BMR Report 282

# Australian Geoscience 1986–87




Bureau of Mineral Resources, Geology and Geophysics

DEPARTMENT OF PRIMARY INDUSTRIES & ENERGY
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

REPORT 282



# Australian Geoscience 1986–87

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



Compiled and edited by
E. P. Shelley

Bureau of Mineral Resources
Geology & Geophysics

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Apart from the formal reports of Council activities, the views expressed in this report are those of the individual contributors and are not necessarily those of the Australian Geoscience Council nor of the Bureau of Mineral Resources, Geology & Geophysics. Publication of this report is supported by BMR to ensure wide dissemination of information on geoscience in Australia.

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## AUSTRALIAN GEOSCIENCE COUNCIL EXECUTIVE 1986-87

## 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

In pondering the content of this, the fifth President's Report of the Australian Geoscience Council, during the sixth year of the Council's existence one is acutely aware of the dynamics and hard reality of the world we live and work and try to achieve our goals in. The economic context has changed since John Lovering's report a year ago. The result is all the more complex because of the wide range of endeavours on which earth science has significant impact as reflected by the spectrum of your Council's member societies, associates and affiliates.

Beside the traditional input to the minerals and energy industries based on non-renewable resources, earth science contributes to agriculture via water resources and soil science, to the construction industry, to environmental science, and to urban planning. Backing these up is a substantial education and research component spread over many institutions, not to mention the geoscientific basis required by Governments for resource assessment and regulation. So wide is the field that changes affecting one sector favourably do not necessarily work in favour of others. What is clear, however, is that geoscience has a direct contribution to a large proportion of the nation's exports.

The severe competitive threat set by the rest of the world to the export-oriented extractive and primary industries served by geoscience, such as base minerals, energy minerals and agriculture, has come home to us all in the last year, as has the potential of these industries to help correct the balance of payments. Change is in the air and focus-on-objectives is the theme. Ironically the struggle for survival goes hand in hand with new opportunity. The research dollar, despite incentives, is hard to attract, while the precious metals industry is in a physical and financial state of boom, the likes of which we have not seen for nearly twenty years. As this is being written, goescientists with some specialities are able to write their own contracts, yet only a year ago large numbers were unsuccessfully seeking employment. CSIRO is undergoing high-level restructuring to meet change and service the community better. Some sectors of our geoscience industry are looking increasingly to overseas business to meet the challenge of change.

Can the earth sciences and the Australian Geoscience Council respond to these actual and impending changes? I believe that they can. The reason for this confidence lies in the nature of geoscience itself.

In the application of geoscience and translation of its implications to scientists in other disciplines and to lay people, I have come to the conclusion that geoscience is characterised to an unusual degree by several features. It carries a much wider gulf of the unknown and the inscrutable than most other sciences; thus its powers of prediction, though useful, are still limited. The field of geoscience is so wide that the oldest geoscientist is still a learner. Thus experience is at a premium and pragmatism is important. Geoscience is particularly international in context. Training, ideas and employment still flow strongly across national boundaries; thus geoscientists as a group have a broad perspective on the world. Most geoscience is essentially field based with the earth being both the prime laboratory and the final arbiter of theory. Arthur Holmes the famous geologist used to tell his students 'while we may often be wrong, Nature cannot be', so that they learned to respect the paramountcy of field evidence. Although geoscience as practised can be most sophisticated, when the results are applied the message for the user is usually relatively simple. Hence translation and qualification of results is important if our science is to be well utilised. Geoscience looks back in time. This capability is a prerequisite to looking forward to visualise possibilities and opportunities.

Geoscience therefore tends to attract people who can handle the unknown, who are pragmatic and experience seeking, who generally have a broad perspective, who can separate evidence from opinion while respecting the difference, and who can look ahead. With such characteristics it is clear that geoscience and geoscientists are well equipped with the tools to handle change.

What then of the role of the Australian Geoscience Council? We need to focus on the areas and objectives outside and beyond those covered by our members. Our member societies are the best medium to ensure the professional standards and scientific excellence which must set the tone for change without hindering its acceptance. Following from this there appear to me to be three major areas for focus. The first is geoscience education, its quality and relevance. The council has made a start in this area with the 1985 education workshop and subsequent wide-ranging discussion. Progress in the last year has been unacceptably slow and our proposed Standing Committee has not yet been formed. A review of tertiary geoscience education by CTEC does not seem any closer. Therefore this focus needs ongoing attention from Council.

The second focus is on the formulation of science policy and the allocation of the Government research dollar. This topic is covered by Council's membership of the Federation of Australian Scientific and Technological Societies (FASTS) and Council representation on the FASTS Executive Committee by Dr C.D. Branch as Secretary. FASTS has established a full-time executive office in Canberra which puts it in a strong position to pursue its objectives of regular review of Federal science policies and budgets. At this stage FASTS is doing what it set out to do. However, results can only be fully gauged in the time frame of the next fiscal year and beyond.

The third focus is on the role and contribution of geoscience to the economy and thus to the community. We have done little so far to identify and quantify our contribution to the economy. I suspect it may be larger than most of us think. If we can determine that contribution, it will form a useful framework on which to resolve and interperet matters like education priorities, research-fund allocations, employment opportunities and environmental guidelines. It will give us the means to form a bridge to the community explaining how essential is the role of geoscience. As a step in this direction the Council has been asked to sponsor and organise a symposium on 'The contribution of geoscience to the national economy' at the 1988 ANZAAS Conference in Sydney. I commend the symposium to all constituents of Council as a means of carrying our position and views into a public forum for the benefit of fellow scientists and the public at large.

If the Council maintains such a focus it will, I am sure, be able to fulfil its now-established role and reconcile the differing viewpoints and claims which surface at times of change for the good of geoscience as a whole.

I am grateful for the support and patience of my colleagues on the Executive in what has been a difficult year with many competing demands and changing circumstances affecting the time of all. Particular thanks are due to Dr C.D. Branch

who has carried the geoscience flag as Council Representative and Executive Secretary on FASTS since its inception and now wishes to be relieved of the position. For the last two issues the substantial task of editing the Council Annual Report has been carried by Professor John Roberts. It is a pleasure to record appreciation for this dedicated contribution in establishing the outgoing and informative style of the Report.

Outside the Executive there are unsung helpers who further the objectives of the Council. Not least of these is Dr K.A.W. Crook to whom I am personally indebted for informal and constructive assistance throughout the 1986-87 term.

As always the employers of members of the Executive and representatives on Council are acknowledged for their generosity in making time, travel, moral support and facilities available without which the Council could not function. CSIRO is to be thanked for making a venue available regularly for Council meetings and BMR for special assistance with production of the Annual Report.

*D. H. Mackenzie*
*President*

# SECRETARY'S REPORT

## *The Council*

The Council consists of the Member Societies, whose nominated Representatives elect six of their number to form the Executive Committee. In addition, related geoscientific organisations who are not full Members may be invited to join the Council as non-voting Associate Members of Observers.

Membership of Council at the end of session 1986-87 was 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)

### *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 NSW
Statistical Society of Australia

### *Observers*

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

It is with regret that the Council lost the membership of the Petroleum Exploration Society of Australia during the year. An Associate Membership was offered to the Australian Clay Minerals Society.

The Council met at CSIRO Headquarters, Canberra on 23 May and 10 October 1986. Thanks are expressed to Dr A.F. Reid, Director of the Institute of Energy and Earth Resources, for permission to use this venue for meetings.

## *The Executive*

The Executive elected on 31 May 1986 comprised:

| | |
|---|---|
| President | Dr D. H. Mackenzie |
| Past President | Prof. J. F. Lovering |
| Vice-President | Mr R. J. Henderson |
| Secretary | Dr K. D. Tuckwell |
| Treasurer | Dr G. J. Burch |
| Editor | Mr E. P. Shelley |
| Executive Member | Prof. B. G. Thom |
| Public Officer | Dr P. F. Walker |

Council and Executive expressed appreciation for the contribution of the outgoing Editor, Prof. J. Roberts towards improving the Annual Report in the last two years.

The Council representative on the Federation of Australian Scientific and Technological Societies (FASTS) was Dr C.D. Branch who was also elected Secretary of that organisation.

The Executive met in Canberra in July and October 1986 and June 1987. The employers of members of the Executive are again thanked for their generosity in assisting with attendance at meetings.

### *Activities*

The Annual Report was again a major focus of the Council's activities in 1986. It has gained wide acceptance especially by those wishing to gain an overview of the status of geoscience in Australia. The format was enhanced with inclusion of diagrams and photographs.

Feedback from the Council's tertiary geoscience education workshop in 1985 continued to flow in a vigorous way from many quarters. The topic is still timely and pressure on education and geoscience funding requires that geoscientists think and talk through the serious matters raised in 1985. The Council requested Dr C.D. Branch to present a paper on the workshop at the AusIMM symposium on *Education and research for the mineral industries* in Melbourne in November 1986.

Council participated in FASTS but Members increasingly wished to see evidence of the benefits arising from membership of FASTS which began to get into stride in 1986 with appointment of an Executive Director resident in Canberra. FASTS conducted a second annual review of the federal science and technology budget allocations and held a well-attended public forum on the subject in November 1986. Advice was received from FASTS on the financial liability of officers of incorporated societies, a matter of concern raised by the Australian Society of Exploration Geophysicists.

The organising committee of ANZAAS 1988 in Sydney requested nominations for symposia and the Council's proposed topic — *The contribution of geoscience to the national economy* — was accepted.

Centres of concentration for water resources research were canvassed during 1986 by the Australian Water Research Advisory Council and Council offered its services to assist in the progress and assessment of geoscientific proposals for such centres.

In the public arena the Council lent its support to the Director-General of Education of NSW in the matter of rejection of creationism from the secondary school science curriculum, and made a submission to the Federal Government's gold tax enquiry from the point of view of its possible impact on geoscientific employment.

On the publicity front a small brochure on the nature and activities of the Council was prepared and printed for circulation with Council correspondence.

*K. D. Tuckwell*
*Secretary*

## TREASURER'S REPORT

A number of changes to the finances of the Council are described in this report for the 1986 financial year.

Initiation of the Federation of Australian Scientific and Technological Societies (FASTS) and the nominated role of this Council to corporately represent each of our member organisations on the Board of FASTS has required us to take responsibility for collection of subscriptions to the Federation. While this task is not especially onerous it does place Council in a difficult position with regard to potentially new or existing members who find the costs of FASTS a strain on their financial situation. Council could find, and has already found, that it is in the position of having to accept the liability of defaulting Council members.

The final cash balance for 1986 of $7146.40 represents a healthy state of liquidity for Council but with the subscription to FASTS presently standing at $7500 some caution needs to be exercised. As in the past, Council is greatly indebted to the continuing financial support provided by the State Geological Surveys and the subscriptions from member societies. In addition, the assistance of the Bureau of Mineral Resources (BMR) in publishing *Australian Geoscience*, produced annually by Council, has significantly eased our financial commitments. Nevertheless, to obtain an adequate number of copies to circulate to our regular recipients, Council was required to purchase a further 1000 copies in 1986 at a cost of $1723. No other major costs were incurred during 1986.

Members will have been encouraged by the energy and impact that FASTS has achieved during its first year of operation. An Executive Director, Dr David Widdup, has been appointed and an office established in Canberra. Regular newsletters have been circulated to member organisations which bear testimony to the range of activities being undertaken by FASTS. This Council has been ably represented on the Board by Dr Colin Branch, who also took on responsibility of Secretary to the Federation. In addition, the representations on Council's behalf by Dr John Truswell of BMR in preparing submissions for Federal Government budgetary allocations to geoscience have been most valuable. Therefore, I commend the activities undertaken by this Council and of FASTS during 1986 and thank all member organisations for their support over the past financial year.

Auditors for the Council are Price Waterhouse, Chartered Accountants, and our appreciation is expressed for the services given free-of-charge by their Canberra office.

Financial Statement

| | | |
|---|---|---|
| Receipts | | $ |
| Subscriptions | | 300 |
| Donations | | 2179 |
| FASTS subscriptions | | 2005 |
| Bank interest | | 576 |
| | | 5060 |
| Expenses | | |
| Meetings | | 20 |
| Annual Report 1985 | | 1723 |
| FASTS subscriptions | | 3240 |
| Miscellaneous | | 20 |
| | | 5003 |
| Balance brought forward | (31.12.85) | $7089 |
| Cash balance | (31.12.86) | $7146 |

*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 1986. 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*

1986 was the most difficult, financially, in AMF's existence.

The year started out reasonably well with high expectations that the course program would be completed with most of the original program of 106 courses operating. However, the

sudden drop in the oil price early in the year had a significant effect. Not only were retrenchments among professional staff in the industry extensive but also training budgets were slashed. As a result, 55 of the original 106 courses were cancelled.

### *Library and Information Services*

Two events of special significance to AMF's Information Services Group occurred during the year. The first was the Third International Conference on Geoscience Information (3ICGI) organised by and held at AMF, and the second, was the decision in late 1986 to relocate AESIS on CLIRS (Computerised Legal Information Retrieval System) as a key database in a suite of files to be clustered on CLIRS for the resource industries. Also of significance was the selection of the Information Services Manager, Mr Tellis, for two overseas assignments under the auspices of UNESCO and ESCAP.

The Third International Conference on Geoscience Information was held at AMF from 1-6 June 1986. The Conference was organised and managed by an Organising Committee chaired by the Director, Dean Crowe, with Des Tellis as the Secretary. The conference was attended by about 130 delegates, 36 of whom were from overseas. In the light of the serious downturn in the mineral and petroleum industries, especially the latter, the attendance was considered good. Notwithstanding the absence of southeast Asian delegates, overseas participation was 25% better than at the Second International Conference at Denver, Colorado, in 1982 when the petroleum industry at least was certainly more buoyant. The Conference provided the opportunity for Australia and the AMF in particular to be placed in the spotlight of the world earth sciences information scene.

AESIS (Australian Earth Sciences Information System), the Australian national reference database for the earth sciences, has been available on-line for many years through AUSINET. From early in 1987 AESIS will become part of ARID (Australian Resources Industry Database), a cluster of databases on the CLIRS network. This development has significant potential for AESIS as well as for other industry-related systems which hitherto have not been available on-line. AESIS database creation and maintenance, production of products, and on-line public access will now be affected through CLIRS. AESIS will not be available on AUSINET after March 1987.

The move to CLIRS should provide an enhanced service for the earth sciences disciplines and the resources industry through the very progressive, conceptual and operational philosophies being adopted by the CLIRS organisation.

In addition to the range of standard products from AESIS, the section is now involved in producing cumulative indexes as camera-ready copy for organisations whose publications are normally processed into AESIS. This service is to be expanded in 1987. A 33-year index for the Geological Society of Australia journal is to be produced early in 1987.

### *AMF Bookshop*

The past twelve months has seen the Bookshop establish its place within the mining and petroleum industry as a reliable supplier of publications. In August the new catalogue was published and was well received. Sales increased substantially at this time. The number of publishers represented has also increased to 26 and are as follows:

- American Association of Petroleum Geologists
- Association of Exploration Geochemists
- Australian Academy of Technological Sciences
- Australian Geoscience Information Association
- Australian Mineral Foundation
- Australian Society of Exploration Geophysicists
- Bureau of Mineral Resources, Geology and Geophysics
- Centre for Resource Studies, Queen's University
- CSIRO
- Field Geology Geology of South Australia
- Geological Association of Canada
- Geological Society of America
- Institution of Mining and Metallurgy
- International Union of Geological Sciences
- Mineralogical Association of Canada
- Mining Journal Books
- New South Wales Department of Mineral Resources
- Oil and Gas Consultants Inc.
- Petroleum Exploration Society of Australia
- Geological Survey of Queensland
- Society of Economic Paleontologists and Mineralogists
- Society of Mining Engineers of AIME
- South African Institute of Mining and Metallurgy
- South Australian Department of Mines and Energy
- The Australasian Institute of Mining and Metallurgy
- Uranium Institute

A steady increase in sales has proved the importance of establishing the Bookshop. It is projected that not only will the number of agencies held increase in 1987 but also a one-stop book order centre will be developed. This will enable those seeking publications in the earth sciences and related subjects to order agency and non-agency items at the one time through the Bookshop.

1987 is expected to be a year of change for AMF with industry seeing a higher-profile organisation through increased marketing of the services and training of professionals in how to use information services.

### *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 590 including some 250 scientific staff.

BMR's projects in 1986 were grouped into eight programs: Fossil Fuels, Minerals, Groundwater, National Geophysical Observatories, National and International Geoscience Maps, Overseas Operations, Petroleum and Minerals Resource Assessment, and National Geoscience and Mineral Industry Databases. Many of BMR's projects are of a multidisciplinary and interdivisional nature, and there is active cooperation with State Geological Surveys, Universities, other geoscience research organisations and exploration companies.

During 1986, the BMR Advisory Council met to advise the Minister and the Director, BMR, on BMR's research program. Members of the Council are 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 1986, BMR continued its program of marine research cruises using the research vessel *Rig Seismic*. Successful cruises were carried out on the

Queensland Trough, Exmouth Plateau, North Perth Basin and southern margins (from the Eyre Terrace to the Polda Trough).

A Data General MV/20000 computer was installed in June to replace BMR's ageing HP/1000 system and to reduce reliance on external computing facilities. In late 1986, the ORACLE database management system was installed on the Data General computer to provide the basis for many of BMR's database applications.

BMR's national geoscience database coordination responsibility was enhanced by the ratification by the Australian Minerals and Energy Council of a policy to facilitate coordination between government organisations. This policy provides for the establishment of an advisory committee to assist in the coordination process which is aimed at avoiding duplication of effort and ensuring that geoscience data can be readily transferred between organisations.

Brief reports of BMR's Divisions and Branches follow.

*Division of Petrology and Geochemistry*

This Division has the main carriage of the Mineral Deposits and Metallogenic Provinces sub-programs. Within the Mineral Deposits sub-program, the Division is carrying out research into aspects of gold, diamond, platinum-group element and a range of base-metal and tin-tungsten 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 in 1986 involved the completion of field studies in Permo-Carboniferous felsic volcanics in north Queensland and laboratory studies in the Red Dome skarn-related deposit in northeast Queensland. New programs of integrated petrological, geochemical and geophysical structural-tectonic studies have been established in the sedimentary-volcanic Drummond Basin province of northeast Queensland which contains epithermal-style gold mineralisation. Long-lived, high-level hydrothermal systems associated with radiogenic granitoids are to be investigated in relation to the timing and controls effected on gold, tin and tungsten mineralisation in Tasmania, New South Wales and South Australia. Regional geochemical surveys of orogenic granites in relation to mineral provinces will also form part of the developing program and will provide essential data for the modelling of Phanerozoic tectonism in eastern Australia and a key database for regional mineral exploration. The results of a major collaborative study with industry and the Geological Survey of Western Australia relating to the origin and distribution of diamond deposits and lamproites were published at the International Kimberlite Symposium in August 1986. The regional distribution of intraplate alkaline volcanics will continue with focus on carbonatites and rare earths.

Installation of a Laser Raman Microprobe, coupled with the development of thermal decrepitation-mass spectrometry has provided a focus for fluid-inclusion research in Australia. The recognition of complex hydrocarbons in fluid inclusions from a wide range of deposit types provides the opportunity to develop a quantitative basis for ore-source rock correlations paralleling approaches used in the petroleum industry. Fluid-inclusion studies have also been initiated in the Pb-Zn deposits of the Lennard Shelf and in Archaean gold vein deposits.

During 1986 the Division also organised and co-sponsored an International Geological Correlation Program meeting on tin-tungsten mineralisation and undertook a significant role of collaborative research work as part of the Australia-China Memorandum of Understanding.

The main advance in the Mount Isa province study was the recognition, in collaboration with research groups from Utrecht University (The Netherlands) and the University of Queensland, of major extensional structures formed at around 1700 Ma. The structures include domino-style listric faults and a major detachment structure, and may represent the basin-forming event for the Mount Isa Group and related rocks. In addition, widespread transpressional structures were found to be associated with the regional strike-slip faulting late in the inlier's history. The transpressional structures apparently contribute substantially to the structural complexity with the Leichhardt River Fault trough.

General application of the detachment model of continental extension to the rift phase of passive margin development was completed. This study has resulted in a new framework for understanding the architecture, structure, uplift-subsidence history and thermal evolution of passive continental margins. The concepts will be tested against and applied in more detail to individual segments of the Australian margin in collaboration with BMR's Division of Marine Geosciences and Petroleum Geology.

*Division of Continental Geology*

Field research continued in the Clarence Moreton Basin in 1986, chiefly in the southern portion of the basin in New South Wales. By the end of the year several detailed transects across the latest Triassic and Early Jurassic Bundamba Group had been completed. There exists a stratigraphic framework and a data bank of palaeoenvironment measurements for this part of the sequence. Well and seismic data need to be synthesised to construct a workable sedimentological model of basin evolution from the beginning of basin development to the onset of Middle Jurassic sedimentation.

The major effort in the Amadeus Basin is directed to the parts of the stratigraphic section which are known to be or may be important petroleum source or reservoir rocks. Seismic stratigraphy has provided a framework for detailed sedimentological studies on potential source rocks such as the Bitter Springs Formation, Chandler Limestone and the Horn Valley Siltstone and on potential reservoir rocks such as the Mereenie, Arumbera and Pacoota Sandstones. A biostratigraphic framework is being provided by palaeontology. Based on the above studies a thermomechanical model for the evolution of the basin has been developed showing that the basin developed in three discrete stages: an initial period of extension in the Late Proterozoic; a second period of extension at about Proterozoic-Cambrian boundary time; and then shortening during the Devonian-Early Carboniferous.

The Palaeogeographic Mapping Project neared completion in 1986. Maps are being produced for 68 time slices in the Phanerozoic. A wide range of data maps, interpretative maps and structural element maps are being produced and these, together with the accompanying notes and stratigraphic charts, will provide an excellent summary of the Phanerozoic of Australia. This project is being pursued in cooperation with the exploration industry through the Australian Petroleum Industries Research Association (APIRA).

Palaeontologists within the Division are directing attention to the production of a set of biostratigraphic correlation

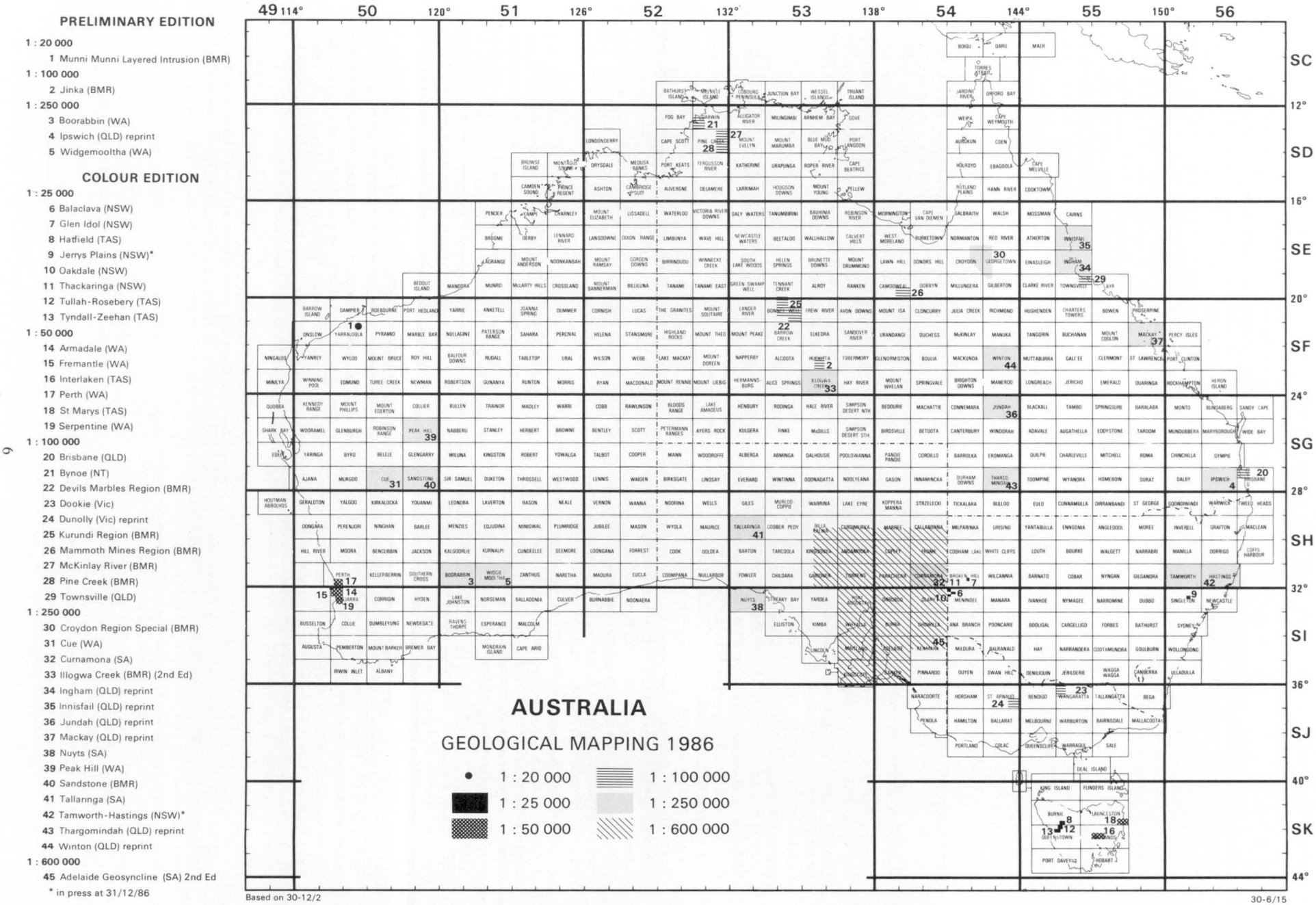


Fig. 1. Geological mapping in Australia, 1986.

Queensland Trough, Exmouth Plateau, North Perth Basin and southern margins (from the Eyre Terrace to the Polda Trough).

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*Division of Continental Geology*

Field research continued in the Clarence Moreton Basin in 1986, chiefly in the southern portion of the basin in New South Wales. By the end of the year several detailed transects across the latest Triassic and Early Jurassic Bundamba Group had been completed. There exists a stratigraphic framework and a data bank of palaeoenvironment measurements for this part of the sequence. Well and seismic data need to be synthesised to construct a workable sedimentological model of basin evolution from the beginning of basin development to the onset of Middle Jurassic sedimentation.

The major effort in the Amadeus Basin is directed to the parts of the stratigraphic section which are known to be or may be important petroleum source or reservoir rocks. Seismic stratigraphy has provided a framework for detailed sedimentological studies on potential source rocks such as the Bitter Springs Formation, Chandler Limestone and the Horn Valley Siltstone and on potential reservoir rocks such as the Mereenie, Arumbera and Pacoota Sandstones. A biostratigraphic framework is being provided by palaeontology. Based on the above studies a thermomechanical model for the evolution of the basin has been developed showing that the basin developed in three discrete stages: an initial period of extension in the Late Proterozoic; a second period of extension at about Proterozoic-Cambrian boundary time; and then shortening during the Devonian-Early Carboniferous.

The Palaeogeographic Mapping Project neared completion in 1986. Maps are being produced for 68 time slices in the Phanerozoic. A wide range of data maps, interpretative maps and structural element maps are being produced and these, together with the accompanying notes and stratigraphic charts, will provide an excellent summary of the Phanerozoic of Australia. This project is being pursued in cooperation with the exploration industry through the Australian Petroleum Industries Research Association (APIRA).

Palaeontologists within the Division are directing attention to the production of a set of biostratigraphic correlation

aeromagnetic surveying and in the production of magnetic charts for the region at five-yearly intervals. The first of these models — for epoch 1985.0 — is in preparation.

### *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 develoment 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 in Australia. Greater emphasis is given the study of energy minerals — in particular petroleum — because of their economic and strategic importance. Increased attention was given in 1986 to some minor commodities, including rare earths and the 'electronic metals' such as gallium and germanium.

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 possiblity of improving utilisation and interaction between the various geoscience databases in BMR.

The Division continued its well-established series of regular publications and information releases on the mineral and petroleum industries. Production of a series of reports summarising information on oil accumulations in sedimentary basins or regions of Australia has also been commenced and the first two reports in this series (on the Amadeus and Bass Basins) were completed in 1986.

A new assessment of Australia's undiscovered crude oil and sales gas resources was published in 1986 and the results of a new assessment of Australia's condensate resources, which was also completed, will be published early in 1987. Contributions were also prepared on the petroleum potential of Australia's sedimentary basins for a proposed Australian Petroleum Exploration Association bicentenary publication on Australia's petroleum resources.

Grants were received from NERDDP for the continuing development of the Petroleum Exploration Data Index (PEDIN) and for evaluating the potential for enhanced oil recovery (EOR) in Australia.

During 1986, design of the location segment of MNDEP, a major database on mineral deposits, was completed and testing begun. In addition, BMR's two existing mineral prices databases, METPRI and IMPRI, were merged to increase overall efficiency.

Staff presented eight papers at the Petroleum and Minerals Review Conference in March 1986, and a paper on mineral sand resources at an AusIMM conference on mineral sands in Perth.

The following studies were completed during 1986:

- Assessment of Australian resources of vanadium and hard rock titanium
- A study of world titanium resources for the International Strategic Minerals Inventory
- A draft commentary on the Minerals maps of the Third Edition of the Atlas of Australian Resources, for the Division of National Mapping

and the following studies were begun:

- An assessment of undiscovered hard rock tin resources
- An assessment of mineral sand resources in the ESCAP region
- Compilation of information for a gold resources database

### *Special Projects & Geoscience Services Branch*

In conjunction with the Specialist Group for Tectonics and Structural Geology of the Geological Society of Australia, compilation of a tectonic map of the Tasman Fold Belt System at a scale of 1:2 500 000 is nearing completion. Contributions are being prepared by State geological surveys and universities. Regolith maps of the Kalgoorlie and Hamilton 1:1 000 000 sheets based on Landsat imagery and published geology and soil maps are in press.

A bicentennial project that aims to publish two volumes on Australian geoscience for 1988 is being coordinated with scientists from BMR and other organisations. The volumes planned are 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 during 1986 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 1987 and compilation of the 1:10 000 000 mineral resources and energy resources maps continues. A second edition of the Plate Tectonics Map of the quadrant (1:10 million scale) was published during the year.

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 cooperation with the Geological Research and Development Centre (GRDB) of the Indonesian Department of Mines & Energy and funded by the Australian Development Assistance Bureau. Nine Australian staff members in Bandung work in cooperation with Indonesian geologists and geophysicists in a helicopter-supported mapping project in Kalimantan. As part of the training program during 1986, Indonesian geologists, geophysicists and draftsmen undertook three months of on-the-job training with State Geological surveys and BMR in Australia. As well, five geoscientists are enrolled at universities for MSc and PhD degrees.

Previous work in Irian Jaya (Indonesia) reached fruition with the printing of the two-sheet 1:1 million scale Geological Map

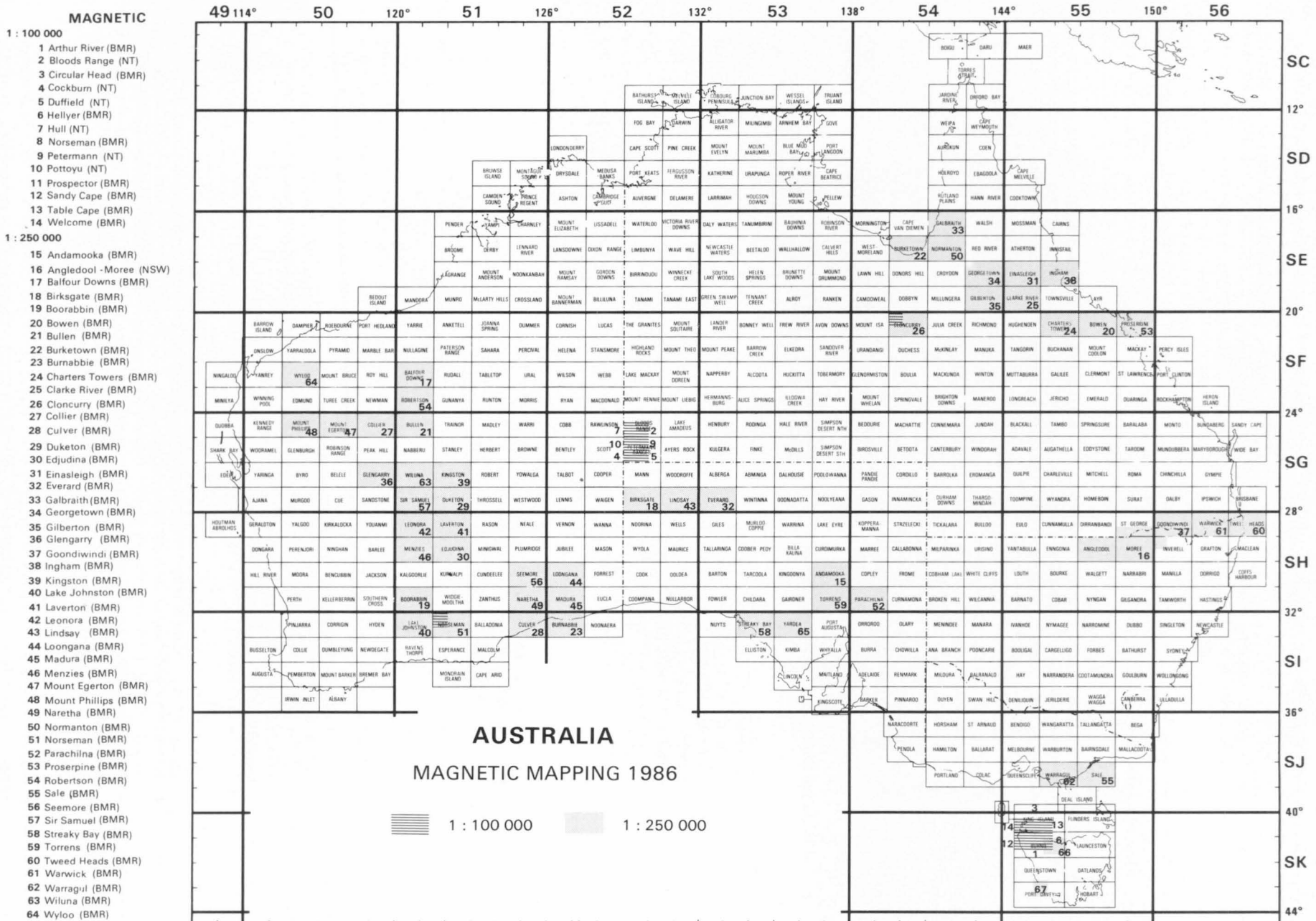


**Fig. 2. Magnetic mapping in Australia, 1986.**

of Irian Jaya in December 1986 as a joint BMR/GRDC undertaking.

In the Australian Antarctic Territory, BMR scientists participated in Australian National Antarctic Research Expeditions (ANARE) field operation in the Bunger Hills/Denman Glacier area west of Casey station in early 1986. The area was examined and sampled on a first-pass basis in what is the first Australian field program in the area since Mawson's 1911-14 expedition. Almost all accessible outcrops were visited by helicopter. At the Bunger Hills, Precambrian gneisses are intruded by charnockites, gabbros and minor granites, and all are intruded by mafic dykes. In southern outcrops — which were not visited because of bad weather — a red sandstone sequence of possible Cambrian age is exposed. Similar rocks have been reported in moraines from as far afield as Commonwealth Bay, 1500 km to the east, and may indicate that much of the Wilkes Land ice cap is underlain by a major early Palaeozoic sedimentary basin. In the 1986-87 season, severe pack ice conditions precluded access to this field area. Elsewhere, BMR Antarctic geophysicists determined the position of the South Magnetic Pole and maintained magnetic and seismological observatories.

## *NSW Department of Mineral Resources*

### *Organisation*

During 1986 regionalisation of the Department's geological work continued. Branch offices of the Geological Survey continue to operate at Broken Hill and Armidale and there is a Coal Geology office at Singleton in the Hunter Valley. A Geological Survey office will be occupied at Orange in early 1987. The Specialist Services and Applied Research Section of the Geological Survey was relocated in 1986 to the campus of the University of NSW at Kensington.

### *Regional studies*

Around Cobar, nine 1:100 000 sheets have now been mapped and are being progressively published. These data are being synthesised to produce new 1:250 000 maps of the Cobar and Nymagee sheet areas. Metallogenic maps at 1:250 000 scale are also in preparation for the Bourke, Cobar and Nymagee sheet areas. Compilation of geology and geophysics for new 1:250 000 maps of the Walgett and Nyngan sheets has commenced. Near Broken Hill, seven 1:25 000 sheets have been published and others are in press. Three 1:50 000 metallogenic sheets and a stratigraphic synthesis are in preparation. In the New England region, preliminary geological notes became available for the Manilla 1:250 000 sheet and preliminary map compilations became available for the Dorrigo/Coffs Harbour sheet. The Tamworth/ Hastings metallogenic map and notes are in press. Geophysics interpretation reports are also available to cover these sheet areas.

Geological map compilations and notes covering a strip of four 1:100 000 sheets from Muswellbrook to the coast have been prepared and accompanying notes compiled by staff from the Universities of NSW and Newcastle. These are now being edited for publication.

In the Sydney Basin, the Wollongong/Port Hacking 1:100 000 sheet was published, the Penrith sheet and notes were completed, and the Gosford/ Lake Macquarie sheet and notes progressed. A geological map of the Hunter Coalfield at a scale of 1:100 000 was compiled and will be published in 1987.

In the south of the State, preliminary work was commenced on a long-term project to compile 1:250 000 series geological maps covering the New South Wales portion of the Murray Basin, and compilation of a new edition of the Bega 1:250 000 geological sheet is under way. A reconnaissance study of the geology, geophysics and gold deposits of the West Wyalong/ Temora/ Adelong district is almost complete, and re-mapping of the remainder of the Cootamundra 1:250 000 sheet has started. A preliminary report is available on gold mineralisation associated with the Gilmore Suture Zone near Temora.

The systematic compilations described above, and also a number of commodity studies (see below) are supported by both task-based and long-term systematic work. Particular projects include State-wide studies in Cainozoic and earlier pollens and in Palaeozoic corals, conodonts and radiolaria; and the continuing development of a petrological and whole-rock geochemistry data base.

### *Commodities*

Investigations on metalliferous commodities included work on platinum near Fifield and coastal rutile-zircon sands.

An assessment of dimension stone resources of the State has been completed and some detailed studies of possible sources for 'yellow block' (Sydney) sandstone have been made. Friable sandstones of the Sydney Basin have been assessed as a future source of construction sand, and a major study is continuing into clay/shale sources southwest of Sydney. A study of potential future sources of gravel and sand in the floodplain of the Hunter River was commenced.

The first stages of major projects on NSW sapphires and zeolites are nearing completion. New concepts developed on the origin of sapphire deposits are to be presented and discussed at a workshop in early 1987.

A mineral deposits map of NSW at a scale of 1:1 500 000 is in preparation.

### *Petroleum*

During 1986 a full analysis was undertaken of results from the Department's petroleum stratigraphic hole DM Lake Stewart DDH1 in the Eromanga Basin. A seismic traverse in the Gunnedah Basin near Narrabri was followed by drilling of a fully-cored stratigraphic hole (DM Bellata DDH1) which has been extensively analysed geologically, geophysically, geochemically (in conjunction with CSIRO), and palaeontologically. Computerised reprocessing of 1961 magnetic data over the Surat Basin was undertaken for a number of 1:250 000 sheets.

### *Geophysics*

Regional geophysical investigations continued in close association with mapping and resource assessments by regional groups. A project to enhance interpretation of NSW magnetic data using the DIPIX image processor and supporting software is well established, with data for 60% of the State entered.

Developments of new applications of geophysics continued with a project sponsored jointly with AMIRA to develop a borehole induced polarisation (IP) logging system which will have application to mineral, coal, engineering, and petroleum

assessment. Other new applications of geophysical methods to opal search at Lightning Ridge and petroleum potential near Narrabri have been undertaken.

### *Resource assessment*

The State's marine resource assessment program has continued with cooperative studies of the NSW Coastal Zone in association with the Department of Geography, University of Sydney. Studies were completed at Wooli and Eden, and work has also been done at Ulladulla and Byron Bay.

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

### *Coal*

The Coal Geology Branch activities for 1986 included an exploration drilling program at Rylstone and completion of a preliminary report on an earlier program at Narrabri. These investigations were conducted as joint ventures with the Electricity Commission. Two boreholes near Picton were also completed; this program was a joint venture with Methane Drainage Pty Ltd.

Land-use drilling programs were conducted to assess the coal resources near Bulga and Mitchells Flat in the Hunter Valley. Other programs have been planned for the Maison Dieu area near Singleton and for urban expansion in the Wyong Shire. An update of the 1984 *Coal Industry Profile* is nearing completion to provide a more detailed profile on mining and proposed mining in the State. A publication on the coal resources and reserves of NSW was completed and sent out for publication. Work continued on overviews of the Western and Hunter Coalfields to provide a database for the Department on which 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.

### *Environmental geology*

Environmental assessment and management of new mining projects continued. Baseline hydrogeochemical studies were carried out at Junction Reefs, and water pollution investigations were carried out at Wild Cattle Creek antimony mine, Cowarra gold mine, and the Mongarlowe River. A report on shallow-burial waste-disposal sites in NSW was completed for the Commonwealth Government. A new project was commenced on environmental constraints mapping for the Southern Coalfield.

### *Information*

The Department continued to upgrade its bibliographic database, *Minfinder*, which now contains references plus abstracts of Exploration Licences, Petroleum Licences, and other geological reports. The other database, accessed through the CLIRS Australia network, *Corefinder*, catalogues the Department's diamond drill core collection. A pilot study is under way which may lead to all Coal Authorisation Reports being incorporated into Minfinder during 1987.

The Department's new Core Library Complex at Londonderry was completed during 1986. Over 90 000 boxes of petroleum, metalliferous and coal core have been catalogued and incorporated.

### *The Mining Museum*

A Board of Management was formally established by the Minister to advise him on various aspects of the Museum, especially its redevelopment. The Board has undertaken to raise funds and to promote and market the Museum proposals. The Museum attracted 150 000 visitors during the year.

### *Computerisation*

The Department arranged in 1986 for the installation of a computerised mining title system and a computer graphics mapping facility. This system will hold data covering mining titles, mineral deposits and geology, and borehole locations, and will enable interactive interrogation of any combination of data sets.

## *Northern Territory Geological Survey*

This year has been one of transition with the major field component of mapping projects in both the Northern and Southern Regions completed early in the year. The emphasis has been placed on publication and the dissemination of information to assist explorers within the Northern Territory. There has been a review of the direction of future programs and priority has been given to those areas of greatest economic potential and those in which existing information is least reliable.

Although only two maps, Anson in the 1:100 000 series, and Huckitta in the 1:250 000 series, were published and released during the year, six sheets were in the final stages of preparation at the end of the year. An industry excursion was successfully conducted in November using the new Huckitta Explanatory Notes and map — the first in the NTGS series of 2nd edition maps. The excursion highlighted little — known mineral occurrences to prospective explorers.

In conjunction with the geological field work, the regional mapping program has continued to utilise stratigraphic drilling to provide subsurface information in areas of extensive cover. Stratigraphic holes in the Elkedra area provided a highlight when they intersected residual live oil within the Chabalowe Formation of the Georgina Basin. Extensive study of these cores has led to the publication of a detailed report and scientific papers prepared for a major international conference. Oil explorers have been quick to follow up the NTGS information and much of the southern Georgina Basin is now covered by exploration licence applications. A stratigraphic drill hole in the Stray Creek area of the Daly Basin was completed to basement in December and logged. The hole was drilled to obtain a reference section of sediments of the Daly River Group and subsequent core study will now go ahead.

The ongoing program to provide industry with semi-detailed airborne geophysical data as a first step towards the delineation of potential exploration areas was continued.

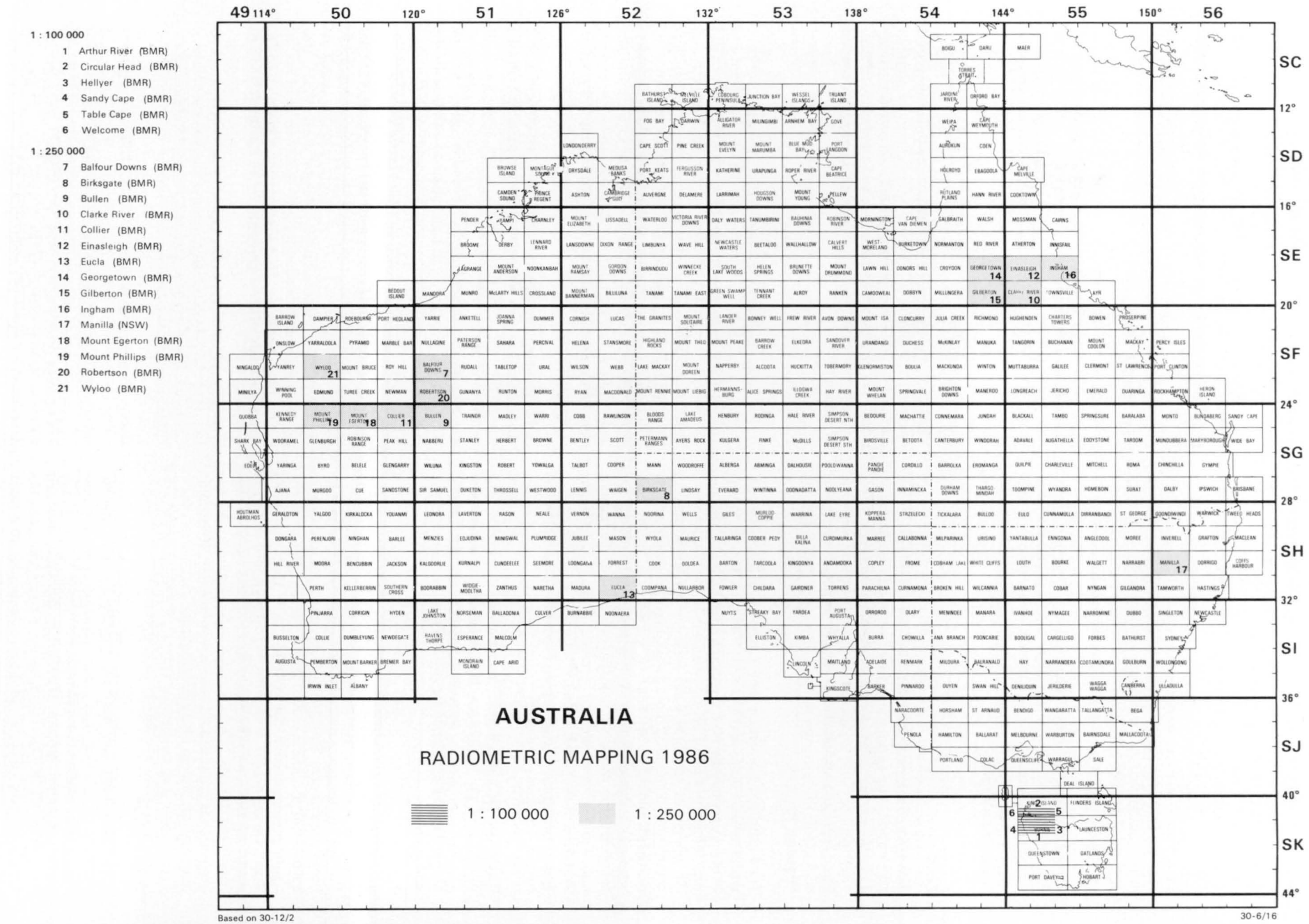


Fig. 3. Radiometric mapping in Australia, 1986.

Three 1:100 000 sheets were flown in the Petermann Ranges, bringing the total in the project to nine sheets. This survey — the first new data gathered from this area for over 25 years — stimulated exploration interest and has led to a number of permit applications.

Heavy demands were made on the Technical Information Section to supply to industry the geoscientific data resulting from exploration company and geological survey activities. The computer databases have been maintained and improved and continue to be important tools used by government and industry in the search for minerals and hydrocarbons in the Northern Territory. GEOSYSTEM grew to over three thousand documents and continued improvements were made to the presentation of report data for the exploration and mining industries. CORERECORD — a listing of drilling data — is now available and covers all mineral exploration drilling in the NT. The listing is approximately 80% complete back to 1972, and the remainder of the data is going on computer now. The Minister for Mines and Energy, the Hon. Barry Coulter, officially opened the completed core library in Darwin in October.

While the provision of information related to mineral exploration was one of the priority tasks, the importance of geology to the general public, particularly as an adjunct to tourism, was not neglected. The series of popular pamphlets on Parks and Reserves was continued with the addition of pamphlets on Ruby Gap and Kings Canyon. Of particular interest and wide acclaim was a pamphlet on *Astro-Geological Features of Central Australia* which provided information on meteorite impact structures. This was released in conjunction with the return of Halley's Comet, an event that attracted much attention to the central Australian region. The second edition of *A Guide to Fossicking in the Northern Territory* was printed in December and is now available for sale to the general public.

Metallogenic mapping kept up with demand by producing compilations for the six 1:100 000 component sheets of the Calvert Hills 1:250 000 sheet. Due to further exploration company demand, mapping of sheets in the McArthur River, Tennant Creek and Pine Creek regions are planned using standard metallogenic symbols.

Preliminary planning went ahead for major new mapping projects directed towards the Musgrave Province in central Australia and the McArthur Basin in the north.

The goals of providing information and new data on prospective areas as an efficient service to the exploration and mining industry and to the general public are reflected in the NTGS program for 1987. The Northern Territory's geoscientific database will be continually upgraded and this information will be disseminated and promoted with a view to attracting interest in the mineral resource potential of the NT.

### *Geological Survey of Queensland*

The regional geological mapping program (RGMP) continued as a major effort. Three field parties operated during the 1986 field season in this program to revise 1:250 000-scale map sheets in northern Queensland. Field work in the Atherton sheet area has been completed, including areas in the Featherbed Range mapped jointly with BMR. Photoscale field compilation sheets are available for three of the component 1:100 000 sheet areas, and progress reports have been issued. In Mossman, mapping of the southern half of the sheet has been completed and significant new data on the depositional and structural history of the Hodgkinson Basin sediments have been obtained. Field work in the Einasleigh and Clarke River sheet areas has been completed, and included coordinated sedimentological and palaeontological studies of Palaeozoic sedimentary basins. These studies were assisted by a program of stratigraphic drilling. Photoscale field compilation sheets are available for six of the component 1:100 000 sheet areas, and progress reports have been issued.

Field work in the Mount Coolon sheet area also has been completed and a progress report on the 1985 mapping prepared. Field work was commenced in the Townsville and Charters Towers sheet areas. A regional study of aeromagnetic data for the Townsville 1:100 000 sheet areas has been commenced in support of RGMP. Recording of field data on a computer- based system has been established and was trialled during the 1986 field season. A series of seminars was held in April and May on the results of the 1985 mapping program. In southeastern Queensland, compilation for the revised edition of the Maryborough Sheet was completed.

Mapping of urban and near-urban sheet areas at 1:100 000 scale has been suspended. Results of previous mapping were in various stages of preparation at the end of the year: cartographic work has commenced on the Cairns Region, and was advanced for Gladstone, and compilation of field data for Mackay remained deferred until staff are available. The Townsville and Brisbane Sheets were published. Commentary booklets for these sheets are in various stages of preparation.

The stratotectonic compilation was completed for the Queensland part of the Tasman Fold Belt System for the tectonic map at 1:2 500 000 scale to be published by BMR as a bicentennial project. Substantial progress was also made on a companion compilation of the structural geology. A report on a supporting study of basement cores from petroleum exploration wells is being written, and various reviews on tectonic evolution and metallogenesis of the Tasman Orogenic Zone have been prepared. A joint project with the Australian Museum on basic rocks in central and southeastern Queensland continued. Advice was provided for a government-funded seismic risk study of Queensland, carried out by a consultant to the University of Queensland.

The metallogenic studies program continued in north Queensland. Investigations in the Mungana and Chillagoe 1:100 000 sheet areas were completed, and were in progress in Lyndbrook and Bullock Creek. Data from this program will be issued in an unpublished format in the first instance. The continuing high level of interest in and exploration for gold deposits determined an increased level in administrative and advisory support. Platinum, tin, and base metals were also the subject of significant attention. Drilling of the EM and IP/resistivity anomalies in the Departmental Area west of Blair Athol failed to locate any potentially economic mineralisation.

The compilation of data for the Queensland mineral reserves and resources inventory was updated to December 1985, and is being prepared for the issue of the open file component. Advice and assistance to the industrial rocks and minerals industry were provided, principally on silica, limestone, phosphate, kaolin, clay, heavy minerals, diatomite, and bentonite. Work continued on the inventory of the State's resources of construction materials. Studies of the Nambour-Caloundra area were published, were completed for the Waggamba Shire, and commenced for the Gympie district. Information on the inventory continued to be transferred to

an automated database, and access to the database on major quarries and pits has been enhanced.

Basin investigations continued to be concentrated in the Bowen and Eromanga Basins. Compilation for the 1:500 000-scale solid geology map of the Bowen Basin has been completed, and a hand-coloured draft was displayed at the 12th International Sedimentological Congress in August. Publication is planned for early 1988. Work is continuing on organic petrology aspects of the upper part of the Permian section in the Denison Trough, and preliminary results were also presented at the 12th ISC. Biostratigraphic studies of the Permian of the Cracow-Theodore area of the Taroom Trough continued, and a critical assessment of previous correlations and fossil zonations with other parts of the Bowen Basin has been commenced. Research continued on Permian foraminifera, and was commenced on Permian ostracodes. A lithostratigraphic and petrographic study of the Triassic sequence of the Taroom Trough also continued.

In the Eromanga Basin, the deep stratigraphic drilling program to test the relatively poorly-known southeastern sector was continued with the compilation of a further four holes (4432 m). Another was in progress at year's end. Basic data gathering has commenced on a NERDDC-funded project to establish and integrate a broad set of geological parameters including lithostratigraphy, regional structures, and sedimentary facies, for a model to be applied to the petroleum-bearing areas of the Eromanga/Cooper Basin west of the Canaway Ridge. The model will be applied to the as yet unproductive southeastern Eromanga/Galilee Basin together with data on source and reservoir rock characteristics to delineate areas favourable to hydrocarbon generation and accumulation. Work continued on the regional hydrogeology of the Charleville and Cooper Creek 1:1 000 000 Sheet areas, mainly in relation to the Eromanga Basin. In the Surat Basin, taxonomic and biostratigraphic studies continued of plant microfossils from the Jurassic sequence.

Investigations continued of continental shelf sediments, including the joint study (with the University of Queensland under AMSTAC funding) of the recruitment of sedentary foraminifera of Heron Island Reef, the development of a model of sedimentation in the Gulf of Carpentaria (in collaboration with the Australian National University) and the study of the geological controls on reef development (with the University of New England). Additional shallow cores were obtained for the integrated study of the post-glacial history of the Brisbane River delta, and further echo-sounding and sampling were carried out in the Point Lookout area for the southeastern Queensland continental shelf study.

Phase II of the NERDDC-funded project to compile the Queensland Energy Resource Database continued during the year. Information on a number of additional geological and analytical parameters are being added to the database, mainly on wells and bores in the Surat/Bowen and Eromanga/Cooper Basins. At the end of the year, data was available on 1488 wells and bores.

Coal exploration drilling in the Bowen Basin continued, with most activity concentrated on the Rangal Coal Measures in the central part of the basin. Two phases of drilling at Taroborah were completed, and a third phase to fully core seams of non-coking coal of economic significance was commenced. A further program was completed at Picardy in a structurally-complex area, and a third commenced at Fernlees. In the west of the basin at Rugby, drilling assisted by a gravity survey has delineated a seam at the base of correlatives of the Blenheim Formation with up to 70 million tonnes of non- coking coal. A high-resolution seismic reflection survey using the newly acquired DSS 10A system was undertaken at the structurally-complex Lake Vermont deposit. A test reflection survey using this equipment was run earlier in the year west of Toowoomba to assist BMR planning for completion of a major deep-crustal seismic line across southern Queensland. A NERDDC-funded study of geological factors affecting coal mining in the Bowen Basin was commenced in association with CSIRO.

Engineering geological projects included an investigation for a railway tunnel through the Little Liverpool Range, and further work for the Baroon Pocket Dam on the Sunshine Coast. Work for the latter project included drilling and mapping of excavations for the diversion conduit and investigations of additional sources of rockfill for the dam. Reports for tenderers for the diversion conduit, on geology and construction materials for the dam, and on the associated Blackall Range Tunnel were issued. Seismic refraction surveys were carried out for the Queensland Water Resources Commission at several other damsites and water supply projects, including damsites on the Proserpine River and Cloncurry River, at Lake Clarendon near Gatton, at the Broadwater Creek site near Stanthorpe, and at the Elliot Pump Station site on the Burdekin River. Monitoring of seismic activity in the region of major dams was continued.

Investigations for the Beach Protection Authority of active sedimentary processes, sediment distribution and evolutionary history of the Hervey Bay coastline was completed and similar studies commenced at Mackay. Sand resources of the Gold Coast are being studied to determine relative influences of opposed littoral drift and ocean current on sand transport. Other offshore projects included a side-scan sonar survey in Moreton Bay to assist a feasibility study for a new shipping channel, and seismic profiling in Jervis Bay for a NSW Government sand resource survey.

GSQ involvement in environmental geology and land-use matters was mainly directed towards the provision of Departmental advice on disposal of intractable wastes, applications for various forms of lease or freehold, proposals for special purpose reserves, major development projects, and draft town and similar planning schemes.

Relocation to new office accommodation during the year resulted in improved facilities for public access to the various information resources managed by GSQ. Reports issued during 1986 included five papers on palaeontological and related topics as No.387 in the *Publication* series, 17 articles in the *Queensland Government Mining Journal*, 40 reports in the *Record* series, and a commentary to accompany the Rockhampton Region 1:100 000 geological series map.

### *Geological Survey of South Australia*

The Curnamona and Nutys 1:250 000 geological maps were published and final colour manuscripts of Tallaringa and Yardea completed. A final colou manuscript of Olary is in preparation and a preliminary manuscript of explanatory notes completed. Preliminary field work has been completed on the Elliston, Kimba, Kingoonya and Curdimurka 1:250 000 sheet areas. A public field excursion was conducted over the Tarcoola sheet area and a field guide written for this. Among other map sheets, a paleosol-geological map of the Adelaide region was published, final colour manuscripts of the 1:50 000 Rudall and Tepko geological maps have been completed and Gawler-Vincent is well advanced.

A questionnaire on published maps and related reports received 123 replies, generally favourable to current formats.

Vibrocoring has been carried out across Gulf St. Vincent in conjunction with the University of Adelaide under a Commonwealth research grant.

Publications or work in press include a paper on Skillogalee Dolomite (Curdimurka), excursion guides for southern Eyre Peninsula and Lake Eyre, a paper on the Warburton Basin, and articles on Dalhousie Springs, geochemistry and geochronology of Proterozoic igneous rocks, and the tectonic evolution of the Gawler Craton. A report on the groundwater resources of the Barossa Valley was published as part of the *Report of Investigation* series.

Superbly-preserved plant fossils uncovered in a sand pit at Golden Grove, creating considerable public interest, have been palynologically dated as Middle Eocene, contemporaneous with the Maslin Bay flora in the North Maslin Sand. Another locality with very well-preserved plant fossils was discovered at Nelly Creek near Lake Eyre South in the Eyre Formation. Field and laboratory palynostratigraphy of the Eromanga Basin in outcrop and subsurface has continued, including studies of the Cadna-owie Formation, Bulldog Shale and Murta Member, and Palaeo-climatology.

The palynostratigraphy of Barossa Valley Tertiary sediments is being written up and a major study of molluscs from Quaternary coastal sediments in the West Coast region is nearing completion.

Significant advances have been achieved in facies analysis of Early Cambrian carbonates in the Stansbury Basin. These data, together with structural and source-rock analyses, were combined with information from other Cambrian basins in the State, for a poster display for the 1987 APEA Conference in Brisbane.

Gas reserves for all Cooper basin fields were updated to account for drilling results during the year. A more uniform mapping method is now being used which separates proven from probable reserves by limiting proven reserves to a fixed area around each well.

Digitising and reprocessing of analogue airborne magnetic data continued, with attention being given to broad-scale regional data (Penola, Adelaide and Barker 1:250 000 sheets) and more detailed local surveys (Warramboo on Gawler Craton).

Gas reserves outside of the Subject Area in PELs 5 and 6 (not under current gas contracts) have been re-evaluated following seismic remapping, and completion and testing of wells.

A multi-well digital pressure recording system was set up for production testing of water bores and a spectral gamma borehole logging probe has been developed for application to hydrogeological problems.

Mineral exploration for metallic and non-metallic minerals, gemstones, and building stones has continued in many areas of the State with emphasis on gold, brick clay, construction sand, granite, limestone, slate and flagstone.

A major program of reverse circulation drilling was completed at the Golden Grove sand and clay pits on the northern outskirts of surburban Adelaide. Geological investigations have been completed at Black Hill norite (black granite) quarries, Sienna brown granite quarry and Mount Gambier limestone quarries.

Final and summary reports were released on exploration for Mississippi-Valley-type lead-zinc mineralisation in the Flinders Ranges National Park. Four prospects worthy of diamond drilling have been delineated. A Lead-Zinc Task Force was established to review existing data and to generate targets for further investigation either by the Department of Mines and Energy or industry.

Nephrite jade deposits at Cowell were revalued at $226 million for an estimated 60 000 tonnes of recoverable rough-graded jade.

Regional assessment of groundwater resources continues in the Tatiara Proclaimed Region, the Murray Basin, the Great Artesian Basin and Barossa Valley. Evaluation work continues at Woolpunda related to the proposed Murray River groundwater interception scheme. A *Bulletin* on the Adelaide Geosyncline has advanced to a stage where publication is expected in mid-1987.

Field work is complete for the Adelaide Metropolitan Area soils study and a comprehensive report is in preparation. Engineering geological mapping has been undertaken in connection with the location of alternative road access to the suburbs of Adelaide lying south of the Eden-Burnside fault scarp.

Tenders for the following computing systems were let:

- A MV20000 computer plus peripheral equipment from Data General Aust. Pty Ltd
- Geographic Information System (GIS) to EASINET Pty Ltd
- Coal Deposit Evaluation System (CDES) to Engineering Computer Services Pty Ltd.

Most of the systems have been installed.

Following a successful trial during 1986, the SAMREF computerised bibliography will be made available for public access through the commercially-operated Computerised Legal Information Retrieval System (CLIRS) network. The network is available Australia-wide and can be accessed on-line by computer terminal.

## *Geological Survey of Tasmania*

The Geological Survey Division of the Department of Mines of Tasmania is organised into three operational Branches and two Sections:

- Regional Geology Branch
- Engineering Geology Branch
- Economic Geology Branch
- Geophysics Section
- Petroleum Section

### *Regional Geology Branch*

During the summer months, January to March and December, geologists were actively engaged in field work in

the Lyell, Macquarie and Montgomery 1:50 000 Geological Atlas Series map areas of western Tasmania. At Lyell, field work was completed and material compiled for publication. The Lyell sheet (in press) includes data being used in mineral exploration programs, an evaluation of the structural soundness of the proposed Lake Burbury, and information on the availability of rock materials for hydro-electric dams, roads, and tunnels. More than three-quarters of the Macquarie 1:50 000 map sheet has been completed and more data has been collected on newly-found structural relationships where Precambrian sequences have been thrust over the younger correlates of the Mount Read Volcanics, which elsewhere in the State are associated with mineralisation. Most of the Montgomery 1:50 000 map sheet has been mapped and the correlates of Mount Read Volcanics and associated rocks have been divided into mappable units.

In the winter months, April to November, mapping continued on the Woolnorth and Trowutta 1:50 000 map sheets of the far northwest, and the St Helens, Snow Hill, Ben Lomond and Alberton sheets of eastern Tasmania. In the Woolnorth and Trowutta regions particular attention was given to relation- ships between Cambrian volcanics and other rock-units, and at Snow Hill, Ben Lomond and Alberton tin granites and successions associated with coal- bearing sequences were of special interest. The Snow Hill and Ben Lomond map sheets are nearing completion and the St Helens sheet is in press.

### *Engineering Geology Branch*

This Branch provides and accumulates geological information which is of assistance in the design and construction of engineering works and buildings, and in the provision of groundwater supplies.

The Branch is currently working on the geology and engineering feasibility of the Meander Irrigation Scheme, a 120-km system of channels, flumes and siphons, based on the proposed Warns Creek dam immediately at the foot of the Western Tiers dolerite escarpment. The review work in landslide zones in the Tamar Valley has not progressed far, but the Branch is convening the 5th International Conference and Field Workshop on Landslides — 'ANZSLIDE 1987' — to be held in NSW, Victoria, Tasmania and New Zealand in August.

The urban soil mapping plans for greater Hobart are proceeding and ground- water drilling continues in the Lower Midlands and the Sheffield area of the north-west. Long-term monitoring continues in basalt-aquifer irrigation areas.

### *Economic Geology Branch*

The main emphasis of the Economic Geology Branch's programs is the specially-funded and integrated project on the Mount Read Volcanics — host rocks to the main ore deposits in Tasmania — to provide industry with the basic information for exploration planning. The components are geological mapping, geochemical prospecting (soil and water geochemistry), geophysics, alteration and isotope studies, lineament analysis and remote sensing, and the production of mineral deposit maps. The entire exploration report collection is being organised into a database for computer access and all reports are being microfilmed. Results are available for all components of the study. Geological maps at 1:25 000 scale have been produced for the following areas: Mount Charter — Hellyer, Rosebery — Mount Block, and Henty River - Mount Read, and 1:50 000-scale mineral deposit maps are available for the Andrew, Queenstown, Tullah and Rosebery areas.

Another major project is the drilling of an extensive area of Tertiary basalt in north-west Tasmania. The aim is to provide information on sub-basalt basement lithologies prospective for base and precious metal deposits as well as tin-tungsten deposits. Associated geophysical logging is providing physical properties on the cover and basement rocks so that geophysical exploration methods can be used more effectively in this environment. Other significant activities are the production of a bulletin on coal resources of Tasmania and a computer-accessed register of construction materials in the State.

### *Geophysical Section*

The year has been devoted to the Mount Read Volcanics project. An aero- magnetic survey with a 500-m line spacing has been completed over the Mount Read Volcanics and associated rocks between Elliott Bay and Deloraine. A gravity survey with a nominal station density of one per square kilometre has been completed over much of the western portion of the Mount Read Volcanics. Measurements of physical properties of rock types throughout the area and signature studies over known deposits have been performed to assist in the selection of appropriate exploration techniques.

### *Petroleum Section*

Much of 1986 was spent analysing new data from the offshore Bass Basin obtained as a result of drilling activity during the period 1985–1986 when six new wildcat wells were drilled.

A sedimentological study was commenced on a reconstruction of the Tertiary palaeogeography of the Bass Basin from wireline log and core analyses.

A study of Miocene volcanism in the Bass Basin and its environs was also initiated. This work involves petrological and geochronological investigations and is being jointly undertaken with the Australian Museum in Sydney.

A major multi-authored synthesis of the Late Mesozoic/Tertiary rift basins of Tasmania (offshore and onshore) was completed for inclusion in the forthcoming bicentennial volume on the geology of Tasmania.

## *Geological Survey of Victoria*

The Geological Survey of Victoria continues to undertake geological and geotechnical investigations in accordance with Departmental programs and priorities. It is also responsible for the administration of the *Groundwater Act* (in cooperation with the Rural Water Commission) and gives information or advises on matters relating to minerals, stone, groundwater and engineering geology. Drafting services are provided by the Draughting Branch to other Divisions of the Department.

### *Groundwater development*

Building on the achievements made since the early 1970s, innovative work at Barwon Downs during 1986 was aimed at assessing the viability of artificially recharging the groundwater storage during winter to allow greater extraction

rates during summer. At Gellibrand, a wide array of methods, including surface mapping and high-resolution seismic methods, was used to delineate the aquifers and to assess the groundwater resources in the area. The information gathered will be incorporated in the Water Management Strategy for the Southwestern Region being developed by the Department of Water Resources.

### *Salinity*

The year saw an unprecedented expansion in salinity research and investigations within all government agencies involved in land and water management in Victoria. The Geological Survey undertook the collation and preparation of all relevant geological, hydrogeological and geophysical data for the Riverine Plain which is now forming the basis for regional and sub-regional numerical projects in the coming year. A second major salinity investigation was initiated in the Mallee Region. Six bores, out of a ten-bore program to cost $800 000, were completed. The aim of drilling was to determine the hydrogeological processes that caused salination.

It is now generally recognised that salinity is a basin-wide and not merely a State-wide problem. Collaborative studies are therefore undertaken with New South Wales, South Australia, and the Bureau of Mineral Resources. Substantial progress has been made towards the preparation of a hydrogeological map of the entire Murray Basin to assist in assessing and controlling salinity.

### *Extractive Industries Strategy Plan for Melbourne*

As in other capital cities in Australia, the establishment of new quarries in Melbourne has in recent years often been a controversial issue, reflecting conflicts between quarry development and other land uses. This has caused lengthy delays in the issuing of permits and has resulted in uncertainty for both the quarry industry in planning for resource development, and for the communities affected by quarry proposals. In response to these problems, the Government initiated in 1985 the preparation of a Strategy Plan for Extractive Industries in the Melbourne area. The aim of the plan is to ensure that adequate quarry materials are set aside to meet Melbourne's long-term needs, and that economic, social and environmental effects are fully considered in achieving this objective.

In February 1987, the Government released for public comment the draft report *Extractive Industries Strategy Plan for Melbourne* which had been prepared by an Interdepartmental Committee. The report deals with the hard-rock resources of Melbourne, and make a number of proposals which have the objective of improving the planning and administration of new and existing extractive industry operations.

### *Bendigo Goldfield*

Re-mapping of the Bendigo Goldfield has been a major commitment for the Geological Survey Office at Bendigo in order to update the geological map published in 1923. The resurgence of interest in gold in general, and the exploration program by Western Mining Corporation at Bendigo since 1978 in particular, provided the incentive to initiate a project to produce a set of three 1:10 000 geological maps of the Bendigo Goldfield. Employment of geologists and field assistants under Government Employment Programs during 1983 — 1985 enabled detailed lithological mapping to be carried out on two of the three map areas. Several hundred fossil localities have been used to determine ages of rock strata at Bendigo. Combining this information with the lithological mapping has resulted in a very thorough revision of the biostratigraphic zonation, and a re-evaluation of the major geological structures, which have a bearing on the distribution of gold. While it is true that gold has been mined from all stratigraphic zones at Bendigo, it does appear that the principal economic concentrations of gold were in two distinct horizons, separated by a relatively unproductive interval. If further work confirms this, it will obviously have a significant impact on future gold exploration. Drafting of the first map (Spring Gully 1:10 000) has commenced, and publication is planned for 1988.

### *East Gippsland mapping*

The geological mapping program over the Bendoc-Erinundra areas in East Gippsland which started in 1982, was completed after the field season of 1986 — 1987. The aim of mapping in the area was to delineate the the geological structure and mineral potential of the formations. A number of prospective geological environments are present in the area surveyed and the results of the investigations are being used by companies to guide mineral exploration in the the area. An important benefit of the program was a better understanding of the nature of the 430 and 380 million-years-old acid volcanic rocks which are potential hosts to substantial gold and base-metal mineralisation.

## *Geological Survey of Western Australia*

On August 31, Dr Alec Trendall voluntarily stepped down from the position of Director to become Senior Principal Geologist in the Precambrian Geology Section. In this way, after six-and-a-half years in office, Dr Trendall was able to shed the administrative commitments of the Directorship in order to concentrate on projects relating to Precambrian geological history, which is of such economic importance to Western Australia's mineral industry.

The new Director is Dr Phillip Playford who, for the preceding three years, had been Assistant Director-General of the Deparment of Mines, and before that, Deputy Director of the Geological Survey Division.

Despite the withdrawal of Federal funds for national water resources assessment in 1986-1987, exploratory drilling for groundwater continued in the Perth Basin. During the year four sites were drilled on the Gillingarra Line (latitudinal, about 110 km north of Perth), the deepest bore being completed at 1007 m; one bore was drilled to 1450 m on the Cowaramup Line (210 km south of Perth); and 41 bores were drilled at 24 sites for the Cataby shallow drilling project (about 140 km north of Perth) in which bores ranged in depth to 111 m and drilling totalled 1762 m.

In an area immediately north of the Stirling Range, 12 bores were drilled and are being monitored to obtain an understanding of the mechanism of land salination in that area. This project is being conducted with the cooperation of the Department of Agriculture.

The Hydrogeology Section has also dedicated the services of the equivalent of six geologists to cooperative work with the Western Australian Water Authority. Some of the more important works undertaken were: evaluation and assessment of groundwater resources in the Metropolitan Area; contri-

## PRELIMINARY EDITION

1 : 1 000 000

1 Bathymetry of Western Solomon Sea (BMR)

1 : 5 000 000

2 Magnetic Dykes of Australia (BMR)

3 Regolith Terrain of Australia (BMR)

## COLOUR EDITION

1 : 10 000

**Engineering Geology**

4 Central Canberra

1 : 1 000 000

**Total Magnetic Intensity Pixel Maps**

4 maps of each area

1. Total magnetic intensity (coloured) (BMR)
2. Total magnetic intensity (greyscale) (BMR)
3. East-West gradient (greyscale) (BMR)
4. North-South gradient (greyscale) (BMR)

5 Albany (BMR)

6 Cooktown Area (BMR)

7 Newcastle Waters (BMR)

8 Roper River (BMR)

**Magnetic Domains**

9 Albany (BMR)

**Project Investigator 1**

10 Australian Antarctic discordance-aeromagnetic investigation (Mid. Southern Ocean) (BMR)

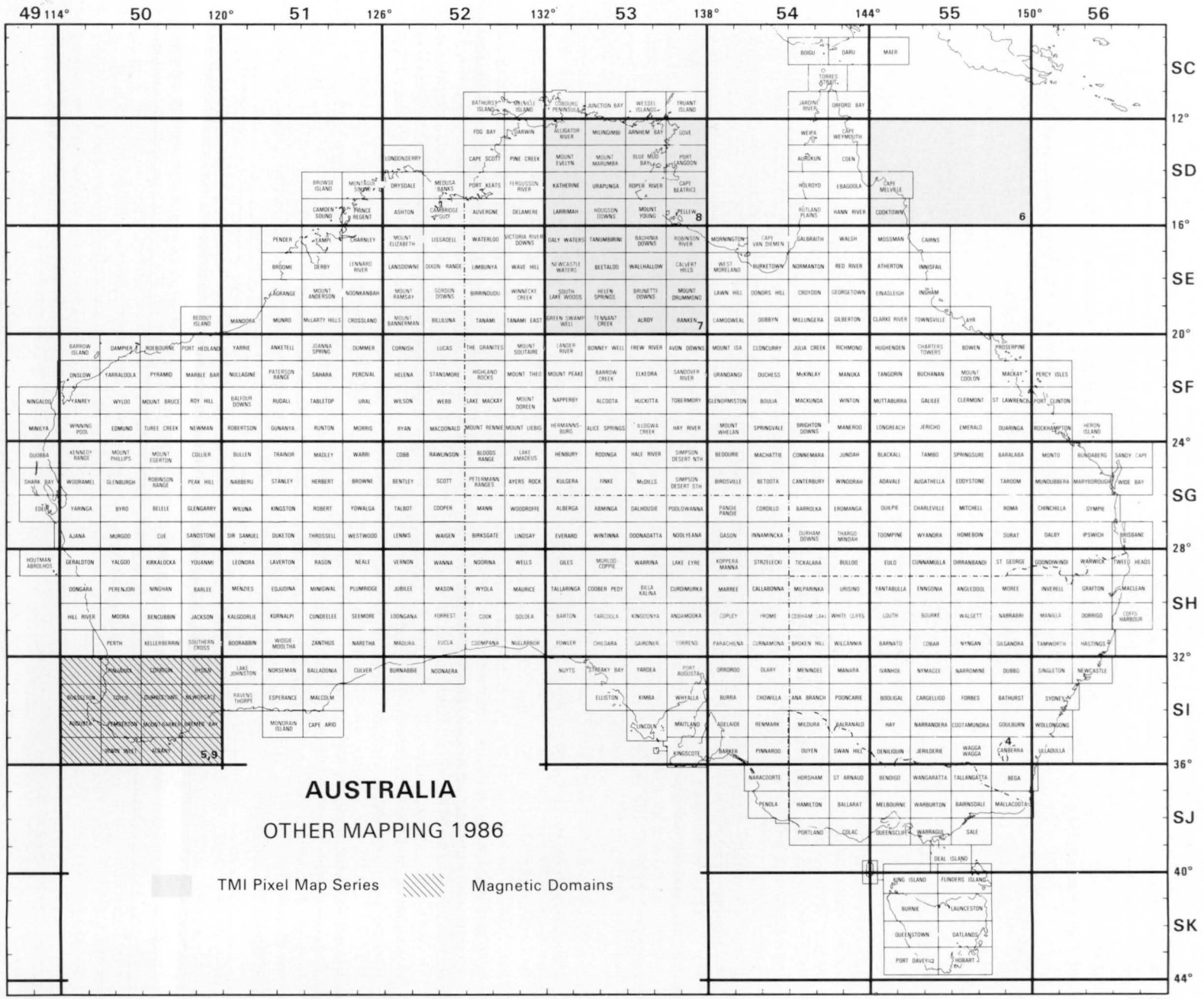


**Fig. 4. Other geoscience mapping in Australia, 1986.**

bution to the Perth Urban Water Balance Study and the Gnangara Mound Environmental Review and Management Program; review of monitoring at Lake Coogee; and preparation of an exploration program for the Derby town water supply.

During the year an agreement was entered into with Petroleum Information Energy Services Pty Ltd (PI) under which PI will sell to the public full- scale copies of electric logs, seismic cross-sections and shot-point base maps. These items are open-file data released under the *Petroleum Acts*. They were sold previously in 35 mm roll film format and there were many objections to the quality of enlarged reproduction. PI will progressively build up a library of transparent copies from which full- scale reproductions can be made quickly.

Two bulletins — on the Carnarvon and the Bonaparte and Ord Basins — were completed and submitted for publication. Work continued on the seismic stratigraphy of the northern Canning Basin. The regional study of the offshore part of the Bonaparte Basin continued.

Palynological studies continued on the Permian strata of the Collie Basin. It was demonstrated that the three sub-basins at Collie can be correlated by means of selected palynomorph species.

Scrutiny of stromatolites from the Glengarry and Earaheedy Sub-basins assisted in a better understanding of stratigraphy, correlation and palaeoenvironments. Preliminary examination of stromatolites from the Waltha Woora Formation and Yeneena Group, and of problematic bedding-plane structures from the Manganese Group provided evidence for stratigraphic correlations.

Because of a lack of local contractors, geophysical logging of privately- owned water bores on a contract basis was undertaken by the Geophysics Section for the first time. Of the total of 102 bores logged, 22 were privately owned.

Considerable progress was made for the Department of Agriculture in evaluating the use of geophysical techniques for assistance in defining the causes of dryland salinity. Magnetic, seismic refraction, resistivity, SP, and electromagnetic surveys were carried out in these studies.

A project to study the magnetic properties of the weathered layer continued, with detailed surveys being repeated over laterite areas after they had been stripped for bauxite. Results to date suggest that maghemite in the pisolitic near-surface material magnetically obscures basement features. Filtering in one dimension does not remove this 'noise'.

Compilation of the first 1:100 000-scale map sheets of the Kalgoorlie region (Cowan, Lake Lefroy, Kalgoorlie and Yilmia) was completed as was a detailed study of the structure of the Golden Mile and surroundings.

Field mapping on the Newman and Robertson sheets was completed, and mapping was carried out in the northern sector of the Western Gneiss Terrain. Field mapping commenced on the King Leopold Orogen.

Samarium-neodymium isotope analyses were carried out at Curtin University on rocks from the Murchison Province, Sylvania Inlier, Balfour Downs sheet area and the Fraser Range. Late tectonic activity is being dated by the biotite rubidium-strontium technique along the western margin of the Yilgarn Block.

A study of gold mineralisation in the Bullfinch — Forrestania and Westonia greenstone belts of the Southern Cross Province began with mapping of selected areas at 1:50 000 scale. The aims of the study are to elucidate structural and stratigraphical controls on gold mineralisation and to classify the various types of gold deposits in the area.

An investigation of the nature and geological setting of skarn-hosted tungsten mineralisation in the northeastern Gascoyne Province was nearly completed. Preliminary synthesis of the data indicates that the Gascoyne skarns are of the type that is equivalent to a group which contains most of the important tungsten skarn deposits in the world.

A team of four geologists and eight general assistants (comprising permanent, Community Employment Project and contract personnel) was assembled late in the year to eliminate the backlog of indexing and microfilming that existed in the *WAMEX* database and holdings of *M Series* company mineral exploration reports.

The Perth, Fremantle, Armadale, and Serpentine environmental geology maps at 1:50 000 scale were published during the year, and cartography, compilation and field work were advanced on 15 other sheets.

## *Commonwealth Scientific & Industrial Research Organisation*

### *Division of Energy Chemistry*

The Division of Energy Chemistry is based at the Lucas Heights Research Laboratories and has 90 staff including approximately 50 professional scientists (mostly chemists) and engineers. Its terms of reference are to undertake 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 and substitute liquid fuels, including reducing their health and environmental impacts. Major emphasis is therefore placed on process research. However, geoscience 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.

NAA can determine a wide range of elements in a variety of samples, ranging in concentration from sub-parts per million to several percent. In collaborative studies with universities, rare earth concentrations have been determined in ancient volcanic rocks from the Glenrock Station area to enable the magmatic affinity of these rocks to be assessed. Results from work carried out on alteration haloes of ore deposits, exhalites from Broken Hill, epithermal gold deposits on Lihir Island (Papua New Guinea) and laterites overlying the Mount Welt carbonatite intrustion (Western Australia) have been used as guides to the genesis of these deposits.

A recently-developed hydrogeochemical prospecting technique for gold has been successfully applied to river, bore and thermal waters in Queensland, Western Australia and New Zealand.

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 mobilisation of trace elements during retorting has been studied for a range of Australian oil shales. A combination of X-ray diffraction, inter-element correlation techniques, selective leaching

procedures, and electron microprobe analysis is 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 studies of coal seam correlation and of the genesis of tuffaceous claystone marker beds. For example, the marker beds have a distinctive trace-element profile which can be used to distinguish them from other sedimentary beds. This profile is being used to study the tectonic development of the New England Block.

### *CSIRO Division of Fossil Fuels*

Research activities at North Ryde in 1986 concentrated on coal production, coal characterisation, coal utilisation, natural gas conversion, oil shale characterisation, petroleum exploration, and environmental protection. Geoscientific principles have impinged on many of these studies.

Changes occurring during coalification are a sensitive indicator of thermal conditions during subsidence in a sedimentary basin. During burial, plant material progressively changes from peat to brown coal to bituminous coal and finally to anthracite. Sensitive chemical parameters have been used to detect subtle changes in geological environment. During 1986, high resolution nuclear magnetic resonance (NMR) spectroscopy (solution and solid state) and Fourier transform infrared (FTIR) spectroscopy have been used, particularly to show changes in functional groups containing oxygen during coalification. X-ray photoelectron spectroscopy (XPS) has confirmed that surface oxidation occurs before and after coal mining. Uniform environments of deposition for coals in the Western Coalfields of NSW have been confirmed by the occurrence of only minor variations in trace metal distributions. X-ray diffraction and thermal analysis have identified a disordered phosphatic phase in certain NSW bituminous coals.

Two problems have been addressed in oil shale geochemistry. Firstly, the uncertainty surrounding the Kjeldahl and Dumas methods for nitrogen analysis in oil shales has been resolved. The Kjeldahl procedure gives a good estimate of organic nitrogen, while the difference (Dumas minus Kjeldahl) is a measure of inorganic nitrogen in minerals such as buddingtonite. The second problem concerns weathering of oil shales and its effect on oil yields during retorting. Research has shown that this is a general phenomenon and affects shales as different as Rundle and Julia Creek in Australia and Green River in the USA. Weathering can be simulated under laboratory conditions and losses in shale oil of up to 90% have been measured due to oxidation kerogen.

More insights into the generation of petroleum from terrestrial precursors was obtained in 1986. Experimental studies have shown how cracking reactions can produce normal, branched and cyclic alkanes, and a speculative attempt has been made to quantify the oil-generating capacity of coal macerals. As a general rule, exinite can produce ten times more oil than vitrinite and a hundred times more than inertinite. Approximate calculations suggest that thermal maturation of coals can account for all the known oil and gas reserves in the Gippsland and Cooper Basins, even if only 1% of generated hydrocarbons is trapped.

### *Division of Environmental Mechanics*

Research in the CSIRO Division of Environmental Mechanics centres on a quantitative understanding of mass and energy transfer in the environment. Highlights during 1986 include use of soil physics theory to investigate water entry into macropores, cavities and tunnels; and the development of TDR (Time Domain Reflectometry) as a rapid, nondisturbing technique for measuring the water content of porous materials.

Quasilinear analysis — a powerful technique for the solution of the highly nonlinear flow equation on which modern studies of soil-water movement depend — has been adapted to investigate the steady downward flow of water around air-filled cavities in an otherwise uniform soil. The generally accepted effect of holes and macropores on unsaturated soil-water flow is that they take no part in the flow except when they extend to a source of free water, usually at the soil surface. Otherwise, they are in regions of negative water pressure, and water from the surrounding soil cannot enter them.

From our recent analysis, the build-up of water pressure at the walls of the cavity was determined. We found that the presence of a cylindrical or spherical hole caused a build-up of water pressure above the hole, and a lowering of the moisture content below it, with the wettest point at the centre top. The larger the hole, the greater is the build-up of water pressure above it. Also, we found that the larger the hole, the more prone it is to have water seeping through it. This seems rather obvious, but is contrary to the conventional picture where the larger the hole is, the less it can be expected to have water in it.

The applications of this class of problem are numerous, as the solutions apply to caves, tunnels, and underground storage cavities. In particular, the results lead to the establishment of design criteria for most efficient prevention of seepage into tunnels and underground repositories in unsaturated zones. Thus, in an engineering context, the results lead to optimal designs for underground repositories for nuclear wastes in deep, unsaturated seepage zones in arid areas.

TDR is a technique in which an electromagnetic pulse is sent down a probe inserted in a porous material. The time taken for the pulse to travel down the probe and return to the receiver depends on the dielectric constant of the porous material, which, in general, is a direct function of the volumetric water content of the material.

Divisional staff have recently made two improvements in the use of TDR. Firstly, they have developed a three-pronged probe for use in the determination of water content of field soils. This probe produces a sharper signal and hence a more accurate measurement of water content than the conventional two-pronged probe. Secondly, they have adapted TDR for the measurement of water conents of a wide range of other porous materials, including stored wheat and coal dumps.

### *Division of Minerals and Geochemistry*

The aim of the Division of Minerals and Geochemistry is to develop new methodologies for exploration, particularly in weathered terrain, to enhance exploitation of existing ore bodies, and to develop or improve processes for the production of higher-value products from minerals.

The Division's Exploration Section is located at Floreat Park and it has two Mineral Processing Sections, one at each of the Floreat Park and Bentley Laboratories. There are 15 professional staff in the Exploration Section and 11 in each of the two Mineral Processing Sections; the total staff is 71 excluding site services personnel.

The Division's exploration research focuses on the chemical and physical processes of ore formation and element dispersion as a basis for new concepts and new or improved geochemical techniques for mineral exploration.

There is close integration with the Division of Mineral Physics and Mineralogy through a multi-module task force on *Exploration for Concealed Gold Deposits in the Yilgarn Block of Western Australia.*

This is being conducted in collaboration with industry and is coordinated through AMIRA. The four modules of research are: Controls of Primary Gold Mineralisation Weathering Processes, Laterite Geochemistry, and Remote Sensing.

The Division has combined its studies on nickel and platinum in a project *Mineral Deposits Associated with Mafic and Ultramafic Rocks.* Recent nickel research has been concentrated on deposits in the Agnew- Wiluna Greenstone Belt, and a study of the Agnew Deposit, sponsored collectively by WAMPRI, BP Minerals and Carpentaria Exploration Co Ltd, has shown that the sulphides and their ultramafic host rocks are the result of extrusive processes. Another study, jointly sponsored by CRA Exploration Pty Ltd and WAMPRI, has been initiated to refine the extrusive genetic model and study the physical volcanology of ultramafic rocks (komatiites) of the Yilgarn Block.

Research is being undertaken to develop strategies for assessing layered mafic complexes as hosts for primary concentrations of platinum mineralisation. A study of the layered rocks from the Windimurra Hills area of the Windimurra Layered Gabbroic complex has been completed and published. In addition, precious metal studies are being conducted on nickel sulphide ores and komatiitic host rocks and on low-grade platinum- group metal occurrences to develop and improve exploration, mining and recovery techniques. Results of a study of the nature, distribution and recovery of platinum-group minerals in Kambalda nickel ores have been published.

Studies of the palaeogeography and stratigraphy of mineralised Archaean basement rocks are being conducted in the Pilbara region of Western Australia. The research is being conducted to develop a model of palaeoplacer mineralisation for exploring for gold and platinum. Research in the west Pilbara has shown that gold and base-metal occurrences in the younger Archaean fit into stratigraphic and structural provinces which can be extrapolated to areas hidden below the Mount Bruce Group Supergroup cover.

Research on the petrology, genesis and classification of Precambrian iron ores is sponsored by industry through AMIRA. A detailed study of the relationship between the high-grade export ores and their chrono- stratigraphy has led to a conceptual model for the genesis of iron ore from banded iron-formation. Potential exploration areas for the high-grade ores are being delineated. The genetic modelling resulted in a classification of ore types currently in use in industry and to a broadening of the project to investigations of foreign ores.

An expanded program is to be carried out in 1987-88 following agreement with AMIRA to increase funding levels. The program includes the completion of current studies on the Marra Mamba ores, silica-iron reactions, magnetic properties of banded iron-formation (with the Division of Mineral Physics and Mineralogy), and a video on the research achievements. New studies are being carried out on shales in ores, trace- element movement during the enrichment process, pisolitic iron ores, and the nature of Brazilian ore deposits.

Research on laterite geochemistry aims to establish practical methods of exploring laterite-covered terrain for a broad range of ore deposit types. Initial focus is on the exploration for precious metal deposits, particularly gold. The scope of the project includes the development of strategies for sampling, analysis, and interpretation of multi-element geochemical data from lateritic materials and includes studies at several representative locations where gold mineralisation occurs within or beneath laterite. Detailed studies of the mineralogical, textural, and geochemical characteristics of pisolitic and nodular laterite form an important part of the research. Development of relevant techniques of data interpretation using multivariate statistics is included. A high-quality database on laterite geochemistry includes some 9000 samples, the majority of these data arising from company collaboration.

A private minerals exploration consulting and service company, GEOCHEMEX AUSTRALIA, was set up in January 1987 to fulfil the increasing need for the application of laterite geochemistry to mineral exploration involving the techniques developed by the Division.

The existing and proposed open-cut gold mines offer unprecedented opportunities for geochemical and mineralogical studies to document the distribution of gold and other elements of geological and economic interest within the deeply-weathered regolith. Research conducted in this area has specific objectives to obtain a better understanding of the nature and genesis of lateritic and supergene gold deposits and to determine characteristics useful for exploration both for other such deposits — particularly in areas of transported overburden — and for the primary mineralisation from which they have been derived. More generally, the research will increase knowledge of the properties and genesis of the regolith and be applicable to interpretation of data obtained during exploration for other commodities in and beneath the weathered zone.

### *Division of Mineral Chemistry*

Geochemical studies to evaluate the very large magnesite deposits, recently discovered at Kunwarara (Hillview) near Rockhampton , have continued. The magnesite occurs as nodules of very pure, cryptocrystalline magnesite, found just below the surface. Reserves are estimated to exceed 500 million tonnes.

The mineralogy of spodumene-bearing rocks from pegmatites at Greenbushes, WA, are being studied, with a special emphasis on the distribution of gallium and rubidium.

The crystal structures of senarmontite (cubic $Sb_20_3$), valentinite (orthorhombic $Sb_2O_3$), and cervantite (orthorhomic $Sb_2O_4$) have been refined using neutron diffraction data.

Crystal structure studies at room temperatures have commenced on monazite and xenotime samples obtained from beach sand deposits in Western Australia.

A joint CSIRO/University of Tasmania research project, initiated in 1984, to carry out structural studies in mineral and inorganic chemistry, has characterised four new phases of zinc arsenate. In a collaborative study with CSIRO's Division of Minerals and Geochemistry, the University of

Massachusetts and the Geological Survey of Canada, several new minerals have been characterised and their structures determined. Most of this work involves the titanium-containing minerals that derive from hydrothermal gold-bearing deposits, and from diamond-bearing kimberlites and lamproites. Structures have been determined for tomichite ($AsTi_3(Fe,V)_4\ O_{13}(OH)$), barian tomichite ($Ba_{0.5}AsTi_2(Fe,V)_5\ O_{13}(OH)$), cerium titanate ($CeTi_2O_5(OH)$) and a new metasomatic mineral from the Argyle diamond deposit, magneto-plumbite ($BaTi_3Cr_4Fe_4MgO_{19}$).

The study of the crystal chemistry of sulphosalts has been continued with determinations using single crystal X-ray diffraction and electron microprobe techniques of ramdohrite. Controversy over the composition of this mineral has continued for over forty years, however this latest work suggests that the original formula ($Pb_6Sb_{11}Ag_3S_{24}$) is correct. The crystal structure of izoklakeite ($Pb_{51.3},Sb_{20.4}$, $Bi_{19.5},Cu_{2.9},Ag_{1.2}Fe_{0.7},S_{114}$), has also been determined.

## *Division of Mineral Engineering*

The research objectives of the Division of Mineral Engineering are the development, improvement and control of operations and processes in the mineral, energy and base-metal industries by means of theoretical, experimental and application studies. Particular emphasis is placed on instrumentation and control, on the handling and beneficiation of metalliferous ores, coal and oil shale, and on smelting and basic metal production. Although the majority of the Division's research is in the field of mineral processing, several of its projects are related to geoscience.

QEM*SEM (Quantitative Evaluation of Materials by Scanning Electron Microscopy) is a fully-automated, computer-controlled scanning electron microscope developed at the Division. It can identify minerals and their features in indiviudal ore particles sampled at any stage of a mineral processing operation. It was originally designed to produce information on sulphide ore samples and concentrates. However by the end of 1986 it was being used routinely for the analysis of complex sulphide ores, tin ores, concentrated gold ores, heavy minerals from sediments, and phosphate deposits. Research on adapting the system to the analysis of mineral matter in coal and the products of coal combustion is well advanced.

QEM*SEM Mineralogical Services, a bureau operation established by the Division in 1983, performed analyses for many of Australia's largest mineral processing companies during 1986 and is now fully self-supporting.

The Division has developed a fully-quantitative nuclear borehole logging technology (SIROLOG). The techniques have principally been applied to the measurement of iron ore grade and the ash content of coal, and have also been successfully tested for exploration and mine development applications.

During 1986, a NERDDP project to develop procedures for ash analysis in coal boreholes was completed and projects with the State Electricity Commission of Victoria and Esso

Resources Canada Ltd, culminated with the transfer of SIROLOG technology. In addition, a non-exclusive licence was granted to Geosource for the marketing of the system. Feasibility trials of a system for the measurement of iron ore grade and density and borehole diameter were completed.

Laser techniques are being developed for remote sensing applications and for the characterisation of coal. A rapidly-tuned $CO_2$ laser system has been used to measure silica and shale spectra in the laboratory at a 5-m range, and the feasibility of using the system to collect 9–11 $\mu$m spectra in milliseconds at ranges of several hundred metres has been established. The method could be developed for measurements of mine faces or for rocks on conveyor belts, but not for fine powdered minerals (–200 $\mu$m) as they exhibit low-contrast spectra in the mid-infrared.

In a NERDDP-funded project, large areas of bulk coal samples were excited at a 1-m range by a nitrogen laser (337 nm wavelength). The visible fluorescent emission spectra were found to correlate well with coal rank, oxygen content and other parameters. The method may be suited to on-line measurements of coal on conveyors, to bore core and bore hole use, or to measurements at mine faces.

Industry-sponsored investigations are currently in progress for the purpose of evaluating the physical, chemical and mineralogical properties of Australian fine ores as factors which affect sintering performance and processing behaviour of sinter products in the blast furnace. Sinter-making, testing and analysis programs with an 80-kg capacity pilot-scale rig are now being undertaken to test theories that have been developed from the results of earlier fundamental scientific and bench-scale thermal-response investigations of the ores. Special small-scale pot- grate firing experiments are also being carried out to generate products specifically for studies of sinter structure development and other associated flame-front reaction phenomena.

## *Division of Mineral Physics and Mineralogy*

The charter of this CSIRO Division is to develop instrumentation and techniques for mineral and oil exploration so that private exploration programs are cost-effective and result in early recognition of economic deposits.

Highlights of 1986 were:

- Commissioning of a Laser Raman Microprobe
- The PACLARK research cruise . Successful completion of the experimental upgrade of the Australian Landsat Station at Alice Springs
- Keen commercial interest in an enhanced oil recovery technique which uses surfactant-producing bacteria

*Laser Raman Spectroscopy.* This instrument enables molecular spectra to be obtained from micron-sized particles of minerals and organic matter, and even from solid, liquid and gaseous inclusions in minerals. The method is based on analysis of the inelastically-scattered light from materials irradiated by an intense source of monochromatic radiation.

A major problem in petroleum exploration is to recognise rocks which have generated and expelled oil or gas in sufficient quantity to form commercial accumulations. All existing methods for the evaluation of petroleum source rocks have shortcomings so new, more widely applicable methods are continually being sought. The feasibility of taking both Raman and fluorescence spectra from solid organic particles in Australian sedimentary rocks will be assessed, and the spectral indices will be calibrated against industry-accepted standard methods of assessing thermal maturity, that is the degree to which the organic matter has been heated in the Earth's crust. Organic material in older rocks, where vitrinite particles do not occur, will also be examined. Success in this

area may stimulate exploration in basins where vitrinite is absent or not abundant.

The same technique will be applied to obtaining Raman spectra of fluid inclusions in mineral samples. These spectra will be applied in developing a new method for mapping the distribution of ore-forming saline fluids in fluid inclusions in prospective terrains.

*PACLARK Research Cruise.* A vital ingredient for future exploration methods is a better understanding of how orebodies form and evolve through geological time. It was with this objective that Dr Ray Binns of this Division initiated PACLARK, the **P**apua New Guinea-**A**ustralia-**C**anada cruise to the Wood**lark** Basin off PNG using the CSIRO research vessel *Franklin.*

The aim of the PACLARK cruise was to seek evidence of present-day ore formation on the seafloor off Papua New Guinea as a basis for improved exploration methods on land. The cruise took place in April 1986 and was led by Dr Binns and Dr Steve Scott from the University of Toronto. A team of twelve scientists from Papua New Guinea, Australia and Canada took part with support for one of the participants being provided by industry.

Laboratory work is now being carried out to compile the results of the cruise and to characterise and analyse the hundreds of rock and water samples.

*Landsat Signal Processing.* A project, which began in 1984, to modify Landsat reception facilities in Alice Springs was completed. The work was undertaken because it appeared that a particular part of the Landsat system of satellites might fail before the reception facility was fully upgraded.

The project was funded by a group of 36 private and government organisations, and in August 1986 modifications were completed, and data reception commenced.

Several commercial products are likely to result from this work: a decoder of data, a real-time display system which produces images of Landsat data, an intelligent file server for image processing, and an interactive digital-image display system.

*Enhanced oil recovery using bacteria.* By the end of 1986 the Division completed negotiations with several companies to extend this work to field trials in oil reservoirs.

## *Division of Oceanography*

During 1986 the field program of WEPOCS (West Equatorial Pacific Ocean Circulation Study) was completed. WEPOCS was carried out in conjunction with Scripps Institution and the Universities of Hawaii and Miami and was designed to examine the origins of disturbances in the Equatorial Pacific which may account for the early stages of the El Nino Southern Oscillation (ENSO) phenomenon. The project involved oceanographic sounding at a 'section' of stations bracketing the Equator north of the Bismarck Sea, coupled with observations using acoustic doppler profiling and surface buoys moored in 5000 m of water on the Equator. The cruises were among the first using the new RV *Franklin.*

Analysis of results is proceeding but already the existence of a new westward undercurrent along the northeast coast of Papua New Guinea has been revealed, with a volume transport of about eight million cubic metres per second. The response of surface waters to seasonal monsoon wind forcing was found to be rapid, and salinity was unexpectedly found to be of major importance in the dynamics of these surface waters.

In November the *Franklin* was also used to study a meridional section along 150° E extending across the Antarctic convergence zone to 57° S. The cruise sought identifiers associated with water-mass characteristics and history of trace-metal levels and speciation, trace organics, and bacterial and planktonic composition.

Networks for the monitoring of changes in upper-ocean heat content have been expanded by the addition of three observing lines involving six new ships on the Port Hedland — Japan, Fremantle — Persian Gulf and Fremantle — Red Sea routes. The network, now comprising six lines and eleven commercial vessels which ply between Australian and overseas ports, involves the deployment of XBTs (expendable bathythermographs) provided by CSIRO, the RAN and the United States, in an international program to detect the early signs of ENSO.

The satellite tracking station at the Marine Laboratories in Hobart for the reception of infrared TIROS-N images has been upgraded to receive and process filtered, visible image from the NIMBUS satellite. Although it is in its dying stages, this satellite has provided previously-unattainable information on plankton distribution in the East Australian Current.

In collaboration with Steedman Ltd, a waverider buoy has been moored off Strahan on the west coast of Tasmania to obtain data on the wave climate of the oceans south of Australia, which are among the roughest in the world. The data, displayed in real time, are also providng valuable to fishermen.

The RV *Franklin*, operated by CSIRO as a national facility, has completed 18 months of successful operations on geological, biological and oceanographic projects. The complex on-board systems are in full operation and early winch troubles have been overcome. A recent success was the on-board reception and processing of satellite imagery which enabled the ship to be guided through a rare doublet of eddies in the East Australian Current.

Good theoretical advances have been made on the formalism of quasi- horizontal and vertical mixing in the deep ocean, the dynamics of the Leeuwin Current, continental shelf waves, and global wind-driven oceanic circulation.

## *Division of Soils*

During 1986 field and laboratory studies were completed in a collaborative project with the South Australian Department of Mines and Energy on the engineering properties of soils and sediments of metropolitan Adelaide. The work has already been reported at conferences and a Departmental bulletin and associated research papers are at an advanced stage of preparation.

Collaborative research with the Department of Applied Sciences, Canberra College of Advanced Education, on the distribution and properties of Miocene Lake Bunyan clays near Cooma, NSW, was completed with journal publication. The Bunyan Formation is notable for the thickness of its kaolinitic clays and their ultra-fine grain size.

In the latter part of 1986 the Division assembled a multi-disciplinary task force to undertake contract field and

laboratory research for Ranger Mines Ltd at Jabiru, NT. The contract related to the long-term stability of waste-rock dumps under construction at the mine. The work was essentially concerned with the rates of weathering of the various rock types on the dumps, the products of long-term weathering of the rocks, identification of potential contaminants, and an assessment of the resistance or susceptibility of the dumps to erosion. A comprehensive report was completed and submitted to the Company in December.

In 1986, a collaborative research program, funded through the Office of the Supervising Scientist, Jabiru, NT, was begun on the soils and hydrology of sites for disposal of uranium mine waste water. The first phase of the program has been completed with detailed field and laboratory characterisation of soils at the disposal sites. It is intended to determine the long-term soil conditions, and the escape of possible pollutants (uranium, radium, manganese and sulphate) to the nearby river system from prolonged irrigation with mine waste water.

A major research effort was directed towards the development of an international standard method for the analysis of iron ores using X-ray fluorescence (XRF) techniques. The work is a collaborative effort involving 24 international laboratories and the Division of Soils in Adelaide, and the method devised has recently been accepted as an International Standard. Additional research, at the request of Mt Isa Mines Ltd, has concentrated on methods for the analysis of base-metal sulphide ores using XRF techniques. The methods developed have now been adopted by the Company for routine ore assays.

In collaboration with Ecole Nationale Superieure des Mines de Paris, field-based studies of weathering processes were concentrated on silica accumulations, including precious opal deposits and the widespread red-brown hardpans in the complex and ancient landscapes of arid central Australia. Zones of silicification have a systematic distribution through the deeply-weathered regolith. Highly-structured, silicified horizons which formed in former pedogenic environments occur near the land surface, whereas silicified horizons at depth preserve the detailed structure of the regolith material and relate to ancient groundwater tables. Mineralogical studies have identified the systematic organisation of silica polymorphs in the regolith profiles, and studies of this distribution are continuing. Models for the formation of ferruginous horizons and crusts (laterite) have been developed. Other studies have concentrated on biomineralisation involved in the formation of calcretes in calcareous soil environments widely developed across Southern Australia.

The Division has detailed field and laboratory records of approximately 4000 soil profiles sampled in various parts of Australia. These data are being computerised in a project supported by State authorities and funded by the National Soil Conservation Program. Compilation of these data is the first step in developing a nationally-accessible soil database from CSIRO and State records.

The Brisbane group of the Division has completed the initial phase of a geostatistical soil survey of the Edgeroi 1:50 000 sheet in the Namoi alley, NSW. This has entailed field sampling and description of soils to 3-m depth and recording of surface conditions at each site. Corresponding sets of chemical and physical data are being obtained in order to characterise the soils for agricultural management. The relationship between soil properties and remotely-sensed images is also being investigated.

Laboratory studies have proceeded on induced hydrolysis reactions relating to the mobility of Fe, Si and Al as complexes which may degrade under certain conditions to form commonly observed soil minerals such as allophane-imogolite and gibbsite. Reactions between organic compounds and iron oxides were investigated to demonstrate that organic matter is an important factor in the formation of different assemblages of iron oxide and oxyhydroxide minerals in soils. Research on the synthesis of ultrafine magnetite in relation to its occurrence in soils and biological systems is continuing.

The soils of the terraces in the middle section of the Mary River near Gympie are being examined with the aim of relating them to terrace development and geomorphic history. The Brisbane group has also been involved in the selection of soil experimental sites at Gympie and Ingham for eucalypt forest research by several CSIRO Divisions and funded by the Shell Company of Australia.

During 1986, detailed crystallographic studies of the sodium mica ephesite were completed, together with preliminary work on lepidolite and an investigation of a vermiculite-diamine intercalate. This work is primarily concerned with elucidating the detailed atomic ordering in layer-lattice silicate minerals, and the mechanisms by which the three- dimensional atomic arrays adapt to interactions with organic molecules.

### *Division of Water and Land Resources*

As part of last year's major reorganisation of CSIRO's water research, the Division of Water and Land Resources was abolished and approximately half of its staff absorbed into the new Division of Water Resources Research. This Division is to have laboratories in Perth, Adelaide and Canberra.

As in previous years, geoscientific research was only a part of the work undertaken in the Division, although this proportion is likely to increase in future. Significant progress in a number of these projects is reported below.

*Estimating sediment yields from small catchments.* Reduction of reservoir capacity and a decline in water quality are two serious and widespread concerns associated with sedimentation of reservoirs. Given the importance of catchment management practices in overcoming these, especially in agricultural areas, a method for rapidly assessing the amount of sediment being washed from a catchment would be valuable to water management authorities.

Using existing topographic maps (at 1:50 000) and land cover data (notably from Landsat), a prototype technique for estimating sediment production was completed in 1986. The principal elements of the method area are:

- the collection of data on the depth of farm or town dams, dam surface area, sediment volume and dam age
- the use of rainfall data and catchment area measurements to calculate water runoff and inflow to the dam
- the calculation of sediment-trap efficiency and sediment yield

This work has been a useful complement to the Division's longer and more extensive research into the sedimentation of Burrinjuck Reservoir (described elsewhere in this report — Wasson & Clark).

*Erosion modelling.* With over 200 000 km$^2$ of Australian croplands affected by soil erosion, new techniques for managing the problem are urgently required. In this context a newly-developed model for predicting where erosion and deposition is likely to occur promises to find widespread application across Australia's agricultural lands.

The US-developed Universal Soil Loss Equation has long been the mainstay of soil loss theory and calculation. Nevertheless it is known to be unreliable when applied to long or steep slopes, and to converging or diverging land surfaces. The strength of the new model lies in allowing for this topographic variation and for the consequent changes in erosion and deposition.

Work at Wagga Wagga during 1986, sponsored by the Australian Water Research Advisory Council and in collaboration with the NSW Soil Conservation Service, has focussed on two 7-ha catchments. One is untreated and yields 2200 kg of sediment/ha/yr, the other treated with contour furrows yields 32 kg/ha/yr. It was found that sediment transport measurements were in close accord with the model's predictions.

Potential users of the model need:

- a digitised version of a topographic map with a contour interval spacing of 1-5 metres, depending on the size of the area
- data on the size of the soil's constituent particles, and on a number of soil hydraulic properties, and
- data on the intensity and frequency of rainstorms.

Model refinement is in progress, and further applications are planned.

*Automated digital elevation modelling.* One of the main weaknesses of elevation grids produced by general-purpose interpolation techniques has been the creation of apparently land-locked drainage basins, or sinks. In general these sinks are fictitious, being creations of the technique itself.

In a new digital elevation modelling program (SPLIN2H) developed in the Division during 1986, a 'global drainage condition' is imposed on the data, automatically removing such sinks. In practice this has been found to significantly improve the accuracy of interpolation from limited data sets. In addition it appears that the data sets required can be an order of magnitude smaller than the sets normally needed to describe elevation data using digitised contours. This represents significant savings in data capture and storage.

The conservative nature of the constraints imposed by the program has the effect of highlighting errors in input data as well as making it tolerant of moderate errors in streamline position.

The program is currently being used to calculate a reliable digital elevation model for the Australian continent at a grid spacing of 0.025 degrees of latitude and longitude. It is also being used routinely by the Divison and a number of government agencies, including NATMAP and the Australian Survey Office, to calculate more detailed elevation models at 1:100 000 scale.

*Electromagnetic survey for detecting salinity risk & potential aquifers.* The time required for field work and data analysis, plus the risk of sampling from unrepresentative sites, are problems with both laboratory-based techniques of soil salinity measurement, such as the saturated paste extract method, and with field techniques using contact probes, such as resistivity.

The potential of the non-contacting terrain conductivity meter (the EM meter) has attracted the Division for some years, beginning with a large- scale survey of the mid-Lachlan Valley in 1981. Last year's issue of *Australian Geoscience* carried an account of various EM applications by the Division in the alluvial soils of the Riverina.

During 1986, further investigation into the value of this technique was conducted at Yarralaw near Canberra and on a property near Benalla in northern Victoria. Soil conductivity maps of both areas were produced, and good correlation established with salinity data collected by conventional sampling methods.

Researchers have now concluded that the technique is sufficiently proven to warrant more general use in salinity and aquifer surveys by soil and water consultants and authorities. Although the interpretation of survey results remains a matter of skill, the production of reliable and consistent soil conductivity maps for farms or larger areas is now relatively straightforward.

In an attempt to publicise the potential of this technique more widely, a number of demonstrations were given at field days during 1986, including the National Field Days at Orange. The only EM Equipment available is an imported Canadian device, and CSIRO staff feel that an opportunity exists for an Australian manufacturer to produce a local version tailored more closely to Australian needs, and at a price well below that of the imported model. The adoption of this valuable technique could well depend on such local initiative.

# NOTEWORTHY MINERAL AND HYDROCARBON DISCOVERIES 1986

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 1986. Many 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*

**Table 1. Noteworthy mineral discoveries — 1986**

| Name | Companies | Location | Type of deposit | Grades and reserves |
|---|---|---|---|---|
| Cadjebut | BHP Minerals/Billiton Australia | 70 km SE of Fitzroy Crossing | Mississippi Valley Type | 3.5 Mt grading 14.0% Zn and 5% Pb |
| 12 Mile | BHP Minerals/Cyprus Minerals | 90 km SE of Fitzroy Crossing | Mississippi Valley Type | Not detailed |
| Cooljarloo | $TiO_2$ Corp. | 230 km N of Perth | Fossil Strandline | 110 Mt @ 3.6% heavy minerals Known mineral sands province |

**Table 2. Noteworthy hydrocarbon discoveries — 1986 (a)**

| Basin | State | Field Name | Company (Operator) | Type of discovery |
|---|---|---|---|---|
| Bonaparte | NT | Skua* | BHP | o |
| Bowen/Surat | Qld | Taylor | Bridge | g |
| Carnarvon | WA | Campbell* | Bond | g/c |
| Cooper/Eromanga | Qld | Black Stump | Lasmo | o |
| Cooper/Eromanga | Qld | Cooroo | Delhi | o |
| Cooper/Eromanga | Qld | Cooroo North | Delhi | o |
| Cooper/Eromanga | Qld | Okotoko | Delhi | g |
| Cooper/Eromanga | Qld | Tennaperra | Delhi | o |
| Cooper/Eromanga | SA | Bagundi* | Delhi | o |
| Cooper/Eromanga | SA | Bimbaya | Santos | g |
| Cooper/Eromanga | SA | Dirkala | Delhi | o/g |
| Cooper/Eromanga | SA | Garanjanie | Delhi | g |
| Cooper/Eromanga | SA | Kidman* | Delhi | g |
| Cooper/Eromanga | SA | Kidman North | Delhi | g |
| Cooper/Eromanga | SA | Mundi | Delhi | g |
| Cooper/Eromanga | SA | Nanima | Delhi | g |
| Cooper/Eromanga | SA | Nungeroo | Crusader | o |
| Cooper/Eromanga | SA | Pira | Delhi | g |
| Cooper/Eromanga | SA | Spencer | Delhi | o |
| Cooper/Eromanga | SA | Thurakinna | Delhi | g |
| Gippsland | Vic | Kipper | | g |

(a) Gas discoveries with flow rate 100 × $10^6$ $m^3/d$
Oil discoveries with flow rate 20 $m^3/d$
* New pool discoveries
o Oil
g Gas
c Condensate

# GEOSCIENCE IN AUSTRALIA IN RELATION TO IGBP: A STUDY OF GLOBAL CHANGE

B. G. Thom[1]

## *Establishment of IGBP*

On 19 September 1986, a major step was undertaken by the International Council of Scientific Unions (ICSU) to ensure the survival of the human race. It launched what could become 'the largest, most complex, and most ambitious program of international scientific cooperation ever to be organised' (Roederer, 1986). ICSU accepted a recommendation to initiate an International Geosphere Biosphere Program (IGBP). This would involve a preparatory phase of about four years, and then the implementation of an operational phase beginning in the early 1990s (Cole, 1987). The operational phase will last at least 10 years.

The *prime objective* of IGBP is:

> 'To describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth systems, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions' (ICSU, 1986).

This objective arose from discussions held since 1983 between members of the various unions involved in ICSU. To those who participated it became obvious that:

> '. . . a major international cross-disciplinary effort was necessary to obtain a truly comprehensive, quantitative understanding of the complicated terrestrial 'machine', the functions of and interactions between its parts, and the major geophysical and biogeochemical cycles by which it is driven . . . To preserve or expand the life- support systems during the 21st century, governments of all nations would have to design long-term plans that, while addressing their own specific national goals, would have to be based on basic scientific knowledge of the global terrestrial environment and or anticipated natural and anthropogenic change. *The required detailed and quantitative scientific knowledge simply does not yet exist*' (Roederer, 1986).

To achieve a global view of the Earth system, a view which emphasises the connection of all intervening parts, a number of programs are envisaged. These programs will focus on those areas of each of the fields involved that: (1) deal with key interactions and signficant environmental change on time scales of decades to centuries; (ii) most affect the biosphere; (iii) are most susceptible to human perturbation; and (iv) will

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most likely lead to a practical, productive capability (ICSU, 1986).

To accomplish this goal, the programs should focus on the major biogeochemical cycles involving the atmosphere, hydrosphere, cryosphere, litosphere, and biosphere, and they should consider the energy sources that are internal and external to the earth and the related energy transfer process. In particular, the study of Earth climate, past and present, should represent a pivotal point of the entire effort.

### *Relevance of geoscience to IGBP*

In planning for IGBP, 'ICSU established five working groups who were to define key research initiatives that could be undertaken in the course of 10 — 20 years. The groups were:

- Terrestrial ecosystems and atmospheric interactions;
- Marine ecosystems and atmosphere interactions;
- Geological processes, past and present;
- Upper atmosphere and new space environment; and
- Remote sensing

These groups reported to the ICSU General Assembly last September, and it was through their efforts that ICSU decided to accept IGBP. One of the major goals of IGBP as a result of the working group on geological processes will be to require collaboration of different disciplines or fields within geoscience) who are involved in 'the recovery of the environmental history of the past' (Roederer, 1986).

Raymond A. Price, the Director of the Geological Survey of Canada, was the Chairman of the working group on *Geological processes, past and present.* Last year he published in *Episodes* a summary of the report of the group to the General Assembly (Price, 1986). An earlier report of the group appeared in the proceedings of the ICSU-sponsored symposium on global change in 1984 (Price, 1984). This volume contained an article on palaeoclimatic research by a group of quaternarists (Webb & others, 1984).

Price (1986) makes it clear that we live in a time of biotic crisis. He says:

> '. . . when viewed from the perspective of the geological record, rapid growth in the human population, in the per-capita consumption of natural resources, and in the disruption of established ecosystems represent drastic departures from the state of stable dynamic equilibrium that characterises most of Earth history'.

He argues that the record of the development of our global ecosystem provides an essential framework for answering the nature and significance of contemporary global change.

> 'Working out this record will provide both a baseline against which to compare and evaluate contemporary global change, and a framework within which to explain the basic processes in the coupled geosphere-biosphere system' (Price, 1986).

Stress is placed on the record of the Holocene Epoch — the last 10 000 years — involving retreat of ice sheets, rise of sea level, changing patterns of precipitation, warming (and cooling) of the Earth, migration of plant and animal communities, and last but by no means least, the explosive growth, technological development and impact of the human population. The database is large, dispersed, highly variable in place and quality, and inadequately coordinated.

> 'However, new technological developments offer great scope for improvements and an IGBP on Global Change could provide the necessary stimulus and coordination to achieve this' (Price, 1986).

It was recognised that gaps in our knowledge of landform, climate, vegetation, animal life and soil conditions during critical periods of the past few thousand years inhibit efforts at understanding the dynamics of global change. Until more comprehensive records in space and time are available, which can be used to interpret past changes in the chemical composition of the atmosphere, oceans and soils, then we are severely limited in our ability to develop global models of what is happening to the interacting Earth system. In addition, geoscientists are being required to improve their histories of climate for proxy records (eg analysis of sediment cores), and to document further their records of volcanic and neotectonic events. Fundamental to IGBP is the improvement of our knowledge of natural perturbations to the global system and local environments against which man-induced changes can be measured.

> 'This will require the acquisition and rigorous study of continuous records that contain quantifiable environmental indicators such as isotope ratios, chemical ratios, vegetation, and accumulation/deposition ratios. Such records are to be found, for example, in lake and ocean sediments, ice caps, tree-rings and coral deposits as well as in rocks. These records provide unique and valuable insights into the past hisotry of the Earth, each covering a characteristic space of time, and with different temporal resolution' (ICSU, 1986).

Finally, Price makes it very clear that geoscientists have a responsiblity in the context of IGBP for examining anthropogenically-induced descriptions in the global ecosystem in relation to past and present natural changes. They cannot remain aloof, but should be in a position to relate their science to human activities. He cites, as examples, the need for more information on the use and transport through erosion of phosphate fertilisers, and more knowledge of processes controlling both the origin and evolution of soils, and their erosion and degradation under different climatic and land-use conditions.

In studying the global effects of changes in land cover on soil, such as desertification, remote sensing will be of substantial use. It will be possible to monitor soils as they lose their carbon content (through lower emissivity), oxidize (increased red ferric irons) or lateritise (detection of hydrate bands). It will also be possible to monitor the movement of erosional products across the land surfaces (eg. sand dunes), in lakes and rivers, and to the sea (Price, 1986).

### *Australia and IGBP*

Several Australians have been involved in the development stage of IGBP. They include Professor R.W.R. Rutland who participated in a workshop chaired by Price in February 1986, on Geology and problems of global change. Professor Keith Cole of Latrobe University presented a paper at the earlier Global Change Symposium sponsored by ICSU in September 1984 (Cole, 1984). He recently reviewed two ICSU symposia in *Search*: one on the consequences of nuclear war and the other on global change (Cole, 1987).

The Australian Academy of Science decided to establish a Special Committee on the IGBP following the ICSU decision in September 1986. National Committees for IGBP have been established in other courntries (eg. USA — see National

Research Council, 1986). The Foreign Secretary of the Academy, Profesor Cole, was appointed Chariman of the Australian Committee. The Committee represents a broad spectrum of science and consists of:

Professor K. D. Cole
Professor K. Lambeck
Dr K. McCracken
Dr A. McEwan
Professor C. B. Osmond
Dr G. Pearman
Professor J. P. Quirk
Professor B. Thom
Dr B. H. Walker (Australian Representative on ICSU Special Commission for IGBP)
Representatives of Federal Departments of Science, and Arts, Heritage and Environment

The Australian Committee met in April 1987, and agreed to undertake a number of activities to make scientists in Australia more aware of the importance, opportunities and scope of IGBP. Measures to disseminate information about IGBP were agreed to. Most importantly, plans were made for an IGBP Symposium to be followed by a Workshop in early 1988, probably in late February in Canberra. People interested in attending should write to Professor Cole at the Academy of Science.

During 1987 and 1988, a number of conferences will be held which involve an appreciation of global change. Some of these conferences will be devoted to the Australian region and others will involve Australian participation at international congresses and meetings. In August 1987, at the International Quaternary Association (INQUA) meeting in Ottawa, a number of sessions will be held on problems of global change. INQUA, a member of ICSU, probably reflects the integrated concern of many disciplines more than most other member unions (Rutter & Faure, 1987). Palaeoclimatic reconstructions are a major function of INQUA commissions, and the Cooperative Holocene Mapping Project (COHMAP) is one group which has demonstrated the capacity to integrate historical information over this time scale. Dr John Dodson of University of New South Wales is an Australian representative on this project. At the INQUA meeting there will be sessions on the impact of sea-level changes as well as a general session on IGBP.

In late 1987, there will be two Australian meetings which will highlight problems of global environmental change from an Australian perspective. The first is GREENHOUSE '87 to be held at Monash University (30 November — 4 December 1987). This conference is a natural outgrowth of the Villach Conference in October, 1985, which assessed the role of carbon dioxide and other greenhouse gasses in climatic variations and other impacts (Zillman, 1986). Dr Graeme Pearman, CSIRO Division of Atmospheric Research, is organising this meeting which aims to:

- encourage further research into the impact of climate and sea-level changes in Australia;
- establish a basis for a rational approach to the changes in order to minimise undesirable impacts and optimise the potential benefits;
- communicate the scientific knowledge about the changes to policy makers, engineers and planners.

Almost concurrently the Institution of Engineers will be holding a meeting on Coastal and Ocean Engineering. One session at this meeting will focus on sea-level change resulting from a rise in global mean temperatures.

In 1988 there will be the Academy-sponsored symposium mentioned above. The International Geographical Union, another member of ICSU, will hold its main congress at the University of Sydney in August. Geographers are concerned, amongst other things, with the interaction between environmental change and human activities. Professor Martin Williams of Monash University will convene a symposium on 'Lessons for human survival: nature's record from the Quaternary'. Undoubtedly there will be other meetings on global change. Information about these meetings will be published in future issues of *Australian Geoscience.*

The Australian Geoscience Council has discussed on several occasions in the last two years problems facing our society as a result of global environmental change. It endores the position taken by Price and his working group (Price, 1984, 1986) and seeks to inform Australian Geoscientists of the issues arising from the initiatives of ICSU. In this Annual Report, we take the opportunity of presenting two articles which highlight selected aspects of the problem in Australia. On the one hand, Wasson & Clark summarises the state of knowledge on Quaternary climatic change and indicates deficiencies and difficulties we face in providing information for the global program. On the other hand, Allison & Peck examine one of the major man-induced environmental problems in Australia. These two papers represent different aspects of enviromental change which has been and is being experienced in Australia. We hope to be able to use this Annual Report of the Austalian Geoscience Council to inform readers of further developments in these and related matters.

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obliquity (41 000 years) and changes in amplitude were smaller (Mix & Fairbanks 1985). Whatever caused this global change, it is likely that ice sheets were able to grow faster and larger in the Late Pleistocene.

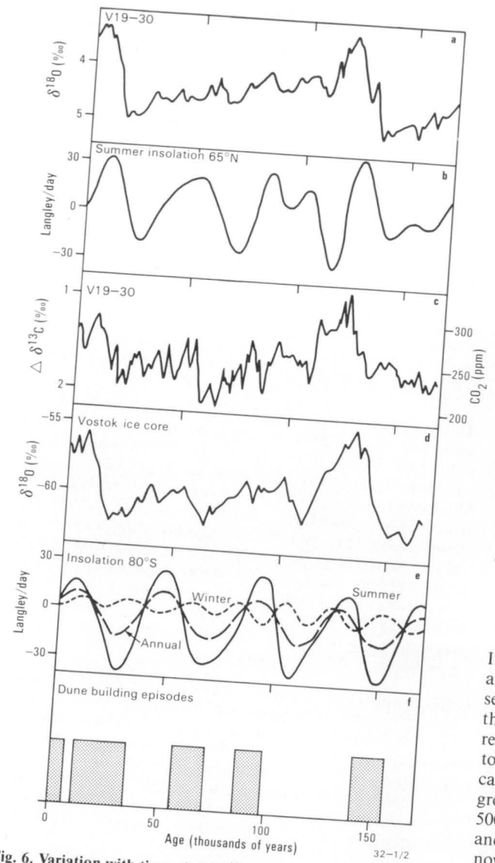


**Fig. 6. Variation with time of: (a) $\delta^{18}O$ in the V19-30 deep-sea core for the foram *Uvigerina Senticosa*; (b) summer insolation at 65°N, reconstructed from orbital geometry; (c) $\delta^{13}C$ in deep-sea core V19-30 with an indicative atmospheric $CO_2$ scale; (d) $\delta^{18}O$ in the Vostok ice core, Antarctica; (e) winter, summer and annual insolation at 80°S, reconstructed from orbital geometry; (f) dune building episodes derived from both Australian dune stratigraphy and aluminium in the Vostok ice core. (a-e after Lorius & others (1985); f — after Wasson (1986)).**

## *Long-term change in Australia*

The long high-resolution records available from deep-sea cores cannot be matched on-shore in Australia, so we cannot make palaeoclimatic linkages between ice sheets, ocean circulation, atmospheric behaviour, landform development and biotic change with any precision for most of the Quaternary (cf. Kukla, 1977). Stratigraphic sequences are either incomplete (e.g. Lake George — Singh & Geissler, 1985) or absent from large areas of the continent. Vegetation change through the Quaternary is largely reconstructed by comparing Pliocene fossil assemblages with those from the last 40 000 years (Kershaw, 1981; Walker & Singh, 1981; Hope, 1984).

The Australian continent has become progressively more arid since the Miocene. Late Tertiary plant fossils suggest widespread closed forests becoming more restricted as open communities expanded (Truswell & Harris, 1982), possibly as a result of increasing seasonality and extremes of both thermal and water regimes (Nix, 1982). As the vegetation changed, so did the fauna, with radiation of species into new environments and the progressive confinement of arboreal animals — together with the forests — to the edges of the continent (Hope, 1982). Central Australian Pliocene and Early Quaternary faunas contain the same arid-adapted genera that are found there today, but they also contain aquatic animals. The aquatic fauna disappeared by the Late Quaternary when water bodies became less reliable (Callen & others, 1986). The record from Lake Bungunnia in the Murray Basin suggests much higher rainfall between 700 000 and 2.5 million years ago (An & others, 1986; Stephenson, 1986) (Fig. 7).

Bowler (1982) suggested, on the basis of convergent evidence across the continent, that summer rainfall dominated the whole of Australia until the Late Miocene. In the Pliocene and Early Quaternary, the gradual establishment of winter rainfall over southern Australia brought increasing seasonal aridity. The first evidence of the arid sediments and landforms that are now widespread occurs within the last 700 000 years (Bowler, 1982; Wasson, 1982; An & others, 1986). This is the same period in which the cycles of glacial growth and decay increased in amplitude and the 100 000-year periodicity became dominant, increasing in strength at the expense of other periodicities over the last 500 000 years (cf. Jansen & others, 1986).

## *The last 500 000 years*

In this period, there is more information on changes on land and to sea level. Chappell & Shackleton (1986) correlated the sea-level curve from the Huon Peninsula in New Guinea with the deep sea $\delta^{18}O$ record to produce a 260 000-year reconstruction of sea-level change with a time scale tuned to the orbitally-induced variations of insolation (Fig. 8). This can be regarded as a global record, largely reflecting the growth and decay of ice sheets. During most of the last 500 000 years, sea level has been lower than it is at present, and former coastal landforms on the continental shelf are now submerged. Sea surface temperatures (Fig. 5) and air temperatures were lower than at present and hemispheric windspeeds up to 20% higher (Wilson & Hendy, 1971; Newell & others, 1981; Lorius & others, 1985).

The modern climate of Australia has equivalents only during brief interglacials over the past 500 000 years. If climate is critical for the evolution, survival and distribution of plants and animals, then any equilibrium between modern biota and climate is at most only a few millennia old. Pollen records confirm this: vegetation in the present interglacial is different from that at any time in the past. For most of the last 500 000 yeras, the vegetation over large areas was more open or treeless; forests expanded only during brief interglacials (Hope, 1984; Kershaw, 1985; Singh and Geissler, 1985). Species composition of modern forests is different from those in past interglacials and therefore the structure of the forests may be different.

Truly arid aeolian sediments and evaporites appear only in the last 500 000 years (Gardiner & others, 1987). Quartzose dunes were formed at times of low soil moisture and vegetation cover. Clay-rich pelletal dunes in the Murray Basin and parts of the the Simpson and Strzelecki Deserts



The world-wide impact of industrial development is recorded in ice cores and lakes with high sedimentation rates. One of the most important changes is the increase of atmospheric $CO_2$ as a result of the burning of biomass and fossil fuels. Observations since 1958 record an increase in $CO_2$ concentration, but only analysis of gas in bubbles trapped in ice has provided an estimate of pre-industrial concentrations: 260-270 ppmv compared to 345 ppmv in 1984 (Raynaud & Barnola, 1985; Neftel & others, 1985). A decrease of about 10 ppmv during the 'Little Ice Age' is indicated. The post-industrial increase in $CO_2$ is comparable in magnitude and rate with changes recorded over the last 150 000 years (Fig. 6c). If a long-term, high-resolution pollen record could be obtained, it might provide analogues of future effects on vegetation of $CO_2$ change.

## *The next 10 000 years*

If Earth/Sun orbital geometry initiates glaciation and deglaciation, then cooling towards the next glacial will begin in about 5000 years (Berger, 1981). But the present interglacial is radically different from those in the past in that vast numbers of human beings have spread across the globe, clearing forests, changing the landscape to a greater or lesser extent, burning fossil fuels, and releasing into the environment newly-created chemical compounds. The long-term effects of human activity cannot be predicted, but the release of greenhouse gases, including $CO_2$, into the atmosphere could rapidly change the natural course of events. At the present rate of increase, mean temperatures in Australia could rise by 2-4°C within the next hundred years (Pittock & Nix, 1986), the present distribution of rainfall will change, plant productivity should rise in response to the $CO_2$ increase, and sea level will rise between 20 cm and 140 cm, flooding low-lying coastal cities (Bolin & others, 1986). If global warming continued, it could affect the timing, magnitude and rate of onset of the next glaciation.

## *Time scales of climatic change and responses*

The changes of climate and the responses and feedbacks of landforms and the biota are components of a complex system.

Insolation changes in high northern latitudes, driven by Earth/Sun orbital geometry, seem to ramify non-linearly through ice-sheet growth and decay, sea-level change, oceanic circulation, $CO_2$ concentration and atmospheric change, to effect major changes onland. Studies of the palaeo-environment provide the only means of understanding responses and feedback mechanisms operating in the lithosphere, hydrosphere, atmosphere and the biosphere, over time scales from years to hundreds of millennia. The instrumental record and its extrapolation are important in the face of, for example, ocean/atmosphere interactions that may produce effects centuries after a perturbation (Wasson & Clark, 1985). Will the 'Little Ice Age' have an effect, via the oceans, on the atmosphere of the future? Do the rapid changes of temperature and $CO_2$ concentration in the palaeorecord provide clues to feedback mechanisms not yet included in models designed to predict the effects of increasing amounts of greenhouse gases?

The time scales of responses and feedbacks form a central theme for the use of palaeoenvironmental data as analogues of future environmental change. Subsystems can be defined for this purpose, as, for example, those shown in Figure 10 where they are plotted against the range of their average internal adjustment time, that is, the time required to come to quasi-equilibrium after being perturbed from some other state by an external factor (Bolin, 1974). The atmosphere is a fast-response subsystem while ice sheets are slow-response phenomena which carry the memory of the climatic system. The lag between summer insolation at 65°N and $\delta^{18}O$ in deep-sea core V19-30 (Fig. 6) is an indicator of this slow response. On land, the lacustral phase prior to 25 000 years ago was perturbed by falling temperatures and effective precipitation (Fig. 9). Some 10 000 years were needed for a new quasi-equilibrium to be established at about 15 000 years ago, at about which time another perturbation occurred in the form of deglaciation followed by variations of insolation. Quasi-equilibrium may only have been reached in the last few millennia, although the number and amplitude of perturbations through time may be too frequent for quasi-equilibrium ever to be reached.

High-resolution records of the last few millennia from the oceans, ice, lakes and rivers will provide the most useful data for models of ocean-atmosphere- biosphere interactions.

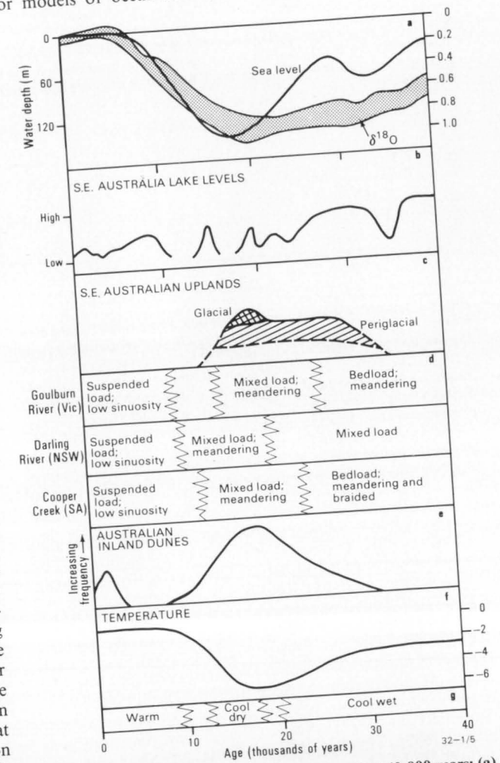


**Fig. 9. Environment change in Australia in the last 40 000 years: (a) sea level from Chappell & Grindrod (1983) and deep sea core $\delta^{18}O$ envelope plotted on a dimensionless scale, from Shackleton & Opdyke (1973) and Hays & others (1976); (b) composite lake levels from Bowler & Wasson (1984); (c) schematic periglacial and glacial environments in southwest mainland Australia and Tasmania, from Bowler & Wasson (1984); (d) fluvial sedimentation and large river types in southeastern and central Australia, from Bowler & Wasson (1984) and Wasson (1983); (e) frequency distribution of inland dune building, after Wasson (1986); (f) mean annual temperature (°C from present), largely in eastern Australia, from Chappell & Grindrod (1983); (g) generalised climatic descriptions, from Chappell & Grindrod (1983).**

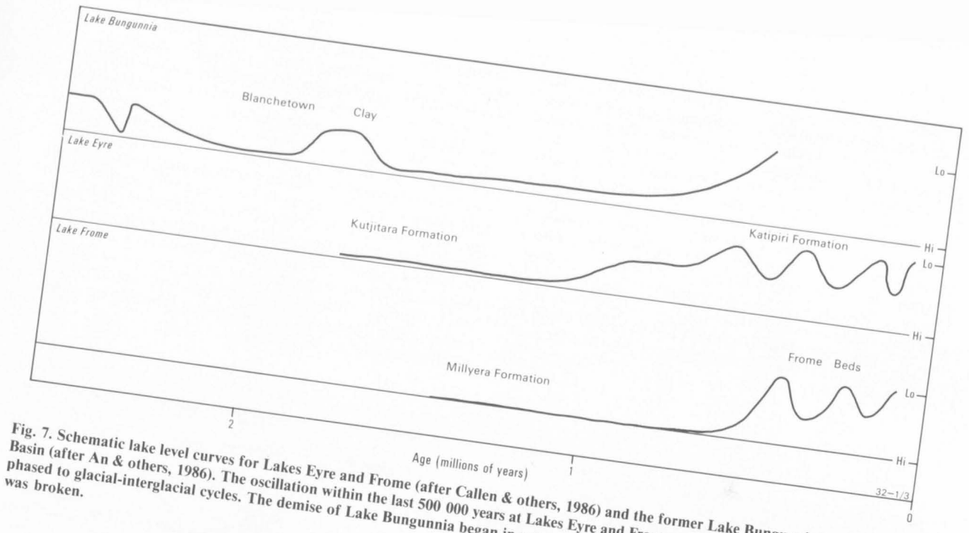


**Fig. 7. Schematic lake level curves for Lakes Eyre and Frome (after Callen & others, 1986) and the former Lake Bungunnia in the Murray Basin (after An & others, 1986). The oscillation within the last 500 000 years at Lakes Eyre and Frome were rhythmic, possibly non-linearly phased to glacial-interglacial cycles. The demise of Lake Bungunnia began in response to climatic deterioration but then its tectonic dam was broken.**

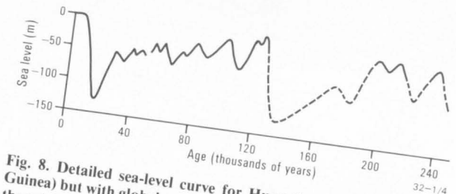


**Fig. 8. Detailed sea-level curve for Huon Peninsula (Papua New Guinea) but with global application. The curve is recalculated from the original by correlation with the $\delta^{18}O$ record from deep-sea core V19-30. The time-scale is based upon dating of uplifted coral reefs and is tuned to the orbital periods in the $\delta^{18}O$ record (after Chappell & Shackleton, 1986). The low of −130 m at 18 000 years is the last glacial maximum. Interglacials occur at present, and at 125 000 years when sea level was about 6 m above the modern level. The penultimate glacial maximum was at about 135 000 years, and earlier features of glacial/interglacial alternations are clear from Figure 1.**

developed when saline groundwater rose into interdunal corridors and pelletised the surface sediments by crystallisation of salts (Bowler & Magee, 1978; Wasson, 1986). These dunes could not have begun to form prior to the evolution of groundwater brines in response to climatic drying (Bowler, 1986). Dune building episodes in Australia over the past 150 000 years are shown in Figure 6, reconstructed from the record in dunes themselves (Wasson, 1986),and from the record of aluminium in Antarctic ice. The aluminium is thought to have been deposited with dust from southern continents (cf. Joussaume & others, 1986; De Angelis & others, 1987). Times of dune building are associated with periods of low temperatures and high windspeeds or of prolonged droughts.

### *The last 60 000 years*

This period provides the immediate setting for the modern landscape and biota, and the last 40 000 years is within the range of $^{14}C$ dating. Major changes are shown in Figure 8. The period begins in an interstadial and passes through the Last Glacial Maximum and the Holocene to the present. Far more information is available for the most recent period. Sea level fell from 40 000 to 18 000 years ago in response to glacial growth. Lake levels in southeastern Australia were high during the interstadial when absolute precipitation was probably higher than at present (Chappell, 1987). As air temperatures and precipitation decreased and windspeeds increased towards the Last Glacial Maximum, lake levels dropped. Salinisation of lake beds led to clay dune construction (Bowler & Wasson, 1984). Rivers which drained the eastern uplands changed from energetic streams transporting sand to streams carrying clay and silt. The vegetation became more open or changed to drier forest types (Hope, 1984; Kershaw, 1985), some plant species disappeared from the Australian mainland (Kershaw, 1984), and many animals became extinct (Horton, 1984).

Sea level rose rapidly from about 15 000 years ago as a response to Northern Hemisphere deglaciation (Thom & Chappell, 1975; Grindrod & Rhodes, 1984). Air temperature and precipitation rose to a maximum between about 8000 and 6000 years ago, forests expanded, the altitudinal tree-line rose, wet forest types re-established and lake levels rose (Thom & Wasson, 1982). Modern coastal landforms began to form only after sea level stabilised at about its present level around 6000 years ago. The period from about 6000 to 1000 years was drier than the preceding period and *Eucalyptus* forests and woodlands continued to spread, replacing the *Casuarina* and *Callitris* woodlands of the early Holocene in much of southeastern Australia (Clark, 1983).

Over the last 1000 years, climate, vegetation and landforms have changed little, except for the impact of European settlement which has radically altered the landscape. The effects of earlier Aboriginal occupation, particularly through the use of fire, may have been important, but there is no clear-cut evidence (Singh & others, 1981; Clark, 1983). In the Northern Hemisphere, the 'Little Ice Age', from 1500 AD to 1850 AD was a time of lower mean annual temperatures (as much as 1°C) and expanded glaciers. The change from the preceding warm period, from 300 AD to 1000 AD, had far-reaching effects on human society in Europe (Morgan, 1985). Although not yet clearly identified in Australia, evidence for the 'Little Ice Age' has been found all over the globe (Morgan, 1985; Thompson & others, 1986).



# THE QUATERNARY IN AUSTRALIA — PAST, PRESENT AND FUTURE

R.J. Wasson & R.L. Clark[1]

We live in the Quaternary period which has been assigned a beginning of 1.8 million years ago. Spanning only 0.04% of the estimated age of the earth, this time has seen dramatic fluctuations in climate, with periodic glaciation of land at high latitudes and altitudes, large accompanying changes in sea level, and migrations, speciation and extinctions of plants and animals. Modern *Homo* evolved in this time, and the biota and soils which are crucial to our survival developed to their present state. These changes are continuing, so it is essential to understand Quaternary history when studying the modern natural environment and managing landscapes for the future. Geologic and palaeoecologic studies thus lead to applied environmental history. The whole complex of interacting process that has changed the face of the Earth in the past is still operating.

### *Climate, glaciers and oceans*

Glacial moraines stranded thousands of kilometres from extant ice sheets and glaciers in Europe and North America are powerful evidence of the climatic changes of the Quaternary. The record from till deposits is imperfect because each new advance of glaciers obliterates former moraines. By contrast, the oxygen isotope composition of the shells of foraminifera in oceanic sediments preserve an almost complete record of fluctuations of glacial ice volume (Emiliani, 1955), although changes in oxygen-18 are also affected by oceanic temperature and salinity (Chappell & Shackleton, 1986). The record from many cores taken throughout the world's oceans are very similar and contain the same periodicities in ice-volume fluctuations, as deduced from $\delta^{18}O$ (Martinson & others, 1987), and in sea surface temperatures, reconstructed from foraminiferal assemblages (Hays & others, 1976; CLIMAP Project Members, 1981) (Fig. 5).

Explanation of these changes lies in Milankovitch's (1941) hypothesis that the orbital geometry of the Earth and Sun leads to variations in the amount of solar radiation that reaches the Earth, and that those variations cause the fluctuations in glacial ice volume. Periodicities in the deep-sea sediment record correlate with the orbital periodicities of precession (19 000 and 23 000 years), obliquity (41 000 years) and eccentricity (100 000 years) (Hays & others, 1976). The deep-sea $\delta^{18}O$ record (Fig. 5) shows a primary periodicity of 100 000 years, that is, at the eccentricity period, but this has least effect on insolation, so the orbital effect must be linked to ice-sheet response in a non-linear manner. This non-linearity is also shown by the 'saw-tooth' pattern in the $\delta^{18}O$ record — slow change from an interglacial to a full glacial and very rapid deglaciation.

As northern hemisphere ice sheets have been the largest (Budd & Smith, 1979), summer insolation at about 65°N provides a plausible forcing mechanism for ice-sheet variation (Imbrie & Imbrie, 1980). While orbital geometry explains the cycles of glacials and interglacials, there must be some means of transferring the effects of process operating in far northern latitudes to the rest of the world as southern and northern hemisphere glaciations have been in phase (Nelson & others, 1985; Lorius & others, 1985) (Figs 6a, d). General circulation models suggest that the albedo effects of expanding ice sheets would reduce atmospheric temperature only in the northern hemisphere and that changes in ice-free land albedo would have minor global effects (Manabe & Broccoli, 1985; Broccoli & Manabe, 1987). The prime candidate is $CO_2$.

Atmospheric $CO_2$ trapped in ice (Dansgaard & others, 1982, Lorius & others, 1985), or recorded as $\delta^{13}C$ in deep-sea sediments (Shackleton & Pisias 1985), show high concentrations in interglacials and low in glacials (Fig. 6c). Shackleton & Pisias (1985) analysed a 350 000-year $\delta^{13}C$ record. They found that Earth-Sun orbital frequencies dominate and that atmospheric $CO_2$ concentration leads ice volume as deduced from $\delta^{18}O$. The mechanism by which these long-term changes in $CO_2$ occur is not yet known, but it is apparent that atmospheric $CO_2$ exerts some control over ice-volume changes as well as being a major element in the cooling and warming of the global atmosphere via the greenhouse effect.

Another effect of changing solar insolation in high latitudes would be variations in meridional temperature gradients and, hence, hemispheric windspeeds (Newell & others, 1981). By contrast with the global effects of insolation changes, monsoon circulations at middle to tropical latitudes appear to be controlled by both insolation and land/sea temperature contrasts (Kutzbach & Street-Perrott, 1985; Kutzbach & Guetter, 1986; Short & Mengel, 1986; Pokras & Mix, 1987).

While the 100 000-year eccentricity period has dominated over the past 700 000 years, the dominant periodicity in the $\delta^{18}O$ signal in the preceding 2 million years was that of

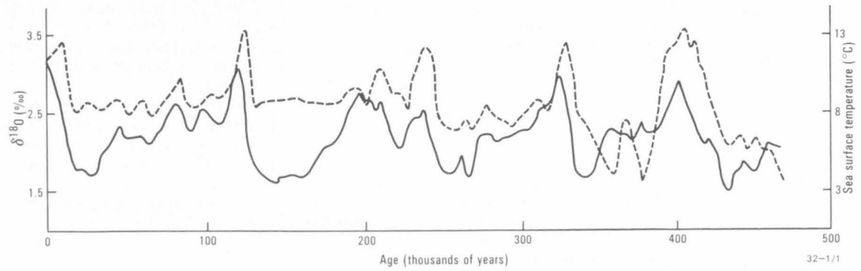


**Fig. 5. Variations of $\delta^{18}O$ (solid line) and sea surface temperature (SST) (dashed line) over the past 500 000 years as recorded in two South Indian Ocean cores RC11-120 and E49-18, based on Hays & others (1976). High SST and $\delta^{18}O$ mark interglacials. Glacials occur at low levels of $\delta^{18}O$. Intervening periods are interstadials.**

[1] CSIRO Division of Water Resources Research

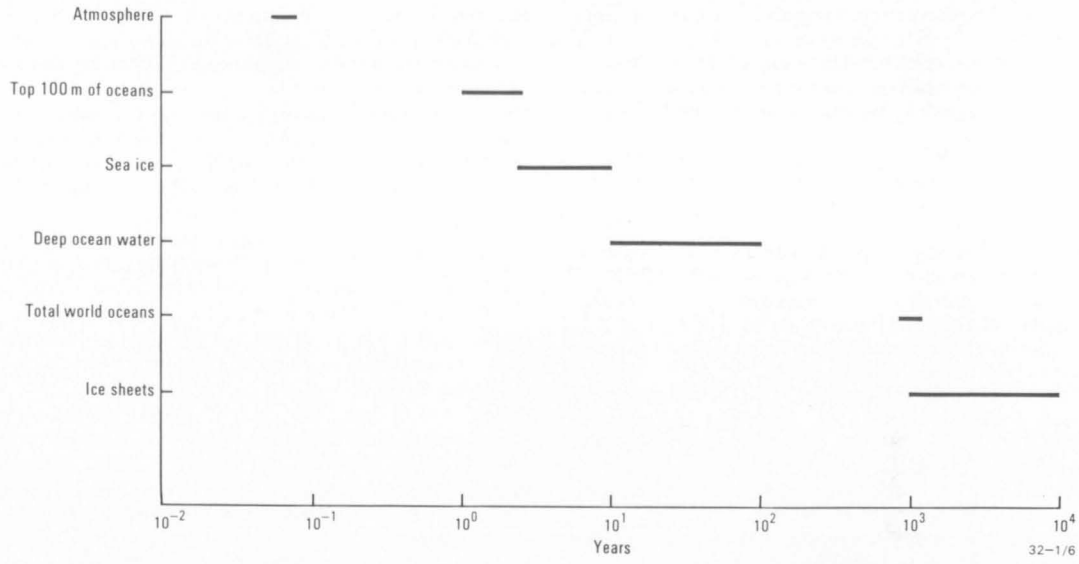


**Fig. 10. Range of average internal adjustment times for major physical subsystems of the natural world (after Bolin, 1974).**

Nature has carried out the experiments and the records lie in geologic and palaeoecologic evidence.

## *Conclusion*

Climatic change and terrestrial responses and feedbacks operate on a wide variety of time scales. Vegetation response to climatic change occurs on time scales of centuries to millennia. Equilibrium is hardly ever attained because climatic perturbations are too frequent by comparison with the internal adjustment times of most parts of the natural world. An important implication of these findings is that assumptions of equilibrium, embodied in many theories used as the basis for natural resources management, are false. Instrumental records are only useful for perturbations and adjustment times shorter than the period of record (Wasson & Clark, 1985).

It follows that stratigraphic techniques are essential adjuncts to instrumental monitoring if natural resources are to be managed in a way appropriate to their time constants. Predictions of the effects of rising $CO_2$ concentrations depend in part on analogues from the past (e.g. the mid-Holocene climatic optimum) and on a more complete understanding of the links between the ocean, atmosphere, cryosphere, lithosphere and biosphere. This understanding can only be gained from the stratigraphic record for slow-response subsystems, and can then be input for models of the natural world.

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# MAN-INDUCED HYDROLOGIC CHANGE IN THE AUSTRALIAN ENVIRONMENT

G.B. Allison & A.J. Peck[1]

## *Introduction*

A large body of evidence reflects global climatic changes which have occurred over time scales ranging from centuries to geological epochs. Data from many sources, for example ice and sediment cores, suggest that climate is continually changing. Precipitation and evaporation have a profound influence on the hydrological regime, and consequently hydrologic information can be used to obtain information about climatic history. For example, Bowler (1981) used a historical record of lake levels to estimate the ratio of lake area to catchment area and used this to obtain information about the change of aridity with time.

It is within this framework of continual climatic change that the effect of man on the hydrological cycle fits. There is no evidence that man had any significant effect on the global hydrologic cycle until the last century or so. However, the impact of man in terms of hydrologic or environmental degradation and instability in small localised areas has been dramatic over the past few thousand years. One of the first areas of irrigation-induced salination is thought to have occurred between the Tigris and Euphrates Rivers some thousands of years ago (Jacobsen & Adams, 1958).

On a global scale, debate continues on the possible hydrologic consequences of increasing levels of atmospheric $CO_2$. Aston (1984), using a runoff model, predicted that for the same rainfall, a doubling of atmospheric $CO_2$ levels would bring about an increase of between 40% and 90% in streamflow. This results primarily from an increase in the stomatal resistance to loss of water vapour. However, Aston needed to make many assumptions and in particular he noted the importance of any changes in leaf-area index. Much more work is needed to increase the level of confidence in his conclusions.

In contrast to the as yet rather small effects of a man-induced increase in atmospheric $CO_2$ on rainfall and runoff, the effect of the large-scale clearing of the Australian landscape has had dramatic hydrologic consequences in some areas. Many studies have shown the dramatic increases in streamflow which can occur following clearing of the native forest. Among the best documented of these are the studies by the Melbourne Metro- politan Board of Works on the Melbourne water supply catchments (Langford & others, 1982). Also Stokes & Loh (1982) found a doubling of water and salt yields following clearing of a small catchment in Western Australia where the average annual rainfall was 1150 mm. Changes in surface runoff were most noticeable in the above examples, but equally important changes in subsurface hydrology also occur as a result of changes in land use. For example, Peck (1983) found that the water table rose at an average of 1 m per year in 27 boreholes after clearing in a catchment area where the average rainfall was 1150 mm per year.

In this paper we consider the broader-scale effects of man's activity; thus we do not discuss irrigated agriculture and the sometimes devastating effects it can have.

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## *The onset of salinisation in Australia*

Of particular importance to agricultural lands and water supplies in Australia is the observation that the load of chloride in many streams has increased markedly following clearing of the native vegetation. The relationship between the load of chloride in a stream and vegetation clearance in Western Australia was hypothesised by Wood (1924). Fifty years later, Peck & Hurle (1973) — still with rather limited data — were able to show that groundwater recharge, averaged over a whole catchment, increased by up to 130 mm per year.

Salinisation has developed and is developing in many areas of Australia primarily because rainfall is much less than potential evaporation over most of the continent. As a result, our native flora have developed root systems which are capable of removing almost all of the water that infiltrates into the soil. The small quantity of chloride and other dissolved salts which enter the soil in rainfall are therefore concentrated in the root zone. Water percolating beyond the root zone can have a chloride concentration exceeding 10 000 mg $l^{-1}$. As a result, many of our soils and aquifers contain saline water.

After clearing, the hydrology of a catchment has been found to respond in the following way. Surface runoff increases so that it becomes a larger component of streamflow. At the same time, a wetting front, resulting from a lower potential for storage of water in the now shallower root zone, moves downwards slowly through the unsaturated soil. When this wetting front reaches the water table, groundwater levels begin to rise. Hydraulic gradients steepen, and the rising water table results in an increasing area of water-logged soils and seepage of groundwater to the land surface, generally in low-lying areas within the catchment. Thus following clearing, a catchment moves towards a new hydrologic equilibrium in which a larger proportion of the incident rainfall moves through its groundwater systems which, as mentioned earlier, may contain water of moderate to high salinity.

The rise in groundwater levels and establishment of a new hydraulic steady-state (where there is no longer a change of water storage in the catchment) may be relatively rapid and take place in about 10 years — as in some of the water supply catchments in Western Australia (Hookey, 1987), — or very much longer such as in the Murray Mallee region where recharge fluxes following clearing are low, but still much higher than those beneath the native mallee (Allison & Hughes, 1983).

After clearing, much of the groundwater discharging from a catchment will have been recharged under the native vegetation and will therefore have a higher chloride concentration than that being recharged under the new land use. Therefore, following the hydraulic response referred to above, the input of chloride in rainfall and as dry fallout will be less than that leaving the catchment as stream and groundwater flow. Peck & Hurle (1973) found that the ratio of chloride load in output to that in input was as high as 20 in the catchments in Western Australia that they studied. Eventually a catchment will come to a new hydrologic equilibrium such that both the water and the chloride fluxes input to a catchment are again equal to the outputs, provided that weathering or other processes do not provide a

significant source of chloride. We refer to the change in outflow of chloride from a catchment as the hydrologic response, and the time taken for attainment of a hydrologic steady state is much longer than that for a hydraulic one. For example, Peck & Hurle (1973) concluded that the half-time taken to establish a new hydrologic equilibrium was between about 30 and 400 years for systems similar to that described by Stokes & Loh (1982) which exhibited a rapid hydraulic response (less than a few years).

Macpherson & Peck (1987) provide detailed data for a small catchment which was cleared eight years earlier. Although rainfall is high and a rapid streamflow response was observed, both groundwater levels and the load of chloride in streamflow were still rising, indicating that hydraulic equilibrium has not yet been reached. As discussed above, hydrologic equilibrium will take much longer.

In environments where recharge is much lower than in these catchments in Western Australia — such as in the western part of the Murray Basin where recharge rates are 0.1 mm per year beneath the native mallee and change to 5 mm per year after clearing for dryland agriculture (Allison & Hughes, 1983) — unpublished work by Allison has shown that hydraulic and hydrologic equilibria may be of the order of 2000 and 200 000 years respectively. In areas such as this, where water tables are deep and the recharge flux has increased greatly in percentage terms but not in absolute terms, the water table may not yet have responded to the change in recharge flux even though the land may have been cleared some decades ago. This occurs because of the great depth of the unsaturated zone and the need for water contents to increase to allow passage of a higher recharge flux. This delay is aproximately the ratio of the initial depth of the water table to the derivative of the hydraulic conductivity in the unsaturated zone with respect to water content (Gelhar, 1975). For the area referred to above, where the water table is at a depth of 30 m, the delay should be about 100 years. Thus, lack of evidence of rising water tables in areas which have been cleared as long as 50 or 100 years ago does not indicate that a problem will not occur in the future.

The groundwater system may be approximated by a slab of porous material which initially contains saline water which is displaced by locally- recharged water after vegetation clearance. Peck (1973) showed that under conditions of hydraulic equilibrium, the salt concentration of the discharging water would approach that of the displacing water exponentially. His model assumed laterally-uniform input of the recharge. However, it is becoming increasingly apparent that recharge can show considerable lateral variability as a result of redistribution of water on the ground surface and non-uniform local hydrogeology. In some areas these factors lead to relatively rapid flow either direct to the permanent aquifer or in an ephemeral perched aquifer (Johnson, 1978). Such phenomena are not considered in simple displacement models such as that described by Peck; nevertheless the exponential decay of concentration is a good approximation to the behaviour both predicted and observed for complex catchments.

While large areas of dryland salting or secondary salinisation are apparent in much of Australia, particularly in Victoria and Western Australia, there is a potential for the area of salt-affected land to increase considerably. An example is the Murray Mallee region in South Australia where recharge fluxes have increased by about two orders of magnitude to 5 mm per year (Allison & Hughes, 1983) after clearing. Even though the water table is deep (30 m beneath the surface) and the absolute value of the recharge rate is small, it is likely that dryland salting will develop in this region in the next 1000 years or so as a result of the clearing which has taken place over the past 50-80 years. Even within the next 50 years, the rising groundwater level, which will bring about increased discharge of saline groundwater, is likely to cause the salinity of the River Murray at Morgan to increase significantly.

The problems of hydrologic change resulting from changes in land use can be considered under the following broad categories:

*Steeply incised areas.* In these regions, the length of an aquifer from a water divide to the nearest stream is relatively short (100 m). The unsaturated zone may be deep enough to accommodate both a thicker saturated zone and a higher potential gradient to enable the increased recharge flux to reach a stream with only a minor increase in the surrounding discharge area. In this situation the main effect of clearing areas where aquifers are saline will be on stream ecology and on water quality in any storage reservoirs within the catchment. Catchments within the Darling Range in Western Australia fall into this category.

*Areas of low relief.* This is the situation in which the length scale of an aquifer is larger (1-2 km) and even deep unsaturated zones are not sufficient to enable the hydraulic gradient and the aquifer thickness to increase sufficiently to transmit the additional water. For example, if recharge doubles following clearing, then for the aquifer to accommodate the additional flow, the product of hydraulic gradient and aquifer thickness must also double. If it cannot, the water table will rise to a level at which evapotranspiration increases, thereby reducing the net recharge. Under these conditions either waterlogging or secondary salinity of soils must develop. For some agricultural areas a doubling of recharge is likely to be an underestimate and the increase may even exceed an order of magnitude.

Most of the land degradation which occurs in agricultural areas falls into the low-relief category and the problem is becoming serious indeed, in both irrigated and dryland areas in southern Australia. Peck & others (1983) have reported on the national extent of all forms of the salinity problem. For example, in Victoria dryland salinity affects about 4500 $km^2$ and is increasing by 2-5% per year. In Western Australia, where the seriousness of the problem was first recognised, more than 2420 $km^2$ of land which once supported crops or pastures is now saline. In South Australia both water supplies and farming land are under threat. Very large areas where irrigated agriculture is practised in the Murray-Darling Basin are affected by salinity and even greater areas are judged to be saltprone. Amelioration of these lands requires a reduction of recharge rates, or improvement of drainage conditions, or a combination of both. In many cases drainage is not a feasible solution because of the problem of disposal of saline water and the economics of this technology. It is ironic that large areas of our agricultural land and many of our streams have become saline as a direct result of the plants we have introduced to increase agricultural production.

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# THE FUTURE OF AUSTRALIAN PALAEONTOLOGY

B.J. Cooper[1]

In late 1985, members of the Australasian Association of Palaeontologists were asked to complete a questionnaire which dealt with:

- future research directions of Australian palaeontology
- teaching and practice
- publicising palaeontology

Forty-one responses were received from palaeontologists in all States and representating all major areas of palaeontology. The report which was prepared on the survey reflects the present concerns of Australian palaeontologists and many of the suggestions and comments may provide useful ideas for international palaeontologists and Australian geologists in general. Key issues in the report are summarised below.

## *Future research directions*

The improvement of correlation within Australia was the highest priority area for research in the minds of respondents. Better correlation between the marine succession and the widespread non-marine sequences in Australia was regarded as critical. Improved correlation also meant improved integration of information from different fossil groups, revised palaeogeographic maps and correlation charts, along with better system/stage boundary recognition in Australia.

Of equal importance was the vital need to integrate palaeontological research with sedimentology, biology, geochemistry and geophysics.

The need for monographic studies of most groups of Australian fossils was emphasised. Some respondents realistically qualified their remarks by noting that certain fossil groups had greater practical importance than others. Suggestions were also made that palaeontologists should orientate their research towards providing a better understanding of the evolution of the Australian biota and major events in geological history.

## *Teaching and practice*

Palaeontologists are conscious of the need to make the teaching of their science more dynamic and interesting with less emphasis on morphology and more concentration on theory (e.g. evolution, event stratigraphy), practical value, modern techniques, quantitative methods, palaeoecologic interpretation and interaction with other disciplines.

Production of an Australian palaeontological textbook with numerous local examples was suggested along with the publication of research theses.

More teaching of palaeontology in secondary schools was encouraged as well as greater liaison with amateurs.

The importance of communication between Australian palaeontologists via regular national meetings and interdisciplinary symposia was accepted by all respondents.

## *Publications*

Australian palaeontologists were highly satisfied with their research journal, *Alcheringa*, although more review papers were recommended. The national newsletter, *Nomen Nudum*, was similarly appreciated.

An *Atlas of Australian fossils* was considered a worthy publication venture along with an Australian palaeontological textbook mentioned previously.

## *Publicity*

Australian palaeontologists are increasingly conscious of the need for more publicity. In some Australian States this has been stimulated by the recent growth of creationism, a development viewed by many as a professional threat.

Vertebrate (or other giant fossil) discoveries are recognised as the best advertisement along with aspects of biogeography and the beginnings of life, i.e. Precambrian palaeobiology.

[1] South Australian Department of Mines & Energy

A different line of ideas suggested an Australian geological time chart for schools, a series of postage stamp depicting fossils, proposals for State fossil emblems, and a calendar showing Australian fossils. The need to advertise known highlights of Australian palaeontology, e.g. Devonian reefs, was also appreciated.

### *Perceptive quotations?*

The following edited quotations from individual responses indicate the attitudes and diversity of opinion among Australian palaeontologists.

- The biostratigraphic value of fossils has done more than any other discovery to change the character and accelerate the progress of geological inquiry.
- The absence of a formal response to the creationist challenge by Australian palaeontologists has done palaeontology a great disservice, even in the eyes of other geologists.
- The public has great curiousity about fossils and their meaning but they receive little help from Universities, Geological Surveys and Companies where most palaeontologists are employed.
- Taxonomic work on Australian fossils of all ages needs to be intensified; an estimated 75% remain to be described or reinterpreted.
- Palaeontologists are gaining a reputation of knowing more and more about less and less.
- Australian palaeontologists should be making a concerted effort to be truly interdisciplinary.
- Palaeontology courses should be less of an ordeal of memorising dry facts and more a study of dynamic processes with general implications — a means of understanding the present day natural world. Palaeontologists have forgotten that their greatest value is in solving other people's problems.

If you have any comments regarding the survey please contact:

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or

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# AUSTRALIA'S OBJECTIVES IN GEOSCIENTIFIC MAPPING — A POSITION PAPER OF THE GOVERNMENT GEOLOGISTS' CONFERENCE

### *Introduction*

At a meeting of the Government Geologists' Conference in Alice Springs in 1984, a body which comprises the heads of all State Geological Surveys and the Bureau of Mineral Resources (BMR) a discussion took place concerning national objectives in geoscientific mapping. Among the factors which sparked the discussion were the approaching completion of first edition 1:250 000 scale geological mapping of the whole Australian continent, recent contraction of BMR commitment to the production and publication of systematic geological maps, and the belief that a proposed review of geological mapping should be extended to include all types of geoscientific maps.

It emerged that no specific national objectives existed for systematic geoscientific map coverage of Australia, and in view of the major part played by the States in this area it was agreed that a survey should be carried out to establish State as well as Commonwealth views. This position paper incorporates the results of that survey, and essentially tabulates, summarises, and comments on the answers that were received to the simple question: 'What systematic geoscientific map coverage should exist for the Australian continent, and why?'. It is hoped that by publicising these results through the Australian Geoscience Council the attention of the wider geoscientific community may be focussed on this important question.

### *Types of geoscientific map*

#### *Geology*

The reduction factor (RF) 1:250 000 is the unanimous choice for presentation of basic regional geological data. For most areas the scale is adequate to present the detail required for appreciation of rock-type distribution and near-surface geological structure. The RF is also the largest that still permits reasonably accurate ground identification of a point, and the 500 sheets needed for continental coverage has already been demonstrated as attainable (though only with the assistance of BMR in the larger states). It is the largest RF that can be used as a field working map and is suitable also for a wide variety of land-use planning purposes. However, in many areas systematic coverage at RFs of 1:100 000 or 1:50 000 is necessary for adequate representation of the geological complexity.

The RF 1:2.5 M is most widely accepted for a one-sheet state or territory wall map, although Victoria and Tasmania, with smaller areas to portray, can show greater detail at 1:1 M and 1:500 000, respectively.

The RF 1:1 M emerges as a useful scale at which to illustrate larger structural and smaller tectonic features derived from 1:250 000 mapping. It is suggested that, with less than 40 sheets needed for on-shore continental coverage, 1:1 M geological maps would provide an excellent base for comparison of regional geophysical data, further consideration of structure within tectonic units, and planning exploration strategy on a broad scale. BMR has already made considerable progress with this concept.

According to the amount of geological detail necessary and the area to be covered in any investigation, other geological map RFs would obviously be needed.

#### *Hydrogeology*

Again the 1:250 000 RF is most favoured for presentation of basic field data on a regional basis but almost all agree that there is no need for total coverage at that scale. Other RFs according to requirements are suggested for selected areas. The principal requirement for continental coverage is for a wall map at RF 1:2.5 M or smaller.

### *Engineering environmental and urban geology*

Scales of 1:25 000 or 1:50 000 appear to be the most favoured presentation scales for information of this kind where considerable detail and accurate ground positioning are necessary. As this type of map is used in areas of proposed intensive development only selected coverage is needed.

### *Mineral deposits and metallogeny*

Most favour a wall map at a scale appropriate to territory size. An RF of 1:2.5 M would be capable of presenting available data for most areas with smaller RFs for selected localities or provinces.

### *Tectonic*

Tectonic maps tend to be at the higher RFs with 1:2.5 M being an average. Greatest data density could be accommodated at that scale (e.g. BMR map of Tasman Fold Belt System) and an Australia-wide map at RF 1:5 M should be useful.

### *Geomorphology and Cainozoic geology*

Most states incorporate information on geomorphology and/or Cainozoic geology on their geology maps. Western Australia has particular interest in geomorphology (effect of ancient weathering profiles on iron ore and bauxite ore development; ancient drainage patterns controlling calcrete development; and inland groundwater occurrence) and would be interested in BMR 1:1 M regolith compilation sheets even if not published.

### *Metamorphism*

Like the previous category, there is insufficient support to nominate a need for this class of map. In regional studies of metamorphic grade in Western Australia, 1:1 M has been found a suitable scale for plotting results.

### *Magnetic*

About 70% of the continent has been covered, predominantly at RF 1:250 000. There is a clear indication that states regard total coverage at 1:250 000 as a worthwhile objective and it is understood that BMR is prepared to complete the work in those states in which this has been one of its traditional roles. The system of map copying is adequate for the 1:250 000 RF which is principally used for comparison with 1:250 000 geology. Ideally, production of RF 1:1 M magnetic maps should precede presentation of 1:1 M geology. An appropriately scaled, continent-wide wall map showing total magnetic intensity contours would be of interest.

### *Gravity*

Despite nearly complete coverage of Bouguer anomaly contour maps at RF 1:250 000, main demand is for 1:250 000 and 1:1 M to correspond with existing or proposed geological maps scales. BMR has both in hand and preliminary compilation scale (RF 1:250 000) copies are available through the Australian Government Printer Copy Service.

### *Radiometric*

Whereas there is a clear requirement for Australia-wide aeromagnetic and gravity coverage, the key need is for radiometric maps in selected areas only. As aeromagnetic and radiometric data are commonly gathered simultaneously, it is suggested that this continue and that the radiometric data be stored and only processed to map form on specific (justifiable) request.

### *Seismic, geothermal, and marine*

The requirements for seismic and geothermal map types are only for large RFs with continental coverage. BMR requires selected coverage of offshore geophysical maps at scales appropriate to data density. In addition to the range of smaller RF maps suggested above, BMR, in the course of numerous research and compilation projects, has in progress (or is contemplating) publication of a number of larger RF maps, few of which have been included in the accompanying tabulation.

## *Costs and format*

An analysis of the costs of producing and publishing the maps dealt with in the survey was outside the scope of the exercise; the objective was to establish what maps Australia needs, not what those maps would cost. The relative cost of issuing the various maps in different styles and formats also was not examined. However, the 1986 Government Geologists' Conference recognised that all geoscientific maps should be published in formats that not only meet the technical needs of the user but also do credit to Australian geoscience in a cost-effective manner. Thus conventional geological maps demand full-colour publication, while many geophysical maps involving contoured data only need to be issued in black-and-white format, either in solid or transparent overlay form.

## *Computer-assisted drafting (CAD)*

The application of CAD in geoscientific map production and research is expanding at an increasing rate. Digitising, and manipulation of digitised data, is being used now in the preparation of maps covering most if not all of the earth science themes dealt with in this paper. For example, CAD is being used to plot maps from databases, for simultaneously changing scale and projection during the transfer of information from one map to another, and for scribing drawings to be sent for printing. Its application in some areas is resulting in the construction of increasingly complex cartographic and information databases. While it is likely that there will always be a need for large print runs of certain basic series maps, it seems inevitable that current trends will lead eventually to a significant proportion of earth science maps prepared by State Geological Surveys and BMR being one-off products meeting specific requirements. For example, the integration and interpretations of data sets such as aeromagnetic and gamma spectrometric maps, geological maps, and geochemical and hydrogeological data, would provide comprehensive and flexible data packages for more effective exploration and research.

**Table 3. Summary of replies from Government geologists on needed geoscientific map types and scales**

A(..) = proposed whole of territory cokverage and approximate number of sheets
B = proposed needed scale for only part territory coverage

| Map type | Redn Factor 1: | BMR | NSW | NT | QLD | SA | TAS | VIC | WA |
|---|---|---|---|---|---|---|---|---|---|
| Geology | 25 000 | | B | | | | | | |
| | 50 000 | B | B | | | B | A(84) | B | B |
| | 100 000 | B | B | B | B | B | | B | B |
| | 250 000 | A | A(52) | A(81) | A(118) | A(68) | A(7) | A(21) | A(163) |
| | 500 000 | B | B | | B | B | A(1) | | B |
| | 1 000 000 | B | A(2) | A(8) | ?A | B | | A(1) | A(15) |
| | 2 500 000 | | | | A(1) | A(1)* | | A(1) | A(1) |
| | 10 000 000 | A | | | | | | | |
| Hydrogeology | 50 000 | | | | B | B | B | | B |
| | 100 000 | | | | B | B | | B | B |
| | 250 000 | | B | ?B | B | | A(8) | B | B |
| | 500 000 | | | | B | B | A(1) | | |
| | 1 000 000 | | | | B | B | | A(1) | B |
| | 2 500 000 | | A(1) | | A(1) | | | | A(1) |
| | 5 000 000 | A | | | | | | | |
| Engineering, Environmental & Other 'urban' information | 25 000 | | | | B | | B | B | |
| | 50 000 | | B | B | | | | | B |
| | 500 000 | | | | | | A(1) | | |
| Mineral deposits & metallogeny | 100 000 | | B | | B | B | A(49) | B | |
| | 250 000 | | A(52) | B | | | A(7) | B | |
| | 500 000 | | B | | ?B | | A(1) | A(1) | |
| | 1 000 000 | | | | ?B | | | A | |
| | 2 500 000 | B | A(1) | | A(1) | A(1) | | A(1) | A(1) |
| | 5 000 000 | A | | | | | | | |
| Tectonic | 500 000 | | | | | B | | | |
| | 1 000 000 | | B | | | B | | A(1) | |
| | 2 500 000 | B | A(1) | A(1) | | A(1)* | | | |
| | 5 000 000 | A | | | | | | | A(1) |
| | 10 000 000 | A | | | | | | | |
| Geomorphology & Cainozoic geology | 250 000 | | | | | | | B | |
| | 500 000 | | | | | B | | B | |
| | 1 000 000 | A(38) | | | | | | B | |
| | 2 500 000 | A(1) | | | | | | | A(1) |
| Metamorphism | various | | | | | B | | | B |
| | 10 000 000 | A | | | | | | | |
| Magnetic | 25 000 | | | | | | | B | |
| | 50 000 | | | | | B | B(18) | | |
| | 100 000 | | A(300) | | B | B | A(50) | B | |
| | 250 000 | B | A(52) | A(81) | | A(68) | | A(21) | A(163) |
| | 500 000 | | | | | | A(1) | | |
| | 1 000 000 | | A(4) | | | A(4) | | A(1) | A(15) |
| | 2 500 000 | A | | | | A(1)* | | | A(1) |
| | 10 000 000 | A | | | | | | | |
| Gravity | 100 000 | | B | | | | | B | |
| | 250 000 | B | A(52) | A(81) | | A(68) | A(8) | A(21) | |
| | 500 000 | A(..) | B | | | | A(1) | | B |
| | 1 000 000 | A(38) | A(4) | | | | | A(1) | B |
| | 2 500 000 | A(1) | | | | A(1)* | | | |
| | 5 000 000 | | | | | | | | A(1) |
| Radiometric | 100 000 | | B | | | | | | |
| | 250 000 | B | B | A(81) | | A(68) | | B | B |
| Seismic risk | 5 000 000 | | | | A(1) | | | | |
| Geothermal gradient & heat flow | 500 000 | | | | | | | B | |
| | 10 000 000 | A | | | | | | | |
| Marine | 1 000 000 | B | | | | | | | |
| | 2 500 000 | B | | | | B | | | |

* South Australia has completed a geological atlas at RF 1:2 000 000

# APPENDIX
# DATA ON MEMBER SOCIETIES, 1986-87

**Association of Exploration Geochemists (AEG)**

Address:
P.O. Box 523
Rexdale, Ontario
M9W 5L4, Canada
48 Empire Avenue
City Beach WA 6015

Membership:

| | |
|---|---|
| Voting | 110 |
| Affiliate | 6 |
| Student | 78 |

Worldwide Membership over 700 in 60 nations

Objectives:
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.

Meetings, activities:
- 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.

Publications:
- *Journal of Geochemical Exploration*, Elsevier (6 issues/yr)
- 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.

Awards:
- Honorary Membership.
- Annual Student Prize.

Association with other organisations:
- Australian Geoscience Council.
  Canadian Geoscience Council.
- International Union of Geological Sciences.
- United States National Committee for Geochemistry.

Other information:
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, Southern Africa and Brazil.

**The Australian Institute of Mining and Metallurgy (AusIMM)**

Address:
Clunies Ross House
191 Royal Parade
Parkville VIC 3052

Membership:

| | |
|---|---|
| Honorary Members | 18 |
| Members | 1931 |
| Associate Members | 2856 |
| Company Members | 168 |
| Affiliate | 232 |
| Junior | 1022 |
| Student | 643 |
| Unknown | 1 |
| TOTAL | 6871 |

Objectives:
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.

Meetings, activities:
- Annual Meeting
- Annual Conference
- Specialist Symposia and Conferences
- International Conferences.

Committees:
Membership; Publications; Education and Accreditation; Awards; Mineral Heritage; Program; Public Relations; Long-range Planning and Strategy; Membership Extension; Ore Reserves; Also Mineral Industry Consultants Association; Australasian Mineral Heritage Trust.

Publications:
- *The AusIMM Bulletin and Proceedings*
- Annual Conference Volume
- Symposium Volumes
- International Conference Proceedings

Awards:
- *The Institute Medal*
- Honorary Membership
- *President's Award*
- *Students Essay Prize*
- *O'Malley Medal*
- *Operating Technique Award*

Association with other organisations:
- Australian Geoscience Council
- Australian Geomechanics Society (Joint technical unit with the Institution of Engineers, Australia)
- Council of Mining and Metallurgy Institutions
- Australian Underground Construction and Tunnelling Association

Other information:
The Institute has 35 branches in capital cities and major mining centres in Australia, New Zealand, Papua New Guinea and Fiji.

**Australian Geomechanics Society (AGS)**

Address:
C/o Mr Roy Bushnell
Committee Secretary
The Institute of Engineers, Australia
11 National Circuit
Barton ACT 2600

Membership:
Financial Membership 599

Objectives:
To promote and advance the science and practice of geomechanics.

Meetings, activities:
- Australia-NZ Conference on Geomechanics held every four years.
- Each of the State groups meets approximately nine times per year for technical sessions.
- Each of the State groups holds technical seminars to meet specific requirements.
- National Committee meets twice yearly (usually Canberra, Sydney or Melbourne).

Publications:
- *Australian Geomechanics*is published twice yearly
- *Australian Geomechanics Computing Newsletter*, an occasional series.

Awards:
- *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.
- *The E.H. Davis Memorial Lecture.* The lecturer is selected by an AGS panel every two years for distinguished recent

contributions to the theory and practice of geomechanics in Australia.
— *The D.H. Trollope Medal.* Awarded every two years to the author of the most outstanding doctoral thesis accepted by an Australian university during the previous five years in the broad field of geomechanics.

Association with other organisations:
— AGS is sponsored by IE Aust and AusIMM. Each member of the society shall, upon payment of annual subscriptions become affiliated with one or more of 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.
— New Zealand Geomechanics Society.
— The Australian Underground Construction and Tunnelling Association.

Other information:
The objectives of AGS are carried out by organising technical conference, 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 publications.

**Australian Institute of Geoscientists (AIG)**

Address:
C/o Geological Society of Australia
10 Martin Place
Sydney NSW 2000

Membership:
600

Objectives:
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.

Meetings, activities:
— Annual General Meeting.
— Monthly Council Meetings.
— State Branch Meetings.
— Seminars.

Publications:
— Special publication of Seminars.
— Guidelines/Handbooks on professional matters.
— Quarterly Newsletter.

Association with other organisations:
— Australian Geoscience Council
— Australian Society of Exploration Géophysicists.
— Geological Society of Australia.
— Petroleum Exploration Society of Australia.

Other information:
Founded in October 1981 following the report of 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)**

Address:
P.O. Box 44
Eastwood SA 5063

Membership:

| | |
|---|---|
| Active and Associate | 652 |
| Student | 45 |
| Honorary | 6 |
| Corporate | 29 |
| TOTAL | 832 |

Objectives:
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.

Meetings, activities:
— Annual Conference Adelaide 14-21 February 1988.
— State Branch Meetings, four to 12 times per year.
— Annual General Meeting, April each year.
— Executive Committee, monthly.
— Workshops/seminars/conferences (as advertised).

Publications:
— *Exploration Geophysics: The Bulletin of the Australian Society of Exploration Geophysicists*, four issues per year
— Newsletter bimonthly preview.
— The Geophysics of the Elura Orebody.
— Magnetic Exploration Models.
— Downhole Electromagnetics.

Awards:
— *Honorary Membership.*
— *ASEG Medal.*

Association with other organisations:
— Society of Exploration Geophysicists.
— Australian Geoscience Council

**Australian Society of Soil Science Inc. (ASSS)**

Address:
C/- A. Pinkerton
CSIRO Division of Plant Industry
G.P.O. Box 1600
Canberra ACT 2601

Objectives:
To advance soil science. To provide a link between soil scientists and members of kindred bodies within Australia and other countries.

Meetings, activities:
— approximately monthly meetings in each of seven geographical Branches.
— Annual Conferences between four Branches.
— National Soils Conference (4 yearly). The next National Soils conference is being organised for 1988 in Canberra.
— Regular Federal Council Meetings.

Publications:
— *No formal journal, although ASSS has a representative on the Advisory Committee of Aust. J Soil Res.*
— Occasional publications produced on specific topics, e.g. soil classification, soil conservation, hydrogeology, soil analysis and interpretation.
— *Soils News* (quarterly) includes summaries of talks and newsletter material.

Awards:
— *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.
— *John K. Taylor, OBE, Gold Medal in Soil Science* awarded four-yearly for excellence in both research and the reporting of that research by publication.
— *National Soils Conference Student Travel Awards* awarded four-yearly to enable an outstanding student from each Branch to attend the National Soils Conference.

Association with other organisations:
— International Society of Soil Science.
— Australian Geoscience Council.

Other information:
ASSS was formed in 1956. It is a federation of seven Branches. The Executive moves from Branch to Branch every two years.

**Geological Society of Australia Inc. (GSA)**

Address:
The Business Manager
Geological Society of Australia
Room 1001 Challis House
10 Martin Place
Sydney NSW 2000.

Membership:

| | |
|---|---|
| Ordinary | 2790 |
| Associate | 238 |
| Student | 200 |
| Honorary | 16 |
| Retired | 27 |
| Company | 29 |
| TOTAL | 3300 |

Objectives:

To advance the geological sciences in Australia.

Meetings, activities:

- Australian Geological Convention held approximately every two years, 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.

Committees:

Stratigraphic Nomenclature; Geological Monuments; Education.

Publications:

- *Australian Journal of Earth Sciences* published quarterly.
- Special Publications usually major thematic publications (latest release, No. 12, 1986).
- *Australian Geologist*, a newsletter published quarterly.
- *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.

Awards:

- *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. Earch Sci.
- Some Divisions offer prizes for outstanding tertiary and secondary students in Earth Science.
- Honorary Membership.

Association with other organisations:

- 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 AusIMM 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.

Other information:

- 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 two years.
- GSA welcomes overseas members.
- Sale of publications is through the Business Manager.

**Institute of Australian Geographers (IAG)**

Address:

c/- Dr G. Cho
Hon. Secretary IAG
School of Applied Science
Canberra College of Advanced Education
PO Box 1
Belconnen ACT 2616

Objectives:

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.

Meetings, activities:

- IAG Meeting every 12 months.
- Meetings of study groups.

Publications:

- *Australian Geographical Studies*published twice yearly.
- *IAG Newsletter*, two issues per year.

Awards:

- *IAG Honours Award*, for a paper based on honours research at an Australian tertiary institution.
- *Griffith Taylor Medal* for distinguished contributions to professional geography in Australia in tertiary level teaching and/or applied geography. One award per every four year period.
- Fellowship of IAG for distinguished service to the Institute. One award per every three year period.
- Professional Service Commendation in recognition of distinguished professional service in applied geography or for an innovative teaching programme in geography in Australian tertiary institutions or for an outstanding record of service in teaching secondary school geography in Australia. Maximum of three awards annually.

Association with other organisations:

- Australian Geoscience Council.
- International Geographical Union.
- International Geographical Congress 1988.

Other information:

IAG was founded in 1958. Membership is by one to 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.

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