protection of the State's mineral resources is becoming a more important segment of the Department's tasks.

The Coal Geology Branch activities for 1985 included the commencement of an exploration drilling program at Rylstone and the completion of a similar program at Narrabri. These investigations were conducted as a joint venture with the Electricity Commission. A land-use drilling program was also conducted to assess the coal resources near the township of Scone. In conjunction with the Geological Survey, the Branch compiled geological notes to accompany the Gosford-Lake Macquarie 1:100 000 sheet. A draft publication to update the assessment of coal resources and reserves in NSW was completed. An update of the 1984 Coal Industry Profile, commenced in 1985, will provide a more detailed profile on mining and proposed mining in the State. Overviews of the Western and Hunter Coalfields are currently being prepared to provide a database to enable the Department to make informed decisions on the future allocation of coal resources and for future planning and development strategies. The Coal Geology Branch is a major contributor to a bicentennial publication on the Geology and Coal Resources of Australia, and is preparing chapters on the Sydney, Gunnedah and Oaklands Basins and material on resources and mining.

The main activity of the Information and Extension Services Branch has been the promotion of the New South Wales mineral industry and the dissemination of information, particularly by the computerised CLIRS system. Information was provided to industry, overseas importers and the local community. Displays presented at the Tokyo Exhibition and the International Gemmological Conference included gemstones and non-traditional minerals. Additional displays on gemstones, Halley's Comet, and caving were exhibited at the Geological and Mining Museum. The branch was also involved in the organisation of an AMF/Departmental Seminar *New South Wales—The Potential for Development* held in late 1985, and in the presentation to industry of core obtained from the Department's cored petroleum stratigraphic holes.

Northern Territory Geological Survey

Geological mapping by staff of the Regional Mapping Sections of the Northern Territory Geological Survey (NTGS) continued in the Northern and Southern Regions (Darwin and Alice Springs offices respectively), but fieldwork was generally reduced from the levels of 1983 and 1984. Major projects in each region (Litchfield and Davenport Provinces respectively) progressed to the report-publishing stage for a number of map sheets. Standard 1:100 000 Geological Maps plus accompanying Explanatory Notes for Koolpinyah and Fog Bay were released during the year, with another (Anson) being in press. The first 1:250 000 publication (Huckitta—second edition) of the NTGS was also in press. Compilation of maps summarising the results of past exploration activities (NTGS Exploration Series) continued by all Sections. Three 1:250 000 items (Robinson River, Calvert Hills and Mount Drummond, and two 1:100 000 items (Seigal and Wollogorang) were released.

In addition to the standard mapsheets, geological mapping was also undertaken (particularly by the Environmental Geology Section) in several of the National Parks and/or Conservation Reserves of the NT in order to assist in the preparation of Plans of Management and to provide geoscientific information for visitors to the areas. The first publication in the Report Series of the NTGS dealing with the geology of Keep River National Park was released in 1985. A further two items, relating to Arltunga Historical Reserve and Katherine Gorge National Park are close to publication. Following completion of current Park mapping, staff of the Environmental Geology Section will commence studies of extractive mineral resources near the Territory's main population centres of Darwin, Katherine and Alice Springs to assist land-use planning.

The Metalliferous Section continued work on the mineral deposits in the Calvert Hills 1: 250 000 sheet area. A metallogenic map is scheduled for publication in 1986 and will be the first of a standard series for the NTGS over areas of significant mineral potential. Particular attention has been paid to gold and uranium mineralisation. Current exploration for diamonds is now giving added significance to this work. The Metalliferous Section also provided information to a submission by the Northern Territory Department of Mines and Energy to the Senate Standing Committee on Kakadu National Park. In this submission, the mineral potential of the Gimbat and Goodparla Pastoral Leases (proposed Kakadu Stage 3) was assessed. Recent drilling at the Coronation Hill gold-platinoids prospects highlights the high prospectivity of the general region.

Airborne geophysical surveying by the Geophysics Sections continued to be a major part of the NTGS's field program. In the Petermann Survey, six 1:100 000 sheet areas in the Musgrave Province (Hull, Bloods Range, Pottoyu, Petermann, Cockburn and Duffield) were flown for magnetics and radiometrics prior to geological mapping. Release of data, including maps and magnetic tapes, is expected in early 1986.

Sedimentological studies were undertaken on carbonate units in the Daly and Georgina Basins. Biostratigraphic work is also in progress in order to assist mapping and interpretation of the basins. Indications of petroleum in a NTGS stratigraphic drillhole (Elkedra 7) in the Georgina Basin were followed up by geochemical and hydrocarbon maturation studies.

The Technical Information Section experienced heavy demand for computer database information, especially before the closing of bids to the Commonwealth for oil permits in the Ashmore-Cartier region. GEOSYSTEM continued to be in demand and a drilling database (CORERECORD) proposed for 1986 should prove likewise. The Section also provided a significant level of assistance to Darwin secondary schools, prepared a pamphlet on the meteorite and comet impact craters of the Alice Springs region, and has almost completed a second edition of the highly popular 'Guide to Fossicking in the Northern Territory'.

The expansion of the existing core libraries in both Alice Springs and Darwin should be completed in early 1986. The policy of core storage has also been reviewed and increased use will now be made of palletised, open-air storage and selective culling. Important and/or readily weathered core will continue to be stored under cover in tray racking.

Geological Survey of Queensland

In 1985, the major Regional Geological Mapping Program (RGMP), begun in 1983-84, was continued. The number of field parties increased from two to three, with base camps established at Dimbulah, Charters Towers and Mount Coolon. Mapping concentrated on the Mossman and Atherton 1:250 000 Sheet areas (from Dimbulah), on the Einasleigh and Clarke River Sheet areas (from Charters Towers), and on the Mount Coolon Sheet area. The Dimbulah program was augmented by sedimentological studies to elucidate the origin of the Chillagoe Formation, and by conodont chronostratigraphic and palaeoenvironmental interpretations of the Chillagoe Subprovince which yielded new data on limestone deposition in the region. Other projects undertaken by the Regional Investigations Branch include the production of a satellite (Landsat) map of the Mount Isa region. The map illustrates prominent geological features, gives a brief explanation of the geology and was produced as a wall poster in conjunction with the Department of Mapping and Surveying. Work on volcanics and their entrained xenoliths from localities in southeast Queensland formed part of the study of upper mantle-lower crustal conditions and composition.

Projects of the Palaeontology Section included a study, funded by AMSTAC, of sedentary foraminifera in the vicinity of Heron Island which provided significant data on settling and growth rates. Research was also undertaken on foraminifera, ostracodes and plants from the Permian of Western Australia, shelly faunas from the Permian of Tasmania and the southern Bowen Basin of Queensland, the Jurassic palynology of the Surat Basin, and palaeoenvironmental features of Silurian and Carboniferous limestones.

The Marine and Coastal Investigations Section studied coastal erosion in the Cairns region and at Hervey Bay and prepared a paper describing geological approaches to coastal zone management. A site investigation of a proposed major marina and associated access channel on the margin of Moreton Bay involved extensive offshore seismic profiling and shallow drilling. Research into the Quaternary history of the Gulf of Carpentaria continued. Preliminary interpretations focussed on the existence of a lake on the gulf floor during low sea-level periods.

Activity in the Coal Exploration Section of the Fossil Fuels Branch centred on testing for coal seams within the Rangal Coal Measures at several locations in the Bowen Basin. An intensive shallow drilling program at Lake Vermont was followed up by a further program of holes designed to obtain additional structural information. Limited drilling was also carried out in the Moorlands and Rugby Basins. A 30-hole program at Vermont North investigated the subcrop of the Rangal Coal Measures and tested to the base of the Girrah seam in the Fort Cooper Coal Measures. A drilling program of deep, fully-cored holes at Picardy, commenced in 1985, was continuing at year's end.

A new solid geology map of the Bowen Basin at 1:500 000 scale is being compiled jointly by staff of the Petroleum Resources and Coal Exploration Sections. A major achievement during 1985 was the completion of Phase I of the NERDDC project which saw the Queensland Energy Resource Data Base become publicly accessible. Phase II of the project was commenced. Work also commenced on a project to examine the relationship between groundwater hydraulics and petroleum migration. Specific projects aimed at data acquisition, compilation or review were continued for the Bowen Basin (including the Taroom and Denison Troughs), the Galilee Basin, some older Palaeozoic basins, and the Eromanga and Surat Basins.

As part of the Stratigraphic Drilling Section's ongoing program of deep stratigraphic drilling in the Eromanga Basin, three bores (3700 m) were completed in 1985 and another was in progress at year's end. A 3-year grant under NERDDC to study hydrocarbon-generation potential in the southern Eromanga Basin was awarded to this program in November 1985. Two bores were drilled in each of the Bundock and Clarke River Basins (total 2700 m core), in support of the north Queensland RGMP. All bores were wireline-logged and a detailed study was made of the cores.

Activities of the Computer Services Section included provision of computer services to other sections, training in computer concepts, evaluation and acquisition of hardware and software, systems analysis, design and program writing, documentation, and systems software maintenance and engineering. Major ongoing programs included the Queensland Energy Resource Data Base, the Coalfile system, and the Company Report system, and new programs included a Company Report library system and a Queensland quarry and pit file. Further work was carried out on the keyworded bibliographic (reference) data base, involving design of an interrogation system to access data stored in this file.

Within the Metalliferous and Geological Services Branch the Economic Geology Section initiated a major metallogenic study program, complementary to the RGMP, in order to provide greater understanding of mineralisation styles. Work began in the Mungana and Chillagoe 1:100 000 Sheet areas in view of their diversity of mineralisation and availability of RGMP compilation sheets. A revision of the published Queensland Gold Localities map was completed. A high level of interest in various industrial minerals was maintained, especially for high technology minerals such as silica. The section also prepared the geological part of a comprehensive Departmental publication on the Anakie sapphire fields.

Major engineering geology and hydrogeology projects included an investigation for a 7-km railway tunnel through the Toowoomba Range, and further work for the Baroon Pocket Dam project on the Sunshine Coast. Work for the latter project involved locating and proving environmentally acceptable quarry sites below full supply level, and a 2.7-km tunnel route entirely within Mesozoic sandstones. Regional assessments of groundwater resources concentrated on the southeastern and central parts of the Eromanga Basin, and on coastal aquifers near Innisfail.

Urban and environmental geology activities largely comprised a continuation of projects begun in or prior to 1984. The Cairns 1:100 000 geological map was submitted to the Cartographic Branch and a draft of the map commentary was completed. The Rockhampton 1:100 000 Special geological map was issued and the map commentary awaits final editing. The Townsville 1:100 000 Sheet is also well advanced in map drafting and map commentary preparation. The section continued a survey of road materials in the Goondiwindi region, revised information on extractive materials in Caboolture Shire, and prepared short papers on rocks and landscapes in the Chillagoe and Cairns areas for release in a proposed guidebook series.

The Geophysical Services Section's capabilities were upgraded by the delivery of a new DSS 10 Seismic system, which will be employed principally in refraction surveys for engineering investigations. In 1985, three refraction surveys were carried out at the Proserpine damsite and one at Finch Hatton, as well as a reflection survey at Dyer's Lagoon. The route for the Isis main channel in the Bundaberg irrigation area was also surveyed. The Clermont EM survey was further evaluated and as a result a ground IP survey was undertaken. The area was reserved as a Departmental Area and a drilling proposal formulated. Seismic monitoring of earthquake activity continued at the Burdekin Falls, Boondooma, Awoonga and Wivenhoe dams.

An increased number of orders for sales or reproduction of geological reports was received by Information Services staff, and use of the library and reference services again increased during the year. Microfilming of company reports and logs was maintained and the supply of duplicate sets of microfiche to the Economic Geology Research Unit at James Cook University continued.

The District Office at Charters Towers received numerous requests for information, mainly concerning gold exploration. Field work continued on limestone deposits in the Broken River area and support was provided to the RGMP field camp at Charters Towers and to the Economic Geology Section's metallogenic studies program at Mungana. A proposal to upgrade the District Office, approved by the Public Service Board during 1985, will see the transfer from Head Office to Charters Towers of a Senior Geologist and a Geological Assistant in April 1986. Further upgrading is planned, including extensive changes in the laboratory, to provide services to the RGMP and metallogenic mapping programs.

South Australia Department of Mines & Energy

Regional geological mapping was carried out on the Gawler Craton, mainly in the Barton, Ooldea, Kimba, Lincoln, Kingoonya and Yardia 1:250 000 sheet areas. Mapping also continued in the Curdimurka area, where seven cored stratigraphic wells have been drilled to assist in interpretation of the Eromanga and Lake Eyre Basins. The Ooldea 2, and 3 and Watson 1 wells were also drilled in western areas to help explain rock relationships in Proterozoic and younger rocks. Revision of the Adelaide area is proceeding, aided by production of selected 1:50 000 sheets. Regional geological information published during 1985 includes the Tarcoola 1:250 000 and Echunga 1:50 000 geological maps and explanatory notes for the Dalhousie 1:250 000 sheet. Notes for the Abminga sheet were completed. Other activities of the section included the organisation of excursions to examine silcrete, contribution to a handbook on Eyre Peninsula, studies of the Eucla, Warburton and Officer Basins, compilation of information on mafic dyke swarms for an international project, manipulation of Landsat tapes to aid mapping of Kingoonya, coring of Quaternary coastal deposits, U-Pb dating through AMDEL, and drilling in the Ooldea Range.

Palaeontologists have prepared a chapter entitled 'Eocene/Oligocene boundary, Adelaide region, S.A.' for a forthcoming Elsevier book, *Geological events at the Eocene/Oligocene boundary*(IGCP Project 174). An analysis was made of the foraminiferal biofacies of Recent sediments from Tourville Bay, near Ceduna. Palynological reports were issued on Pidinga Formation palynofloras in Wilkinson 1 well, subsurface and outcrop material from the Lake Eyre region, Algebuckina Sandstone palynofloras from the western Eromanga Basin, and on the succession in SADME Toodla 1 well in the southwestern Eromanga Basin.

Exploration for metallic and non-metallic minerals, gemstones and building stones continued, with emphasis on gold, lead-zinc, gypsum, kaolin, jade and construction sand. Metalliferous projects completed by the Survey included the geological mapping and sampling of lead-zinc prospects in the Flinders Ranges National Park and a major machine-auger drilling program for kaolin and gold in the Birdwood district. As part of an ADAB program and in conjunction with AMDEL, survey geologists participated in a training and inspection program on gold geology, mining and metallurgy for 20 Burmese scientists and engineers. Non-metallic projects included work on building stones for a special Jubilee 150 publication in 1986, and a review of three diamond drilling programs on nephrite jade.

Regional assessments of groundwater resources have continued in the southeast in the Tatiara Proclaimed Region, the Murray Basin, and Metropolitan Adelaide, and have commenced on the Great Artesian Basin. Specific investigations have been carried out for town water supplies at Quorn, Glendambo, and various townships in the southeast and Eyre Peninsula, for the proposed Wollpunda groundwater interception scheme, and for groundwater supplies for the Whyalla-Cowell road. Significant progress, including the completion of 154 cored holes, has been achieved on the investigation of soils in metropolitan Adelaide.

The NERDDC-funded study on the petrophysics of Jurassic reservoirs of the Eromanga Basin will be completed in September when algorithms for improved log interpretation are finalised. The petroleum potential of the Cambrian sequences in SA is being reviewed to promote increased exploration activity, and compilation of all petroleum exploration and production statistics and preparation of trend maps for exploration discoveries is in progress.

A major new geotechnical computer system soon to be put to tender will include new hardware and systems in petroleum exploration and production, geographic information, coal deposit evaluation, seismic interpretation and graphics. The new SAMREF computer bibliography on the existing system now offers on-line access to over 16 000 Departmental and open file company reports.

Publications issued during 1985 include the Ludbrook Honour Volume which contains papers on palaeontology, stratigraphy and malacology, and which was published and presented to Dr Nell Ludbrook on 14 June 1985, her birthday; a bulletin on the stratigraphy and tectonics of the Worumba Anticline, central Flinders Ranges, with information on Willouran and early Torrensian rocks and their relationship to the Adelaidean; a handbook on Quaternary molluscs of South Australia; mine and quarry rehabilitation projects in South Australia, published with the assistance of industry; a Report of Investigation on the engineering geology of Little Para Dam, a recently-completed metropolitan water supply project; and a new brochure on groundwater resources in the Murray Mallee.

Geological Survey of Tasmania

The Geological Survey Division of the Department of Mines of Tasmania is organised into four operational Branches: Regional Mapping; Engineering Geology; Economic Geology; and Geophysics.

Regional mapping required for the publication of the Geological Atlas, 1-mile and 1:500 000 Series Maps of Tasmania, continued in the St Helens, Ben Lomond, Snow Hill, Interlaken, Woolnorth, Trowutta, Lyell, Corinna and Macquarie Harbour sheet areas. Regions are mapped at scales varying from 1:5000 to about 1:15 000 depending upon the complexity of the geology and the needs of economic mineral projects. Pedder and St Marys 1:50 000 Series Sheets and the Explanatory Reports for Strahan and Kingborough were published. St Valentines and Interlaken 1:50 000 Series Sheets and the Explanatory Reports for Eddystone and St Marys are in press. On the 74 1-mile and 1:50 000 Series Maps covering mainland Tasmania, 38 have been completed and nine are being systematically mapped.

The Engineering Geology Branch is currently supplying information on the detailed geology of the Craigbourne Dam prior to and during construction, is reviewing landslide zone maps of the north and northwestern parts of the state issued a decade ago, and is collecting and compiling soil information for engineering purposes in the Greater Hobart area. A regional groundwater survey is in the drilling and aquifer-testing phase in the Lower Midlands, and water levels and discharges are being monitored in the basalt irrigation areas east of Devonport.

Under special funding, the Economic Geology Branch is participating in an integrated project (together with the Geophysical Branch) on the Mt Read Volcanics, the host rocks to the main ore deposits in Tasmania. Geological mapping, geochemical prospecting, geophysics, alteration and isotope studies, lineament analysis and remote sensing, and mineral deposits maps are being employed to provide industry with basic information of significance to exploration. The entire exploration report collection is being organised into a database for computer access and retrieval, and all reports are being microfilmed. Commodity reviews in progress include silver-lead-zinc, tin-tungsten, gold, industrial minerals, coal and hydrocarbons.

The Geophysical Branch is currently engaged in aeromagnetic, radiometric, gravity, physical property and signature surveys in western Tasmania to provide a background for further intensive exploration by private companies. The area of the surveys covers, but is not restricted to, the Mt Read Volcanics belt. The systematic gravity coverage of the State at a density of one station per square kilometre is continuing and a program of borehole logging of both groundwater and stratigraphic holes has been initiated.

Geological Survey of Victoria

Following incorporation of the former Department (Office) of Minerals and Energy into the Department of Industry, Technology and Resources (DITR) in mid-1985, re-organisation of the Geological Survey Division into three branches was implemented in principle in September. Nominal staff levels stand at Directorate 4, Minerals Branch 24, Groundwater Branch 29 and Specialist Services Branch 42.

Perhaps of greatest interest was the completion of a joint study, with the Victorian Solar Energy Council, of geothermal energy resources in Victoria. This study demonstrates immediate scope for use of low-temperature geothermal resources in coastal regions of the Otway and Gippsland Basins with potential payback periods on capital works of three years or less. The report entitled *Geothermal resources of Victoria: a discussion paper* (129 pp) will be published early in 1986.

DITR, through the Geological Survey, has been the lead agency in an interdepartmental committee preparing a strategy plan for hard rock quarrying for Melbourne. Mounting environmental and local government opposition to extractive industry has focused attention on the problems of defining suitable resources and protecting them to meet future needs. As part of this study a comprehensive computer database of hard rock resources in the Melbourne supply area has been prepared.

Detailed field and literature studies of gold mineralisation in the Creswick and Beaufort 1:100 000 sheets have been carried out in connection with the preparation of Victoria's first metallogenic map. This work has drawn attention to deficiencies in the geological mapping in both areas. Detailed geological mapping at a scale of 1:10 000 and explanatory notes covering two thirds of Bendigo goldfield have been completed.

The regional geological mapping program is currently focused on the Murrindal 1:100 000 sheet in eastern Victoria, the Deans Marsh 1:50 000 sheet in the Otway Basin and the Nagambie and Heathcote 1:100 000 sheets in the western part of the Melbourne Trough.

Groundwater studies have been substantially stepped up in the Victorian part of the Murray Basin. These studies are a key element in the government's integrated strategy to counter developing salinity problems and will involve total expenditure on salinity programs by all departments of $30 million over the next five years. Extensive use will be made of contract and government drilling, and data will be used to develop a regional groundwater model. Seismic reflection and gravity surveys will be used wherever possible to achieve the most effective siting of bore holes. BMR, CSIRO, and NSW and SA groundwater agencies will collaborate in parts of the study. Major investigations of groundwater resources in the southwestern region are continuing in collaboration with Department of Water Resources, Rural Water Commission, and Geelong Water and Sewerage Board. These studies are aimed at supplementation of the water supplies of Geelong, Warrnambool and Ballarat. Seismic reflection surveys are being carried out to assist this work. The State's first 1:250 000 groundwater map (Bendigo and part of Deniliquin) was published during the year and several other groundwater maps are programmed for 1986, some in collaboration with BMR. The Salinity & Pollution Section of the Groundwater Branch has been involved in advising on the suitability of landfill sites throughout the State, including a site for a secure landfill for Melbourne. They are also advising on disposal of mine waters from a former major goldfield currently being re-investigated by Western Mining Corporation Ltd.

Comprehensive index maps of seismic, gravity, aeromagnetic and other geophysical surveys carried out by the Survey, BMR, oil and gas, and mineral exploration companies throughout the State have been compiled and can be inspected in the Geophysics Section. A computer index organised by map sheet, survey number, year and operating company complement the map series.

Palaeontological studies have focused on further investigations of the planktonic foraminifera of the Torquay-Anglesea area and the palynology of key bores in the Murray Basin. Macropalaeontological and biostratigraphic field and laboratory studies are considerably extending knowledge of the Silurian and Lower Devonian stratigraphy and structure of the Melbourne Trough. Research studies on the macroflora of the terrestrial Lower Cretaceous sediments of the Otway and Gippsland Basins are continuing with the aim of achieving a dependable biostratigraphic subdivision of this thick, lithologically monotonous sequence.

Detailed engineering geological mapping to assist overall planning for the proposed Melton growth centre on the western periphery of Melbourne is well advanced. This area is characterised by expansive and gilgaied soils overlying Quaternary basalts. Use is being made of computer assisted drafting to produce a series of maps to accompany the explanatory notes. Landslip zone maps have been prepared for landslip prone areas in the Otway and Strzelecki Ranges, and subsidence risk maps have been compiled for lands overlying former coal mines at Wonthaggi.

Priority is being given to indentifying the long term geoscience information requirements of the Survey as an essential pre-requisite to setting up an Integrated Geological Data Base (IGDB) on the Department's VAX computer.

The Mount Stavely (part sheet) and Bacchus Marsh 1:50 000 and Pakenham 1:25 000 geological maps, Bendigo/Deniliquin 1:250 000 groundwater map and Dunolly 1:100 000 deep lead map were published during the year. Dookie 1:100 000 and Ballan and Warrnambool 1:50 000 geological maps are in preparation.

Collaboration with BMR and neighbouring States continues in relation to the ongoing investigations of the geology and groundwater resources of the Murray Basin and the preparation of the tectonic map of the Tasman Fold Belt.

Geological Survey of Western Australia

Staff structure of the GSWA remained unchanged in 1985 except that the position of Assistant Director in charge of Basement, Minerals and Geotechnics Branch, created in the previous year, was occupied in September by Mr P. R. Dunn. The principal directions of research continued to be the elucidation of geological histories of selected structural units or provinces and appraisal of resources of minerals, fossil fuels and water in WA.

Earlier work on the component sequences of the Capricorn Orogen (the Gascoyne Province, Nabberu Province, and Ashburton Fold Belt) was collated and the history of the orogen synthesised using lithostratigraphic and chronometric correlation and tectonic modelling. The Capricorn Orogen is similar to other orogenic belts in northern Australia, supporting the theory of a distinctive tectonic style for sequences in the age range 2.0 to 1.5 Ga.

As the study of the Murchinson Province progresses, evidence emerges that the large-scale, dome-and-basin patterns may be due to fold interference. Hitherto, the oval areas of granitoid rocks (ranging up to 50 km in diameter) fringed by arcuate greenstone belts, have been thought to result from diapiric emplacement of steep-sided batholiths. A stratigraphic succession within the greenstones has been indentified for the entire Murchison Province.

Data derived from the completed mapping of the Widgiemooltha and Boorabbin 1:250 000 sheets suggest that the structure of the greenstone belts could be explained by complex faulting and folding of a relatively simple succession. However the possibility of more complex stratigraphy (several cyclic successions) still cannot be eliminated.

A review of Permian fossils in WA was completed. This work, to which numerous Australian and international palaeontologists contributed, includes a review of Permian stratigraphy, lithostratigraphic and biostratigraphic correlation charts, and indexes of fossil, geographic and stratigraphic names.

A bulletin on the kimberlitic and lamproitic rocks of WA was compiled and will be published in time for the 4th International Kimberlite Conference in August 1986 at Perth. This resulted from co-operative work of staff from BMR, CRA and GSWA and contains the exploration history, description, mineralogy, petrology and chemistry of all known kimberlitic and lamproitic bodies in WA.

Field work for 1:50 000-scale environmental geology maps was completed for seven near-metropolitan area sheets and three of these (Rockingham, Fremantle and Yanchep) were published.

A detailed study of the onshore Bonaparte and Ord Basins showed that these basins are remnants of a once continuous basin formed initially by intracratonic movement and then by late Palaeozoic rifting. The Palaeozoic fault movements were vertical rather than transcurrent.

A review of coal resources on the Collie Coalfield was conducted to provide up-to-date advice to the Aluminium Smelter Task Force which was investigating the economic feasibility of establishing a smelter operation near Bunbury. A general review of the lignite deposits of WA was also completed.

A study of elemental patterns in the laterite profile at the Boddington gold prospects was undertaken with the co-operation of a staff member of the operating company (Reynolds Australia Mines). This showed that 'residual' components have been mobilised in the profile but have not been transported any great distance; some components appear suitable as either direct or indirect indicators of bedrock mineralisation.

Drilling and testing of shallow aquifers in the lower parts of the Robe and Fortescue Rivers confirmed that sufficient good-quality groundwater could be extracted from coarse, deltaic aquifers to be considered as supplementary sources of potable water for West Pilbara towns. At the moment these towns are supplied from the Millstream groundwater borefield and from surface catchment water in the newly constructed Harding Dam. Close liaison was established with the newly formed Water Authority of Western Australia (combined Metropolitan Water Authority and Water Supply Division of the Public Works Department) to assist with exploration for, and development and management of groundwater resources throughout the State. Included in joint studies with the Authority were the sampling and measurement of tritium concentration in a representative section of unconfined groundwater near Perth to determine rainfall infiltration under different land-use conditions, and a comprehensive review of groundwater resources in WA.

Commonwealth Scientific and Industrial Research Organisation

Division of Energy Chemistry

The Division of Energy Chemistry, based at the Lucas Heights Research Laboratories, has 90 staff including approximately 50 professional scientists (mostly chemists) and engineers. Its terms of reference are to 'carry out chemical, engineering and materials research directed towards the exploitation of Australia's energy resources, by developing new or improved processes for the production and utilisation of fossil fuels, substitute liquid fuels and renewable energy sources, including their environmental impact'. Earth science related projects comprise about 10% of the research program and include applications of neutron activation analysis (NAA) in geology, and geochemistry and trace element studies on oil shale and coal.

Neutron activation analysis can determine a wide range of elements in a variety of samples, ranging in concentration from sub-parts per million to several per cent. In collaborative investigations with universities, rare earth and other trace element concentrations have been determined in Later Permian shoshonitic lavas from the southern Sydney Basin. Trace element modelling suggests that the magmas were generated by 10-15% partial melting of spinel lherzolites which were enriched previously in light rare earth elements.

A hydrogeochemical prospecting method for gold, based on gold concentration from water and its subsequent measurement by NAA, has been developed and demonstrated on river samples from disused mine sites, thermal waters from New Zealand and bore water samples from the Laverton Region of Western Australia and the Weipa region of Queensland.

The distribution of trace elements in coals and oil shales and their fate during processing and combustion is also being investigated. In the oil shale studies, the concentrations of trace elements are first determined by NAA and spark source mass spectrometry. A combination of X-ray diffraction, inter-element correlation techniques, selective leaching procedures and electron microprobe analyses are then used to establish specific mineralogical residences of the important trace elements.

Multi-element characterisation of coal seams and related geological strata is being investigated in coal seam correlation studies. For example, samples of the Archerfield Sandstone from different locations in the Hunter Valley have shown that it can be identified by above average concentrations of tantalum, niobium, zirconium and hafnium. Samples of claystone marker beds (Althorpe, Saxonvale, Fairford and Greenleek) can also be identified by their distinctive rare earth element patterns.

Division of Environmental Mechanics

Research in the Division of Environmental Mechanics centres on a quantitative understanding of mass and energy transfer in the environment. Highlights during 1984-85 include the discovery and application of an analogue between scattering theory and soil water flow, the development of the disc permeameter for measuring soil-water hydraulic properties, research into gas transfer across air-water interfaces in the terrestrial nitrogen cycle, and a concentrated study of wind flow over complicated topography.

The discovery of an exact analogue between steady quasilinear flow in unsaturated soils and porous media and the scattering of plane pulses and harmonic waves means that numerous established results, and powerful mathematical techniques such as the Watson transform, are available for the solution and understanding of problems of unsaturated flow.

One of the biggest challenges in soil physics is the application of theory to field soils, particularly heterogeneous soils. An important prerequisite for the application of theory in field situations is the ability to measure rapidly *in situ* soil-water hydraulic properties. Divisonal staff have developed recently a rapid, nondisturbing method for measuring sorptivity and hydraulic conductivity, two important soil-water properties. The method involves placing a device, the disc permeameter, on the soil surface and measuring the time dependence of the water flow rate. Tests to date using a variety of *in situ* field soils indicate that the time for measurement is of the order of only 10 minutes.

Collaborative work with the CSIRO Division of Plant Industry and the CSIRO Centre for Irrigation Research has established that gaseous transfers across air-water interfaces play important roles in the terrestrial nitrogen cycle. The work has particular relevance to the use of nitrogen fertilizer in irrigated agriculture, where recoveries of the applied nitrogen are notoriously poor. In rice culture, for instance, some 15 to 50% of N-fertiliser can be lost through volatilisation of ammonia from the flood-water. The Division is examining physical aspects of the volatilisation process.

The ability to predict wind characteristics and turbulent transport over complicated topography is required for the solution of an increasing range of practical problems, including the dispersion of pollutants and aerosols, evaporation from crops and forests, wind forces on structures, and aeolian soil erosion. The Division is investigating this problem at a number of levels, from the development of a theoretical model based on the governing equations of turbulent fluid flow to field experiments designed to give results directly applicable to practical problems. Guided by a new analytical framework in steamline co-ordinates and the results of preliminary field and wind tunnel experiments, the Division is now undertaking two major field studies. The first, over a large 2-dimensional ridge, is intended to resolve the effects of scale, surface roughness and thermal stability as basic parameters in the development of a theoretical model of the situation. The second, in collaboration with the NSW Electricity Commission, is taking place near a proposed thermal power station site on the Central Coast. The Division is attempting to understand the wind regime in this region of very complicated hills and valleys and to apply the results of this work to the practical problem of predicting pollutant dispersion in such a complicated terrain.

Division of Geomechanics

The Division of Geomechanics conducts basic and applied research in geo-engineering operations including mining, underground construction, subsurface isolation of waste and marine geo-engineering. Projects including geological research are undertaken within the Surface Mining and Geo-engineering Sections of the Division.

In the Bowen Basin investigations are being made on the role of geological factors in the development of surface and underground coal mines. Combined sedimentological and structural analyses of the coal measures are being used to understand the geomechanical environment of mining. Sedimentological models developed to predict lithological distribution within the coal measures have highlighted the importance of peat compaction in the early stages of coal formation. A study of the strength of clay-rich rocks and their behaviour in the mine environment includes the interaction between osmotic swelling pressures and interparticle bonding of clays in terms of slaking and dispersion behaviour. The regional distribution of Cainozoic deposits in the Bowen Basin has been reviewed and an assessment of remote sensing techniques undertaken in the Blackwater District using NOAA-AVHRR, Landsat MSS and Satellite Imaging Radar. Future work will concentrate on infra-red wave bands and radar as being the most suitable for geo-engineering purposes.

Investigations continue on the stability of steady frictional sliding and on the influence of water on the deformation of silicates. In the first project, experimental work has been aimed at establishing the influence of changes of normal stress upon the shear stress response at constant sliding velocity. A stepwise increase in normal stress induces a slow logarithmic increase to a new value which is proportional to the new normal stress. A stepwise decrease in normal stress always leads to stick-slip events followed by oscillatory behaviour. These relationships are being modelled using hybrid computer codes. In the second project, now that the dependence of water concentration upon the partial pressure of oxygen, pressure and temperature has been established, creep experiments are being conducted under specified conditions in order to determine the dependence of creep rate upon these parameters and upon water concentration.

Work continues on the characterisation of load-bearing properties of offshore Australian calcareous sands. Techniques of studying deformation fabrics induced during laboratory tests have allowed the identification of microscopic processes of grain boundary fracture, rotation and repacking of grains and crushing of grains and cement. A microstructural model has been developed which describes the initial structure and the changes which occur during deformation.

A project on Geophysical Modelling is applying numerical modelling techniques (particularly stress analysis) to a study of the thermomechanical evolution of extensional sedimentary basins and other areas of the Earth's crust. Initial analyses conducted on contrasting geological cross-sections through the northern margin of the Amadeus Basin in central Australia have indicated different distributions of deviatoric stress in the upper crust and different levels of mechanical stability in two-cross sections.

The Division of Geomechanics operates from sites in Brisbane, Wollongong, and Broken Hill and its headquarters in Melbourne. It has 43 professional and 47 technical and support staff and is actively involved in collaboration with industry and academia.

Division of Groundwater Research

This Division was created in July 1982 to enhance CSIRO's activity in the water resources sector. In broad terms the Division investigates processes affecting the quality and quantity of groundwater systems to various anthropogenic stresses. Major thrusts of the 29 professionals are concentrated in the estimation of recharge from rainfall, mapping and characterising transport of agricultural phosphate and organic contaminants from landfills, quantifying hydrological aspects of landscape salinity problems, applications of remote sensing, and development of techniques for better management of water use. Most of the field work is presently conducted at various sites in the southwest of WA. Some of the projects are mentioned below.

The Collie catchment salinity study, financed by a grant from the AWRC examined the dynamics of salt leaching after clearing for agriculture. Evidence based on daily data from catchment areas indicates that there is no clear sign of a return towards a salt balance 9 years after clearing in this high-rainfall (about 1200 mm/yr) area. An essential component of the study is the effect of clearing on the net recharge rate to aquifers in the mantle of deeply weathered material overlying crystalline basement rocks. During the past year work has continued on mechanisms and patterns of recharge. There is good evidence of substantial variation in recharge rates over distances of only a few metres, with flow being concentrated in much more conductive structures beneath a shallow ephemeral water table aquifer during rainstorms.

The Water Authority of WA is supporting work to estimate recharge rates under softwood plantations and natural *Banksia* woodland of the Gnangara mound, a major water table aquifer on the northern outskirts of Perth. Leaching of applied bromide indicates a substantial local variation of recharge in what is superficially a relatively homogeneous sand mass. This has implications with respect to sampling for recharge estimation using natural tracers such as chloride or stable isotopes, or any other small scale measurements in the unsaturated zone.

At the Canning Vale waste disposal site, analysis of methane in gas samples from only a metre or so beneath the ground surface has been shown to be a simple and effective technique of defining the pollutant plume. Research is continuing into the transport of methane from within the aquifer. This disposal site is closing, and research is beginning at a new location in the Perth suburbs.

In collaboration with the Water Authority of WA, a major study of domestic water use in Perth has been completed. This will be reported and reviewed at a national workshop in the coming year.

Division of Mineral Chemistry

A study of silver mineralisation in the Elura orebody has been undertaken in order to understand the reasons for high silver losses in tailings. The amount of silver in galena was found to vary significantly from the relatively silver-enriched varieties in the outer and uppermost parts of the orebody, to the silver-poor galena present at depth. Significant silver is also present in impure pyrite and minor friebergite.

Mineralogical research has identified a number of complex sulphosalts and sulphide minerals including a range of bismuthinite derivatives and cosalite. A new copper sulphide mineral from Roxby Downs, with a proposed name of roxbyite, is structurally related to djurlite and low chalcocite. Crystal structure relationships have been defined for the newly established cuprobismuthite series.

Other research projects concerned with geoscience include: the determination of the structure of two titanate minerals from kimberlite diamond deposits; electron microprobe studies of the Hinchinbrook peralkaline granites in which the ilmenites and arfvedsonites are enriched in manganese relative to those found in similar granites; and a study of the magnesite deposits in NSW and a recently discovered deposit at Hillview near Rockhampton.

Division of Minerals and Geochemistry

The Division was established in 1985 to consolidate the existing CSIRO minerals research in Western Australia. Dr D. F. A. Koch, formerly the Chief of the Divison of Mineral Chemistry, was appointed Chief of the new Division.

The role of the Division as a component of the Institute of Energy and Earth Resources is to conduct research that will contribute to the better definition, utilisation and management of Australia's mineral resources with special emphasis on WA. The Division undertakes research in the areas of mineral exploration, ore-body characterisation, mineral beneficiation and mineral extraction, with the aim of developing new methodologies for exploration, enhancing exploitation of existing ore bodies and developing or improving processes for the production of higher-value products from mineral raw materials. There are 15 professionals in exploration research, 10 in beneficiation and extraction, and 12 in new products and waste treatment.

Resulting from industry consultation, the Division's resources in exploration research are being redirected to provide a greater emphasis on development and improvement of procedures for locating mineral deposits within and beneath the deeply weathered regolith that characterises so much of the Australian landscape. There is a close integration with the research activities of the North Ryde Laboratory of the Division of Mineral Physics and Mineralogy.

The Division has two programs of exploration research. The first of the two programs has the objective to improve and develop exploration procedures for locating mineral deposits through studies of the characteristics of the weathered zone and an understanding of the processes of weathering and element migration. Included are studies of dispersion from concealed mineral deposits in lateritic terrains, and studies directed at understanding dispersion mechanisms and weathering processes. Current emphasis is on geochemical exploration for gold deposits.

A collaborative research project with Greenbushes-St Joe has established improved methods of multi-element geochemistry based on sampling and analysis of lateritic duricrust together with statistical interpretation of the geochemical data. Compilation of a geochemical database for lateritic terrains within the Yilgarn block is well advanced and forms the base for a phase of research involving the use of multivariant statistical procedures for interpretation. The broader program on exploration methodology has been extended to cover the behaviour of gold and associated elements in weathering profiles of gold deposits in the Kalgoorlie district. Remote sensing techniques have been applied to mineral exploration in the Yilgarn block and to delineate buried palaeodrainages in the Canning Basin of Western Australia. Emphasis has been placed on integrating NOAA thermal imagery with BMR magnetic and gravity data through a joint project on the Yilgarn block.

A CSIRO-developed digital voltammeter for field and laboratory analysis of trace metals in water is now manufactured by Chemtronics under licence from CSIRO. As well as application in geochemical analysis it is being marketed for use in mineral processing and environmental control.

Research on the use of helium as an indicator of hydrocarbon and uranium deposits has been completed and results have been presented in reports published by NERDDC and WAMPRI, who funded aspects of the project, and in journals. Despite apparently encouraging results obtained overseas, the research has shown that helium has little potential in mineral exploration, but that, correctly used, it could assist geochemical exploration for hydrocarbons.

The second program of exploration research is based on studies of unweathered ore bodies and their host rocks with research on the physical and chemical processes of ore formation. An emphasis has been placed on studying the important Precambrian mineral deposits of iron, nickel, gold and platinum in WA with a view to developing geochemical and geological techniques for locating ore mineralisation that occurs beneath the mantle of deep weathering and younger surficial deposits.

Research on the origin of magmatic nickel sulphide ores continued in the Agnew-Wiluna belt and was expanded by the appointment of a WAMPRI-BP Minerals-CEC research fellow to study the ore environment and ultramafic host rocks of the Perseverance nickel deposit. A major conclusion of the research has been that the ore zones are associated with an extrusive rather than intrusive facies of komatiitic volcanism.

The AMIRA-sponsored research project on iron ores of the Hamersley province has continued, with a highlight being a visit to study iron ore mines in northeastern and southwestern provinces of India. Laboratory research has indicated that quartz solubility is greatly enhanced under certain conditions in the presence of iron, providing a mechanism for leaching of silica from BIF in a reasonable time frame.

Research has continued on the petrology and stratigraphy of the Windimurra layered gabbroic complex with a view to assessing its potential as a host for platinum mineralisation. The nature and distribution of platinum and palladium mineralisation at Kambalda has been established as a result of a joint WAMPRI-WMC project. Sperrylite and sudburyite are dominant phases.

Within the Ashburton Trough, detrital gold mineralisation has been shown to occur only where sedimentary rocks have been derived from the pre-Hamersley Fortescue volcanics or Archaean basement. Gold and osmiridium have been recovered from outcrop loaming and stream sediments near Karratha, suggesting that they were deposited in sedimentary rocks derived from older Archaean mafic and ultramafic sequences.

Geoscientific research in other programs of the Division includes work aimed at determining the mineralogy of refractory gold ores, particularly with regard to extraction techniques; the nature of pyritic black shale in iron ore mines and the causes of spontaneous combustion; development of economic extraction processes for Australian rare earth ores; improvements to the extraction of alumina from bauxite, and the influence of clay mineralogy on ceramic products and the production of advanced ceramic materials.

Division of Mineral Physics and Mineralogy

The Division arranged and managed a major remote sensing project in which a consortium of Australian companies and Federal and State agencies, together with NASA and the Jet Propulsion Laboratory of the USA, conducted a month-long series of remote sensing experiments in Australia in October 1985. Some 54 test-sites were examined using the NASA C-130 aircraft which is equipped with spectral scanning instrumentation. The CSIRO F27 research aircraft equipped with scanners and spectrometers developed by the Division was also flown over some of the sites. The major goal of the project is to develop practical remote sensing technologies for the 1990s to be used in Australia for mapping and exploration, and monitoring and management of resources. Such technologies must be researched locally because of the unique characteristics of the Australian vegetation and terrain. The organisations involved in the project will spend two years in analysing the immense amount of data collected and in conducting local 'ground truth' investigations.

The early-time SIROTEM transient electromagnetic equipment and techniques developed by the Division for minerals exploration has been applied to mapping subsurface soil salinity and groundwater pollution. Normal groundwater investigations involve the drilling of a large number of costly boreholes and borehole sampling. TEM may be used to determine the areal extent of sub-surface electrical conductivity, and depth profiles may be determined from joint inversion of TEM and DC sounding resistivity data.

Collaborative research with Aberfoyle has provided a better understanding of the petrological and geochemical setting of the Que River volcanogenic massive polymetallic sulphide deposit in northwest Tasmania. Exploration in this area is made difficult by the lack of clear stratigraphic markers and by problems with hand specimen identification of rocks.

Geochemical studies of the host rocks showed that some elements remained immobile during the intense alteration associated with mineralisation and later regional metamorphism and deformation. A technique based on the ratios of immobile elements, developed for identifying primary rock types in the area, is being used in the current exploration program.

The successful development of the lead isotope technique for mineral exploration led the Division to establish SIROTOPE for a trial period. This is a commercial lead isotope analysis and data interpretation service. During its first year of operation the service attracted a large number of clients from Australia and overseas, and many of the initial contracts have led to more extensive work programs.

Division of Oceanography

The year saw the culmination of a major commitment by CSIRO and the Federal Government to marine science, with completion of the transfer of the CSIRO Marine Laboratories from NSW to Tasmania, the official opening of the new Hobart laboratory complex on 1 May, and the commissioning of the new oceanographic research vessel *Franklin. Franklin* is equipped for the conduct of physical, chemical and biological oceanography, is operated by the Division as a national facility, and is available to all marine scientists in Australia.

The Division undertakes major research programs, covering the dynamical description of Australian regional seas on all scales, and the characterisation of these waters in terms of origins and chemistry. There is participation in the major long-term international Tropical Ocean–Global Atmosphere (TO-GA) program, which is of great potential importance to Australia because its objectives include assessment of predictability of climate in relation to tropical ocean variability. Regions of primary interest are the equatorial west Pacific and eastern Indian Oceans in which the Division has established an extensive long-term observational network, including regular collection of subsurface temperature profiles by commercial vessels, and tidal observations from gauges in Papua New Guinea.

Other projects include the Western Equatorial Pacific Ocean Circulation Study (WEPOCS) undertaken in conjunction with US investigators; and the major Australian Coastal Experiment (ACE), on the dynamics of coastal trapped waves off the southeastern Australian continental shelf, which showed that up 70% of the longshore current variability can be accounted for by such waves.

The facility for the reception and analysis of high resolution infrared sea surface images from NOAA satellites reached full operational status. Station coverage includes most of Australia and the adjoining Southern Ocean as far as Antarctica. The group servicing the scientific needs of the maritime industry continued its modelling work. Industry benefits included tidal current predictions in Bass Strait, and predictions of tropical-cyclone-generated current and storm surges on the NW shelf, both for the offshore oil and gas industry.

In marine chemistry, measurements of the complexing capacity of seawater have shown variations of nearly two orders of magnitude with depth and location, and the possibility of complexing capacity being an indicator of ocean dynamics and biological activity is being investigated. Techniques have been developed for the analysis of a wide range of organic compounds in trace quantities in sea water and marine sediments, and investigations of how their distribution is related to chemical, biological and physical processes are underway.

The Division's increased capability in marine instrumentation development is reflected in commencement of commercial production of a versatile self-contained submersible data logger. Other projects underway include an instrument to provide a continuous profile of chemical concentration with depth, and a programmable towed body (the 'BUNYIP'), designed to profile the ocean in an undulating mode to study vertical mixing and vertical shear stresses.

Division of Soils

Redirection of research at the Division of Soils has resulted in greater emphasis being placed on the physical properties of soils. This research is currently concentrated on two groups of soils—the cracking clays of northern NSW and southern Queensland and duplex (texture contrast) soil. A team based in Brisbane, complemented by soil physicists in Canberra, is characterising the cracking soils of the Narrabri area. The ultimate aim is to provide guidelines to farmers so that farming operations cause the least damage to soil structure. A survey of the soils on the wet coast between Townsville and Cairns, whilst still in progress, is already providing information of use to the Queensland Department of Primary Industries and farmers.

Research continues on the processes responsible for the formation of Australian soils and landscapes. Emphasis is being given to the study of hardpans in arid soils, to the accumulation of secondary silica, and to the dating of sediments using amino acids of fossil organic matter.

In Adelaide, work has continued on defining the extent of boron toxicity in the soils of Victoria and South Australia. Many thousands of samples of barley grain from known locations, obtained from the Barley Board, have been analysed and the result used to produce maps of the incidence of areas of high boron. The analyses have also provided information about the extent of areas of soils with low, marginal and high levels of other nutrient elements. Research on the hydrology of the Murray Basin has been upgraded to provide data on the likely amounts of water entering aquifers as a result of vegetation clearance in the Basin.

A study by the Mineralogy group of the formation of iron oxides in soil has led to the preparation of a number of materials with potential as catalysts for industrial processes, as well as the production of an anti-arthritic compound of considerable promise.

Division of Water and Land Resources

Research at the Division of Water and Land Resources involving geoscience concentrated in four main areas. The first, involving the prediction of the location and extent of waterlogging in forest soils will enable foresters to plan tree felling in order to minimise the area of resulting saturated soil. The model of hillslope hydrology behind this option simulates the effect of removing trees, and has the capacity to predict the growth or contraction of waterlogged zones according to the amount and location of forest cleared within a catchment. Although the rate of transmission of water through the soil and the quantity of water leaving the catchment are not taken into account, the model can determine with considerable accuracy the relative wetness of zones. In a trial with the Queensland Department of Forestry in Tuan Forest near Gympie, good correspondence has been found between an area with current regrowth problems due to soil wetness and an area predicted by the model to be wet. Current work in forested catchments near Eden on the south coast of NSW is likely to lead to further development of the model, especially with respect to the complex issue of soil variability.

In the Murrumbidgee Irrigation Area (MIA) electromagnetic surveys followed by drilling have been used to locate relatively shallow, water-bearing sand lenses and stream beds. The chemistry of shallow (< 10 m) groundwater is being investigated to provide basic information for water re-use and for predicting the value of waste waters for subsequent mineral recovey. A thermodynamic model 'CHEMIX' developed by the CSIRO Division of Mineral Chemistry, is being employed to demonstrate the chemical sequences that can be expected during dilution and/or evaporation of the various classes of groundwater encountered in the MIA. The possibility that the high salt concentrations found in evaporation basins may cause physical changes in soil properties, as indicated by hydraulic conductivity values, is also being examined.

Stable isotopes are being used to measure evaporation rates in the arid Amadeus Basin, one of the major artesian basins of Australia. The Amadeus Basin centred on Lake Amadeus, is bounded to the north by the MacDonnell Ranges and to the south by the Peterman Ranges. A large part of the basin consists of dune fields, and there is a central chain of normally dry saline lakes (including Lake Amadeus). These lakes are thought to be discharge points for groundwater infiltrating through the dunes and creek beds, so that a knowledge of evaporation from them will give an indication of the total flux or movement of water through the basin. A joint project with the Bureau of Mineral Resources is aimed at estimating this flux, as well as giving a more detailed understanding of the hydrology of this region. By measuring the concentration of deuterium in surface sediments at representative points on the dry lake bed, the total evaporation from the lake surface can be estimated. It is postulated that this in turn will give an indication of the total flux of water through the basin, and the amount of groundwater available on a sustainable yield basis.

The radioactive isotope caesium 137, deposited across large tracts of Australia from atmospheric nuclear weapons tests between 1946 and the 1970s, is being used to determine rates of soil erosion. In a collaborative study with the Australian Atomic Energy Commission, the isotope has been used as an indicator of recent topsoil erosion in a grazed poplar-box woodland in southern Queensland. The caesium isotope, which was not present prior to atmosphere testing, adheres to fine clay particles in the top few centimetres of soil. Soils which have undergone significant erosion since the early 1960s, the time of heaviest caesium fallout for Australia, have less of the isotope in their topmost layers than comparable uneroded soils. Data demonstrate clearly that removal of tree and shrub cover in this semi-arid environment increases the rate of topsoil erosion. Even under normal grazing regimes, topsoil loss is significantly greater than in non-grazed areas, and in the long term may lead to serious degradation of the soil resource.

EXPENDITURE OF GEOSCIENCE RESEARCH IN AUSTRALIA

This survey on expenditure on public geoscience research is based on information collected from funding bodies, CSIRO, and BMR only. The expenditure by these organisations is estimated to represent more than 75% of total expenditure of public geoscience research in Australia.

For the purposes of the survey, the term 'geoscience' is defined as comprising the disciplines of, and sub-disciplines within, geology, geophysics and geochemistry, and includes soil science and relevant areas of geography and oceanography.

Information for the survey was obtained from the following organisations:

- Australian Mineral Industries Research Association (AMIRA)
- Australian Research Grants Scheme (ARGS)
- Bureau of Mineral Resources, Geology & Geophysics (BMR)
- Commonwealth Scientific & Industrial Research Organisation (CSIRO)
- Earth Resources Foundation (ERF)
- National Energy Research, Development & Demonstration Program (NERDDP)
- Queen's Fellowship and Marine Research Allocations Advisory Committee (QFMRAAC)—formerly Australian Marine Sciences and Technologies Advisory Committee—Funding Advisory Panel (AMSTAC-FAP)
- Western Australian Mining and Petroleum Research Institute (WAMPRI).

Expenditure for 1984-85 (and comparable figures for 1983-84 and 1982-83) is shown in Table 1. The figures indicate that total expenditure in 1984-85 was up 11% on the 1983-84 figure. This is the same percentage increase that was recorded for 1983-84 but, whereas previously the increase was due to increased spending by CSIRO and the funding bodies, for 1984-85 all the increase can be attributed to increased expenditure by BMR. In fact, BMR's expenditure increased by almost 40% to just under $30 m. The percentage increase is however misleading as the complex negotiations involved in implementing the Continental Margins Program resulted in funds approved for expenditure in 1983-84 not being spent until 1984-85. Had they been spent in 1983-84 the increase would have been approximately 20%. This increase reflects:

- the first full year of the Continental Margins Program
- a new deep-stratigraphic drilling program
- an increase in the program of digitisation of aeromagnetic data
- an upgrade of major plant and equipment items including a new seismic acquisition system and a nuclear-monitoring capability.

Expenditure in 1984-85 was lower in CSIRO and in ERF (both down $0.3 m from the 1983-84 level) whilst spending by the major funding bodies remained largely unchanged.

If it is assumed that total expenditure on geoscience research by tertiary institutions, State Geological Surveys, and other research organisations remained at 1983-84 levels, then total spending on public geoscience research in Australia in 1984-85 exceeded $100m.

Table 1. Comparative expenditures for 1982-83, 1983-84, and 1984-85 by funding bodies, BMR, and CSIRO on geoscience research

Funding body, organisation	Expenditure, $m		
	1982-83	1983-84	1984-85
ARGS	1.47	1.58	1.59
QFMRAAC	0.77	1.17	1.08
NERDDP	1.34	1.68	1.60
ERF	0.52	0.55	0.24
AMIRA	1.95	1.99	2.11
WAMPRI	0.46	0.63	0.72
Sub-total (funding bodies)	6.51	7.60	7.34
CSIRO[1]—Salaries	19.36	23.6	25.41
—Operations	10.59	10.8	11.58
—Capital	7.03	7.8	4.86
Sub-total (CSIRO)	36.98	42.2	41.85
BMR[2]—Salaries	13.16	14.25	15.58
—Operations	6.39	6.50	10.07
—Capital	1.46	0.98	4.22
Sub-total (BMR)	21.01	21.73	29.87
TOTAL	64.50	71.53	79.06

[1] 1984-85 figures include geoscience research by Divisions of Soils ($9.01 m), Water & Land Resources ($3.21 m), Oceanography ($8.39 m), Geomechanics ($4.37 m), Environmental mechanics ($0.84 m), Groundwater Research ($3.98 m), Fossil Fuels ($0.55 m), Mineral Chemistry ($0.87 m), Minerals & Geochemistry ($5.79 m), and Mineral Physics & Mineralogy ($4.83 m).
[2] Includes resource assessment and geoscience database.

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NOTEWORTHY MINERAL AND HYDROCARBON DISCOVERIES 1985

Table 2. Noteworthy mineral discoveries—1985

Name	Companies	Location	Type of Deposit	Grades & Reserves
Coronation Hill	Noranda Aust/BHP Minerals EZ Industries Limited	240 km SE of Darwin NT	Brecciated volcanics (gold and platinum group elements)	800 000 t grading 5 g/t
Pajingo	Pajingo Gold (wholly owned by Duval Mining Australia)	70 km S of Charters Towers Qld	Linear lodes of epithermal origin (gold)	Janet A zone 1.4 Mt grading 12.6 g/t (other parts of the deposit not tested)
Kunwarra	Queensland Metals Corp NL	70 km NNW of Rockhampton	Stratiform	460 Mt containing an estimated 47% by volume of nodular magnesite in an unconsolidated matrix of clay and magnesite

Table 3. Noteworthy hydrocarbon discoveries—1985 (a)

Basin	State	Field Name	Company (Operator)	Type of Discovery
Bass	Tas	Tilana	Amoco	o/g
Bass	Tas	Yolla	Amoco	o/g(c)
Bowen/Surat	Qld	Fairymount	Sydney Oil	o
Bowen/Surat	Qld	Louise	Bridge	o
Bowen/Surat	Qld	Mayfield	AAR	g
Bowen/Surat	Qld	McWhirter	Sunland	o
Bowen/Surat	Qld	Merrit	AAR	g
Bowen/Surat	Qld	Raslie*	AAR	g
Canning	WA	West Terrace	Home Energy	o
Carnarvon	WA	Montague	Woodside	g
Carnarvon	WA	Saladin	WAPET	o
Carnarvon	WA	Elder	Wesminco	g
Cooper/Eromanga	Qld	Cook	Delhi	o
Cooper/Eromanga	Qld	Epsilon*	Delhi	g
Cooper/Eromanga	Qld	Kenmore	Lasmo	o
Cooper/Eromanga	Qld	Mooliampah	Delhi	o
Cooper/Eromanga	Qld	Talgeberry	Hartogen	o
Cooper/Eromanga	Qld	Toobunyah	Hartogen	o
Cooper/Eromanga	Qld	Watson South	Delhi	o
Cooper/Eromanga	Qld	Wippo	Delhi	g
Cooper/Eromanga	SA	Aroona	Delhi	g
Cooper/Eromanga	SA	Bagundi	Delhi	g
Cooper/Eromanga	SA	Baratta	Delhi	g
Cooper/Eromanga	SA	Gidgealpa*	Delhi	o
Cooper/Eromanga	SA	Gooranie	Delhi	g
Cooper/Eromanga	SA	Lepena	Delhi	g
Cooper/Eromanga	SA	Meranji	Delhi	o/g
Cooper/Eromanga	SA	Muteroo	Delhi	o
Gippsland	Vic	Snapper*	Esso/BHP	o/g

(a) Gas discoveries with flow rate >100 Mm^3/d
Oil discoveries with flow rate >20 m^3/d
(c) Condensate
* New pool discovery
o Oil
g Gas

Minerals and petroleum are non-renewable resources. As the known deposits are consumed, it is necessary to discover new sources of supply to maintain Australia's resource inventory at a satisfactory level, thus providing a sound basis for long-term planning for both national development and export markets.

The accompanying tables list noteworthy discoveries made during 1985. Many of the discoveries must be regarded as long term resources until development work determines that they are economically amenable to exploitation.

The data were prepared and compiled by officers of the Resource Assessment Division, Bureau of Mineral Resources.

Resource Assessment Division
Bureau of Mineral Resources

TERTIARY GEOSCIENCE EDUCATION IN AUSTRALIA

Colin D. Branch[1]

SUMMARY

This report from the Australian Geoscience Council results from the Council's long-standing interest in the organisation and relevance of geoscience education in Australia. It represents views obtained from member societies as well as the outcome of a *Workshop on Tertiary Geoscience Education in Australia,* held on 29 November 1985 in Sydney, at which it was agreed that the objectives of geoscience education were threefold: to ensure the health of geoscience in Australia; to meet the broad role of geoscience in society; and to meet the professional needs of a variety of customers.

The first two objectives are achieved by ensuring that geoscience subjects are available on every tertiary campus, with a status equal to other sciences. Geoscience subjects must be available where they are required to support another discipline or form part of a joint degree. Overall, about 4000 tertiary students are presently exposed to geoscience in one of these ways each year.

'Professional' needs (where the term is limited to persons who work full-time as professional geoscientists in easily identifiable fields) are achieved best through four-year undergraduate courses of a classical or applied style or a combination of both, with little or no specialisation. One tentative estimate is that about 200 graduates are required in this restricted class each year, of whom 51% move to industry, 40% to government, and 9% to tertiary

[1]South Australia Department of Mines & Energy, Adelaide.

institutions. Graduates should have a sound education involving the practical application of classical knowledge, an inquisitive nature, an ability to apply scientific methods to investigations, good communication skills, and, for industry, an appreciation of business and economic realities. At present, in the undergraduate geoscience departments teaching geology, staff numbers are barely adequate, and more lecturers are needed in geophysics and most applied fields. For soil science in faculties of agriculture, insufficient staff are available at each institution to cover the required range of subjects, and a pooling of resources is needed to achieve suitable standards.

Most undergraduate courses that seek to produce professional geoscientists should be associated with schools of postgraduate study (MSc by course work or research, and PhD by research). Some of these postgraduate schools should be designated as key centres specialising in a particular classical or applied sub-discipline of geoscience. It is estimated that between 10 and 15 key centres are required in Australia but the range of specialities and the criteria for the selection of key centres have yet to be resolved. However, it is believed that only in this way will the most efficient use be made of the staff and equipment that can be provided by present financial resources. Students will be expected to move for further studies to an appropriate key centre, and adequate levels of support must be provided for travel and living allowances to retain graduates best suited to advanced studies and research.

Once the number of key centres has been decided, together with their specialisation and location, and rationalisation completed (possibly involving multi-campus associations and the joint appointment of staff), regular external reaccreditation procedures must be instituted to ensure the ongoing viability, relevance and excellence of advanced tertiary geoscience education and research in the key centres.

It is expected that the movement of academic staff to appropriate key centres will constitute the major problem in rationalisation, but over the next five years a large portion of retirements are due and this provides the opportunity to implement change more rapidly. The desirability of tenure has been questioned, but may be appropriate at senior levels; nevertheless, periodic review of staff performance should be carried out in all departments.

Future action includes the wide distribution of this report for discussion and comment; an in-depth examination of the key centre concept; and the initiation as soon as possible of an authoritative review of the present system of tertiary geoscience education in conjunction with the Commonwealth Tertiary Education Commission (CTEC).

TERTIARY EDUCATION AND THE RELEVANCE OF GEOSCIENCE TO AUSTRALIA

During the past decade the tertiary education sector in Australia has been under stress and in need of review. Questions have been asked, and generally not answered, about the philosophy and accountability of education; the sociological and political realities; future trends; the efficient use of resources, especially recurrent funds such as staff salaries, and capital expenses such as buildings and equipment; the accreditation of disciplines; and the tenure system.

In 1984 CTEC started a major review of the discipline of law, and reviews of other disciplines including geoscience are planned for the future. Hence the present inquiry by the Australian Geoscience Council into tertiary education in the geosciences cannot be considered in isolation. Nevertheless, the tertiary geoscience sector is faced with making difficult decisions during a time of considerable downturn in the minerals industry and it is feared that the normal expedient of short-sightedness may prevail.

This should not be allowed to happen because of the contribution the geoscience-based industries make to our national standard of living and international stature. The mining and petroleum industry generates 45% of Australia's export income, and contributes significantly to the Australian economy. Perhaps this is most readily understood in relation to petroleum whereby Australia is relatively self-sufficient today but in ten years' time Australia's import bill for crude oil could be several billion dollars a year unless new oil discoveries are made. Similar scenarios can be developed for other minerals. The importance to Australia of appropriate geoscience education in order to maintain the supply of suitably trained graduates to ensure continuing self-sufficiency in petroleum and an adequate economic supply of export grade coal and minerals must not be underestimated.

Soil science is another facet of geoscience covered by the umbrella of the Australian Geoscience Council. Given that agriculture also contributes 45% of Australia's export income, and that soil erosion is perhaps the major current agricultural problem, it is incomprehensible that this country has fewer lecturers in soil science than New Zealand and that none of these is an expert in soil conservation. In relation to tertiary education the situation in soil science is somewhat different from the other geoscience sectors because soil science is not a stand-alone discipline, and the number and range of employers is much smaller, but overall the problems and possible solutions have much in common.

Yet the purpose of tertiary education is not solely to educate for professional careers. Many would argue that graduates in other disciplines, teachers and the general public they influence, company executives, government bureaucrats, and politicians should have a balanced grounding in geoscience together with the other sciences and humanities as part of their educational background. Otherwise opinions will be formed in the community and decisions made by government in relation to matters affecting the Earth we live on which will be to the detriment of our nation.

Consequently it is recognised that the purpose of tertiary education in geoscience is multifaceted and seeks to ensure the health of geoscience in Australia; to meet the broad role of geoscience in society; and to meet the professional needs of customers. How to achieve these objectives more effectively in the future than is done at present was a major theme for discussion at the workshop convened by the Australian Geoscience Council on 29 November 1985 in Sydney, which is the main subject of this review.

THE PRESENT SITUATION

Institutions and courses

Undergraduate courses to bachelor level or its equivalent, in what may broadly be termed the geological aspects of geoscience, are offered by 27 Australian tertiary institutions. Sixteen are universities, five are institutes of technology, five are colleges of advanced education, and one is a school of mines (Balme, 1985). Courses include three- and four-year bachelor degrees, and three year degrees with a fourth year of honours or a graduate diploma. The content ranges from classical (or traditional) geology, through various levels of applied geology, to general earth science. Some institutions, especially those considered to be applied, retain a broad but generally dictatorial approach to course content and allow only slight choice or specialisation during the last stages of the course, whereas others allow a wide choice of subjects from first year onward and moderate specialisation.

At the postgraduate level, all universities offer both masters and doctoral research degrees, and a few provide masters degrees by course work. Within the Australian National University the Research School of Earth Sciences in the Institute of Advanced Studies offers only postgraduate degrees, mainly doctorates. Amongst the other tertiary institutions, only four of the five institutes of technology offer masters degrees, and none award doctorates.

During 1985, CTEC introduced the concept of tertiary key centres for various disciplines, and eight faculties or departments around Australia were identified as the foci for additional funding over three years to assist in the upgrading of undergraduate education. For example, the Department of Geology at the University of Adelaide was designated as a key centre for Petroleum Geology and Geophysics (together with the relevant resources from Flinders University and the South Australian Institute of Technology). CTEC has allocated $150 000 per year for three years to develop the key centre and although there is no guarantee of funds after this it is hoped by CTEC that such a key centre will become a focus for industry backing.

As discussed later, the concept of key centres in geoscience at the undergraduate level was opposed by the majority at the workshop on the grounds that they force specialisation too early in a student's education, but it was agreed that there is considerable merit in the concept at the postgraduate level.

In addition to traditional tertiary courses, graduates are able to avail themselves of intensive short courses in specialised aspects of geoscience provided regularly by the Australian Mineral Foundation, less frequently through the Earth Resources Foundation, University of Sydney, and sporadically by various tertiary institutions.

Geoscience graduates

Surveys by the Australasian Institute of Mining and Metallurgy, and Taap & Watkins (1984) indicate that the 27 geoscience departments are producing about 300 first degree graduates each year. One estimate of the number of professional geoscientists required in Australia is approximately 200 per annum (see also Crook, Appendix 1), but this ignores those moving into teaching, commerce, law, environmental studies, or the other professions where geoscientific knowledge can be usefully applied. These figures should also be viewed with caution because many professional posts are occupied by overseas graduates, and despite the claim that Australian institutions produce too many gruduates, numbers of overseas graduates are still being employed.

A useful analogy may be drawn with biology departments, for example, which produce many more graduates than geoscience departments, yet biology graduates find employment in a variety of areas though they are 'professionally' educated, and the number of professional places is small. It is no coincidence that public appreciation of biological science is at a higher level than that of geoscience.

Predictions of the future demand for professional geoscientists have rarely been reliable in the past, because they have failed to take account of the less obvious areas where professional geoscience training is required, and because economic factors are so unpredictable. Some estimates for the 1990s are as low as 100 to 200 per year. The career fields in which they will work are even more uncertain, but several predictions were made during the workshop and the detailed analysis by Stapledon is discussed later. Many consider that the figures produced are gross underestimates because they fail to take into account the large variety of fields where professional geoscientists gain employment, and must continue to gain employment if geoscience is to maintain even its present inadequate status in Australian society.

Postgraduate students in 1984 numbered about 500 in the universities and in the institutes of technology (Balme, 1985). The annual rate of graduation and placement of these postgraduate students is unknown.

Statistics gathered by Sant (1984a) for the Australian Geoscience Council's human resources survey indicate that 51% of geoscience graduates are employed in industry, 40% by government bodies, and 9% by tertiary institutions. Nevertheless, Sant (1984b) also shows that less than half of the geoscientists entering the profession are in the same field of employment five years after the start of their career (although many return to their initial field later, and the figure stabilised at about 70%).

The multiplier effect

Although the number of first-degree graduates in geoscience is relatively small, each year about 3000 undergraduates are enrolled in first and second year geoscience courses around Australia (Balme, 1985). Most of these students take geoscience units as options while studying another discipline or while undertaking a joint degree. In addition, specialist geoscience service courses are provided for about 1000 students in related professional courses such as mining and civil engineering, metallurgy, teaching, and agricultural science. Hence the presence of a geoscience department within a tertiary institution provides the opportunity for a large and significant segment of the population to be influenced by the staff of that department. Many in the geosciences believe this sphere of influence should be expanded in the interests of the country as a whole.

Geoscientific academic staff

The 27 geoscience departments in Australia employ about 280 mostly tenured full-time academic staff of which 217 are at universities (Balme, 1985). The number of academic staff at any one institution ranges from four to 40, but amongst the universities, if the large number of earth science staff at Macquarie University is deleted, the average is 12; and at colleges of advaneed education the average is six. The range of specialist academic staff expertise indicated by Balme (1985) gives him the impression of 26 essentially conservative courses all offering, on different scales, the same range of course options. This is attributed by Dorothy Hill (quoted by Armstrong during the workshop) to the large numbers of graduates of the 1950s and early 1960s who are now of mature years and teaching in the geosciences; she maintains that the classical content of teaching by tertiary educators today has a thread which runs back through the teaching of geoscience over the last two generations of educators. Nevertheless, it must be recognised that although the title of a topic may remain the same, course content may change radically: for instance, metamorphic petrology as understood today is vastly different from ten years ago.

Balme (1985) considers that it would be unfair to impute the apparent lack of innovation entirely, or even largely, to lack of energy or imagination on the part of academic staff. Part must be the result of financial restriction because most tertiary institutions are now in their tenth year of stagnation or regression as a result of government funding stringencies.

As a consequence little staff mobility has existed and only now are the institutions entering a period of increased flexibility as senior staff reach retirement age. If positions thus vacated **are** retained in the home departments **and** filled by new appointments, and if conditions of tenure remain unchanged, the next five years will therefore set staffing patterns that will survive into the next century. Balme (1985) concludes that it is essential that the decisions taken with regard to staff replacement are based on the advice and deliberations of the widest possible range of informed geological opinion. The Australian Geoscience Council workshop has provided the first Australia-wide forum in which to consider these issues.

Attitudes of those in industry employing geoscientists

Although it is clear that tertiary geoscientific education has a range of objectives, it must be recognised that many of the present graduates are entering professional careers in geoscience, with the majority joining the mineral and petroleum industries. Industrial employers since the mid-1960s have been expressing disquiet about the knowledge and attitudes of many geoscience graduates, and some universities and all the institutes of technology have subsequently introduced courses, generally called applied geology, to overcome perceived deficiencies. Nevertheless, as expressed at the workshop, industry representatives are still highly critical of the education received by most of those they employ, and their arguments and recommendations are discussed and incorporated in this review.

Soil science

At present ten universities in Australia teach soil science at the undergraduate level within faculties of agriculture, but at only two are staff numbers almost adequate to cover the necessary range of specialist fields. Postgraduate courses are available only at the University of Queensland.

The main employer is State government, with some also entering CSIRO. The overall impression is that sufficient graduates are produced in Australia for the positions available but many graduates are inadequately educated to carry out completely the research projects required of them.

Physical geography

Physical geography, which also comes within the ambit of the Australian Geoscience Council, was not formally considered at the workshop.

Physical geography is a major component of the discipline of geography. In most universities it is possible for students to either specialise in physical geography (geomorphology, pedology, hydrology, climatology, biogeography) or to include aspects of physical geography in a more broadly-based major in geography. Geography departments may be located in Arts, Science or Earth Science Faculties but in most universities students may study geography for either BA or BSc degress. All geography departments in Australia offer graduate programs (MA or MSc, PhD).

The complementarity between geomorphology, pedology and geology makes it advantageous for departments of geology and geography to share the education of geoscience students through joint or combined course structures. Graduates in geography are trained in the application of geographic information to a variety of problems and issues arising from the interaction of people with the human habitat. Increasingly, computing and statistical skills are part of their training. Physical geographers find employment in resource exploration, assessment and development; environmental reconstruction; environmental and regional planning; and in aspects of hydrology, remote sensing and environmental geology. They are employed in consulting firms, CSIRO and other environment-focussed institutions, and at all levels of Government from the local to the national in either research or policy-making, commonly forming the link between planners, engineers or ecomomists, and the geoscience community.

THE ROLE AND ACTIVITIES OF THE AUSTRALIAN GEOSCIENCE COUNCIL

At the time of its formation in 1981, the Australian Geoscience Council established a comprehensive review of the human resources in geoscience as one of its main objectives. To date surveys have been completed of 'Employment patterns in government and industry' (Sant, 1984a) and 'The human resource' (Sant, 1984b).

In early 1984, Professor G. J. S. Govett, Council President-of-the-day, approached Senator Ryan as the Commonwealth Minister for Education, to enlist her support for the provision of assistance to the Council to enable it to complete the proposed trilogy in the human resources survey by undertaking a review of tertiary geoscience education. Subsequently, a recommendation by the CTEC to Senator Ryan that it initiate a series of reviews of a range of tertiary disciplines was approved by government. During 1984-85, Dr C. D. Branch, Council President-of-the-day, placed a firm proposal before CTEC setting out the methodology and budget considered appropriate for a survey to be conducted by the Council, arranged for the Chairman of CTEC, Mr H. Hudson to meet with the Council, and initiated the concept of a workshop to discuss the issues involved. On 29 November 1985 under the Chairmanship of Professor J. F. Lovering, Council President-of-the-day, the workshop on 'Tertiary Geoscience Education in Australia' was convened by Dr R. E. Wass and Associate Professor J. Roberts, at the University of New South Wales.

It was the unanimous decision of the delegates at the workshop that the Australian Geoscience Council act as their representative in any future CTEC investigation into geoscience; that Council contact industry to identify areas of deficiency in current geoscience education, and that Council make representations to senior administrators that changes be made in geoscience education in Australian tertiary institutions.

THE WORKSHOP

Over 80 delegates from industry, government and academia attended the workshop on 'Tertiary Geoscience Education in Australia' held at the University of New South Wales on 29 November 1985. Eight speakers during the morning sessions presented a wide range of viewpoints which in the afternoon were discussed and extended by the delegates in a series of small group and plenary sessions facilitated by Mr G. Peters (Manager of Organisational Development, MIM Holdings Ltd).

Because of limited time, discussion was centred on four main areas:

(1) The philosophy of tertiary geoscience education in relation to the needs of the exploration industry, geological surveys and research institutions.
(2) Future directions to be pursued by tertiary institutions in order to achieve the needs of the above organisations. Is there a need for key centres in geoscience, and in what fields?
(3) The need for rationalisation/integration amongst tertiary geoscience departments, and possible mechanisms for implementation.
(4) External accreditation of courses. Should tertiary institutions teach specialist or generalist courses at undergraduate/postgraduate level?

The invited speakers and their topics were:

Professor K. S. W. Campbell, Australian National University—
The classical university view

Professor G. J. S. Govett, University of New South Wales—
The applied university view

Professor D. H. Stapledon, South Australian Institute of Technology—
A college of advanced education view

Mr I. Johnson, CRA Exploration Pty Ltd—
The mining industry view

Dr D. J. Armstrong, Santos Ltd—
The petroleum industry view

Mr H. Rutter, Geophysical Exploration Consultants—
The geophysics industry view

Professor L. Douglas, University of Melbourne—
The soil science view

Professor R. W. R. Rutland, Bureau of Mineral Resources (an extempore presentation at the invitation of the Chairman)—
The government view.

These presentations are summarised in the order listed above, in Appendix 1. This Appendix also contains a review of oral and written contributions.

CONCLUSIONS

Despite the forcefulness of arguments presented during the workshop by highly-motivated advocates from one sector or another of the geoscience spectrum, by the end there was unanimity about the necessity for an authoritative in-depth investigation of the tertiary education system and, in particular, the geoscience sector. Firm concepts emerged that could be used as the basis for investigation into how geoscience education can be made more effective and efficient, but not less costly if national needs are to be met.

It must be stressed that before any move is made to implement the concepts presented here, a thorough external review of the present system must be undertaken and only after that can any decisions be made with regard to changing roles of departments, rationalisation or integration. However, in existing departments as opportunities for change arise through staff retirement or other circumstances, decisions should be made with the national interest in mind as outlined in the conclusions of this report, and not in an attempt to bolster on obtuse grounds the continuation of an ineffectual course or department.

Tertiary undergraduate geoscience education

General science courses

It is essential for the health of geoscience in Australia and to meet the broad role of geoscience in society that the discipline is represented at some level in all tertiary institutions, and that particularly where science is taught the public should perceive that it includes geoscience.

To meet these objectives, geoscience (or earth science) subjects are required to at least first-year level in many, and certainly to second and probably third year in most, general science courses. Geology or physical geography subjects (plus soil science in agricultural colleges) can be adapted or combined to create a suitable curriculum. However it must be recognised that graduates from these courses are not qualified as professional geoscientists, but may obtain status in some subjects should they enter professionally-oriented courses.

Essential component of another discipline

In mining and civil engineering, metallurgy, and some other disciplines such as planning, surveying or environmental studies, geoscience subjects are an integral component of the professional course. In some instances general science-type programs are used in an unmodified form, but generally, if the subjects are to have educational value they should be adapted to the specific needs of the students and the discipline studied. Geoscience lectures in general science courses or professional courses may qualify to lecture also in these special subjects in other disciplines, but only after actual experience of the applications being taught.

Joint degrees

To ensure the wide dissemination through society of geoscience knowledge at a professional level, joint degrees should be encouraged. Disciplines such as law, economics, and education readily lend themselves to this approach. Geoscience subjects to at least third year in a general science faculty would be suitable although applications relevant to the joint degree should be provided.

Professional geoscience courses

It is apparent that geoscience educators and employers require much in common in geoscience education at the undergraduate level. Overall, if the objectives espoused by Campbell or Govett for either classical or applied professional courses respectively are met, the difference is one of bias, not direction. The reality is that the ability of academic staff to achieve the objectives is limited. Hence deficiencies occur, and this issue is discussed later.

Almost unanimous agreement was reached on the question of course length, with the majority maintaining that four years is required, either as a four-year BSc degree course, or as a three-year BSc degree with an honours or graduate diploma course comprising the fourth year. A problem for students with the latter arrangement is that although a satisfactory three-year BSc can be completed, the level of achievement may be insufficient to gain entry to the subsequent honours program; for instance, enrolment figures for 1984 show that on average only a quarter of the third-year students entered the postgraduate year.

All geoscience courses must provide a thorough grounding in mathematics and the 'hard' sciences. Geoscience should be treated broadly and little or no specialisation allowed until at least the fourth year. Generally, the geoscience curriculum as presented in handbooks in most institutions is adequate although the question of scale raised by Johnson warrants serious investigation. But it is also necessary to provide appropriate depth of knowledge in subjects such as geophysics and hydrogeology, particularly so that research-oriented students can make a balanced selection of the postgraduate fields available to them. The same is true of soil science in faculties of agriculture. Whether or not courses include commercial subjects depends on whether the geoscience department wishes to be considered as classical or applied.

From the industry viewpoint geoscience graduates should have a sound education involving the practical application of classical knowledge, an inquisitive nature and an ability to apply scientific methods to investigations, good communication skills, and an appreciation of business and economic realities.

More specific abilities and course requirements are spelt out by Neal & Armstrong (1981) for Canadian undergraduate geoscience courses. They concluded that the most important items in a first degree course were:

- field courses as an integral part of each year of undergraduate study in geology;
- emphasis on a comprehensive thesis in the final year of honours and majors programs;
- lectures on technical writing be introduced—preferably in courses that require written reports;
- an extra year be added to the training of those who seek to become professional geologists. This year would permit the student to integrate and relate the material of the first four years and also develop special skills and problem-solving abilities in a speciality.

These proposals are reinforced by a survey of geoscientists in western European countries to determine the abilities that should be acquired in geological first degree education (Rondeel & Taylor, 1982). Here the highest ranking skills were: four dimensional thinking; report writing; map synthesis; conducting a project; 1:10 000 mapping; fundamental structures; and synthesis and analysis of literature. Although each survey expresses its conclusions in different terms, the underlying philosophy is obviously the same as in Australia.

The number of institutions required to teach professional courses is open to debate, but it generally was concluded that the present surplus of graduates for the mineral industry's need, although not a bad thing, did indicate perhaps that scarce financial resources were being spread too thinly. Fewer geoscience departments mounting professional undergraduate courses would allow more efficient use of resources, and the concept of one such department per one to two million population was proposed. The optimum number is also linked with the postgraduate key centre concept and is discussed in the next section.

Postgraduate geoscience education

Non-professional courses

Graduates from a General Science course which included geoscience would have to complete a professional geoscience undergraduate course before entering postgraduate geoscience studies. Hence it is unnecessary to provide postgraduate facilities in institutions which are dedicated to these types of courses.

In those institutions where geoscience is an essential component of another discipline or is partnered in a joint degree, any postgraduate studies would normally be of a hybrid nature with emphasis mainly on the non-geoscience discipline. The likelihood is that such studies will be undertaken at an institution where professional geoscience courses are offered and collaboration can occur without the need to provide additional facilities.

Professional courses: the key centre concept

It was a unanimous conclusion of the workshop that insufficient funds are available to properly support all the geoscience departments in Australia graduating professional geologists at the undergraduate and postgraduate levels. Another conclusion was that postgraduate research programs were limited to a small number of fields at any one institution because of the restricted research expertise of academic staff and the lack of specialist facilities: however, as Balme (1985) has shown, the academic staff at most institutions have a similar range of expertise, mainly in the classical fields, and large research gaps and an uneven distribution of expertise can be identified for the more applied aspects.

Hence, considerable merit is seen in rationalising the existing postgraduate system, to concentrate research expertise in a particular field at a restricted number of institutions. Each research institution would provide masters degrees by course work and masters and doctorate degrees by research, and be attached to a department providing undergraduate professional geoscience education of either a classical or applied nature as described in the previous section.

It is proposed that the postgraduate centres of specialisation be designated as 'key centres', a term already introduced by CTEC but used by them for a similar concept primarily at the undergraduate level: as intended here the influence of the key centre speciality should penetrate only slightly if at all into the final year of the undergraduate course, thereby ensuring that all first degree graduates have the widest range of career and research options available to them. Nevertheless, academic staff in the key centre would contribute to undergraduate courses where appropriate and the other lecturers providing the broad range of subjects for the first degree would pursue their own research (sharing of staff between institutions may facilitate some of these aspects).

As eleborated in this review, a key centre is *a nationally accredited institution in which staff and equipment are of the highest calibre and where high-level research and postgraduate education are carried out in a specific major sub-discipline of geoscience.*

Implicit in this concept is student mobility: both academic staff and employers have long recognised the value to students of moving to another institution to undertake a second degree but this is still not a common occurrence in Australia. The introduction of key centres will encourage the exchange of students between institutions, but financial support will be required for travel and living allowances to retain the best graduates. It is also considered that the aggregation of expensive equipment in certain key centres will promote academic staff mobility which also should be encouraged.

Fields of specialisation. It was proposed by Stapledon that key centres be established in the following applied sub-disciplines, and that geological and geophysical aspects be included at each one:

- marine geoscience
- coal geoscience
- petroleum geoscience
- engineering geoscience
- hydro-geoscience
- mineral exploration.

He also considered that key centres were needed for aspects of classical geoscience and quoted the Research School of Earth Sciences at the Australian National University which specialises in experimental petrology as an example.

On the other hand, both Rutter and Rutland believed that geophysics deserved a key centre in its own right. Other fields that emerged during workshop discussion included palaeontology, sedimentary basins, mineral deposits, surficial geology, and soil science (in faculties of agriculture).

Many questions have yet to be considered in detail, such as: which specialisations are the most appropriate for key centres in Australia; whether duplication is needed because of the 'tyranny of distance', or because of the influence of local geology and industry; and, where in the various States and Territories key centres should be located.

It is readily apparent that the correct answers to these question are critical to the successful outcome of any restructuring in tertiary geoscience education. Further workshops will focus on this issue.

Criteria for selection of a site for a key centre. The following criteria were considered by Stapledon as basic for the selection of the site for a key centre.

- The key centre should be an existing tertiary institution which includes a geoscience department.
- The parent institution should also include the necessary 'support' departments, e.g. civil engineering and mining engineering departments for an engineering geology key centre.
- It should be within or close to an area in which the relevant industries are active and predicted to remain active over a long period. This is to enable the maximum amount of industry involvement with, and assistance to, the key centre.
- It should be located within or close to a population centre large enough to provide adequate numbers of students with adequate academic backgrounds and capabilities.
- There should be existing residential facilities, or if not, these should be provided.

He purposely omitted 'the presence of well qualified, experienced and capable academic staff' from these requirements. Whilst he is convinced that the success of any centre will depend very largely on the quality of the academic staff involved with its management and teaching, he considers that the sites must be chosen on the above criteria, particularly the first four. Unfortunately, Australia has many examples of 'the right person in the wrong place' and the right people will have to be given encouragement to move, in order to contribute to the key centres.

Somewhat different criteria were proposed in the written submission from the University of Newcastle. There it was suggested that current staff, traditional areas of expertise, local geology and industry be taken into account, but again the aim was to avoid duplication, competition for meagre funds by competing geoscience institutes, and inefficient central institutional facilities; and to create greater staff, student and industry interaction.

Logically it is not possible to select sites or even confirm criteria until the fields of specialisation are resolved, but further discussion of this issue is to be encouraged.

Accreditation of key centres. There was no dissent to the recommendation by several speakers both from academic institutions and industry that once established, key centres should be externally accredited on a regular basis, say every five years. The University of Newcastle submission proposed that external accreditation by a committee of the Australian Geoscience Council would probably be advisable as other organisations (e.g. The Australasian Institute of Mining and Metallurgy or the Petroleum Exploration Society of Australia) have short-term interests and represent only a small sector of the geoscience community.

Funding for key centres. Primary funding for key centres will continue to need to come from the Commonwealth Government, and at least an amount similar to or greater than that provided at present will be required, but the available resources will be used more efficiently. It could be expected that those key centres having an application required by industry would become a focus for financial and other forms of support. These centres and those of more classical mien may also attract support through collaboration with government research organisations as suggested by Rutland.

Academic staff in geoscience institutions

It has been claimed that tertiary geoscience departments suffer from staffing problems whereby only the active research staff and those who have had industry experience can produce modern, relevant, balanced courses. Certainly it would seem that most of the objectives of tertiary education could be achieved, and many of the concerns of industry answered, if lecturers had broader experience and were better educators.

Several reasons have been proposed to account for the perceived problems. One is that some areas of geoscience are taught little differently from the way they were taught to their lecturers thus perpetuating graduates who ape their teachers. The reason why academic staff may pass through this cycle but remain on the payroll is considered by most critics to be an undesirable outcome of the tenure system. However, methods of selection, promotion and assessment of performance and productivity have also come under attack.

Those in the minerals industries together with many from academic institutions consider it essential that the tenure system be abandoned otherwise the problems of the present will be perpetuated. As Armstrong asked: how many of today's tertiary educators have been with the same institution in Australia for more than ten years, and how does this compare with the answer to the same question in respect of industry? Sant (1984b) provides an indication of the answer when he records that the proportion of geoscientists having worked at only one or two locations throughout their career are: companies and consultancies, 44%; government, 79%; and education, 77%.

However, Rutland urged caution and suggested that without tenure of some kind the best people would no longer have any incentive to join the tertiary system, although he would limit tenure to senior lecturers and above.

Regardless of how the tenure question is resolved, there was support for a systematic review of academic performance and one set of criteria put forward by Stapledon is presented as Appendix 2 to this article.

The leadership of academic departments has also been called into question. Most of the present heads of departments have come up through the tertiary education system and often have few managerial skills. In the future, innate ability will not suffice and it has been suggested by Stapledon that an *applied* key centre should be headed by a person with strong entrepreneurial and leadership qualities, a background of experience in the industries relevant to the key centre, and preferably also the ability to teach some of the subjects being offered at the centre. The main function of this person would be to lead, and to ensure that the centre is supported adequately by industry by provision of part-time lecturing staff, sites for field teaching, samples and data from past and current industry projects, research projects for postgraduate students, vacation employment for students, and employment for graduates.

Decisions for implementing change

Following a comprehensive external review of the present tertiary geoscience education system in Australia, decisions must be reached on the following issues, listed in order of priority.

(a) Which sub-disciplines of geoscience, both classical and applied, should be recognised as essential for postgraduate study and research in order to meet national needs?
(b) How should these sub-disciplines be distributed amongst key centres, either on a one-for-one basis, or with related sub-disciplines aggregated at one key centre?
(c) Is there a need for more than one key centre with the same specialisation?

Answers to questions (a) to (c) will determine the number of key centres to be established.

(d) Resolution of the criteria for the selection of key centres, and setting of key centre objectives.

This will identify the institutions destined to become key centres for postgraduate research, and by implication as outlined in the conclusions of this report, these institutions will also house departments providing professional undergraduate geoscience courses.

(e) Are additional departments required to provide professional classical or applied geoscience undergraduate and postgraduate courses, but without key centre status, to meet national needs, the needs of other disciplines in an institutution, and the needs of society?

This will identify the total number of departments, and their location, required to provide professional-level courses in geoscience.

(f) Of the remaining tertiary institutions throughout Australia either with or without existing geoscience departments, in which ones is it necessary to establish geoscience courses suitable for general science disciplines, to meet the needs of society?

Decisions (a) to (f) will determine the location and level of tertiary geoscience education required throughout Australia to meet the needs of the profession and society.

It next becomes necessary to identify existing resources, such as buildings, staff and equipment, and to allocate them in the most efficient manner to meet the educational requirements. At the same time insufficiencies will be recognised, and ways to overcome them devised. This phase will probably take several years to complete, especially where an outcome is dependent on changing the mix and expertise of staff at an institution in order to meet new objectives. But as Balme (1985) points out, the spate of impending retirements from geoscience departments over the next five years provides an excellent opportunity to implement change; thus it is crucial that the decisions outlined above are made as soon as possible to take advantage of this situation.

Very early on in the establishment of the new regime consideration should be given to the ongoing regular assessment of academic staff to ensure their performance is achieving departmental and key centre objectives. Finally, and most importantly, a system of external accreditation of all departments and key centres, their courses, staff, and equipment must be undertaken on a five yearly basis to make certain of the ongoing viability, relevance and excellence of tertiary geoscience education and research in Australia.

Methods for implementing change

The most difficult stage in implementing the decisions outlined above will be the rationalisation of existing geoscience departments to satisfy the national requirements for key centres.

Stapledon proposed that the new structure can be achieved mainly by:

- amalgamation of portions of two or more existing departments
- closure of some departments, and transfer of selected staff to the 'new' departments or geoscience key centres
- transfer of displaced staff, as far as possible, into key centres in other disciplines (e.g. mining) which require geoscience 'service' teaching
- early retirement of academic staff.

Alternatively, the University of Newcastle submission suggested a reorganisation of the institutions in Melbourne, Canberra, Sydney and Brisbane on a model similar to the German Institut system. It is to be expected that useful analogies may be drawn with the institutional systems in Europe and North America, and these must be examined as part of the decision-making process.

Conditions for the appointment of academic staff at overseas geoscience institutions should also be investigated to determine what incentives are available to ensure staff achieve greater interaction with industry and government, and are better qualified to obtain research funding in the changing regime in Australia.

Future Action

Three major lines of action were identified:

(a) the preparation of this review and its widest circulation to provide a focus for discussion and comment. It is realised that many important issues have been barely recognised in the one-day workshop, and others have been overlooked entirely. Other matters on which decisions appear to have been reached may, on further reflection, be changed radically. All constructive comments are welcome;
(b) the need for further discussion on the key centre concept, the choice of appropriate sub-disciplines, and the criteria for the selection of the location of key centres;
(c) the initiation as soon as possible of an authoritative review of the present system of tertiary geoscience education in Australia to provide a benchmark on which decisions for change can be based. It would appear that it is only feasible for this review to be carried out under the auspices of the Commonwealth Tertiary Education Commission, and delegates to the workshop requested that the Australian Geoscience Council act as their representative in liaison with the Commission on the establishment of the review.

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Appendix 1: Summary of workshop presentations, discussion and written submissions

The classical university view (K. S. W. Campbell)

The motto for the Australian National University, in translation, is 'first understand the nature of things'. From the point of view of geoscience education Campbell interprets this to mean 'anything that contributes to our understanding of the history of the Earth': hence the subject matter is the history of the Earth and the techniques are physics, chemistry, and biology, *and* any technique unique to the topic itself.

Universities are classically places where knowledge has been cherished, passed on, and expanded. This cannot be achieved without the proper care of students and the support of government and the community, but knowledge is the prime concern of a university.

All of society should benefit from this knowledge, otherwise the uneducated will challenge the foundations of our discipline. This means universities must see to the proper education of school teachers as well as to the needs of mineral explorers, to economists as well as conservation lawyers, to foresters as well as students of biological evolution.

It is imperative that graduates of universities should realise the boundlessness of knowledge and their own limitations, and be stimulated to maintain an attitude of learning through their subsequent careers. Campbell comments that universities commonly fail to generate this attitude, and Johnson speaking on behalf of the mineral industry would agree; however it is arguable as to how much of this failure is attributable to the level of knowledge of the teacher, and how much to inadequate attitudes in society and an over-emphasis on the supposed practical application of knowledge by the teacher.

Although universities are committed to passing on current perceptions of the history of the Earth, it is equally important to examine the reasons for these perceptions and the limitations imposed by the data on which they are based. Johnson questions the ability of universities to carry out some aspects of this function competently at the present time when more new data are probably generated and held in industry than in academic institutions: the consequences of this are examined in the review of his paper.

Campbell argues that universities providing a classical undergraduate education should not be in the business of teaching techniques, the logic of which is not understood, or which will rapidly become superseded. By this he means that geology departments will not be involved with the teaching of statistics, mathematical handling of data, or satellite image analysis, unless the student can appreciate the basis for, and limitations of the method through the study of other science units. Nor will students have time to cover strictly occupational topics such as drilling techniques or man management. All these topics are much better handled in specific postgraduate courses, some perhaps in universities but others certainly in organisations specially set up to do the job, such as the Australian Mineral Foundation. He concludes that universities should not be expected to provide, at the end of three or four years, students who can go out and undertake supervision of a technical program of any sort.

Undergraduate students need to be instructed about the processes by which our present understanding of the Earth have been achieved because there is always a tendency to reinvent the wheel. Furthermore, a continual complaint heard from science lecturers is the lack of fundamental scientific knowledge. For instance, they are plagued by students who know 'all' about sea floor spreading but nothing about basalts or pyroxenes; therefore there must be a certain amount of teaching in fields which could be considered to be far from the cutting edge.

A commitment by universities to enable students to express their ideas clearly and concisely was not disputed. As Campbell observed, this has always been a responsibility of academics from the time of Plato when rhetoric figured so prominently in the curriculum. Such a responsibility is not discharged by a short course on report writing or seminar presentation. It requires persistence over a long period.

As universities are committed to the extension of knowledge, they are committed to research at the postgraduate level. All teachers at tertiary level must research if they are to remain effective teachers. In a good researcher intellectual competence, coupled with insight and qualities of personality, are essential. Hence long periods are necessary for training, and if universities do not do this, who will? On the other hand, universities have not traditionally been much concerned about the nature of a research project, and Campbell maintains they should not be, so long as it contributes to our basic concept of seeking to understand the nature of the Earth. Moreover, research into problems of immediate economic significance have an equal place in universities with other types of research provided they seek to expand our knowledge of the nature of things, and are not just limited to the use of poorly understood techniques to increase unanalysed databases.

It must be acknowledged that research today requires specialist supervisors and specialist facilities. Consequently, whereas all universities are committed to breadth in undergraduate education, they should also be committed to a limited number of fields in their research programs. Also, because versatility is a key feature of any good researcher's make up, it is important that research students should be exchanged between institutions so that they can gain experience in a variety of environments.

With the advent of research organisations outside the universities, and the constraints on university funding, the proportion of new research areas developed in universities has fallen away dramatically: this proposition is reinforced by Johnson. Nevertheless, Campbell asserts that universities must maintain a forward-looking approach to research. They would welcome appropriate opportunities for staff to collaborate with outside researchers, and for the joint supervision of postgraduate students. Ultimately, scientific advances take place as a result of what goes on in a researcher's head and hypotheses are generated by insightful individuals who know how to expand knowledge. If a university is to be worthy of the name it must seek out such people and encourage them to chance their hand at significant research projects—no research effort, no postgraduates, no university.

The applied university view (G. J. S. Govett)

In the context of undergraduate teaching the distinction between pure and applied geoscience is especially difficult to define. Any tertiary course that claims to produce professional geoscientists must provide the basic elements of the science. Ultimately, Govett believes, the distinction lies in different emphases within courses: he would argue that it is necessary to take into account that for the most part the tertiary degree course is now vocational training and graduates expect to market their skills to earn a living; hence account must be taken of where employment is obtained, and as Sant (1984a) has shown, the majority move to industry.

Thus it is believed that the better students are able to apply their geological knowlede the more employable they are likely to be. As a consequence, students must be given the best possible theoretical training in fundamental principles, as in a classical geoscience course. At the same time practical and applied skills are added.

To achieve this, the first five-eighths of the four-year bachelor degree course at the University of New South Wales is conventional or classical geology, but an applied nuance is imparted by consciously striving in every subject to relate the theory to practical examples: in other words, an actual use of knowledge is demonstrated. In the remainder of the course students are introduced to a range of sub-disciplines with the aim of producing a very broadly-based geologist who has at least an appreciation of basic specialisations, a person who Govett refers to as an applied generalist.

Specialisation is achieved through postgraduate study and research. Every attempt is made to have all research students engaged in a project in association with industry and although this approach is sometimes criticised on the grounds that applied research is not academically acceptable, the reality is that applied research can be more demanding than pure research because if you are wrong in your conclusions you are quickly found out. Advantages to industry of this approach are cited as an opportunity to obtain relatively free advice and research from both student and supervisor, and an opportunity for mutual appraisal in the context of future employment.

In order to enhance the applied aspects of geoscience courses it is necessary to ensure the the majority of staff, if not all, have had employment in industry and/or government surveys and maintain contacts through consulting. A visiting or advisory committee with representation from industry and government which regularly reviews all departmental activities can materially assist in ensuring that teaching and research are relevant to the needs of the market place.

Attempts should be made for undergraduate students to obtain geoscientifically oriented vacation employment in industry or government at the end of second and third year. (Some authorities such as the Australasian Institute of Mining and Metallurgy maintain that such employment should be compulsory and The Institute requires this in any course accredited by them.) The reality is that success in obtaining vacation employment is variable and linked to the strength of activity in the minerals industry. Govett points out that industry should be aware that students who do manage to obtain such employment usually achieve better grades and are certainly better geoscientists after graduation.

From the view point of providing satisfactory tertiary-level education in applied geoscience and graduating sufficient geoscientists to meet the national need, Govett believes that Australia has more tertiary geology departments than the country needs or can afford. His rough estimate is that about half the existing departments should close—or at least simply offer lower-level geology courses and cease attempting to train professional geoscientists. The corollary to this is that the surviving departments must be funded at a realistic level to meet their requirements for a vast array of increasingly costly scientific instrumentation, with appropriate specialised teaching and support staff.

A college of advanced education view (D. H. Stapledon)

As an outcome of the views expressed by the minerals industries in the mid-1960s, the institutes of technology and some colleges of advanced education either initiated new courses based upon the expressed needs of industry, or gradually extended technician-level courses to incorporate these objectives. One college—Salisbury—started courses specifically to provide geoscience training for intending secondary school teachers.

Insofar as the institutes of technology are concerned the views expressed by Govett for applied courses at undergratuate and postgraduate levels in universities are identical with their own objectives, whilst for the colleges of advanced education the proposals for undergraduate training are similar.

Hence Stapledon concentrated on an analysis of the expertise of staff presently in tertiary institutions based of the data in Balme (1985), then he predicted the future requirements for applied geoscientists and their fields of expertise, and finally showed how the existing tertiary education system could be restructured so as to achieve the most effective training of applied geoscientists.

Of the 280 academic staff in the 27 geoscience institutions in Australia, only 15 consider that their specialist interest lies in the applied areas of
- hydrogeology (two)
- petroleum geology (two)
- coal geology (three)
- engineering geology (eight).

However, it is uncertain how much industrial experience these staff have to support their speciality, and unless it is extensive their contribution could be minimal.

Another 32 staff claim expertise in economic geology, of whom probably less than half would have significant industry experience, and for the majority this would be in mineral exploration.

It has to be concluded that:
- in Australia, probably less than 30 academic staff are qualified (by virtue of both qualifications and

experience) to provide training in the application of geology in these most important areas and industries;
- about half of these 'applied' academics provide teaching in the mineral exploration area;
- petroleum geology, coal geology and hydrogeology—three areas of vital national importance—are seriously neglected, consequently petroleum and civil engineering organisations still need to look overseas for qualified and capable geoscientists;
- about half of the 'applied' academics are in institutes of technology which are not accredited to award doctorate degrees and this contributes to the low number of post-graduate courses and theses in the applied geology area.

On the assumption that there must be limits to economic growth, and that Australia will receive successive waves of immigration causing large increases in our population with a concomitant demand for ancillary infrastructure, certain predictions can be made about the number and skills required in Australia's professional geoscientific workforce.

- During the next 30 years the metallic, industrial and extractive minerals industry will continue to grow and geoscientists will be needed both in the exploration and mine operation stages.
- Fossil fuels must continue to be needed and geoscientists will be required for the exploration and extraction stages.
- The pressures of population and land development will increase the problems of environmental protection, and waste disposal and isolation: geoscientists will be required in greater numbers.

To meet these requirements Stapledon estimates an annual long-term 'average' output of about 100 first-degree geoscientists and 50 postgraduates, with an overall greater emphasis on 'applied' subjects. However, it is stressed that the system must have sufficient flexibility to cope with wide fluctuations in these levels, and also should include classical geoscience.

To more effectively utilise available teaching and equipment resources, especially for postgraduate studies and staff research, institutional key centres are proposed in the following applied geoscience (geological plus geophysics) areas:

- marine geoscience
- coal geoscience
- petroleum geoscience
- engineering geoscience
- hydro-geoscience
- mineral exploration.

All key centres should be associated with classical or applied undergraduate departments, and other key centres should be nominated for fields of classical research. Some key centres may need to be duplicated (but not cloned) to meet national needs and to take advantage of distinctive local geology and industry. The concept of key centres is expanded elsewhere in this review and Stapledon's criteria for selection and rationalisation are discussed alongside other viewpoints raised during the workshop. Nevertheless, the number of undergraduate departments teaching professional courses should be limited to about one per one to two million of population, and all key centres should be associated with a department, so the number of key centres allowed on this basis is limited, and Stapledon suggests a maximum of 15 overall.

However, before any irrevocable decisions are even considered a thorough external review is needed of every Australian geoscience department, its individual staff, and the courses it offers. Each review should be carried out during term time, and over a period of at least one week. It should also take into account statistics on the employment of graduates, and comments from employers on the quality of graduates (and Armstrong would argue that comments from students and recent graduates should be included). The performance of every academic staff member should be assessed.

After restructuring, all departments and key centres, their courses and their staff, should be subject to regular external review.

The mining industry view (I. Johnson)

Inquiry within industry has revealed a good deal of disappointment and dissatisfaction with geoscience education at the tertiary institutions in this country. At the heart of this discontent is the belief that at many institutions students are given a narrow view of the geosciences and are not taught how to think.

New graduates generally require considerable periods of training by their employer. This training, as indicated by the content of courses such as those conducted by the Australian Mineral Foundation, has a significant component of retraining in matters that could reasonably be expected to be included in a science degree.

In the early 1930s, there were only two geologists at mines in Australia. But as the number of geologists increased during the 1940s, mining geology developed into a search for new orebodies and thus it became part of the search for solutions to problems of Earth history. By the early 1950s it had become apparent that traditional concepts of geology were inadequate for industry needs; by 1960 the divergence between industry-based, and academically-based geology had become very real, primarily because industry was working in a different field and on a different, regional scale, and from this different viewpoint was seeing different things. Now in the mid-1980s the divergence has reached substantial proportions and the volume of new data generated by industry probably exceeds that of academic institutions. Johnson believes that the surface and subsurface investigations of the petroleum and mining companies represent the most profound geological investigations which are amenable to testing.

In contrast, research within tertiary institutions seems to concentrate increasingly on small-scale studies and the operation of equipment to measure and collate data. Being able to operate this equipment has to some extent become an acceptable form of higher research in itself; and this narrow field of research is often reflected in the content of courses taught. The institutions need to concern themselves more with large-scale studies, and with this will no doubt come an increased appreciation of what we do not know.

Degree courses will then provide not just a snapshot of the traditional ideas of the present day but a geoscientific education in the true sense. Students will be better able to deal with novel situations and real observations and data for which in many cases there is an inadequate theoretical basis. They will have a clear distinction between knowledge and inference. Such changes in emphasis in teaching need to be accompanied by corresponding changes in emphasis in research.

Johnson suggested that the general purpose of a geoscience department in a tertiary institution can be reduced to a few main points:

- development of scientific knowledge of the Earth;
- serving the technical needs of the community;
- development as a cultural activity of the appreciation of Earth history in geological time;
- maintain the highest standards in all activities.

Within this general framework, individual institutions need to identify their particular aims or fields of investigation.

In the administrative area, institutions should become more conscious of industry needs when seeking financial support. If an institution has the particular expertise that a section of industry needs, then industry will be prepared to pay, but industry will not assume the role of benefactor alone. (Such an attitude is reinforced by government initiatives such as the research and development tax incentives scheme introduced in August 1985.)

It is believed that the number of departments teaching geoscience as a major subject should be reduced to a maximum of two per State. Moreover, within these departments it is maintained that there is no place for a system of tenure. In the tight financial times of recent years tenure has meant that tertiary institutions have been unable to recruit what could be regarded as a normal number of young people to their staffs. This is unfair to the current generation of top-flight graduates and the institutions are the poorer for not having them.

The petroleum industry view (J. D. Armstrong)

Thirty years ago there were relatively few oil and gas companies in Australia, and most employment opportunities were in the Geological Surveys, the Bureau of Mineral Resources, and in universities. Today there are some 250 oil and gas companies in Australia, 70 of which are producing petroleum. Clearly there have been major changes in the opportunities available to geoscience graduates, and one might have anticipated a substantial shift by educators in order to service changing professional demands and career opportunities. The reality is that on the whole this situation has not been recognised and acted upon.

A question which need to be asked (and answered) is: to what extent are educators in 1985 geared to teaching in the 1980s and how many have worked in the commercial/industrial environment to understand what and how geoscience knowledge is being applied?

Considering that most geoscience graduates work with industry in one form or another, one must wonder what is the purpose of geoscience education if it is not to be relevant to its industrial users? In addition, allowance must be made for the realities of the commercial world and graduates should be broad-based professionally so that in times of downturn they can be regarded as candidates for promotion or re-assignment/re-employment laterally.

Geoscience, like engineering, can be described as applied science insofar as physical, chemical and biological processes as quantified mathematically are used to describe natural phenomena. Basic knowledge of the sciences and mathematics is essential and geoscientists must be literate in all of these. Also necessary are: the ability for temporal and spatial geoscience conceptualisation; improvements in respect of literacy and numeracy; and an understanding of the nature of accuracy and probabilistic methods. It would also be useful to give more emphasis at the undergraduate level to the teaching of the scientific method, including how to apply scientific knowledge to the achievement of a particular goal. Armstrong considers it necessary to structure courses in such a way that incoming students can see the purpose of undertaking a geoscience degree and recognise career paths after graduation. For instance, whereas 'geoscience' suggests knowledge pertinent to the Earth, for an intending graduate 'petroleum exploration' implies a career based in geoscience but with commercial overtones responding to industrial, economic and social demands.

At the postgraduate level, especially in relationship to the applied key centre concept, Armstrong believes the problem of attracting good students to undertake further studies when they are also able to obtain a position in industry should be recognised. Educators need to be aware that a graduate in the the petroleum industry can expect to earn some $45 000 in two years after an honours degree. The likelihood of a key centre attracting post-honours graduates for two or more years in competition with such an earning capacity would seem low. He considers the integration of key centre objectives with third and fourth year courses would seem an appropriate arrangement.

Other matters which deserve consideration are the need for subject and curriculum review committees, increased mobility of students between tertiary institutions, and a thorough investigation of academic salaries and the tenure system.

Nevertheless, in any review of tertiary geoscience education the debate should not be between the classical and applied aspects of the geosciences, but rather it should be about whether the education of geoscientists in 1985 is fitting graduates appropriately for their various roles in professional life. In particular, it is necessary to examine the number of tertiary institutions teaching geoscience in Australia, and the content of their curricula so that the graduates of the late 1980s and into the 1990s will be increasingly better suited to take their places in Australian society.

The geophysics industry view (H. Rutter)

Geophysics is a major discipline within the field of geoscience. It has assumed increasing prominence particularly through its application in petroleum exploration and more recently in the search for mineral deposits located beneath uneconomic cover rocks. Even in times of downturn in industry, competent geophysicists are always in demand.

Of the 27 tertiary institutions offering a bachelor degree in geology, 13 also offer geophysics at least in the fourth year. This tuition in geophysics is provided in most instances by a single staff member, and few institutions have more than two, although many supplement their staff by inviting part-time lecturers from industry or government. Consequently, only a limited number of courses can be offered, and under these circumstance some institutions aim only to provide sufficient geophysics to enable geologists to be literate in the subject. However, Rutter believes it is practical to produce competent geophysicists at the end of a properly organised four-year course, although Govett maintains this is a field of specialisation that should be developed at the postgraduate level.

Compared with the major geophysical schools in North America, with an average of 15 staff teaching 13 to 52 courses in geophysics, only Macquarie University approaches a comparable size through its association with the Centre for Geophysical Exploration Research which can draw upon expertise from the CSIRO Divison of Mineral Physics and Mineralogy, and the NSW Department of Mineral Resources; but even this centre cannot provide all the basic requirements for an adequate geophysics course. Rutter considers that to be viable a geophysics department should have a minimum of four academic staff, each with their own speciality, plus appropriate computing power and geophysical field equipment. Students entering geophysics must have adequate grades in mathematics and physics and continue to improve in these subjects throughout a four-year course. On graduation students should be competent in both the theoretical and practical aspects of the wide range of specialist techniques required by the petroleum and mineral industries and government. At present those institutions teaching geophysics appear to direct their students mainly to the mineral industry.

In order to improve the quality of geophysical education it is proposed that three departments should be created in Australia by rationalising the present staff and finance, and encouraging further support from industry and government. This approach is the opposite of that proposed by Stapledon whereby the appropriate aspects of geophysics would be combined with other fields of geoscience in postgraduate key centres based on fields such as marine geoscience, petroleum geoscience, or mineral exploration; but Rutland strongly recommended key centres in geophysics, while also having it in the multidisciplinary base at the others.

One way or the other, Rutter is adamant that the quality of teaching geophysics in Australia and the quality of students must improve otherwise there will be an increasing intake of overseas graduates by the Australian minerals industry.

The soil science view (L. Douglas)

Soil science, like geophysics, is a major discipline within the field of geoscience, and generally it is placed within faculties of agriculture. The present situation described earlier in this review indicates too few resources spread thinly over ten universities offering undergraduate courses and one postgraduate course.

Soils underpin the agricultural industry in Australia yet none of the 30 lecturers in soil science is an expert in soil conservation. Hence in future recruitment it is necessary to achieve a balance of expertise to meet national needs. But excellence will not be obtained until sufficient staff are concentrated at each training institution. In a practical way Douglas believes this can be done only by amalgamation so that each State has one centre properly staffed. These staff should be supported by the secondment of officers from CSIRO and State Government Departments of Agriculture to extend the resident skills, especially at the postgraduate level.

Academic staff involved with undergraduates should be encouraged to be good communicators instead of concentrating on research. In particular, chasing the research dollar is a waste of an academic's time yet this task is becoming increasingly necessary and onerous.

The government view (an extempore presentation by R. W. R. Rutland at the invitation of the Chairman)

Although government is the second largest employer of geoscientists and the education of these officers is of considerable importance, government must also look at a broader perspective and view geoscience in the national context.

Different objectives for tertiary courses in geoscience can lead to conflicting outcomes and conclusions about their purpose and content. Primarily the national needs are threefold:

- to ensure the health of geoscience in Australia;
- to meet the broad role of geoscience in society;
- to meet the professional needs of a variety of customers (not only the exploration industry).

Whereas most would argue, probably correctly, that there are too many institutions trying to meet professional needs, there certainly are not too many to meet the first two objectives.

All tertiary institutions throughout Australia should have a geoscience department comparable in status with other departments in science and arts faculties. This is necessary in order to meet our responsibility to ensure that as large a number of people as possible throughout the community are familiar with geoscience and what it has achieved, otherwise our professional needs might be seriously constrained by those people.

Despite the view held by some people, Rutland believes it is not possible to meet professional needs with undergraduate courses, and that these courses should not attempt to meet the needs of a particular industry. Undergraduate courses of two types should be offered. First, a hard science course at selected institutions, based on mathematics and the sciences which can lead on to professional training; and second, a less rigourous type of geoscience course offered at nearly all institutions. If some institutions continue to offer applied three-year courses claiming to meet professional needs at the undergraduate level it is up to industry to decide whether such graduates are also required.

To properly meet professional needs Australia must have continuing postgraduate professional courses specifically directed at particular professional fields, such as the key centres identified by Stapledon but also including geophysics in its own right. Basically, courses should be at masters level and linked into institutions which have research expertise in those disciplines. However, any specialised centre must have a strong basic multidisciplinary support across the full spectrum of geoscience, and this requirement will severely limit the number of key centres that can be both good academically and good in terms of their application to the profession. It follows from this approach that there must be provision for mobility of students after the basic undergraduate degree.

On the question of tenure for academic staff, Rutland argued that the abolition of tenure might tend to produce a reduction in quality—exactly the opposite result to that desired by industry. Whilst abolition may facilitate the movement of staff both within the tertiary system and between the tertiary, industry and government sectors, it would result in a decline in professional training because the best people would have less incentive to join the tertiary system and those that did would probably not see dedication to teaching duties as the best way to retain their position. However, there is a strong case to be made for tenure to be provided only after a substantial period of service as a lecturer, and after appointment to senior lecturer level has been confirmed.

It would also be advantageous if as part of postgraduate professional training, people from industry, government and research institutions were brought in as part of the mix to assist at this more advanced level. In fact the Bureau of Mineral Resources would welcome the opportunity to co-ordinate some of its research activities with specific key centres, as already is the case to some extent with the Australian National University. CSIRO co-operates with Macquarie University. If good key centres are developed there would be greater opportunity for closer integration between Commonwealth government-funded research organisations and those tertiary centres, and that could to some extent solve the funding problem.

Additional views expressed in written submissions and workshop sessions

The need for the discipline of geoscience to have a presence at the undergraduate level in all tertiary institutions was stressed. In particular, wherever science is taught the public should perceive that it includes geoscience[6]*. It is suggested that far more school teachers and other graduates with knowledge or degrees in geoscience would generate greater community awareness of our planet Earth, the environment, and the needs of industry, and that this ultimately could increase the profitability of some sectors of the industry[3]. An argument similar to that used by the humanities may justify any overproduction of geoscientists, whereby the general community awareness, knowledge and culture is enriched[3].

It was argued that the diversity and competition provided by a large number of institutions had certain merit, and also allowed for advantage to the taken of local geology and local industry. Nevertheless the reality of budget constraints was recognised and it was unanimously agreed that key centres must be created to meet the needs of postgraduate professional education, particularly when specialist staff and capital intensive equipment are required.

The general consensus was that professional undergraduate geoscience courses need a sound basis in the 'hard' sciences and mathematics, should be of fours years duration, and have minimum specialisation. Many of the complaints of industry could be sheeted back to inadequate lecturers rather than course content and it was recommended that during their careers academics should lecture at more than one tertiary institution so as to alleviate the parochialism that is affecting several of our present geoscience departments. The formal appointment of staff to two or more institutions is one solution[4], but even greater mobility of academics would be one way in which to overcome the concern of those in important but very specialised disciplines, such as hydrogeology, which deserve key centre status but which at present are either ignored or inexpertly presented in undergraduate courses, thus precluding students from recognising a fruitful field for postgraduate study[8].

The need for key centres for postgraduate studies is clearly established, but the methods for implementation, and the disciplines to be covered, are only beginning to emerge. These matters cannot be decided until there has been a thorough review of geoscience teaching and research throughout Australia, including an understanding of regional needs and industries, links with other disciplines and institutions, and an evaluation of graduates produced over the past two decades after the massive expansion of departments took place[3]. However, it is already recognised that key centre development will increase the requirement for student mobility at the postgraduate level and additional funds will be needed for both travel and accommodation.

Most masters and all doctorate degrees presently undertaken in geoscience are based on student research. Some masters degrees involve course work, and one degree has been introduced recently with incorporated short courses at the Australian Mineral Foundation. Discussion at the seminar suggests that in future an increased demand can be expected for masters degrees based mainly on course work particularly in specialist disciplines treated only briefly in the first degree. Such degrees would also find favour with those studying while employed on a full-time basis.

Australia's responsibility to students from developing countries to provide them with the opportunity to obtain higher degrees may also be achieved through the provision of course work-based masters degrees suited to their abilities which would lead onto research degrees[3], or special graduate-level courses tailored to their needs and conducted either onshore in Australia or offshore under the auspices of Australian authorities[5].

Government should not expect any reduction in the budget provided for tertiary education in geoscience if the suggestions from the workshop are implemented, but greater efficiency would be assured. In addition, increased support for postgraduate education at key centres could be expected from industry and government research organisations which would enhance their ability to meet national needs.

Written submissions were received from the following individiuals and organisations.

1 Dr K. A. W. Crook, Australian National University: Employment opportunities for geoscientists: indicative time series 1979-1985.
2 Dr K. A. W. Crook, Australian National University: The geoscience workforce and the proposal for re-introduction of fees.
3 Department of Geology, University of Newcastle.
4 Dr H. A. Doyle, University of Western Australia
5 Dr M. B. Katz, University of New South Wales.
6 Mr G. W. Williams, on behalf of Bendigo and Ballarat Colleges of Advanced Education.
7 Mr N. Williams, Carpentaria Exploration Co. Pty Ltd.
8 Mr W. Williamson, Australian Chapter, International Association of Hydrogeologists.

* Numbers in superscript refer to a written submission listed at the end of Appendix 1

Appendix 2: Suggested check list for annual review of academic staff (Stapledon)

- TEACHING HOURS/WEEK
- QUALITY OF TEACHING
  - Head of Department assessment
  - Client Department assessment
  - Student/Graduate assessment
- PROMPTNESS OF ASSESSMENT/MARKING
  - Student assessment
- AVAILABILITY TO STUDENTS
  - Student assessment
- ADMINSTRATIVE DUTIES
  - Details
  - Percentage of time
- PUBLICATIONS
  - International journals
  - Local journals
  - Textbooks/chapters
- CONFERENCES ATTENDED
  - Papers presented
  - Invited papers
- RESEARCH
  - Project(s)
  - Funded by/amount
  - Application?
  - Percent of time
- CONSULTING
  - Projects/clients
  - Percent of time
  - Earnings—amount—paid to?
- PROFESSIONAL ACTIVITIES
- FURTHER STUDIES/RETRAINING

THE GEOSCIENCE WORKFORCE, AND THE PROPOSAL FOR RE-INTRODUCTION OF HIGHER DEGREE FEES[1]

Keith A. W. Crook[2]

Abstract

Survey data collected over the past fifteen years show an increasing demand for geoscientists with higher degree qualifications. This matches the increasing complexity and sophistication of the tasks for which geoscientists are employed. This trend can be expected to continue, particularly as industry commits more resources to research, driven by the increasing difficulty with which discoveries will be made.

When the personal cost to individual geoscientists of undergraduate and higher degree training is expressed in terms of income foregone, it is clear that job satisfaction rather than short-term personal gain must be the motivation for undertaking higher-degree studies. Most geoscientists will not recoup the income foregone by undertaking higher degree training until the middle to closing years of their careers. The charging of fees would provide a significant disincentive to geoscientists to secure higher degree qualifications. In practice, this disincentive would be strengthened because it would fall largely on geoscientists under 30 at the beginning of their professional careers when they are least able to meet such charges.

Re-introduction of higher degree fees would lead to de-skilling of the geoscience workforce during a period when enhanced skills are likely to be in demand. Higher degree fees are likely to undermine Government policy aimed at increasing geoscience R&D carried out by industry. The fees are inequitable, because of the element of double taxation involved.

Introduction

Australia has some 5000 geoscientists whose work ranges over research, education, exploration, and resource management (groundwater, soils). This small workforce provides an essential part of the scientific and technical underpinning for the substantial fraction of Australia's GDP (6.7% in 1982-83) derived from the exploitation of minerals and hydrocarbons, as well as some part of the primary produce GDP-fraction (3.75% in 1982-83) which is based in part on the utilisation of groundwater and soils.

Data are available on the geoscience workforce from surveys commissioned by the Geological Society of Australia in 1967 and 1978 (Townley & others, 1968; Berkman, 1980), and from a comprehensive survey in 1982-83 commissioned by the Australian Geoscience Council (Sant, 1984a, b).

Although the data in the earlier surveys are incomplete, and comparable data from the 1983 survey cannot always be extracted, the three surveys provide an overview of the changing size and patterns in the geoscience workforce since 1967. Certain aspects of this information bear directly on the likely effects of re-introduction of university fees for higher degrees.

Geoscientists and Higher Degrees

Since 1967, industrial employers have shown an increasing preference for geoscientists in their employ to have higher degrees (MSc, PhD). In 1967, 15% of employers preferred their geoscience staff to be thus qualified. By 1978, when the number of employers had grown by two-thirds, 20% preferred such qualifications. Over this period Government instrumentalities (excluding education institutions) did not change their preference: 32% of these employers preferred their geoscientists to hold higher degrees.

Comparable figures for 1983 are not available for the whole workforce. However, persistence (at least) of this demand for higher degrees is indicated by qualifications preferred in *junior* employees, that is, geoscientists at the beginning or earliest years of their careers. In industry, 14.4% of employers regard higher degree qualifications as desirable for their junior employees. Government instrumentalities (excluding education institutions) display a stronger preference: 21% regard higher degree qualifications as desirable for junior employees.

Although earlier data are unavailable, the 1983 survey provides a good indication of the relationship between employers' preferences for qualifications held by junior staff and the actual qualifications of the staff employed at all levels of seniority. Among geoscientists employed in industry, 21.3% hold higher degrees. Of those employed by Government instrumentalities, excluding educational institutions, 39% hold higher degrees. In total, 26% of the geoscience workforce is so qualified according to the data in Sant (1984) which covers an estimated 75% of the total Australian geoscience workforce. These 1000 geoscientists with higher degree qualifications constitute a large part of the leading edge of Australia's non-educational geoscience workforce.

The geoscience workforce is believed to have trebled since 1967. Although comparable figures for earlier years are not available, the proportion of geoscientists with higher degrees must also have increased substantially because of the small number of higher-degree graduates in geoscience turned out by Australian universities prior to 1967. Some indications of the growing demand for higher qualifications are provided by the following:

- industrial employers now strongly prefer graduates with at least 4 years training (BSc honours or BSc plus graduate diploma); 3-year-trained graduates find difficulty in securing employment;
- in 1984 the Australasian Institute of Mining and Metallurgy advised higher education institutions that after 1986 the status of Associate of AusIMM would be available only to graduates with 4 years training;
- re-structuring of the Bureau of Mineral Resources as a research organisation in the early 1980s has greatly enhanced its requirements for higher degree graduates.

The overall increase in preference for staff with higher-degree qualifications is readily understandable. It is a direct consequence of the increased sophistication in exploration techniques, the increasing difficulties and costs of discovering new resources, and the increased complexity of programs needed for the management of renewable resources such as groundwater and soils. Furthermore, strategic research requirements, both fundamental and mission-oriented, are correspondingly enhanced as the more easily utilised resources are depleted or fully exploited.

[1] Based on a paper provided to the Federal Minister for Education.

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There is no reason whatsoever to expect any significant change in the historic pattern of increasing demand for geoscientists with higher-degree qualifications. The task of discovering and utilising natural resources will sustain the pattern. Furthermore, a very significant demographic difference in the deployment of geoscientists between industry and non-educational Government instrumentalities will contribute significantly to future demand. In Government instrumentalities, 39.1% of geoscientists are engaged in research. In industry the percentage is one order of magnitude less: 3.8%. Australian industry by and large does not do its own geoscience research. It depends upon the Government instrumentalities and higher education institutions (which are not included in the above figures), or upon overseas parent companies. Both Government policy and market forces will increase the proportion of industrial geoscientists employed in research, through tax incentives from Government and by corporate failures or takeovers where industry is ineffective in mobilising innovation to support corporate objectives.

Another demographic fact will underpin continuing demand for higher-degree graduates. Twenty-five per cent of the geoscience workforce employed by industry and non-educational Government instrumentalities is aged over 40. Many of these geoscientists will retire or move into managerial positions during the next decade. If this attrition is not matched by recruitment which includes a significant component of higher degree graduates, the geoscience workforce will become progressively deskilled. Given the present qualifications of the geoscience workforce, some 250 higher degree graduates will be required over the next 10 years, the majority holding doctorate degrees. This figure takes no account of enhanced demand for higher degree graduates, nor does it allow for any expansion in the total geoscience workforce. Furthermore, it takes no account of the replacement needs of higher education institutions which contain a much higher proportion of staff over 40 years of age.

In summary, the need for geoscientists with higher degrees is already substantial. It will persist, and is likely to grow as a result of both demographic factors and the dynamic objectives for which geoscientists are employed.

Incentives for the acquisition of higher degrees

An apparent justification for charging university fees for higher-degree candidates lies in the assumed financial benefit accruing to higher-degree graduates. This apparent justification cannot stand the test of close analysis.

The crucial tests of the financial benefits conferred by the acquisition of tertiary qualifications is the length of time that it takes a graduate to recoup the income which he or she has foregone as a result of acquiring those qualifications. For the majority of geoscientists, who are not in receipt of TEAS, the income foregone over the 4 years required to obtain basic qualifications will not be recouped until some 10 years after graduation. Four-year-trained geoscientists command $17 000-$22 000 on graduation, depending upon their abilities and field of specialism. If they elect to undertake a higher degree (2 years for Msc, 3½ for PhD), their scholarship stipend during this period will be $7000 (taxable), which is not far above the poverty line for a single person. Masters graduates will forego $20 000-$30 000 in income while obtaining their higher degree; doctorate graduates will forego $35 000-$52 000 in income. Upon graduation, those with higher degrees will command no more than $2000-$3000 more in salary than do their 4-year-trained colleagues. The principal advantage accruing from a higher degree arises from the preference by many employers for geoscientists with higher degree qualifications. Thus, their chances of employment are enhanced. Given the amount of income foregone over the 6 to 7½ years of training, higher degree graduates will, at best, be in mid-career before this income has been recouped. Some doctorate graduates will not recoup their foregone income until the closing years of their careers. Given that the early to middle career years coincide with the period of maximum financial need arising from family responsibilities, it is not surprising that many 4-year graduates who are capable of higher-degree study already reject this option as financially impracticable.

Evidently, short- to medium-term financial gain cannot be a motive for obtaining higher-degree qualifications, except in the case of the small number of 'high fliers' who can reasonably expect accelerated promotion during the 10 years after completion of a doctorate. For the rest, the motivation lies elsewhere—in job satisfaction, rather than financial gain.

If job satisfaction is the ultimate aim of those who undertake higher degrees, a substantial vocational commitment is necessary during the acquisition of the higher-degree qualification. Those who have not undertaken higher-degree work in a technical discipline are unlikely to appreciate this requirement, because they will be unaware of the working conditions which apply in practice. These conditions are not governed by awards, nor are they monitored by shop stewards. They are such that no trade unionist would tolerate them for as long as a week: constant pressure to perform at maximum, long hours including weekends and broken shifts monitoring equipment, master-apprentice relationships of the classical kind moderated only by traditional scholastic community practice and the intervention of departmental heads or faculty boards in cases of difficulty. Statutory and regulatory provisions are minimal, and the academic community (including graduate students) would resist strongly any attempts at more detailed modification. Higher-degree training is probably one of the last unregulated areas of the workforce. It is likely to remain thus because only so can it be effective, and because the potential for exploitation in the classic sense is severely limited by the long-established practices of academic communities.

Because of the costs and pressure entailed, most geoscientists who acquire higher degrees do so at the commencement of their careers, before the age of 30. Secondment on salary or part-salary by industry to enable employees to pursue full-time higher degree studies is rare. Public Service Board post-graduate study awards provide opportunities for small numbers of government employees to undertake full-time higher-degree studies on half salary. In practice this is not an option for employees with substantial family commitments.

This pattern in acquisition of higher degrees is important, given the demographic composition of the geoscience workforce, one-third of which is aged less than 30 years. It is this youngest group, who command the lowest salaries, who would bear the brunt of any reimposition of university fees for higher degrees.

Implications of higher-degree fees

Certain implications of the proposed re-introduction of university fees for higher degrees are clear from the foregoing:

- the charging of fees would provide a further financial disincentive to a course of action—the acquisition of

higher-degree qualifications—which is already financially unattractive in the short- to medium-term; consequently, recruitment into higher-degree courses can be expected to decline;
- among geoscientists, those at the beginning of their careers who are least able to meet additional costs would have to carry the additional costs of degree fees. Consequently attainment of higher degrees would become limited to students from well-off or wealthy families and those who were able to obtain scholarship support from mostly Government sources at greater cost to the taxpayer, because of administrative overheads, than is now the case;
- the consequent decrease in numbers of geoscientists seeking higher degrees would come at a time when demand for such geoscientists has been increasing and where there is every indication that the demand is likely to continue to increase. The net effect of the introduction of higher degree fees would be to de-skill the geoscience workforce at a time when enhanced skill is needed.

The foregoing analysis provides the basis for another objection to the re-introduction of higher-degree fees, on equity rather than human resource grounds. Although it will take decades for most higher-degree graduates to recoup the income foregone during the acquisition of their first and higher degrees, most will from the commencement of their careers receive higher salaries than they would have received without their higher degrees. Consequently, their income tax payments will be increased throughout their careers, and this will be particularly apparent in the closing years of their careers, after they have recouped the income foregone during higher-degree training. In the course of their careers these higher-degree graduates will be a source of additional taxation at least equal to the cost of their higher-degree training. Consequently, the charging of fees for higher-degree courses contains a hidden element of double taxation, quite apart from its negative economic effects.

Conclusions

In the case of geoscientists, the re-introduction of university fees for higher degrees should be rejected categorically because it would be:

- economically counterproductive through de-skilling of the geoscience workforce;
- likely to undermine government policy aimed at increasing R&D carried out by industry;
- inequitable because of the element of double taxation involved.

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EMPLOYMENT OPPORTUNITIES FOR GEOSCIENTISTS: INDICATIVE TIME-SERIES, 1979-1985

Keith A. W. Crook[1]

Abstract

Positions for geoscientists advertised in two weekend papers provide the basis for time-series showing changing patterns in employment opportunities for geoscientists. A weekly time-series, based on a four-week running mean of the total number of positions advertised, clearly shows the onset and collapse of the resources boom in 1979-81, a trough in 1982-83 reflecting the world economic recession, and a plateau since 1983.

Quarterly time-series categorised according to the type of employer show that no employer categories have adopted the practice of counter-cyclic recruitment.

Quarterly time-series categorised by fields of employment of geoscientists show varying patterns. Employment opportunities for some categories of geoscientists show relatively small fluctuations, implying a persistent demand which perhaps indicates under-supply of graduates with backgrounds in these categories.

Time-series data can provide early warning of changes in the pattern of employment opportunities and could serve as a tool for management of the geoscience workforce.

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Introduction

Since the minerals boom in Australia in the 1960s, employment opportunities for geoscientists are recognised to have fluctuated in a broadly cyclic fashion. However, statistical data on the nature of the fluctuation and the way it affects various components of the geoscience workforce are quite limited. Surveys have been undertaken by the Geological Society of Australia in 1967 and 1978 (Townley & others, 1968; Berkman, 1980) and by the Australian Geoscience Council in 1982-83 (Sant, 1984a, b). In recent years the Australian Mining Industry Council has undertaken an annual survey of recruitment and releases of geoscientists by its members. This annual survey will continue.

In 1983 the Australian Institute of Geoscientists held a symposium on 'Cyclic waves in exploration: the employment of geoscientists', the proceedings of which have been published (Emerson, 1984). The papers presented examine aspects of the causes of cyclicity, its implications for geoscience education, and ways in which the cyclicity can be accommodated or moderated. No statistical data on employment opportunities are included.

The available database provides 'snapshots' from a cyclic time-series at particular times during the past 20 years, and a partial annual time-series covering the industrial sector of the geoscience workforce. Ideally one would like complete information of recruitments and releases—including retrenchments, resignations and retirements—across all sectors of geoscience employment, sampled at a time interval much shorter than one year. This ideal is unattainable, but some approximation on the recruitment side can be provided through a weekly time-series based upon advertised positions. That is the subject of this paper.

Recruitment Time-Series

Database

Data were collected by counting advertised positions for geoscientists appearing in the Saturday edition of *The Canberra Times* and in *The Weekend Australian* for each weekend, commencing 14 April 1979. All pages of each paper were examined so as to identify relevant advertisements. Those included in the count either stipulated or clearly implied that a tertiary qualification in geoscience was relevant to the position being advertised, although a title of the position advertised in some cases was not explicitly geoscience-related (e.g. 'museum curator' rather than 'geologist').

Relevant advertisements were found to be scattered throughout the newspapers examined, particularly in *The Weekend Australian.* This pattern continued even after the introduction of a 'Geoscience' category in the 'Positions Vacant' section of *The Weekend Australian.* Introduction of this category resulted from representations made to the management of the paper in 1980 on the basis of early data collected for this study. Subsequently, on 30 March 1981, *The Australian* published an article in its 'Mining & Exploration' section reviewing shortages in the supply of geoscience graduates (Crook, 1981).

In compiling the data, no attempt was made to go beyond the two weekly editions of the papers mentioned. Thus, positions advertised solely in capital city newspapers or in the mining press were not counted. Likewise, positions advertised solely in the 'Higher Education' supplement of *The Australian* were not counted. However, almost all academic positions have been advertised in *The Weekend Australian* as well as in the 'Higher Education' supplement.

Some positions were advertised on more than one occasion, but no adjustments were made to the counts to compensate for this. Such duplication is probably more than offset by advertisements that did not fall within the purview of the survey, and by vacancies for recent graduates which were not advertised, being filled by interviewing panels which visit tertiary education institutions.

Some advertisements were for more than one position in the category described, but the number of positions was not stated explicitly. The counting convention adopted in such cases was to count two positions where the advertisement implied that more than one post was to be filled, and three positions where the advertisement referred to 'several' vacancies.

From 6 September 1980 the data recorded were categorised according to the type of employer and the field of geoscience described in each advertisement. From this data advertisements for 'technical officer' were included in the count. Data on advertisements for 'technical assistant' and 'geological draftsperson' were also collected, but were not included in the total or sectional counts, as these positions do not require tertiary geoscience qualifications.

Employers were categorised as follows: Australian industry, foreign industry, CSIRO, Australian Government, State governments, overseas governments, Australian universities, overseas universities, CAEs, and TAFE plus secondary schools. The foreign industry category included only those positions that were based outside Australia. The Australian Government category included BMR, AMDEL and other Australian Government employers of geoscientists, exclusive of CSIRO. The Australian universities category included advertisements for higher-degree scholarships, where these were open only to geoscientists. Posts in physical geography were included where these nominated qualifications in solid earth science. The TAFE plus secondary schools category included posts in geology and earth science, but not geography. Advertisements for soil scientists were not included unless the job description nominated a background in one of the 'geological' aspects of soil science—surficial geology or mineralogy-petrology.

The fields of employment of geoscientists recorded were: metalliferous geologist, oil shale and coal geologist, engineering geologist and geotechnical engineer, mathematical and computer geologist, marine geoscientist, general geologist, petroleum geophysicist, general geophysicist, mineral resource economist, petroleum geologist and sedimentologist, environmental geologist plus surficial geologist plus hydrogeologist, structural geologist and remote sensing geoscientist, mineralogist/petrologist, palaeontologist, and geochemist. The metalliferous geologist category included positions in uranium and diamond exploration and economic geology positions in tertiary institutions where these were not described in terms of other categories. Geotechnical engineering positions were only included where geoscience qualifications were indicated as relevant. The general geologist classification covered geological positions for which a specific field was not indicated. The general geophysicist category included all geophysicist positions other than those relating to marine geoscience or petroleum geophysics. The mineral resource economist category included only those positions that specified or indicated a geoscience background; posts requiring only an economics background were not included. Posts in geomorphology and other 'solid' earth aspects of physical geography were counted with sedimentology, surficial geology, or remote sensing as appropriate. The palaeontology category included palynology, Technical officer positions were recorded as a separate employment category, and each position was also included in the geoscientist category relevant to the post advertised.

Data Presentation

The total number of positions advertised is shown on a weekly basis, commencing in the second quarter of 1979, in Figure 3. Because weekly totals vary between 0 and 69 and show erratic changes from week to week, the time-series has been smoothed by the application of a four-week running mean. Gaps in the record cover the Easter weekend and Christmas-New Year when positions are not advertised, and occasions on which *The Weekend Australian* was not published or was unavailable. Where gaps occur the running mean has been maintained by averaging the weeks on each side of the gap.

The data for employer categories and geoscientist categories are presented in histogram form as a quarterly time-series commencing in the fourth quarter of 1980 (Figs. 4-6). Certain categories have been combined and others are not included because of small total numbers or lack of apparent relevance (general geologist). The raw data are available from the author on request.

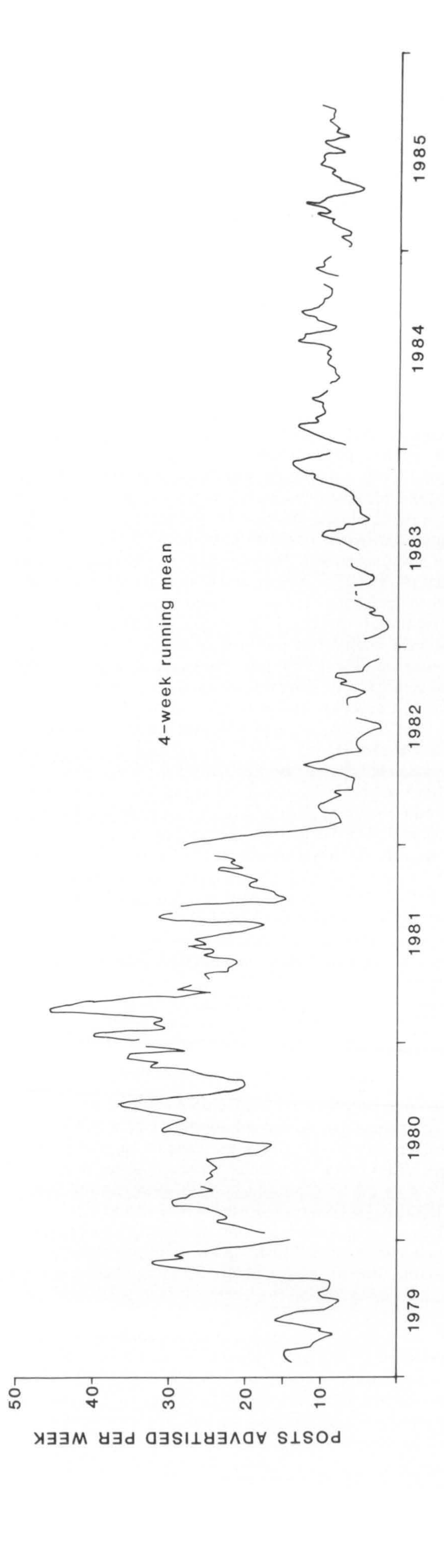

Fig. 3. Time-series for the total number of geoscience posts advertised each week in the Saturday edition of *The Canberra Times* and *The Weekend Australian*, depicted as a 4-week running mean.

Interpretation of the time-series

The time-series presented here (Figs. 3-6) are an index of employment opportunities. The procedures used in collecting the raw data were not intended to ensure complete coverage, nor did they include adjustments for positions advertised on more than one weekend. Attainment of complete coverage is a task requiring both institutional support and cooperation from industry and government to identify positions which are not advertised, being filled by direct recruitment or short-term contract. While some duplications could have been eliminated by cross-comparisons between weeks, this task was both onerous and subject to uncertainties because of variations in the wording of advertisements. It was therefore not attempted.

Despite these limitations, the time-series show clear trends. The resources boom of 1979-81 is clearly apparent on Figure 3, as is the rapid decline through 1982 and early 1983 which reflects the world economic recession. Since mid-1983 employment opportunities have plateaued. Counter-cyclic recruitment has been advocated on various occasions (see Emerson, 1984), but the employer time-series (Fig. 4) shows that neither industry nor government has adopted this practice. With some exceptions the time-series for categories of geoscientists reflect the overall cyclicity. The most notable departures are for the categories of environment geologist-surficial geologist-hydrogeologist, engineering geologist-geotechnical engineer, and petroleum geophysicist, which show less fluctuation than other categories. Marine geoscience shows an increasing trend from 1982; this largely reflects the implementation of the BMR's marine geoscience program and the Australian contribution to marine geoscience in the southwest Pacific under the Tripartite program (Australia-NZ-USA), the Australian component of which has been funded by the Australian Development Assistance Bureau.

Conclusion

The time-series and the data on which they are based have several applications. The onset and decline of the resources boom is clearly evident (Fig. 3), requiring only a few weeks of record to signal the change. Likewise, the climb to a plateau in 1983 is apparent after only a few weeks of record. These gross changes were readily apparent during data collection. Thus, the continued collection of data can provide early warning of changes in pattern, and could thereby serve as a tool to assist with workforce management practices.

The time-series by categories identified fields of geoscience for which demand is rather persistent, perhaps indicating an under-supply of graduates with training or experience in these areas. The employer time-series reflect recruitment practices as well as immediate needs.

The time-series data, if they could be cross-correlated with data on qualifications and seniority such as that in Sant (1984a, b), could provide part of the basis for predicting future needs for geoscientists with higher degree qualifications in the light of expected retirements and movements into managerial positions in both industry and higher education institutions (see Crook, 1986).

Continued collection of data on employment opportunities is warranted. I plan to do this, at least until my next long absence from Australia on sabbatical leave, whenever that may be. However a more systematic and comprehensive data set would be of greater value. Acquisition of such a data set requires an institutional commitment, which could be

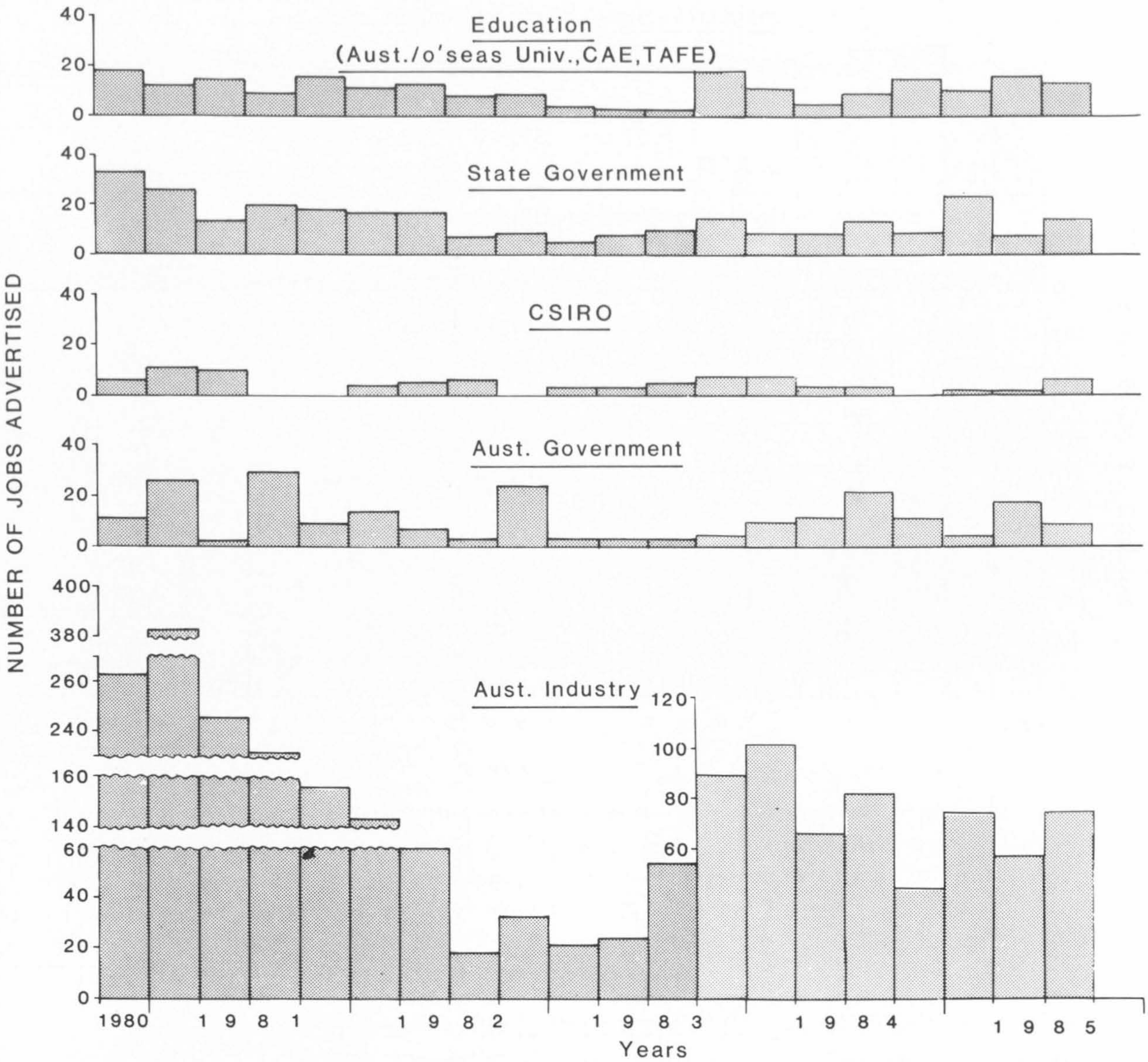

Fig. 4. Quarterly time-series of positions advertised by various categories of employers of geoscientists.

undertaken by the Australian Government or by an organisation such as the Australian Institute of Geoscientists, APEA, and AMIC.

The 1984 Platform of the Australian Labor Party contains the following section in its Minerals and Energy chapter:

'. . . a Labor Government will . . .

56 Promote research in geoscience as a basis for resource assessment, exploration and policy advice by—

. . .

c. encouraging an adequate and sustained supply of geoscientists.'

No action to implement this policy item has yet been taken. Nevertheless it provides a basis for continuing acquisition of data on geoscience employment by government or by cooperation between government, industry and higher education institutions.

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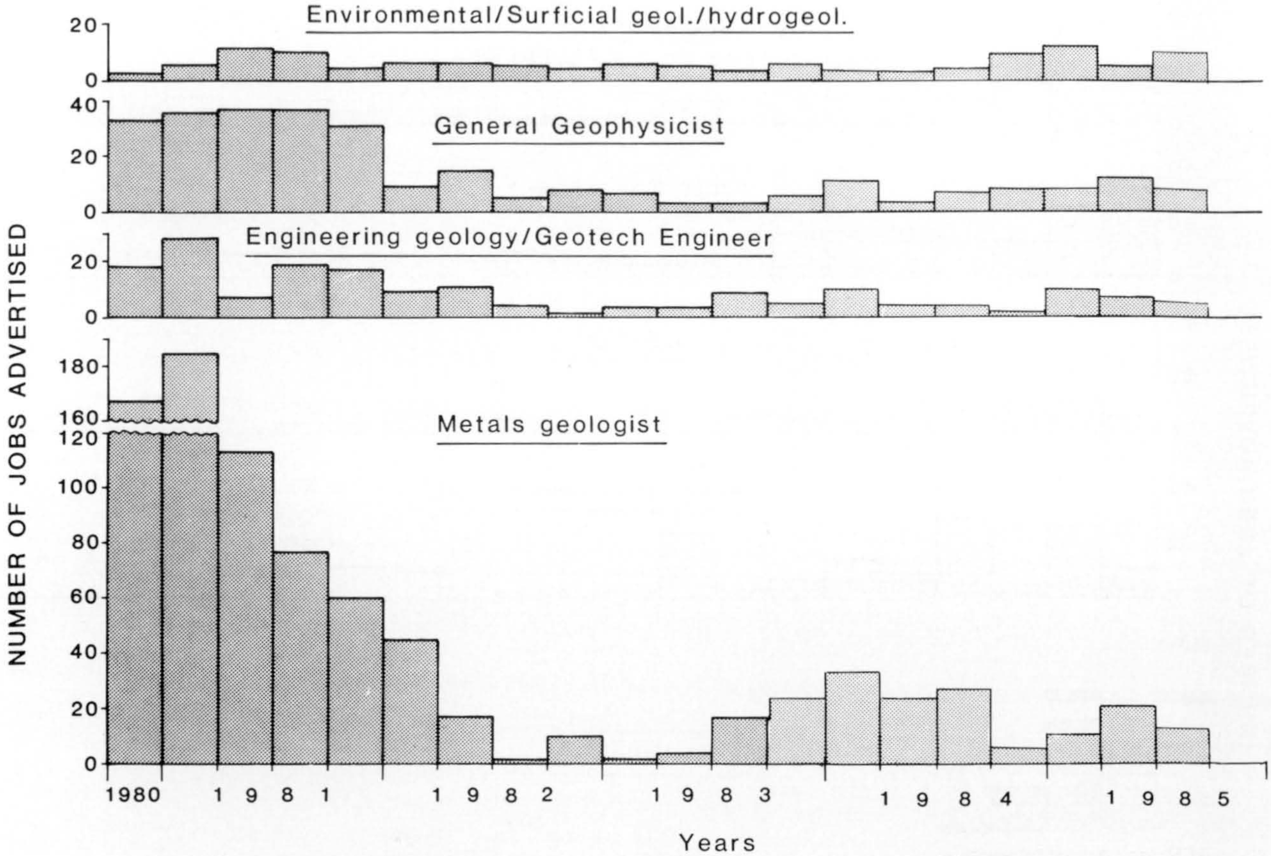

Fig. 5. Quarterly time-series of positions advertised for various categories of geoscientist.

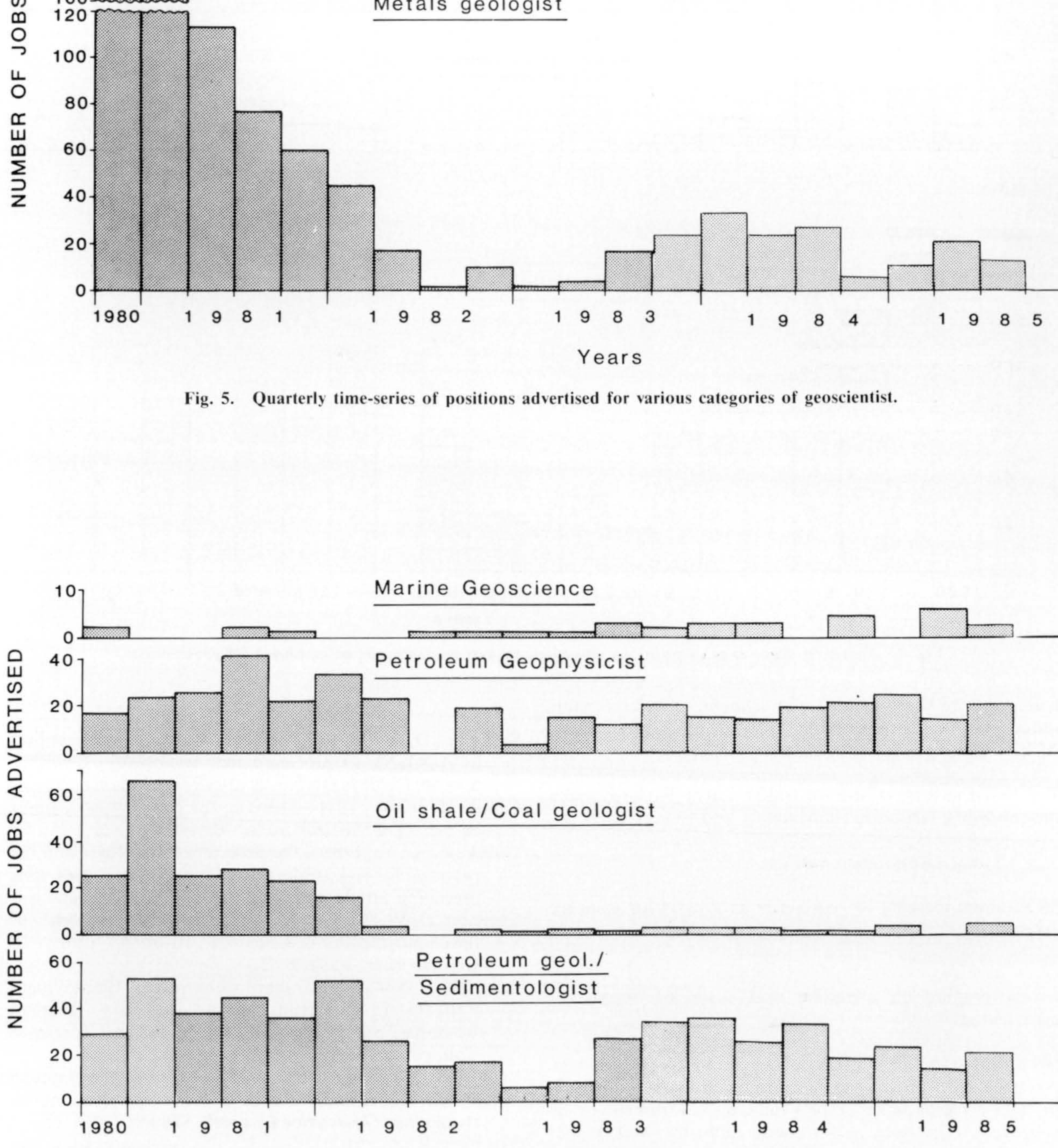

Fig. 6. Quarterly time-series of positions advertised for various categories of geoscientist.

PROFILES OF MEMBER SOCIETIES AND DISCIPLINES

Government Geologists' Conference

The Government Geologists' Conference (GGC) is a committee of the Directors/Chief Geologists of the Geological Surveys of the six States and the Northern Territory and the Director of the Bureau of Mineral Resources. It is a committee of the Australian Minerals and Energy Council (AMEC) which comprises federal and state ministers with responsibility for mineral and energy matters. GGC meets annually to discuss matters of mutual concern; the chairmanship and secretariat rotates among the States, NT and BMR.

GGC prepares position papers from time to time, some of which are designed for consideration and endorsement by AMEC. Two such papers—both favourably received by AMEC—are reproduced below:

Roles for the Government Geologists' Conference

The 14th meeting of AMEC noted this position paper, although it was not formally endorsed. The roles are:

1. Continue to act as a forum for the direct exchange of information relevant to the more effective performance of the geoscientific work of the organisations represented.
2. Continue to foster inter-State and State-Commonwealth co-operation in geoscientific endeavour, and to apply and refine existing formal procedures designed to effect this.
3. Continue to act as an advisory and consultative body to the Australian Minerals and Energy Council.
4. To develop national objectives for systematic geoscientific map coverage of the Australian continent.
5. To arrange and monitor meetings of representatives from within specialist groups in the government geoscience fields to ensure effective development of techniques and concepts.
6. To provide a consultative mechanism for, and to facilitate the co-ordination of major national geoscientific projects whose success is dependent on support from its member organisations.
7. To establish dialogue with other bodies representative of Australian geoscience, where this has potential to assist co-ordination of national effort and standardisation of nomenclature, or to increase understanding of geoscience and its application to the benefit of the community.
8. To encourage exchange of information and ideas on geological matters with New Zealand and Papua New Guinea by according the heads of their Geological Surveys the status of observers at the Government Geologists' Conferences.

Systematic geological mapping

At its meeting in Canberra in March 1985 the Conference considered a position paper on the objectives and strategy of each State and Territory with respect to systematic geological mapping. Discussion at this meeting confirmed that each State and Territory had policies with much in common. Further, it was determined that a statement on geological mapping, which had been prepared by Dr N. F. Markham, Director of the Geological Survey of New South Wales, be submitted to the Australian Minerals and Energy Council for its endorsement, which was given at its 15th meeting in Melbourne in October. The statement had been tabled at an AGC meeting in May. It reads as follows:

1. Geological maps are a means by which information on the composition, structure and evolution of the Earth's crust can be graphically portrayed.
2. Such maps are vitally important in geoscientific research as a basis for mineral and petroleum exploration and resource assessment, and find application also in such fields as environmental geology, land use planning, agriculture, soil science and engineering, and hydrogeology.
3. The responsibility for systematic geological mapping of the Australian continent lies with State and Territory Geological Surveys.
4. Geological Surveys have as one of their prime objectives the maintenance of an up-to-date series of full colour geological maps at 1:250 000 scale covering the whole of their State or Territory.
5. High priority will be given by each Geological Survey to the completion of the 1:250 000 series, and the regular revision of all such maps.
6. Systematic geological mapping at more detailed scales such as 1:100 000, 1:50 000 and 1:25 000 will be carried out in areas selected on the basis of their resource, environmental or special geological importance.
7. Geological Surveys will prepare a 'State' or 'Territory' geological map at an appropriate scale such as 1:2 500 000, 1:1 000 000 or 1:500 000. Such maps will be revised on a regular basis.
8. In order that the above mapping objectives might be achieved, continuation of support from the wider geological community, in the form of assistance in the provision of new geological information and concepts, and continuation of support from State and Territory Governments in the form of staff and finance, will be required.

GGC at its 1985 meeting also determined that a further position paper, on the broader scope of geoscience (thematic) mapping of the Australian continent, be prepared for discussion at its 1986 meeting (Brisbane, April). It is proposed that this statement will address, in addition to the systematic geological mapping of the 1985 statement, other geoscience mapping themes including geophysics (magnetic, gravity, radiometric, seismic), hydrogeology, engineering/environmental/urban geology, mineral deposits/metallogeny, tectonics, geomorphology/Cainozoic geology, metamorphism, geothermal gradient/heat flow data, and marine geology.

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Chief Government Geologist
Geological Survey of Queensland
Chairman—Government Geologists' Conference

Australian Institute of Geoscientists

The Australian Institute of Geoscientists was formed in 1981 after more than 10 years of preliminary work by members of the Geological Society of Australia (GSA). At the instigation of the Hunter Valley Branch, the GSA Council in 1969 decided to ascertain the views of members regarding an extension of GSA activities into the areas of professional regulation, mainly because of widespread dubious practices during the mining boom of that period.

Dr A. F. Trendall, GSA President in 1970, determined that the best way of controlling the profession and those claiming to possess expertise in geological fields was by the establishment of Registration Boards in each State. These Boards would register qualified geologists in a similar manner to dentists, surveyors, architects and other professions. This decision was reached after invited submission from interested parties and individuals. A ballot of GSA members voted in favour of the proposal (621 'Yes' and 121 'No').

A Legislation Committee (LC) was established with Dr Trendall as Convener and four members from each Division, the four members representing industry, education, government and consultants. In December 1971 a formal submission recommending legislation for the establishment of Registration Boards was presented by GSA President, Professor D. A. Brown to the Hon. Mr Swartz, Minister for National Development. This was approved in principle in May 1972 by the Australian Minerals Council (AMC)—a consultative body composed of the Mines Ministers of each State and the Minister for National Development (Convener)—and the Crown Law Department of Western Australia was given the task of producing a Draft Bill for discussion at the next meeting of AMC in 1973. However because of political changes of the period no meetings of the AMC were convened and the proposal for Registration Boards was not advanced—the public and politicians had lost interest in our profession and its problems.

In 1975 GSA formed the Committee for Professional Representations (CPR) with K. Warner as Convener. A survey indicated that a majority of GSA members favoured professional representation, but no clear method was suggested to achieve this purpose. By 1977 the GSA Council had decided to combine the LC and CPR into the Professional and Legislation Committee with C. L. Adamson as Convener. As there was nothing to be gained in pursuing the matter of Registration Boards at that time, the Professional and Legislation Committee concentrated its efforts on the first and second of its terms of reference which were as follows:

- Study methods of achieving increased professionalism and status in the profession of geology.
- Formulate means of establishing a professional group for geologists either within or outside GSA.
- Continue to work towards the establishment of legislation for registration of geologists. It is envisaged that Registration Boards and a professional group would perform different but complementary functions.

After a study of various alternatives the GSA Council at its Hobart meeting in 1980, directed the GSA Executive to proceed with the formation of a professional organisation in conjunction with the Australian Society of Geophysicists (ASEG) and the Petroleum Exploration Society of Australia (PESA) and any other appropriate organisations. The new organisation would be independent but GSA would provide office facilities at a suitable financial rate.

Since incorporation in 1981 the AIG has been continuously active, representing the interests of all geoscientists on the professional front. Foremost in the AIG profile has been the annual seminars—'Science in the Eighties'—dealing successively with professional liability/responsibility, cyclicity in employment, and the superannuation problem. The fourth seminar in the series—'Land and title management for the practising geoscientist'—will address the new role in which the geoscientist frequently finds himself engaged, in addition to normal duties. At the same time AIG has published, as a member service, handbooks on field operators guidelines, the practice of the self-employed geoscientist, and a kit for the student/graduate entering employment. A quarterly newsletter now keeps members aware of activities of the various State branches and individual committees.

AIG has prepared submissions on a diverse range of topics where the profession and its practitioners may be involved. These include the Western Land Commission of NSW, the CSIRO reorganisation enquiry, the WA Aboriginal Lands enquiry and, most recently, the enquiry into the taxation of gold. AIG has also represented geoscientists before the NSW Arbitration Commission and acts as an advising body to the Federal Committee on Overseas Professional Qualifications.

Standing Committees have been established to review membership, Tertiary Accreditation, and Stock Exchange Accreditation, and a temporary Committee has worked to support the NSW Mining Museum. One of the prime aims of AIG is to maintain a recognised professional and ethical standard of its membership, such that the Australian Association of Stock Exchanges will automatically permit AIG members to prepare report and prospectus material subject to its listing requirements. This recognition has not been achieved to date but will be pursued until such recognition is achieved.

AIG membership has been increasing since incorporation; it now stands above 500 and should top 600 by the end of 1986. AIG operates as a non-profit organisation and does not accept funds from external sources. Positions on Council and State branches are honorary and accordingly subscription levels have been comfortably maintained at the 1981 levels of $30 per annum for Fellows, Members and Graduates. A fourth membership level to cover undergraduates in geoscience is under review.

AIG functions through a Federal Council presently based in Sydney, with active independent State branches currently in Western Australia, Queensland and New South Wales. With membership growth and maturation it is expected that the Federal Council will be ultimately made up of representatives of the individual State branches.

AIG's present and future activities are directed to ensuring that the professional status of geoscientists is respected by the membership and recognised by the community at large, and that future provision is made for a rational and orderly supply of geoscientists from Australian tertiary education institutions. By comparison with elsewhere in the world, AIG expects that formal professional registration of geoscientists, under government regulation, will be required in Australia in the next two decades. With this in mind, and considering its original conception, AIG is working to ensure that any registration system is a reasonable, practicable and valid procedure with the interests of the profession being served in all aspects.

For those who have read thus far it is safe to assume that you recognise that AIG seeks to pursue solutions to the major problems facing geoscientists in terms of cyclicity of employment, the establishment of comparative accreditation and recognition, and accreditation by the Stock Exchange. To achieve this, AIG must expand such that all State branches function in a manner that allows individual geoscientists to contribute their experience and express their views on those matters.

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Hon. Secretary, Australian Institute of Geoscientists
c/- 10 Martin Place, Sydney

Soil science in Australia, 1985

In Australia, soil scientists are employed by State Departments, CSIRO and Universities. To these persons is given the daunting task of providing leadership in the quest for the maintenance and improvement in the productivity of Australian soils.

State Departments of Agriculture employ scientists to investigate soil problems and to give advice to property owners. The Western Australian Department of Agriculture has soils personnel in Branches concerned with soil conservation, land management and irrigation, and water resources. Much attention is currently being given to the important salinity problems in that State. The main departmental soils research centres are located in Perth and at Merredin; advice on soils matters is available in all regions.

In South Australia, the Agriculture Department has extension and research programs on soil salinity, land management, hydrology and conservation. The main soils research centres in that State are located at Adelaide and Loxton.

Soils personnel in the Victorian Department of Agriculture are investigating and advising on matters related to soil salinity, land management, fertiliser use and herbicide degradation. The Victorian Department of Conservation, Forests and Lands employs a number of scientists in the soil conservation area. Tatura and Melbourne are the main centres for departmental soils research in Victoria, and extension activities in soil fertility are present in all cropped and grazed areas.

In New South Wales, the Soil Conservation Service employs a large number (approximately 230) of soil scientists. This is almost 70% of the total number of soil conservationists in Australia, and indicates the serious attitude of the leaders in that State to soil erosion losses. (This contrasts with the lack of attention given to this area in some other States .) Whilst the majority of scientists act as advisors, a number are employed as research officers, principally at Cowra and Gunnedah. The State Department of Agriculture employs a small number of soil scientists to work on soil nutrient availability and land management. The main activities in these areas take place at the Rydalmere Biological Research Institute.

The Queensland State Department of Agriculture has strong groups involved in soil surveying and soil conservation, and work on soil management and soil testing is supported at various centres. The main research centres are located at Biloela, Brisbane, Mareeba, Rockhampton and Toowoomba. However, advice is available to property owners with soil problems in all regions.

In the Northern Territory, activities in soil surveying and soil conservation are supported by the Conservation Commission. Similarly, the Tasmanian Department of Agriculture employs soil scientists as research officers and advisors on soil fertility and soil conservation problems.

The CSIRO Division of Soils has research centres at Adelaide, Brisbane, Canberra and Townsville. The Adelaide laboratory, with 60 scientists and 55 support staff, is the largest centre for soils research in CSIRO, and indeed in Australia. Each of the other three centres employ 11-12 scientists together with an equal number of support staff. Important research in the areas of mineralogy, pedology, soil biology, soil chemistry and soil physics is being performed in the various laboratories and associated field areas.

Other Divisions of CSIRO employ soil scientists to work in specific areas. For example, the Division of Plant Industry has 5 scientists plus support staff based at Canberra who are concentrating on problems associated with the use of nitrogen fertilisers. Similarly, a group in the Division of Environmental Mechanics is investigating processes involved in the movement of water in soils. In addition, a number of scientists in the Divisions of Water and Land Resources, Animal Production, and Atmospheric Physics work on soils-related programs.

Small groups of soil scientists are employed in 10 Australian universities to perform teaching and research tasks. These are the Universities of Adelaide, Griffith, La Trobe, Melbourne, New England, New South Wales, Queensland, Sydney, Tasmania, and Western Australia. Of these, the group with five personnel at the Waite Institute, Adelaide University, comes closest to what is regarded as the lower limit for viability in most advanced countries. Soils lecturers at the universities attempt to train students in pedology, soil biology, chemistry, and physics. Such attempts are usually hampered by the lack of personnel in specific areas, and there is clearly a case for the amalgamation of smaller groups. However this would be in opposition to the Australian policy that Agriculture Faculties should teach a little of everything to students. Such a policy unfortunately means that in some cases satisfactory recruits for CSIRO and State Departments are not available from Australian Universities.

In conclusion, it is my opinion that the body of soil scientists outlined above is small, considering the impoverished and fragile nature of our soils. If soil productivity is to be maintained and improved, an influx of good scientists who understand soils is necessary. However, the current number of Australian postgraduate students being trained in soil science is small, a reflection of the few and small departments in this country. This situation will only be rectified when the public and politicians become aware of the importance of our soil resources, and the necessary support is given to extension, research and teaching activities in soil science.

L. A. Douglas
President, Australian Society of Soil Science Inc.
University of Melbourne

Engineering geology in Australia

'The application of geological principles to civil engineering projects has roots in antiquity and surely predates the formal study of both civil engineering and geology. The first practical person who noted the superiority of some types of stone over others in construction was applying geology in engineering. That same type of practical person is the one we geologists have been trying to help to improve the viability, economy, durability and safety of engineered projects in a more formal way for about the last 80 years. It is only during that short period of time that the term "engineering geology" has come to be recognized' (Tilford, 1985).

Major developments in Australian engineering geology practice flowed from the construction of the Snowy Mountains Hydroelectric Scheme in 1949 in NSW and the Kiewa Scheme in Victoria. Geologists and engineers demonstrated the advantages and need for co-operative approaches to engineering works. Many principles developed on these hydroelectric schemes were innovative even on a world scale at the time. One pioneering technique involved the method of describing weathered rock. Though changes have occurred to detailed descriptors there has been international acceptance of the concept of describing the degree of weathering as part of forecasting likely mechanical behaviour in tunnels and road cuttings. With the passage of time engineering geology has broadened and now tends to be less closely linked to the large-scale hydroelectric schemes and high dams that gave the discipline initial impetus. Over the last 25 years the closely associated field of geomechanics has arisen. This particularly covers the mechanical behaviour of rocks and soils that are important for foundations of high rise buildings, bridges and tunnels. Another interrelated discipline is environmental geology which began to be recognised in Australia in about 1970. A brief overview of environmental geology in Australia was provided by Philip (1976) who saw engineering geology as a well-established branch of environmental geology. Since that time 'environmental geology' has taken on a very specific meaning and is now seen as a partner of 'engineering geology' *(sensu stricto)* possibly under a broader heading of applied geology.

Environmental geology currently involves the application of geosciences to problems associated with urbanisation, industrial development and the demands placed on resources such as the sterilisation of needed construction materials (e.g. sand) by incorrect urban planning and development. Siting houses in safe locations to avoid landslide hazards and developing non-polluting landfill waste disposal techniques are also some of the problems solved by environmental geologists. The close relationship between environmental geology and engineering geology can be readily seen in the management of landfill waste disposal sites. An understanding of the mechanical behaviour of waste and cover soil is necessary as heavy compactors are used to minimise both the costly space required and subsequent settlement of the fill (Fig. 7). Properly constructed landfills can reduce environmental problems and turn the final ground surface into a useful and valuable asset such as a playing field.

Over the last few years, there has been perceived the need for engineering geologists to relate on the one hand to civil engineers and on the other to geologists specialising in other fields. This interaction in both directions is considered to be essential for the development of engineering geology. As a result two different but complementary organisations have been formed in Australia, namely the Australian Geomechanics Society and the Engineering Geology Specialist Group of the Geological Society of Australia.

The Australian Geomechanics Society is co-sponsored by The Institution of Engineers, Australia and The Australasian Institute of Mining and Metallurgy. The Society has 552 members, many of whom are civil or mining engineers. However, a significant number of engineering geologists also belong. The Society is particularly important as it is the national group for three international societies:

- International Society for Rock Mechanics (ISRM);
- International Society for Soil Mechanics and Foundation Engineering (ISSMFE);
- International Association of Engineering Geology (IAEG).

As these international groups co-operate closely in organising international conferences and have many members in common it is appropriate that the one society act as the national group for all three international societies.

The Engineering Geology Specialist Group on the other hand has 220 members, nearly all of whom are geologists. The Specialist Group was established by the Geological Society of Australia in 1979 and seeks to include those involved with engineering geology *(sensu stricto)*, hydrogeology, and environmental geology. It sees its role as interfacing with the geological community. Many of its members are also members of the Australian Geomechanics Society, and through that Society, members of the three international societies.

Fig. 7. Heavy compactor in use at the Lucas Heights Regional Waste Disposal Depot, Sydney.

A small number of Australians has joined the Association of Engineering Geologists based in the United States but it is considered that the numbers will remain relatively small because of the coverage offered by the other two groups. Again there is quite an overlap in membership.

It is not possible from the professional groups' membership figures to precisely ascertain the number of engineering geologists practising in Australia, but it is estimated to range between 300 and 500. Precision is difficult because a number are not members of any of the professional groups mentioned and many work in positions classified under other names. State Geological Surveys tend to call their geoscientists geologists but other government departments and instrumentalities may give them a variety of titles such as Scientific Officer, Scientist, Research Scientist or Experimental Officer. Whilst the picture differs state by state it is certain that taking Australia as a whole there are many more people practising engineering geology in government departments and instrumentalities than there are in the various Geological Surveys. For instance in NSW engineering geologists are employed extensively by the Water Resources Commission, Department of Main Roads, State Rail Authority, Pollution Control Commission, State Electricity Commission, Public Works Department, and Metropolitan Water, Sewerage and Drainage Board. In private enterprise, engineering geologists are employed by consultants, large construction companies, the quarry industry, mining companies and the like.

Some of these geologists are being called upon to report the wider environmental implications of development projects such as the adequacy of protection measures and the restoration of abandoned mines. Many engineering geologists are also involved in the traditional areas such as foundation investigations and slope stability. This is especially important in case of road pavements. Engineering geologists and engineers work together to minimise pavement failures such as that seen in Figure 8.

Construction materials are the concern of some engineering geologists, particularly those employed by Government departments and instrumentalities in the public works area such as roads, dams, ports and buildings. Because of stringent budgetary controls it is essential that appropriate materials be used. This may mean the development of treatment procedures so that materials which are not suitable by themselves may be treated to make them acceptable. Examples of such processes are found in road construction where natural materials are stabilised with lime or cement to provide acceptable base or sub-base materials. There is a continuing need for research into uses for waste products such as steelmaking slag or coal washery waste. These materials have been used in roadmaking and are used as land fill.

Most of the work of engineering geologists is included in unpublished reports commissioned by employers. Much of this valuable work will never be published. In Australia, papers on engineering geology can be found in *Transactions of Institution of Engineers, Australia,* and in the proceedings of the various specialised conferences and symposia of The Institution, especialy the various Australia-New Zealand Geomechanics Conferences. A variety of articles, reviews and news items are regularly included in *Australian Geomechanics News* of the Australian Geomechanics Society. Occasionally papers appear in the *Australian Journal of Earth Science* and the Engineering Geology Specialist Group have published collections of papers presented at various conferences. Of particular significance was the publication of a case studies volume for use by students and practitioners in engineering geology (Knight, Minty & Smith, 1983). Another volume is in the planning stage.

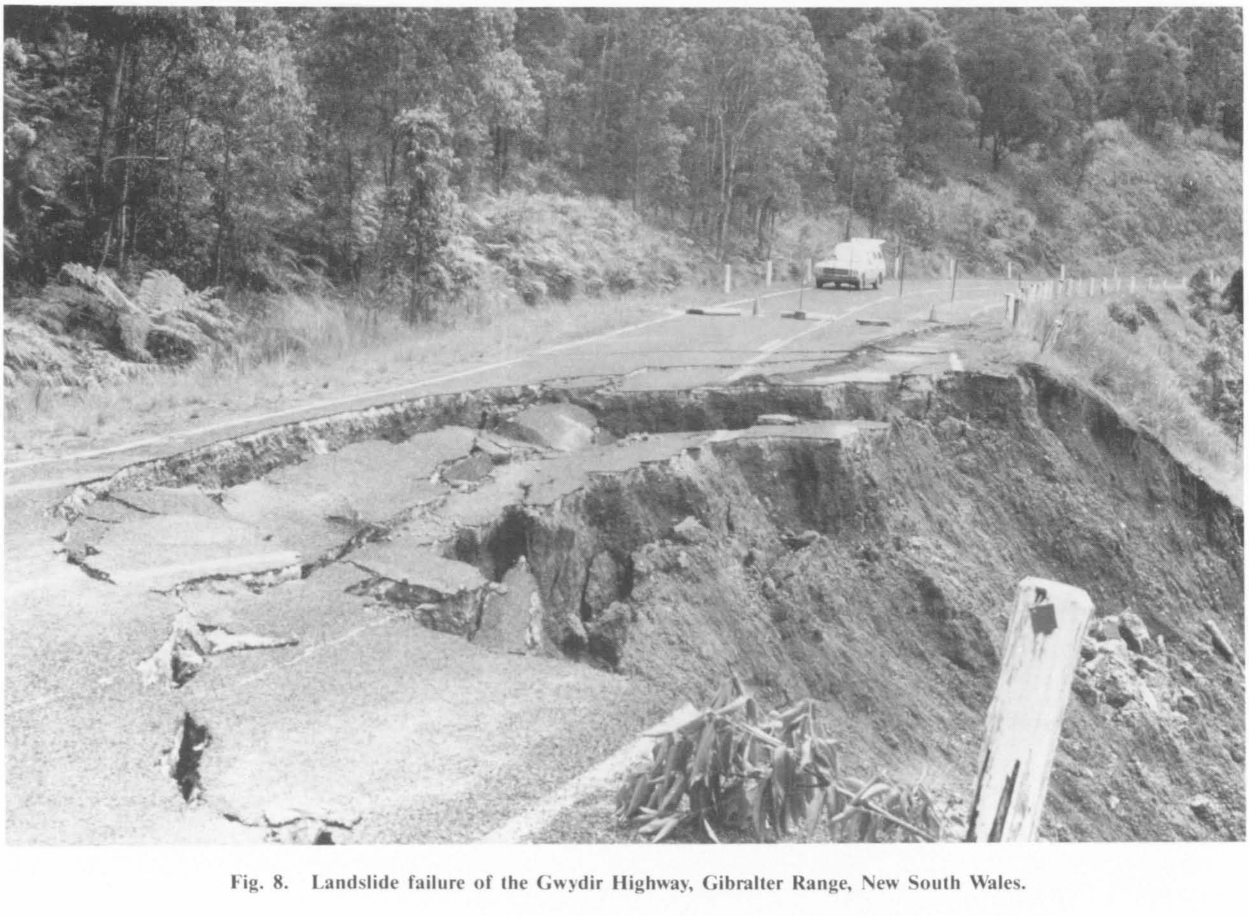

Fig. 8. Landslide failure of the Gwydir Highway, Gibralter Range, New South Wales.

An important source of papers, particularly in the field of construction materials is *Australian Road Research,* and the proceedings of the biennial Australian Road Research Board Conferences.

Australians also publish in the *Bulletin of the International Association of Engineering Geology, Engineering Geology, Bulletin of the Association of Engineering Geologists,* and *Quarterly Journal of Engineering Geologists.* The ISRM, ISSMFE and IAEG hold regional and international conferences on a regular basis. These conferences may be general in approach or specific (e.g. aggregates, *in situ* testing in soil and rock). The papers presented at these conferences are generally published as conference proceedings.

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APPENDIX: DATA ON MEMBER SOCIETIES, 1985

Society and membership	*Objectives*	*Meetings, activities, committees*	*Publications*	*Awards*	*Association with other organisations*	*Other information*
ASSOCIATION OF EXPLORATION GEOCHEMISTS (AEG). P.O. Box 523, Rexdale, Ontario, M9W 5L4, Canada. 48 Empire Ave. City Beach, WA 6015. Membership in Australia: Voting 110 Affiliate 6 Student 78 Worldwide Membership over 700, in 60 nations.	To represent the professional interests of persons specialising in exploration geochemistry: to advance mineral exploration applications of geochemistry: to disseminate geochemical information and ideas among professional geochemists.	—11th International Geochemical Exploration Symposium, Toronto, April 1985. —Regional Meetings for 1986 in Vancouver, China and Johannesburg. —Regular Council Meetings. COMMITTEES: Admissions; Bibliography; Case Histories; Geochemical Analysis; Membership; Publications; Research and Education; Student Prize; Symposium.	—*Journal of Geochemical Exploration,* Elsevier (6 issues/year). —Quarterly Newsletter (to members only). —*Exploration Geochemistry Bibliography,* AEG, updated periodically. —*Handbook of Exploration Geochemistry,* Volumes 1, 2, 3, Elsevier. —Geochemical Exploration Series from AEG sponsored conferences.	—Honorary Membership. —Annual Student Prize.	—Australian Geoscience Council. —Canadian Geoscience Council. —International Union of Geological Sciences. —United States National Committee for Geochemistry.	AEG was founded in 1970 in Toronto as an international organisation. Australia has the third largest membership after the United States and Canada. The office bearers consist of a five-person Executive and 12 ordinary Councillors, all of whom are normally resident in North America, together with four regional Councillors representing Australia, Europe, and Southern Africa and Brazil.
AUSTRALASIAN INSTITUTE OF MINING AND METALLURGY (AusIMM). Clunies Ross House, 191 Royal Parade, Parkville, Vic 3052 Honorary Members 19 Members 1861 Associate Members 2773 Company Members 126 Affiliate 280 Junior 1078 Student 755 Total 6892	The objectives and purposes of the Institute are to promote and advance the science and profession of engineering with special reference to mining, including geology and metallurgy in all its branches. The Institute is both a professional body and a learned society. It serves the interests of geologists (including geophysicists), metallurgists and mining engineers as well as persons in other disciplines of science and engineering associated with the mineral industry. The Institute provides affiliate membership for persons working in responsible positions in the mineral industry and who are qualified in other professional fields.	—Annual Meeting. —Annual Conference. —Specialist Symposia and Conferences. COMMITTEES: Membership; Publications; Education; Awards; Mineral Heritage; Program; Public Relations.	—*AusIMM Bulletin and Proceedings* —Annual Conference Volume. —Symposium Volumes. —Monograph Series (Geology of Australia and Papua New Guinea, Field Geologists Manual, Mining and Metallurgical Practices in Australia. Victorian Brown Coal).	—The Institute Medal. —Honorary Membership. —President's Award. —Students Essay Prize.	—Australian Geoscience Council. —Australian Geomechanics Society (Joint technical unit with the Institution of Engineers, Australia). —Council of Mining and Metallurgy Institutions.	The Institute has 36 branches in capital cities and major mining centres in Australia, New Zealand, Papua New Guinea and Fiji.

Society and membership	Objectives	Meetings, activities, committees	Publications	Awards	Association with other organisations	Other information
AUSTRALIAN GEOMECHANICS SOCIETY (AGS) C/o Mr. Roy Bushnell Committee Secretary, The Institution of Engineers, Australia. 11 National Circuit, Barton, ACT, 2600 Financial Membership 498	To promote and advance the science and practice of geomechanics by implementing the learned society functions of the Institution of Engineers, Australia (IE Aust) and the Australasian Institute of Mining and Metallurgy (AusIMM) in the field of geomechanics.	—Australia-NZ Conference on Geomechanics held every four years. —Each of the State groups meets approximately nine times per year for technical sessions. —Usually each of the State groups holds a major technical seminar each year. —National Committee meets twice yearly (usually Canberra, Sydney or Melbourne).	—*Australian Geomechanics News* is published twice yearly for AGS by IE Aust. —*Australian Geomechanics Computing Newsletter,* twice yearly.	*The Australian Geomechanics Award: The John Jaeger Memorial Medal.* Awarded on the recommendation of the judging panel to an individual, considered to have made a significant contribution to Australian geomechanics over recent years. Awarded every four years to coincide with each Australian-NZ Conference.	—AGS is sponsored by IE Aust and Aus. IMM. Each member of the society shall, upon payment of annual subscriptions, become affiliated with the international Society of Soil Mechanics and Foundation Engineering, the International Society of Rock Mechanics, and the International Association of Engineering Geologists. —Australian Geoscience Council.	The objectives of AGS are carried out by organising technical conferences, symposia and meetings; by promoting research and development and improved practice; by cooperating with appropriate bodies outside the sponsoring societies both within Australia and overseas; and by means of a publication.
AUSTRALIAN INSTITUTE OF GEOSCIENTISTS (AIG) C/o Geological Society of Australia 10 Martin Place, Sydney, NSW 2000. Membership 600	To advance the status of Geoscientists in Australia and to act as a professional institute of geoscientists concerned primarily with technical and ethical standards, patterns and conditions with employment and the regulation of the supply of qualified geoscientists.	—Annual General Meeting. —Monthly Council Meetings. —State Branch Meetings. —Seminars.	—Special publication of Seminars. —Guidelines/Handbooks on professional matters. —Quarterly Newsletter.	No awards.	—Australian Geoscience Council. —Australian Society of Exploration Geophysicists. —Geological Society of Australia. —Petroleum Exploration Society of Australia.	Founded in Oct. 1981 following the report of a GSA committee which recommended that geoscientists required a professional body to represent them. This was supported by PESA and ASEG.
AUSTRALIAN SOCIETY OF EXPLORATION GEOPHYSICISTS (ASEG) P.O. Box 44, Eastwood, SA 5063. Membership: Active and Associate 857 Student 63 Honorary 6 Corporate 48 974	To promote: —the science of geophysics especially as applied to exploration; —fellowship and cooperation; —good standing of the geophysical profession; —close cooperation and understanding between all earth sciences. To assist in: —the design and teaching of geophysics courses; —formation of local branches.	—Annual Conference Perth 22-26 February 1987. —State Branch Meetings, 4 to 12 times per year. —Annual General Meeting, April each year. —Executive Committee, monthly. —Workshops/seminars/conferences (as advertised).	—*Exploration Geophysics The Bulletin of the Australian Society of Exploration Geophysicists,* four issues per year. —Newsletter (monthly) —*The Geophysics of the Elura Orebody.*	*Honorary Membership.* *ASEG Medal.*	—*Society of Exploration Geophysicists.* —*Australian Geoscience Council.*	

Society and membership	Objectives	Meetings, activities, committees	Publications	Awards	Association with other organisations	Other information
AUSTRALIAN SOCIETY OF SOIL SCIENCE INC. (ASSS). C/o Department of Soil Science, School of Agriculture, University of Melbourne, Parkville, Vic. 3052.	To advance soil science. To provide a link between soil scientists and members of kindred bodies within Australia and other countries.	—Approximately monthly meetings in each of seven geographical Branches. —Annual Conferences between three Branches. —National Soils Conference (4 yearly) —Regular Federal Council Meetings.	—No formal society journal, although ASSS has a representative on the Advisory Committee of *Aust. J. Soil Res.* —Occasional publications have been produced on nine specific topics including soil classification, glossary of soil science terms, and hydrogeology. —*Soils News* (quarterly) includes summaries of talks and newsletter material.	*J. A. Prescott Medal of Soil Science,* awarded annually to a person who has made an outstanding contribution to soil science. *ASSSI Publication Medal* awarded annually to a person under 35 years of age whose publications are judged on scientific merit, relevance to soil science, and effectiveness in communication.	—International Society of Soil Science. —Australian Geoscience Council.	ASSS was formed in 1956 as a federation of Branches, and most meetings are organised at the Branch level. The next National Soils conference is being organised for 1988 in Canberra.
GEOLOGICAL SOCIETY OF AUSTRALIA INC. (GSA). The Business Manager, Geological Society of Australia, Room 1001 Challis House, 10 Martin Place, Sydney, NSW 2000. Membership: Ordinary 2749 Associate 290 Student 204 Honorary 18 Retired 6 Company 33 3300	To advance the geological sciences in Australia.	—Australian Geological Convention held approximately every 18 months since 1975, hosted by Divisions on a national roster. —National and regional thematic symposia sponsored by the Society and run by Divisions, Branches or Specialist Groups at frequent intervals, as opportunity exists. —Division and Branch monthly meetings. STANDING COMMITTEES: Stratigraphic Nomenclature; Geological Monuments; Education.	—*Australian Journal of Earth Sciences* published quarterly. —Special Publications usually major thematic publications (latest release, No. 12, 1986). —*Australian Geologist,* a newsletter published five times each year. —*Alcheringa,* an Australasian journal of palaeontology. —Specialist Groups produce publications and newsletters from time to time. —Thematic maps—e.g., Geotectonic Map of Australia and New Guinea 1971. Excursion Guides. Abstract Series.	—*W. R. Browne Medal* awarded by each Executive to a person distinguished in the geological sciences through research, education or administration. —*F. H. Stillwell Award,* awarded annually for the best paper in Aust. J. Earth Sci. —Some Divisions offer prizes for outstanding tertiary and secondary students in Earth Science. —Honorary Membership.	—Australian Geoscience Council. —Australian Academy of Science National Committee for Solid Earth Sciences. —International Union of Geological Sciences. —Fostered the foundation of the Australian Institute of Geoscientists. —Joint meetings with Aus. IMM are commonly held at Division level. —Active scientific liaison is maintained between Australian earth scientists and overseas working groups, in part through collaboration with the International Geological Correlation Program.	—Founded in 1951. GSA has a code of ethics which members must endorse. —GSA is composed of six State Divisions, one Territories Division, two Branches, and nine Specialist Groups; and representatives of these bodies constitute the Council. —The Executive moves from one Division to another on a national roster, and consists of eight members, under the chairmanship of the President, who are elected by Council. —Executive term, and the interval between Council Meetings, is about 2 years. —GSA welcomes overseas members. —Sale of publication is through the Business Manager.

Society and membership	*Objectives*	*Meetings, activities, committees*	*Publications*	*Awards*	*Association with other organisations*	*Other information*
INSTITUTE OF AUSTRALIAN GEOGRAPHERS (IAG). C/o Dr. C. Adrian, Hon. Secretary, A.I.U.S., G.P.O. Box 809, Canberra, A.C.T. 2601	The promotion of the study and discussion of geography in Australia, especially by the holding of meetings at which the results of research may be presented and discussed. The advancement of geography in Australia, and the representation and advancement of Australian geography internationally. Cooperation with other organisations with kindred purposes.	IAG Meeting every 12 months. —Meetings of study groups.	—*Australian Geographical Studies* published twice yearly. —*IAG Newsletter,* two issues per year.	*IAG Honours Award,* for a paper based on honours research at an Australian tertiary institution.	—Australian Geoscience Council. —International Geographical Union. —International Geographical Congress 1988.	IAG was founded in 1958. Membership is by one of the following: —honours or higher degree in geography; membership of a Geography department or section in a tertiary institution; —contribution to geographical research; —engaged in work (recognised by IAG Council) as a professional geographer; —by invitation.
PETROLEUM EXPLORATION SOCIETY OF AUSTRALIA (PESA). C/o S. L. Keenihan, Secretary, G.P.O. Box 1801, Brisbane, Qld 4001 Membership: in Australia 1725 Overseas 92 1817	To promote professional and technical aspects of the petroleum industry throughout Australia by providing a medium for the gathering of individuals interested in oil and gas exploration and the petroleum industry; to present views and discuss technical and professional matters relating to the petroleum industry on a national basis; to foster and provide continuing education for the benefit of its members; to nurture the spirit of research.	—Monthly luncheon meetings held in each State branch in Sydney, Melbourne, Adelaide, Perth, and Brisbane. —Annual General Meeting 8 April 1986. —1986 Australian Distinguished Lecturers October 1986, Melbourne, Perth, Adelaide, Brisbane and Sydney. —Symposia.	—*PESA Journal* (biannually), first issue August 1982. —Course Notes. Distinguished Lecturer from Overseas (June/July 1986).	—The Constitution makes provision for the awarding of distinguished membership. The last award was made to D. McDonald in April, 1981. —An award is made by PESA for the best presented paper at the annual Australian Petroleum Exploration Association Conference.	—American Association of Petroleum Geologists. —Australian Petroleum Exploration Association. —Australian Mineral Foundation. —Australian Geoscience Council. —Geological Society of Australia, Inc. —Australian Institute of Geoscientists. —Earth Resources Foundation.	PESA started out as the Australian Petroleum Exploration Professional Division in 1968, but became independent of APEA and adopted its new title in 1974. PESA was incorporated on 3 March 1983.

Microfiche edition of the two reports from the AGC's 1982-83 Human Resources Survey:

Volume 1 Australian geoscience: employment patterns in government and industry

Volume 2 Australian geoscience: the human resource

The two reports are available as a set for $5.00 from Geological Society of Australia, Challis House, 10 Martin Place, Sydney NSW 2000.

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