National Committee
for Earth Sciences
Australian Academy of Science

National strategic plan for the geosciences

Geoscience — unearthing our future

Constituted under the auspices of the Australian Academy of Science, the National Committee for Earth Sciences (NCES) presents this plan as a framework within which geoscience can develop its contribution to, and role in, major national and global issues and ensure the maintenance of research excellence.

The Australian Government supported the development of this plan by providing a $45 000 Australian Research Council linkage grant. The NCES gratefully acknowledges this and the many other contributions provided by users of geoscientific knowledge and the geoscience community. See section 1 for further details.

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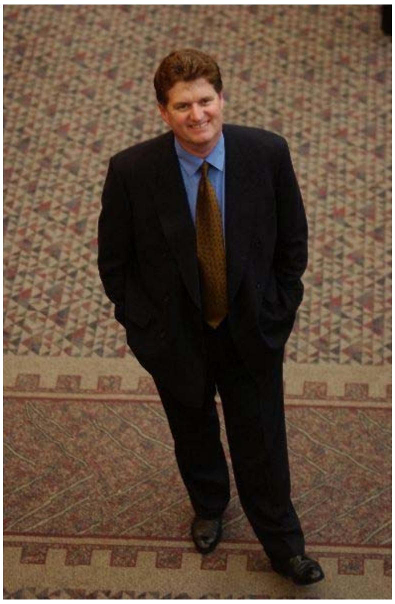
Foreword



The Earth is an indescribably wondrous and intricate organism that sustains all life and incorporates invaluable natural resources such as water, land, energy and minerals. The geosciences help us to understand the complexities of our Earth – how it formed, how it changes, how we shape it and how it shapes us, both now and in the future.

To make well-informed decisions about the management of Australia's natural resources and infrastructure planning, we must appreciate the issues which form the basis of geoscience. It is, therefore, critical that Australia maintains a vibrant and innovative geoscience community. There is also a responsibility upon those working in geoscience to develop a considered viewpoint on how to improve and maintain that vitality, how to gain a better understanding of the Earth and how best to achieve results against the challenges we face as a society.

The time, therefore, could not be better for the National Committee for Earth Sciences (NCES) to have developed its national plan for the geosciences. In doing so it has addressed how the discipline will contribute to the national research priorities expressed by the Australian Government.

The way the national research priorities are implemented will be fundamental in determining the role that research plays in securing Australia's social, environmental and economic future.

I share the NCES's enthusiasm for developing more collaborative partnerships, particularly those that cut across the traditional boundaries of academia, industry and government.

I congratulate the NCES in developing its national plan for the geosciences and encourage other disciplines to follow their lead.

The Hon Peter McGauran MP

Australian Science Minister

October 2003

It is widely recognised that Australia has depended heavily on the exploitation of its mineral resources for its prosperity. What is not so widely recognised by the Australian public is that our ability to use our mineral resources has, in turn, depended heavily on the high-quality research work of our scientists, and on the ability of our scientists, engineers and technologists to use the results of their research as the basis of new technologies, and as the basis for innovative development in existing technologies.

The Australian Academy of Science is well aware that the continuation of our prosperity will depend on a continuation of the flow of quality research results, and the continuation of the tradition of these results feeding into the innovation cycle. The National Committee for Earth Sciences has, in this National Strategic Plan, emphasised the importance of this link between basic research results and the innovation cycle and has further emphasised the importance of concentrating the basic research on challenging problems which will attract the best and brightest to the field of geosciences.

The National Committee has set out an exciting vision for the geosciences in Australia, and has identified some of the steps which will need to be taken by our governments, our government agencies, our research institutions and our universities to achieve that vision.

The Australian Academy of Science commends to you the vision proposed in this National Strategic Plan for the Geosciences in Australia, and encourages you to join in working to achieve it.

Bruce HGMcKellar

Professor Bruce McKellar

Vice President and Secretary (Physical Sciences)

Australian Academy of Science

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- A funding model for higher education that recognises the national significance, and education costs, of geoscience and emphasises quality over quantity.
- A stronger focus on world-class research and graduate centres, networked with smaller departments.
- Broad-scale exposure of Australians to the geosciences through the K-12 school curriculum.
- A high-impact research agenda that will drive major advances in our understanding of Australia in an earth systems context.
- An improved funding model for major research facilities and infrastructure to ensure effective use of the significant capital investment and to facilitate access.
- Investment in a major geotransect to gain fundamental information about the Australian plate, from its basic structure and evolution through to its mineral and petroleum systems and surficial processes.
- An ARC funding model that encourages greater collaboration between universities and government sector geoscience agencies.
- Investment in a modern, effective, national marine-geoscience capacity.
- Investment in a national program to provide information on the geological controls of groundwater distribution, resources and quality.
- Increased support for programs to determine the rate of change of climatic conditions and landscapes and their effect on Australia's land resources and biodiversity.
- Substantially increased investment in the development of core geoscience datasets and in ensuring broad-scale information accessibility and discoverability.

Executive summary

Geoscience — unearthing our future

Vision

> A vibrant Australian geoscience community highly valued for its contribution to the nation's sustainability, wealth, and development of knowledge.

Introduction

Australian geoscience is motivated by two powerful drivers. One is a thirst for new knowledge to satisfy the intrinsic human need to understand the world we live in. The other is the need to apply our geoscience expertise to societal challenges: to improve management of land, water, energy and mineral resources; minimise loss of life and property from natural disasters; and enhance and protect our quality of life.

These challenges are at the core of the Australian Government's national research priorities (NRPs), which address major societal issues where science should play a significant role (appendix F). The Australian Government has recognised the need for sustainable management of the nation's natural environment and resources in order to continue to build wealth. The National Committee for Earth Sciences (NCES) of the Australian Academy of Science applauds the government for thus focusing Australia's research capacity. This plan addresses the role of geoscience in contributing to these priorities.

The national research priorities come at a time when the complex interdependence of earth systems is recognised. Human interactions with these systems have had far-reaching impacts that were not anticipated: salinity, soil acidification and climate change are obvious examples. To develop a sustainable society, it is necessary to understand the behaviour of Earth's life support system, which operates in a time-frame far beyond our daily experience. This is the time-frame embraced by geoscience.

Without geoscientific knowledge, it is not possible to rationally manage the resources of the earth system. It is in the national interest to build this knowledge, which can only come from an effective geoscience community. To remain effective, the geoscience community must develop a strategic perspective on how to advance its capacity to better understand the earth system, and how best to solve the serious societal challenges articulated by the NRPs.

The NRPs provide a vitally important context within which the creative contributions of geoscience can be focused and linked with cutting-edge developments in other disciplines, including information science, mathematics and biology. Developments in physics and chemistry enable new generations of powerful geoscientific instrumentation; new technologies enable us to see through the Earth's surface. The deep Australian continent and marine jurisdiction – store-houses of the nations future wealth – provide exciting and virtually untapped natural laboratories for geoscience researchers.

The potential for the geosciences to contribute to the national good is enormous. To realise that potential, it is necessary to have enough highly-able geoscientists, specialist skills, and a strong national geoscience infrastructure. However, a serious decline in the university sector now threatens the nation’s geoscience capacity. Recovery is possible if remedial action is taken now.

Key challenges facing Australian geosciences

A strong national physical sciences community

The geosciences rely heavily on graduate education in the physical, mathematical and biological sciences. University participation in science, engineering, and technology has declined nationwide in recent decades, with a strong negative impact on the Australian community. The capacity of the geosciences to contribute effectively to the NRPs will seriously diminish unless there is greater commitment to science, engineering, and technology in general, and the physical sciences in particular.

Development of critical specialist skills

Under the current funding model for universities, it is very difficult to develop critical specialist skills where the national need is for relatively small numbers of highly competent graduates. Notable examples in Australian geoscience are seismology, geophysical fluid dynamics, petroleum geoscience, and marine geoscience. The mineral exploration community recognises a similar problem. To attract specialists from overseas is not a solution because similar circumstances exist worldwide. The NCES recommends the development of a new funding model that addresses the high cost of educating small numbers of graduates in disciplines critical to the national good.

Improved geoscience literacy

History shows that humans make decisions without anticipating their environmental impacts. Moreover, unanticipated environmental responses reduce the effectiveness of many decisions about managing natural resources. The provision of geoscience education to as many school and university students as possible will improve the accuracy and underlying wisdom of future decisions about sustainable resource management and use. On a broader scale, Australia’s environment and natural resources will be more readily understood when Australians are educated in basic geoscience knowledge.

A national data information policy

Across Australia, significant resources are used by diverse groups to acquire fundamental geoscientific data. Having local groups acquire data in order to solve local problems is highly desirable but, lacking a national set of data standards, much of the potential cumulative value of these data is lost. A nationally consistent approach supported by government and based on common standards is needed. Moreover, the data must be broadly accessible to university, government, and industry sectors, and to the public.

Accessible and strong national infrastructure

Several of Australia’s major national research facilities are under-utilised, owing to difficulties in obtaining funds to support both the facilities themselves and the work of potential users.

Marine geoscience provides an acute example of the challenge of creating infrastructure. Australia’s Marine Science & Technology Plan recommended ‘strengthening and broadening Australia’s blue water research fleet’ to meet the needs of dealing with the huge Australian offshore jurisdiction to be claimed under the 1994 United Nations Convention on the Law of the Sea. However, the number of Australian blue-water research vessels has actually declined from three in 1998 to just one in 2003. Australia’s oceanographic fleet must be increased in number of ships, range, endurance, and data acquisition systems (especially geophysical survey instrumentation) to meet the challenge of understanding and managing the marine jurisdiction, including the Australian Antarctic Ocean Territory.

Without effective infrastructure and funding, it is enormously difficult to develop the necessary scientific capacity.

Improved cross-sector collaboration

There are immediate opportunities for the geoscience community to maximise use of available infrastructure by strengthening collaboration between universities and government research agencies. The nation has significant geoscience resources in government agencies, such as Geoscience Australia, CSIRO, the Department of Defence, the Bureau of Rural Sciences, ANSTO, and State and Territory Geological Surveys. Government-funded research and infrastructure budgets within these agencies considerably outweigh the total combined efforts of the university sector.

Initiatives such as the new ARC Research Networks program aim to build links and enhance the quality of research across the different sectors. The ARC needs to recognise appropriation funds from government research agencies in such granting schemes, and thus enhance the ability of universities to leverage major research personnel and infrastructure concentrations, and focus the effectiveness of geoscience funding.

Geoscientists have the opportunity to improve their access to funding for major developments by taking more of a community-of-interest approach and by presenting better-integrated cases. Critical mass can be created in key areas by pooling resources across the university sector, and indeed, within universities. In particular the community can improve collaboration and critical mass by recognising the extent of geoscience research taking place in departments and research centres not traditionally thought of as doing geoscience.

High impact research agenda

To draw the best and brightest minds to Australian geosciences requires an inspirational research agenda. Research must focus on questions that will drive major advances in our understanding of the earth system within a reasonable time frame, leveraged by Australia’s unique geological context, and aiming to create excellence while attracting major international collaborators.

The challenge of sustainability

To create a sustainable society is challenging. Australia’s surface waters are overcommitted and groundwater is being mined faster than it is being resupplied. Soils are lost at a far greater rate than they can regenerate. Coal and hydrocarbon consumption continues to grow. These are all geological resources and a systemic approach to sustainability requires geoscience knowledge. Australia has outstanding scientists committed to resolving environmental problems, but better understanding of the production and fluctuation of these resources, in the context of geologic processes including extreme events (natural hazards) and climatic changes, must be accorded a high priority.

Australia's vast marine jurisdiction represents a massive store of biological and seabed resources, yet it is one of the least explored and understood jurisdictions. There is a significant responsibility upon Australia to understand this jurisdiction so as to be able to manage it appropriately.

The need for resources

Society will be unable to maintain its standard of living without ongoing access to resources provided by the minerals and energy industries. Over the next fifty years, it is estimated that the world will use five times the resources that have been mined to date[1]. Global restructuring of the industry and limited access to venture capital has had a negative impact on the exploration sector in Australia. In the past, much of the outstanding geoscience research in Australia has been achieved because of an effective partnership with an energetic exploration sector. A significant proportion of the knowledge generated through this partnership has been valuable in developing a generic understanding of earth processes and so has helped in the development of responsible environmental management. Consequently, a decline in exploration has significant implications beyond the direct implications of wealth generation through the minerals and energy sectors.

National strategic goals and critical factors for the geosciences

Goal 1: Education

A sustainable and wealthier Australia through more effective geoscience education

Critical factors

The critical factors associated with this goal are listed below, with links to the NRP and/or structural objectives (SO) identified by bracketed text.

1. Strong general support for science, engineering and technology disciplines (NRP 1, 3, 4 and SO 2, 3, 4).
2. A funding model for higher education that recognises the national significance, and education costs, of geoscience, emphasises quality over quantity, and facilitates effective development of core and specialist geoscience skills (NRP 1 and SO 1, 2, 5).
3. A stronger focus on world-class research and graduate centres, networked with smaller departments (SO 1, 2, 3, 4, 5).
4. Geoscience-scholarships that encourage students to fill skill-gaps in the nation's ability to address the NRPs (NRP 1, 3 and SO 2).
5. Awareness by Australia's decision-makers of: the value of geoscientific knowledge when making decisions that involve Australia's natural resources; and how the geoscience community can contribute to the effectiveness of their decision-making processes (NRP 1 and SO 4, 5).
6. Motivation of school students to pursue geoscience careers (NRP 1, 3, 4 and SO 1, 2, 4).

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[1] BJ Skinner, Keynote presentation to 31st International Geological Congress, Rio de Janeiro, August 2002.

Goal 2: Research

A vibrant, world-leading, geoscience research community

Critical factors

1. An inspirational research program that contributes strongly to future geoscientific knowledge and skills and attracts high-quality researchers and adequate funds (NRP 1, 3, 4 and SO 1, 2, 3, 4, 5).

2. An improved funding model for major research facilities and infrastructure to ensure effective use of the significant capital investment and to facilitate access (SO 2, 3, 5).

3. Development of an effective oceanographic research capability (NRP 1, 3 and SO 1, 2, 3, 4, 5).

4. Investment in a major geotransect to gain fundamental information about the Australian plate, from its basic structure and evolution through to its mineral and petroleum systems and surficial processes (NRP 1, 4 and SO 1, 3).

5. Relaxation of restrictions on recognition of government appropriation funds in granting schemes (SO 4, 5).

Goal 3: Sustainablity

A sustainable Australian society through understanding the origin and evolution of Earth's life-support system

Critical factors

1. Investment in a modern, effective national marine geoscience capacity (NRP 1, 3 and SO 1, 2, 3, 4, 5).

2. A national program to provide information on the geological controls of groundwater distribution, resources and quality, and determine the causes and mitigation of dryland salinity (NRP 1 and SO 1, 4).

3. Improved information on the rate of change of climatic conditions and landscapes and their effect on Australia's land resources and biodiversity (NRP 1 and SO 4).

4. Improved information on the feasibility, methods, and cost of safe long-term storage of greenhouse gases (NRP 1 and SO 4).

5. Increased investment in research, training, and provision of data and information that results in cessation of land and water degradation (NRP 1 and SO 1, 2, 3, 4, 5).

Goal 4: Wealth

A wealthier Australia through discovery of new clean energy and mineral resources that fuel national and regional economies

Critical factors

1. Increased investment in developing pre-competitive information and data to stimulate resource exploration to find and develop large new mineral and oil deposits and provinces (NRP 1 and SO 1, 4).

2. New investment in Australian tertiary geoscience education, research and training systems to develop world's best facilities and global outlook that will support the exploration industries (NRP 1 and SO 1, 3, 5).
3. Introduction of new government initiatives, especially through R&D programs, that encourage development of prosperous and competitive resource service industries in Australia and overseas (NRP 1 and SO 1, 2).
4. A program or series of new initiatives that build awareness in the community and amongst decision-makers about the opportunities for geoscience to create great wealth for Australia (NRP 1 and SO 4).
5. Maximisation of Australia's ability to use geosequestration of carbon dioxide as an asset (NRP 1 and SO 4).

Section

1

Introduction

Geoscience: Unearthing our future

Background

Plan purpose, scope, audience and approach

Purpose

The purpose of this plan is to provide a framework within which geoscience can develop its contribution to major national and global issues while ensuring continued research excellence and relevance.

Scope

This plan predominantly focuses on Australian solid earth and environmental geosciences.

Audience

The National Committee for Earth Sciences (NCES) believes that this plan is of particular interest to government agencies supporting education and research relevant to the geosciences and to the other stakeholders (geoscientists, universities, education and vocational training institutions, professional associations, industry and associated peak bodies) listed in appendix B.

Approach

The NCES believes that the important issues fall into the following structure. Education processes must be effective so as to ensure an adequate supply of highly skilled and educated people and to ensure that decision-makers and the community at large are aware of the value of geoscientific knowledge. An inspirational research agenda that stimulates the field, and draws in high-quality researchers and adequate funds, is needed to create the intellectual ferment to drive major changes in the understanding of Earth and its processes. We identify several new research opportunities for consideration for priority funding but emphasise the distributed excellence in current geoscience research and the need to maintain that distributed excellence. Funding, top-quality accessible infrastructure, collaborative networks, and outstanding people are needed to provide the generic capacity to undertake the research and to achieve the targeted goals of geoscience programs. From this will then flow the knowledge to achieve overall economic and environmental sustainability. Consequently, this report addresses the following key issues in turn: education; research; sustainability; and wealth.

Introducing the geosciences

Our planet is made up of a collection of evolving dynamic systems including the solid Earth, the atmosphere, the hydrosphere, the biosphere, and the liquid core, which interact remotely with the Sun and other planets. Processes in the various systems take place over a range of length scales (from atomic to planetary) and time scales (from a fraction of a second to eons). For example, earthquake activity leads to large scale crustal deformation and transport of sand grains leads to the complete erosion of mountain belts.

Traditionally, the geosciences have been reductionist in focussing on each system in isolation. However, as the complex interactions between systems are becoming better understood, the study of the Earth has evolved towards a multi-disciplinary approach (e.g. understanding the linkages between crustal deformation, the erosion of mountains, and climate).

Against international measures of research performance, Australian geoscientists have consistently performed well for many years. As a community, they have an enviable international reputation for their ability to generate innovative and valuable knowledge. The track record of technology development includes the Australian invention of atomic absorption spectroscopy, X-ray fluorescence analysis, the Sensitive High Resolution Ion Micro-Probe (SHRIMP) for geological dating, and laser ablation *in-situ* isotopic techniques. Australian geoscientists have had remarkable success in helping the minerals and petroleum industries achieve their goals and generate enormous wealth for the nation. Leading-edge geophysical data-acquisition systems, such as airborne magnetics, radiometrics, and electromagnetics, together with the associated interpretation methodologies, have been developed and refined by Australian geoscientists. Regolith and environmental geoscientists have made advances in understanding surficial processes unique to the Australian landscape. The list of outstanding successes by Australian geoscientists is long. However, over the past decade, there has been serious decline in the geoscience capacity within the university sector. This jeopardises the overall capacity of the geosciences to continue to perform well and to continue to contribute to the national public good.

Modern geoscience draws heavily on a wide range of the enabling sciences, including physics, chemistry, biology and mathematics. Indeed, in order to study the various earth systems, it has become critical for the geosciences to routinely cross disciplinary lines. As a consequence, technologies are emerging for the acquisition, integration and interpretation of increasingly precise and comprehensive observations on various aspects of the earth systems. Thus the potential for fundamental changes in our understanding of the dynamics of earth systems is great.

There is also growing awareness of the strong interactions that occur between earth systems and humankind and this is leading the geosciences to interact increasingly with the social sciences – for example in areas as diverse as economics, law and management. Indeed, as society becomes more generally aware of issues regarding the sustainability of our fragile planet, the need increases for fundamental scientific knowledge and technology related to the geosystems.

Ultimately, the geosciences provide the knowledge that underpins the nation’s ability to:

- manage its land, water, marine, energy and mineral resources;
- minimise loss of life and property from natural disasters; and
- enhance and protect its quality of life.

Consequently, it is critical for the nation to continue to develop and maintain a strong geoscience capacity and for the geoscience community to work together to achieve effective outcomes.

The geosciences represent a large and diverse body of investigation that produces knowledge critical to the nation's ability to generating wealth while sustainably managing its resources and environment. This then demands a substantial document in order to canvass the breadth of pertinent issues.

NCES mission

The NCES is one of thirty-one National Committees constituted under the auspices of the Australian Academy of Sciences (AAS).

The role of the NCES is to foster the geosciences in Australia; to serve as an effective link between Australian scientists and overseas scientists in the same field; and to advise the AAS Council on relevant matters.

National committees of the AAS are frequently called on to advise on science policy matters, on proposals for Academy sponsorship of scientific conferences, and on proposals for grants from special purpose funds. They are also encouraged to prepare occasional reports and other documents on the state and outlook of their respective disciplines. National committees maintain active links with relevant scientific societies and international organisations.

NCES membership details are provided in appendix C.

Australia's key geoscience research groups

Research in the geosciences, from curiosity driven to that wholly of an applied nature, contributes to overall knowledge and understanding of the Earth and its dynamic systems.

In Australia, geoscience research is primarily carried out within higher educational institutions, by government research agencies such as Geoscience Australia and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), by industry, by Cooperative Research Centres (CRCs), and by Australian Research Council (ARC) Special Research Centres (SRCs) and Major National Research Facilities (MNRFs). Increasingly, it is also being undertaken by departments and agencies not traditionally associated with the geosciences.

Higher education institutions

Australian universities employ 315 teaching and research geoscientists distributed through some 27 departments/schools. University-based scientists are responsible for much of the curiosity-driven geoscience research carried out in Australia. This research, which tends to reflect the interests and skills of individual geoscientists, is primarily supported by ARC Discovery Grants. In 2003, the geosciences received Discovery Grants totalling $5 million of the total $75.5 million awarded by the ARC.

Research of a more strategic or applied nature is also undertaken by academics, with funding support from ARC Linkage Grants, CRC, the Australian Antarctic Science Program, Australian Mineral Industry Research Association (AMIRA) and direct industry grants. In 2003, the geosciences received Linkage Grants totalling $0.7 million of the total $62 million awarded by the ARC. Section 3 provides further information about geoscience research in higher education institutions.

Government research agencies

The overwhelming majority of geoscientists employed by government agencies work for Geoscience Australia, CSIRO or a State/Territory geological survey. Geoscientists employed by government agencies undertake research of a strategic or agency-mandate oriented nature. Research goals tend to be determined corporately, with individual geoscientists applying their geoscientific skills to the realisation of these goals.

Industry

According to the 2001 census, there were 4441 geoscientists employed by industry, of which 2507 were employed in the mineral and petroleum sector. The majority of the others were in business services and consulting engineering.

Research undertaken by geoscientists employed by industry tends to be of an applied nature, focussing on the current and perceived future sectoral needs.

In 2001-02 industry invested $534 million on research and development and devoted over 800 person years to R&D projects[2]. Industry also contributes financial and other forms of support to a range of research undertaken by academia and government agencies.

Some peak bodies coordinate industry research on a collaborative basis, developing and managing jointly funded research projects on a fee-for-service basis on behalf of members. For example, by taking a partnership approach to research and development, AMIRA members are able to enhance their competitive position through access to leading edge research and technology. Other bodies, such as the Minerals Council of Australia (MCA), advocate concerns and promote issues of relevance to the minerals industry.

Cooperative research centres (CRCs)

CRCs are a government mechanism to bring together researchers from universities, CSIRO and other government-funded research agencies and the private industry, in long-term collaborative arrangements. These support research and development and education activities that achieve outcomes of national economic and social significance.

In 2002–03, there were eight mining and energy CRCs (see appendix E). Over their lifetime, these CRC’s will have received, in total, $1100 million, with $220 million contributed by industry and $259 million contributed by government participants such as Geoscience Australia, CSIRO and the universities. Five new CRCs commencing in the 2003–04 round are of particular relevance to the geosciences.

Special research centres (SRCs)

SRCs are funded by the Australian Government on the basis of research excellence and potential to contribute to the economic, social and cultural development of Australia. Although the ARC no longer funds new centres under this program, several existing centres are of relevance to the geosciences.

Appendix E provides further details on CRCs and SRCs. It also provides details on other national research centres of relevance to the geosciences.

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[2] Australian Bureau of Statistics, *Research and experimental development*, cat. no. 8104.0, ABS, Canberra, 2003.

Professional geoscience societies

Professional societies and associations play an important role in maintaining the effectiveness and coherence of the geoscience community through professional accreditation, support of scientific publication, sponsorship of conventions and conferences, representing the community to government, and providing educational programs. Larger ones include the: Geological Society of Australia (GSA); Australasian Institute of Mining and Metallurgy (AusIMM); Australian Society of Exploration Geophysicists (ASEG); Australian Institute of Geoscientists (AIG); and Petroleum Exploration Society of Australia (PESA). The Australian Geoscience Council is the peak body representing geoscience interests in the formulation of science and technology policy and facilitates cross-disciplinary communication. These organisations are vitally important to the well-being of the geoscientific community.

Australia's national research priorities (NRPs)

On 5 December 2002, the Australian Prime Minister announced four national research priorities and their associated priority goals:

1) An environmentally sustainable Australia;

2) Promoting and maintaining good health;

3) Frontier technologies for building and transforming Australian industries; and

4) Safeguarding Australia.

These priorities have been articulated as major societal challenges for Australia where science should play a significant role in achieving important outcomes. In establishing these priorities, the government has recognised that a central challenge for Australia is sustainable management of its natural resources while continuing to build wealth on the base provided by those natural resources. The NRPs recognise the major national threats to Australia's natural resources, while building on Australia's strengths and seeking new opportunities in emerging areas. They are also aimed at strengthening collaboration between research bodies and with industry, and building critical mass of excellence in key research areas.

Government has put the onus on Australia's research community to drive the implementation of these priorities.

Each of the critical factors identified by the NCES is directly linked to one or more of the NRP goals and structural objectives listed below, with link-details provided in bracketed text.

NRP goals

Much of the work undertaken by the geosciences will contribute to the NRPs, particularly to the following goals:

Goal 1: An environmentally sustainable Australia

NRP 1.1 Water – a critical resource
NRP 1.2 Transforming existing industries
NRP 1.3 Overcoming soil loss, salinity and acidity
NRP 1.4 Reducing and capturing emissions in energy generation
NRP 1.5 Sustainable use of Australia's biodiversity
NRP 1.6 Developing deep earth resources

Goal 3: Frontier technologies for building and transforming environmentally sustainable Australia

NRP 3.1 Breakthrough science
NRP 3.2 Frontier technologies
NRP 3.4 Smart information use

Goal 4: Safeguarding Australia

NRP 4.1 Critical infrastructure
NRP 4.3 Protecting Australia from terrorism and crime
NRP 4.4 Transformational defence technologies

NRP structural objectives

There are five structural objectives associated with the NRPs:

SO 1	Knowledge creation
SO 2	Human capacity building
SO 3	Infrastructure development
SO 4	Knowledge diffusion/awareness
SO 5	Collaboration

Acknowledgments

In June 2002, the NCES issued an open invitation to formally seek the views of users of geoscience knowledge and the geoscience community on matters related to the development of this strategic plan. These thoughtful contributions were subsequently used by the NCES to guide their deliberations and are acknowledged in appendix G. The NCES also formally acknowledges its appreciation to:

- the employers of NCES members (see appendix B) for their ongoing support in enabling their employees to participate in NCES activities;
- the ARC for providing a $45 000 Linkage Grant to the NCES and to those listed below who also provided the NCES funds to assist with this plan's development
    - School of Geosciences - Monash University: $3000,
    - School of Earth Sciences - University of Melbourne: $3000,
    - Woodside Energy: $909.09;
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Section 2

Vision and goals

Geoscience - Unearthing our future

The vision

> A vibrant Australian geoscience community highly valued for its contribution to the nation's sustainability, wealth, and the development of knowledge.

Key challenges for the geosciences

To a greater degree than most developed nations, Australia's ability to maintain a sustainable society requires solutions that arise in the geosciences. Continuing to obtain the energy, mineral, and water resources that fuel the economy, and remediating the effects of withdrawing these assets from the earth system, requires a vital group of geoscientists who address the complex and changing problems that these challenges present.

Sustainability is perhaps the most complex and pressing issue of today. It is critical to understand the Earth's role as the medium that mediates the processes that provide life with its basic support. Only then will it be possible to fully recognise and understand the constraints that nature imposes on what is appropriate human activity.

When dealing with complex issues that have societal impact, it is a common approach to investigate and treat symptoms (e.g. salinisation). Instead, in order to translate knowledge from one specific instance to another, it is necessary to separate and understand causes, effects, and random perturbations: in effect, to understand the nature of the system. Thus a systemic approach demands that an understanding of these problems be rooted in the geosciences.

But true sustainability requires more than an understanding of the environment. Australia is among the richest nations on Earth, in large measure because of its extraordinary endowment of natural resources. Yet those major mineral deposits and oil provinces that remain to be discovered are hidden beneath thick cover either deep within the crust or beneath deep waters offshore. Maintaining our strong economy requires continued innovation in geoscience to create new technologies to detect and develop these hidden resources.

Australia derives a higher percentage of its energy from fossil fuels and uses a higher percentage of coal than any other developed nation. The geosciences are key to resolving associated societal challenges, such as determining how best to prevent the release into the atmosphere of the resultant greenhouse gases and in the development of innovative clean-energy solutions.

Australia's agricultural industries rely on ongoing supplies of water and good soil, yet land and water quality is rapidly degrading and water supplies are scarce. High salinity is consuming Australia's soils, at a rate predicted to increase seven-fold by 2050, and threatens the foundations of some cities. Accordingly, geoscience research will be vital to repair the degradation to land and water during this century.

As a nation whose population is concentrated along the coastal fringe, a key geoscience challenge will be the assessment and mitigation of the potential impact of natural hazards, such as earthquakes, landslides, storm surges and tsunamis.

The national research priorities (see section 1 and appendix F) were arrived at after extensive consultation between government and the research community, and represent a considered national perspective of the major societal issues where science has a significant role to play in achieving important outcomes. The geosciences have a key role to play in addressing most of these research priorities. Given that these priorities represent major societal issues for Australia, it is not surprising that the number one priority is *An Environmentally Sustainable Australia*. For the reasons identified above, an effective approach to addressing this national priority has to be systemic and demands an integrated understanding of the Earth and its processes. This places a significant responsibility on the geosciences to rise to the challenge.

There is then the question of whether Australian geosciences have the capacity to respond effectively to the national priorities. Unquestionably, that capacity has existed in the past. The list of outstanding successes by Australian geoscientists is long, and many of those responsible for these successes remain active. Furthermore, significant resources (both from government and industry) are directed toward the geosciences. However, unless it is arrested, long-term decline in the university sector will seriously diminish the capacity of Australian geoscience to contribute effectively.

Decline in the university sector, with all its attendant problems for national capacity, is to a large extent shared with other science, engineering and technology disciplines (see section 3). The problems are exacerbated in the geosciences because of its lower tertiary education catchment and associated higher education costs, smaller student numbers, and flow-on effects from the neighbouring sciences.

Problems in Australia's education system are perhaps the major threat to the ongoing capacity of the geosciences to serve the nation effectively[3]. Because the geosciences are largely absent in Australia's school system:

- many decision-makers are not exposed to the geosciences and are therefore largely uninformed about the processes, flexibilities, and limitations of Earth as the fundamental life-support system; and
- most young people entering tertiary education are not acquainted with the geosciences, which limits the catchment for geoscience as a career.

Among the key challenges that need to be addressed in order to ensure an appropriate future for the geosciences are:

- levels of education and funding and ability to produce graduates with critical specialist skills, even if only small numbers are required;
- career prospects;
- the lack of national structures that facilitate systemic understanding; and

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[3] See also Australian Academy of Technological Science and Engineering, *The Teaching of Science & Technology in Australian Primary Schools: A Cause for Concern*, ATSE Education Committee, ATSE, Victoria, 2001.

- the lack of awareness of the role of the geosciences by those outside of the traditional users of geoscientific expertise.

Clearly, the systems in Australia that support the geosciences, and the science, engineering and technology disciplines in general, need to evolve a more inter-disciplinary approach in light of our new appreciation of the earth system. Similarly, the approaches taken by the geoscience community to maximising the effectiveness of Australia’s resource base need to improve.

The ultimate measure of our success as geoscientists will be the degree to which we succeed in making the Earth and its processes intelligible and relevant to ourselves, to our colleagues, to the nation’s decision-makers and to the general public.

National goals for the geosciences

National goals

Goal 1: Education

A sustainable and wealthier Australia through more effective geoscience education.

Goal 2: Research

A vibrant, world-leading, geoscience research community.

Goal 3: Sustainability

A sustainable Australian society through understanding the origin and evolution of Earth’s life-support system.

Goal 4: Wealth

A wealthier Australia through discovery of new clean energy and mineral resources that fuel national and regional economies.

Values

The NCES believes that in order to be an effective discipline, the geoscience community must be committed to:

- a systemic understanding of the Earth and its processes through collaboration with related sciences; and

- achieving societal outcomes through collaboration with other disciplines, including the humanities and social sciences.

Section

3

Education

Geoscience - Unearthing our future

Background

Introduction

Awareness of geoscience and its role in well-informed, effective decision-making processes is critical when responding to societal challenges involving natural resources and the physical environment, such as those articulated in the national research priorities. This section considers the adequacy of the nation's education system in ensuring a supply of high-quality professionals and in ensuring that Australia's future decision-makers and researchers are appropriately educated about the geosciences. However, the cyclical nature of industrial employment, and its amplified feedback into geoscience student numbers, creates instability in university geoscience departments. Coupled with increased pressures on university funding over the past decade, this instability has become acute and threatens the viability of many geoscience education programs. Current funding models within Australian universities challenge the existence of many small departments, which, in turn, threatens the viability of the entire geoscience community and its ability to contribute to Australia's well-being.

Analysis

In the 2001 census, 5067 individuals declared themselves to be geoscientists. Approximately half were registered in the resources industry, with 1303 in business services, 366 in consulting engineering and 425 in government administration and defence. Although it is reasonable to assume that most of these individuals have received tertiary level geoscience education, the total number of Australians educated in the geosciences at the tertiary and pre-tertiary levels is only approximately known.

Tertiary education system

While the numbers of people involved in geoscience research and tertiary education were not identified in the census, Department of Education, Science and Training (DEST) figures indicate that 1288 equivalent full time students (EFTSU) commenced higher education geoscience education in 2002. Fewer than 200 are expected to graduate with an honours degree, widely regarded as the basic professional qualification. Over the past 12 years, approximately 20 000 Australians have been educated at first year university level in geoscience, with the total number since 1960 estimated to be approximately 40 000. This equates to about 1 in 500 Australians (or 0.2%) having some tertiary education in geoscience.

The supply of high-quality graduates with an appropriate mix of skills is becoming a major long-term issue for science, engineering and technology disciplines in general and for the geosciences in particular. For example, over the past ten years Australia has graduated only about 2000 geoscientists with an honours degree[4] and since 1960 has graduated an estimated 5000 geoscientists at honours, or equivalent, level.

Student enrolment patterns

Figure 3.1 reveals the strongly cyclical nature of enrolment patterns in geoscience courses. This has long been known as a difficulty for maintaining a stable funding base for university departments under current funding models, because the base depends on student numbers. The major cycles, typically of 7-10 years duration, have been recognised at least as far back as the 1970s. It is perhaps an encouraging sign that second and third year student numbers have once again begun to increase over the past two years from a low-point in 2001. However, a sustained downward trend in the number of honours students suggests that enrolments in masters degrees will drop and that PhD completions will decline sharply for several years yet.

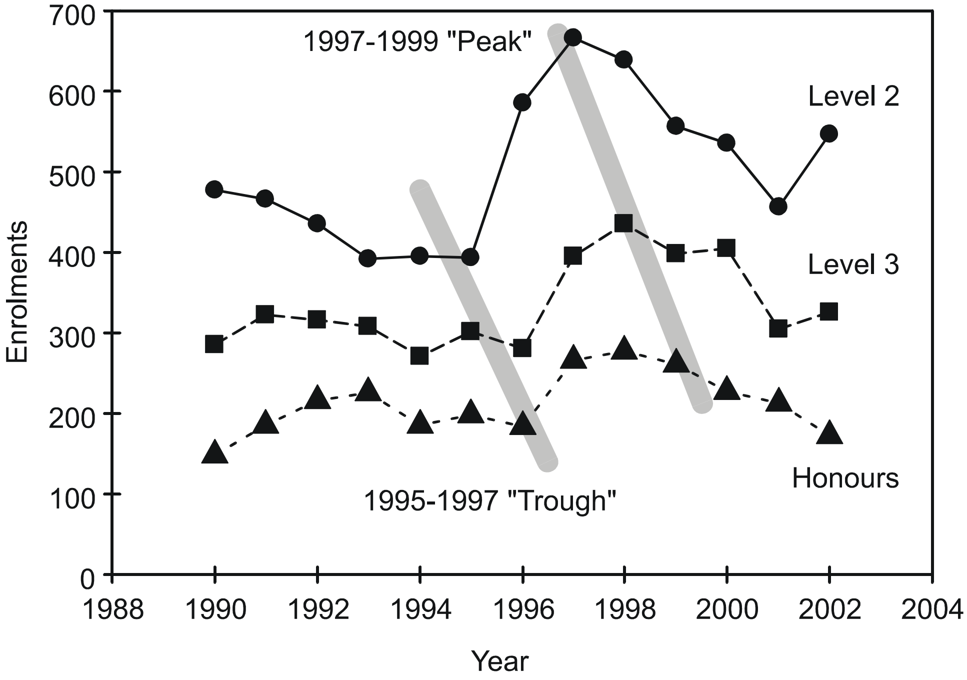

Figure 3.1: A comparison of the trends in total enrolments at levels II, III and honours in geosciences at Australian universities since 1990 (Foden, 2003)

When compared with other science disciplines, the number of geoscience students in tertiary education is extremely low, even at the high points of the enrolment cycles. For example, 1 in 50 Australians have some tertiary education in biological sciences, a discipline that attracted 11 845 new EFTSU starters in 2002. For geosciences, the number is 1 in 500. These low numbers provide a challenge to host faculties as to how to fund an essential, but small, discipline at levels consistent with viability both in teaching and research.

Degree course program

Globally, undergraduate enrolments in the geosciences are highly cyclic with large peak to peak variations that generally track changes in the value of natural resource commodities; mineral exploration expenditure in Australia (figure 3.2) and the price of a barrel of oil in the United States. Australian geology departments have tended to deliver a vocationally oriented degree focussed on producing numbers of professional

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[4] J. Foden, 'A survey of the changing enrolment and staffing levels in the geosciences at Australian universities since 1990', *The Australian Geologist*, vol. 127, 2003, pp 21-24.

geologists roughly in balance with the requirements of the resources industry. Over the past decade, teaching-staff numbers have declined while the student-staff ratio has significantly increased.

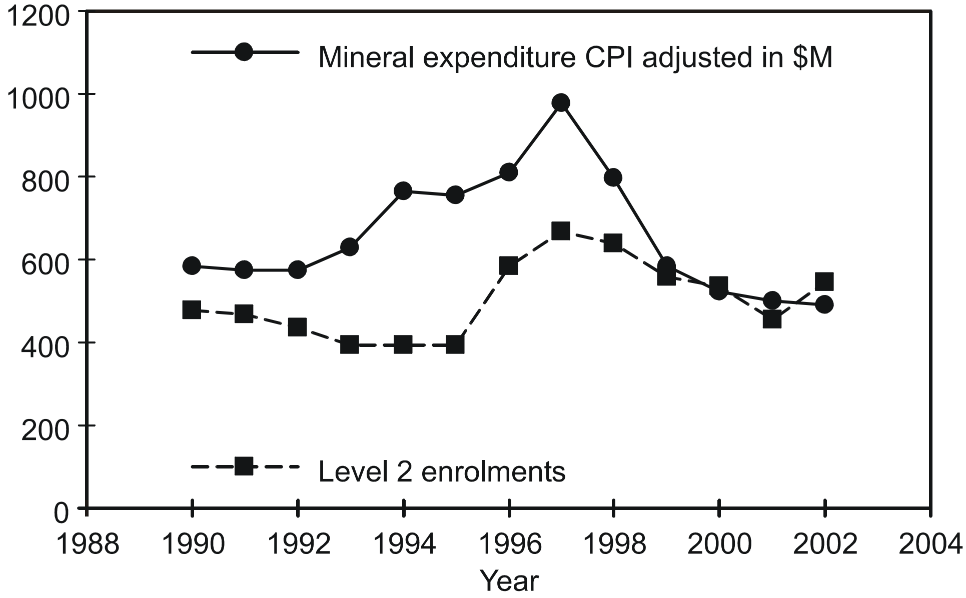

Figure 3.2: Relationship between expenditure in mineral exploration and geoscience enrolments at Australian universities since 1990 (Foden, 2003).

Despite the relevance of modern geosciences to areas other than the resource industries, table 3.1 shows that the geosciences profile remains that of a highly vocational, specialist subject such as processes and resources engineering[5], rather than a general science such as biology, physics or chemistry, with which it might more naturally be grouped.

Clearly, tertiary geoscience education can diversify, integrate and grow, but it must also fundamentally change the way it attracts and educates students in order to meet Australia's need for a wide range of geoscience skills.

Table 3.1: A comparison of national earth science EFTSU with other disciplines in 2002[6]

	Undergraduate	PhD	Postgraduate	Total
Earth Science	2843	696	956	3897
Biological Science	26 465	2724	3600	30 512
Physics and Astronomy	4087	523	783	4994
Chemical Sciences	6617	695	811	7621
Processes & Resources Engineering	2792	530	881	3705

The traditional curriculum in university geoscience departments has aimed at providing a sound coverage of the fundamental themes, including petrology, structure, sedimentary geology, stratigraphy and tectonics, typically with some focus at senior levels on economic geology. There is an increasing demand, however, to expand these programs to include areas of rapidly increasing importance such as hydrogeology, geoinformatics, geophysics, environmental geoscience, and remote sensing. Furthermore, society now demands breadth and flexibility in graduates, who are likely to change career paths several times. These developments are placing increasing pressure on undergraduate courses and the 4-year honours degree,

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[5] One of 11 engineering disciplines.

[6] Department of Education, Science and Training, 2003, *Statistics relating to higher education*, Canberra, 2003, http://www.dest.gov.au/highered/statistics/students/02/student_tables.htm.

despite its success in the past, is seen by some as an international aberration that restricts flexibility and limits student options. For example, Europe is moving to a '3-2-3' model for the major, masters and doctoral degrees. Increasingly, undergraduate studies are seen as providing only a basic grounding in the field and a prelude to a lifetime of professional development and continuing tertiary study[7]. Although the past decade has seen significant adjustment in degree offerings in response to demand, it is timely for government, universities, and industry to take a pro-active role in determining and implementing degree structures that will maximise the effectiveness of tertiary education for the nation.

Staffing levels and departmental structures

The distribution of academic staff in university geoscience teaching departments has changed significantly over the past decade. The great majority of departments in existence a decade ago have seen significant reductions in staffing levels, many have ceased to exist as independent discipline units, and several have ceased to exist.

Two surveys have recently been undertaken to monitor these trends. The first was by questionnaire circulated to heads of current departments[8]. The second was by survey of staff listed on departmental web sites in 1998 and 2003, together with a similar survey in 1991 of its pre-web equivalent, a directory of earth science departments[9]. The two surveys reveal broadly comparable numbers and similar trends.

The major trend is that there has been an overall decrease in the number of tenured teaching staff since 1990. The directory-based survey suggests that this decrease has been large, 34% since 1990 (figure 3.3), which is consistent with experience common to virtually all departments in existence in 1990. Several departments have been reduced to the point of extinction (e.g. Flinders and UTS) with others (e.g. La Trobe) soon to follow. While the responses to the questionnaire circulated to heads of current departments might appear to suggest that academic staff numbers have remained relatively constant, this is due to departmental amalgamations and inclusion of 'soft money' research-only staff and staff from related discipline areas not counted in the earlier survey.

The strong trend towards merged discipline units means that, of the 28 departments in existence in 1990, only 13 are still operating as independent geoscience-based units. Although one or more individual geoscientists remain in all but one of the universities surveyed, the majority are now merged into amalgamated departmental entities where they are grouped with a variety of other disciplines. This change makes the separate reporting of geoscience staffing levels much more difficult. The most common mergers have been with geography or environmental science departments, but in some cases include even wider physical and even biological science groupings. There has been a clear reduction of geoscience identity across the university sector as a result of such changes, which have occurred in large measure due to the small size of the former geoscience units.

Against international benchmarks, Australian geoscience-teaching departments are understaffed[10]. The Australian Geoscience Council Working Party expressed this

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[7] Minerals Council of Australia, *Back From the Brink: Reshaping Minerals Tertiary Education*, MCA National Tertiary Education Taskforce, MCA National Tertiary Education Taskforce, MCA, Canberra, 1998, p79.

[8] J. Foden, 'A survey of the changing enrolment and staffing levels in the geosciences at Australian universities since 1990', *The Australian Geologist*, vol. 127, 2003, pp 21-24.

[9] A Gleadow, *Submission to the National Committee for Earth Science*, held by the Australian Academy of Science, 2003 and RM Carter, *Australian Geoscience Directory*, 4th edn, Economic Geology Research Unit, James Cook University 1991.

[10] This discussion does not include the much larger Research School of Earth Sciences at ANU, which focuses its efforts on research and postgraduate training, and is not considered to be a teaching department.

concern in 1992[11] and the situation has since deteriorated. A recent comparison was undertaken by one of the largest Australian geoscience departments with two overseas departments, one in the United States and one in the United Kingdom, that were judged broadly similar in terms of their student numbers. This comparison revealed that the two overseas departments had 2.5 and 2.9 times the number of academic teaching staff compared with the Australian department, which illustrates the magnitude of the difficulty Australian university departments face in remaining competitive in an international context.

In contrast to the situation for academic teaching staff, both surveys reveal a strong growth in the numbers of research-only staff over the past decade, approximately doubling over the period 1990 to 2002. Indeed, on current trends, it is likely that there will be more research staff than teaching staff soon after 2005. There has also been a clear trend towards a range of seniority levels amongst the research positions, which in the past were largely restricted to junior-level postdoctoral fellowships. The expansion of support for research funded positions at up to professorial level by the ARC, as well as new research opportunities in universities created by CRCs, SRCs and other major centres, have changed the nature of research employment, so that for many it has become a long-term career option. In addition, this pool of researchers represents a substantial reservoir of expertise that will be essential for maintaining the viability of geoscience education programs into the future.

Another important trend is that the strong growth in research staff has occurred almost entirely within the ten largest departments, which also account for the majority of geoscience students[12]. It is significant that virtually all of the largest departments include one or more major research centres. If the aggregate number of teaching staff and research staff are considered, then these ten departments have overall levels of between 15 and 35 academic staff, which can realistically be considered to achieve critical mass in geoscience research capability. However, a substantial fraction of these staff members are supported by short-term external contracts without a defined career path. This creates an unstable staffing environment and leads to reduced incentives to take on high-risk/high-payoff research and greatly reduces the attractiveness of research careers to younger geoscientists.

Implications of university structural change

Australia has historically enjoyed a diversity of geoscience departments – from large to small – that have provided some form of geoscience education at virtually all tertiary institutions. This widespread presence in Australian universities has been important in providing the greatest possible ‘catchment’ for potential students into the discipline as the geosciences are not generally taught in secondary schools. With strong downward pressure on university science budgets, the current system is under great stress, leading to the loss of some smaller departments and the merger of many more into broadly based environmental or other more-general science programs. There is a significant risk that more geoscience departments may close in the immediate future, leading to even fewer opportunities for students to major in this discipline. It was argued by a working party of the Australian Geoscience Council in 1992 that Australia needed fewer departments that offer full undergraduate to postgraduate programs[11], but that introductory programs in geoscience should be offered at all universities to at least first-year level. The structural changes since that time have certainly led to a significant reduction in the number of comprehensive programs and a resulting concentration of research activities, but have also led to the demise of important undergraduate-teaching programs.

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[11] Australian Geoscience Council, *Towards 2005: A prospectus for research and research training in the Australian earth sciences*, Australian Research Council Discipline Research Strategies, National Board of Employment, Education and Training, Canberra, 1992, p. 55.

[12] J. Foden, 'A survey of the changing enrolment and staffing levels in the geosciences at Australian universities since 1990', *The Australian Geologist*, vol. 127, 2003, pp 21-24.

Many geoscientists enter the discipline by taking geoscience as an ancillary course in first year, discover their passion and change direction to move into geoscience as a career. Consequently, when a university geoscience program is closed, these students do not have the opportunity to discover geoscience as they simply take another course at the same university. The closure of undergraduate programs thus leads directly to a reduction of recruitment into the discipline with long-term consequences for the supply of graduates. To increase awareness of geoscience in the Australian community and to enable geoscientists to work in multi-disciplinary teams, it is important that mechanisms be put in place to make small geoscience programs viable while larger departments maintain critical mass in important disciplines.

Australian geoscience teaching staff struggle to maintain excellent teaching standards across an ever-expanding discipline range, whilst the research staff spend an inordinate amount of time on applications to renew their positions. The system is inefficient, as much of the support for both groups eventually comes from a single source (i.e. government) but requires a much higher workload and greater administration than in other countries.

Thus, a real threat to tertiary geoscience education in Australia is extinction due to the uncertain viability of small departments and small disciplines within the current funding model (see below). Many departments face closure or forced mergers/takeovers with no resulting benefit to the remaining geoscience departments, with the consequence that the overall numbers of geoscientists could spiral downwards.

Another major threat is the questionable viability of physical science education generally throughout Australian universities. Figure 3.3 shows the decline in the number of teaching staff in physics, chemistry, mathematics and earth sciences over the past decade. Clearly, the well-being of geosciences rests on a foundation of the enabling sciences. If, say, physics disappears from a university curriculum, the study of any physical science at that institution ceases to be realistic.

Tertiary education funding

Funding for undergraduate education at Australian universities is largely based on the estimated relative cost of a given program together with the number of students participating in that course (EFTSU). At the largest scale in academia, this approach makes sense as support for teaching staff reflects both student demand and the relative cost of instruction. However, the weighting for science courses relative to other fields has been eroded over the past ten years. For small departments, the relatively high variability in student numbers from year to year potentially creating an unstable funding environment. Furthermore, student numbers may decrease below a threshold beyond which the critical mass of a discipline cannot be sustained. The near universal response to such difficulties across the university sector has been to reduce staffing levels and require departmental mergers, often with a consequent loss of discipline-based course offerings.

Such a purely market-based approach to higher education funding assumes that students are well informed to make appropriate decisions about course offerings. However, the lack of geoscience education in secondary schools argues strongly that this is not the case and is an important reason why geoscience programs should be widely available at university level. Present funding policies that are biased towards large class sizes could potentially have dire consequences for a small discipline, even though it is central to national research priorities. This, the NCES argues, is the case for geosciences in Australia.

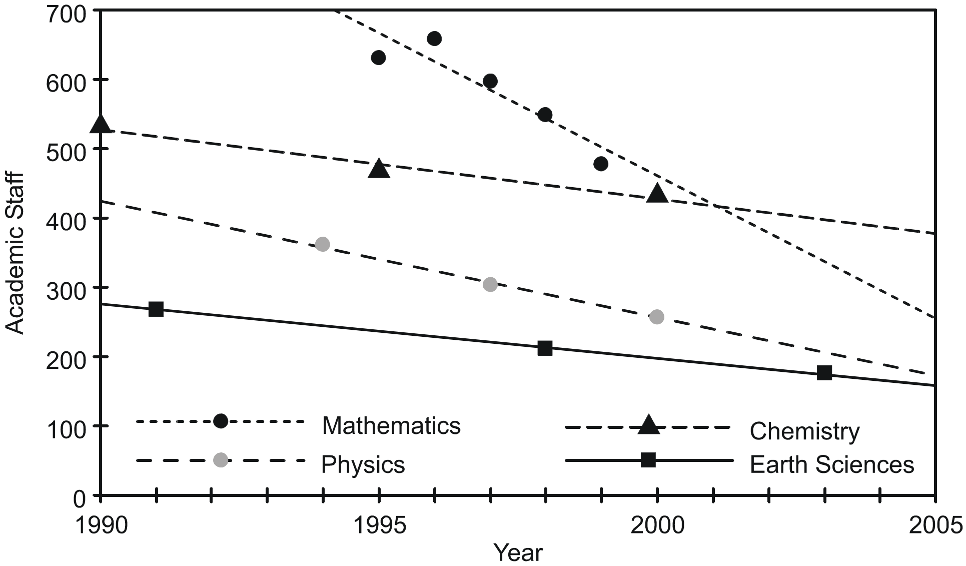

Figure 3.3: Number of university teaching staff at Australian universities in physics, chemistry, mathematics, and earth sciences[13,14]

Inspection of figure 3.1 shows that undergraduate enrolments in the geosciences have experienced fluctuations as much as 40% in the past 10 years, driven in part by the cyclic nature of the resources industry (see figure 3.2). If the tertiary education system is forced to respond purely to the market perceptions of prospective students, it loses the capacity to invest in education for the national good. The variable rate learning-entitlement model proposed in the review of higher education provides a mechanism for addressing this issue. To be effective, however, the NCES believes that implementation of this mechanism requires recognition of the value of creating graduates with critical skills even when the need is satisfied by a small number of highly competent graduates. The proposed increase in funding[15] for undergraduate places in science is a welcome move in the right direction to stop the precipitous decline in academic staff numbers in all the physical sciences (figure 3.3). However, it must be combined with a mechanism that both buffers short- to medium-term cyclicity in undergraduate enrolment figures and provides critical mass support for research concentrations.

Monetary incentives to increase student numbers, regardless of the value of those students to the national good, has led to universities and university departments competing with each other in negative ways rather than co-operating to make Australia a world leader in tertiary education. For example, relative to other developed nations, there is little mobility amongst Australian post-graduate students; many university staff now do their utmost to retain ‘their’ honours students for PhD programs, because of the funding implications, rather than encouraging these students to broaden their horizons and capabilities by undertaking PhD programs at other institutions. Australia is losing the full value of its research training dollar by tolerating and tacitly encouraging this behaviour. Currently, it is almost impossible for any university or group of universities to offer degree courses in specialist areas with only a small number of students per year, despite the fact that such specialist skills in small numbers might be exactly what is required and critical to the national capacity. This is due to a range of interactions in the implementation of the funding model that, unintentionally, become disincentives to cooperative shared teaching. The NCES

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[13] Australian Institute of Physics, Sept 2001, *National Initiatives in Education - a joint statement by Royal Australian Chemical Institute, Australian Mathematical Sciences Council and Institution of Engineers Australia*, press release, AIP, Aug 2003, http://www.aip.org.au/initiative2001.

[14] A Gleadow, *Submission to the National Committee for Earth Science*, held by the Australian Academy of Science, 2003.

[15] Department of Education, Science and Training, 2003, *Our Universities: Backing Australia's Future*, Canberra, 2003, http://www.backingaustraliasfuture.gov.au.

believes that, in many instances, a critical component of being able to educate small numbers of people with critical skills will be co-operative teaching across departments in different universities.

It is entirely appropriate that the offerings of Australian universities be market driven, but it is essential that the market be well informed. However, the funding model, particularly the high priority given to EFTSU, and the way in which it rewards universities and university departments, means that geoscience offerings of universities have for some time been driven by the perceptions of school leavers unacquainted with the geosciences or by external full-fee paying students. The NCES believes that this is *not* the appropriate basis on which to build Australia's future.

The NCES is of the view that it is important for Australia's future to modify the higher education policy to be in alignment with the national research priorities. The NCES welcomes the fact that, in its most recent budget, government has proposed that increased relative weighting be given to science students in general. It is hoped that a new funding model will help to reverse the potentially disastrous trends of the past decade.

The government has made a start to this process by clustering the different discipline areas based on the nation's perceived need for skilled people in those areas, and by providing extra public-funded places for priority areas. The NCES applauds this. However, the NCES is of the view that Backing Australia's Ability fails to recognise that the geosciences provide an enabling capacity for each of the discipline areas in cluster 10. Without sufficient capacity in the geosciences, it will not be possible to achieve the desired outcomes for the discipline areas in cluster 10 nor against the broader goals of the NRPs, particularly the goal of the development of deep earth resources (see section 6).

Pre-tertiary education

The situation for geosciences in Australia's K-12 education is mixed and reflects larger issues related to K-12 science education in general. Most teachers have little or no training in the geosciences and there remains an inadequate array of high-quality resources that could help teachers to weave geoscience into the subjects they teach.

Dedicated education programs, such as those delivered by Geoscience Australia and the minerals industry's National Education Program, attempt to address the shortage of geoscience teaching materials and also provide professional training to teachers to increase their ability to use these resources effectively. However, greater effort is required by governments to provide the necessary incentives for teachers to obtain further geoscience education and training.

While it is encouraging to see many in the geoscience community helping schoolteachers, this is at best a piece-meal approach and not sufficiently effective. A more coordinated and adequately resourced strategy is required to ensure that the desired outcomes for all stakeholders are achieved. The strategy needs to ensure that geoscience is integrated within future curriculum frameworks and syllabus documents and taught by a sufficient number of teachers trained in the geosciences and provided with high-quality and inspirational support materials.

The NCES commends the geoscience community in its efforts to fill some of the many gaps. For example, the MCA provides a long-term program of educational support for primary and secondary schools. Increasingly government bodies, such as Geoscience Australia and the CSIRO, are also providing a range of geoscience education resources developed by teachers to raise awareness of the geosciences, and help teachers ensure the decision-makers of tomorrow are aware of the value of the geosciences. It is particularly encouraging to see multiple delivery modes being used (e.g. via the web, hardcopy and through hands-on-activities). However, more needs to be done, and education departments across Australia need to be more effective at ensuring school teachers and trainee teachers are able to motivate students to pursue geoscience careers and to expose Australia's future decision-makers to the breadth and value of the geosciences.

Strategic goal and critical factors

Goal

A sustainable and wealthier Australia through more effective geoscience education.

Critical factors

1. Strong general support for science, engineering and technology disciplines (NRP 1, 3, 4 and SO 2, 3, 4).
2. A funding model for higher education that recognises the national significance, and education costs, of geoscience, emphasises quality over quantity, and facilitates effective development of core and specialist geoscience skills. (NRP 1 and SO 1, 2, 5).
3. A stronger focus on world-class research and graduate centres, networked with smaller departments (SO 1, 2, 3, 4, 5).
4. Geoscience-scholarships that encourage students to fill skill-gaps in the nation's ability to address the NRPs (NRP 1, 3 and SO 2).
5. Awareness by Australia's decision-makers of: the value of geoscientific knowledge when making decisions that involve Australia's natural resources; and how the geoscience community can contribute to the effectiveness of their decision-making processes (NRP 1 and SO 4, 5).
6. Motivation of school students to pursue geoscience careers (NRP 1, 3, 4 and SO 1, 2, 4).

Recommendations

The NCES recommends the following.

1. That government moves to a funding model for higher education that recognises the national significance, and education costs, of geoscience so as to ensure the long-term viability of geoscience education and training, including:
    - relocation of the geosciences from *Cluster 8* to *Cluster 10*[16];
    - extension of funding under the Higher Education Innovation Program for a further five years; and
    - strong support for science, engineering and technology disciplines in general.
2. That government and universities collaborate to modify the university funding model and its implementation, ensuring:

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[16] Section 2 of *Backing Australia's Ability*[#] details a new model for Australian Government funding of student places from 2005 - with disciplines grouped into 10 clusters.

[#] Department of Industry, Science and Resources, *Backing Australia's Ability - an innovative action plan for the future,* AusInfo, Canberra, 2001.

- provision for stable, base-level funding to maintain viability of a diverse group of university geoscience departments, despite cyclicity in undergraduate enrolments — specifically, implementing the ‘variable rate learning entitlement’ funding model proposed in the Higher Education Review, to give direct recognition to the costs and significance of geoscience, as an area of national priority, and of small but vital disciplines such as geophysics;

- investment in critical core-skills, including those highly specialist skills where the need is critical but is satisfied by a small number of highly competent graduates;

- provision of scholarships by industry, government and other employers, particularly geoscience-scholarships[17] that encourage students to fill skill-gaps in the nation’s ability to address the NRPs; and

- increase incentives for universities to create graduates with the multi-disciplinary and inter-disciplinary skills necessary to address the NRPs.

3. That the geoscience community expand and broaden existing and emerging networked geoscience centres (e.g. Victorian Institute of Earth and Planetary Sciences, Sydney Universities Consortium for Geology and Geophysics, Earth Systems Dynamics Network) in order to establish world-class graduate centres, networked with smaller departments. Specific initiatives associated with this strategy are:

   - provision of dedicated personnel for networking with smaller departments, state government agencies, Geoscience Australia, CSIRO and industry;

   - use of infrastructure for networking;

   - geoscience promotion, by a dedicated geoscience teacher in each centre, to schools and to the general public;

   - establishment of new chairs, particularly in areas of national priority (including geophysics and marine geoscience);

   - introduction of a ‘50 early career explorer’ scheme for new graduates and doctorates, with staff to be rotated between government research agencies and industry; and

   - increased research and teaching collaborations between geoscience departments, and those in environmental science, geomorphology, meteorology, geoinformatics, engineering, commerce and social science.

4. That all national and state geoscience bodies (government agencies, professional and peak industry associations and lobby groups) work with the Australian Academy of Science, the Academy of Technological Sciences and Engineering and the Australian Science Teachers Association to provide professional development to teachers and schools with inspiring K-12 teaching resources. This should:

   - include excellent geoscience-based learning experiences for primary and secondary students, underpinned by affordable professional development in how to use them;

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[17] Sectors requiring geoscience graduates, include, for example, the resources sector, environmental management sector, and city planners. Consideration should be given to providing some scholarships that cover tuition and living expenses so that access is available to those with the brightest minds regardless of economic circumstances.

    - ensure program gaps, specifically including at the K-3, 4-6, 7-10 and 11-12 levels, are effectively targeted through cooperatively funded strategies; and
    - provide geoscience-based learning experiences, including case studies that can be used by non-geoscience disciplines.

5. That the geoscience community encourage government to:
    - undertake a more rational distribution of existing funds to university-based geoscience programs to reduce the large amount of time lost in applying for funding of research positions; and
    - increase the general level of science education funding so that Australia is internationally competitive.
6. That government, universities and industry collaborate to:
    - determine and implement degree structures that will maximise the effectiveness of the geosciences, particularly in addressing the national research priorities;
    - ensure that a geoscience component is in undergraduate and post-graduate courses for primary and secondary science-teacher trainees; and
    - establish effective, affordable, programs and incentives that encourage teachers and trainee teachers, at all levels and across specialist areas, to acquire the knowledge and skills they need to effectively teach the geosciences.
7. That, whenever it is practical and feasible to do so, the geoscience community adopts a coordinated and integrated promotion of the geosciences and their relevance.
8. That government reinstate its support for the Mineral Council of Australia's Mineral Tertiary Education Council program and support other similar private sector initiatives.

Section
4

Research

Geoscience - Unearthing our future

Background

Introduction

Curiosity-driven research underpins a knowledge economy. It is an investment that generates new knowledge, allowing the nation to create wealth (e.g. each $1 invested by government in geoscience R&D results in a $180 increase in sub-soil assets[18]) and find new ways to improve the environment (from remediation of gully erosion to improved weather forecasting from global/regional climate models). For Australia to continue to realise the yield on this investment requires not only a monetary commitment to excellence in research and development, but also the presence of a vital group of geoscientists within a world-leading research community. Australian geoscience can only hope to attract the best of the next generation by asking the most compelling questions about the Earth and its relationship to the life that it sustains.

This section focuses on identification of exciting, emerging research opportunities with the caveat that few major geoscience discoveries of the previous century had been anticipated by the community at large. Thus it is vitally important that diversity remain a key feature in our research funding environment. The NCES also emphasises the overall excellence of current Australian efforts in the continuum from basic to applied geoscience research and recommends that the balance be retained. Because of its direct relevance to national research priorities, research within that continuum related to sustainability and wealth generation is discussed in sections 5 and 6 respectively.

Analysis

An inspirational research agenda

Australia’s continued ability to extract the natural resources that fuel its economy while remediating the effects of their withdrawal from the earth system requires her brightest minds to address the changing problems that these challenges present. But the health of any community of scientists is critically dependent on the supply of fundamentally challenging questions of basic science. For example, the practical benefits of post-world war II physics (e.g. semi-conductors, magnetic resonance imaging) stemmed from pre-war revolutions in relativity and quantum theory. When the best young minds focus on the most challenging scientific issues of the day, a vibrant community of the most talented problem-solvers results. Thus solutions to problems of sustainability begin with the fostering of a dynamic geoscience community focussed on the most compelling research questions and the provision of the support for this group to prosper. The intellectual ferment that results is a component part of the infrastructure from which resource and sustainability issues can then be addressed.

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[18] M Matthews, *Opportunities for assessing the impact of geosciences via the system of national accounts*, Policy Intelligence, Canberra, 2003.

An inspirational research agenda also helps fuel a cycle of public interest needed to attract the next generation of scientists. By maintaining public support for research in this way, the geosciences can continue to excite young people to be future geoscientists. Australian research into the evolution of dinosaurs, the deep structure of Earth, and the origin of life have not only increased scientific knowledge but have drawn public interest to television series such as The Planets, Life on Earth and Walking with Dinosaurs.

While the Australian geosciences lie at the leading edge of knowledge-based and high technology research, they have also demonstrated their ability to transfer the results of this research to commercial, technology manufacturing, and information technology sectors. Outcomes have included state-of-the-art analytical instrument development, GIS-based applications, satellite-based imagery and spectral science products, X-ray analytical technology, laser applications to material science analysis, and market and risk analysis.

Challenges to geoscience research

By any measure, Australia is a world leader in geoscience research. With only 0.3% of the global population, Australia produces more than 5% of all geoscience publications and receives an equivalent share of citations; the highest of any scientific field in Australia[19]. Over one third of the 53 Australian researchers in the top 0.5% of cited researchers worldwide are geoscientists[20]. The highest ranked Australian university program in terms of citation impact is in the geosciences[21]. These outstanding achievements reflect the historic recognition of the value of geoscientific research to Australian economic development. To the extent that university-based research has been at the core of this effort, Australia's global leadership is under threat. As described in section 3, the viability of many geoscience departments and their research output is challenged by existing higher-education funding mechanisms. Equally counterproductive are some policies through which research training funds are distributed. For example, government funds supporting university research activities have, for the past decade, been allocated in part on the number of publications rather than their quality. The result was predictable; university publications increased significantly since 1993. However, while the university sector's share of publications in the top two quartiles (ranked by quality) of journal impact rose by about 20%, the third quartile increased by 50% and the bottom quartile doubled[22]. Australia was ranked seventh among OECD nations in terms of citation impact in 1988, but dropped to eleventh position by 1993 and the distance between Australia and tenth place has continued to widen[19]. If there is little or no incentive to strive for the top journals, Australia's geoscientists will continue down the path along which they write more, but are listened to less. Clearly, the impact of funding research training solely on the basis of quantitative measures of productivity (numbers of publications, postgraduate students, and income) can be counterproductive and the NCES urges government to seek objective measures of quality for all elements of their funding formulae.

A significant problem in Australia is that infrastructure funding initiatives are often *ad hoc* and are insufficiently integrated with other funding processes. This is exemplified by the MNRF program. This program is pivotal in the development of scientific infrastructure, yet there is no ongoing commitment to the program. Consequently, it is difficult to achieve an effective long-term plan for coherent development of national scientific infrastructure through this program. Furthermore, the current approach does not maximise the opportunities to develop effective co-investment from other sources

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[19] L Butler*, Monitoring Australia's Scientific Research*. Australian Academy of Science, Canberra, 2001.

[20] Thomson ISI, December 2001, ISI Web of Knowledge, 2003, http://isihighlycited.com.

[21] Thomson ISI, December 2001, ISI Web of Knowledge, 2003, http://isi1.isiknowledge.com/portal.cgi.

[22] L Butler, 'A list of published papers is no measure of value', *Nature*, vol. 419(6910), no. 877, 2002.

(e.g. from State and Territory sources)[23]. The NCES supports the endeavours of the National Research Infrastructure Taskforce to develop an improved approach.

In several of the major national research facilities, the significant capital investment in creating the facility is severely under utilised. This is because the MNRF program is not sufficiently well integrated with the rest of the funding system. In particular, there is difficulty in obtaining the funds needed for ongoing maintenance of the facility and potential users experience difficulties in obtaining funding to access the facility.

Indeed, there are instances where it is actually easier for researchers to get funds to duplicate infrastructure locally than it is to get funds to visit a major national research facility and access the infrastructure there. Many quality researchers, particularly those in small units, simply do not get access to available infrastructure. This means that the significant capital investment in some of the major national research facilities is not effective. It also means that individual researchers and small research teams are frustrated by the knowledge that they have good ideas needing data and testing, that excellent facilities exist for just this purpose, yet they are unable to access those facilities. Furthermore, a thriving infrastructure facility with visitors from around the country and overseas provides a cauldron of intellectual activity where new ideas can be developed, cross-fertilised, and grow to fruition.

There is, therefore, a twin cost to the nation: the cost of providing facilities that are under-utilised and the opportunity cost of good ideas that are never developed.

The Australian National Seismic Imaging Resource (ANSIR) is an example of a major national research facility. It pursues world-class research and education in the field of seismic imaging of the Earth's interior. Potentially, it is a major resource for Australian geoscience researchers throughout the university, government, and industry sectors, yet, as with several other major national research facilities, it is under-utilised. This under-utilisation does not reflect an over capacity as there are numerous issues requiring seismic data. Instead, it reflects the difficulties that researchers have in obtaining the funding needed to use the facility. This needs to be rectified. To assist this process, ANSIR should ensure that researchers are aware of the capabilities of the facility and know how to obtain funding to access the facility. Subsequently, ANSIR should draw together potential users in a workshop to determine the most effective use of the facility.

The government sector has significant capacity in the geosciences, in agencies such as Geoscience Australia, CSIRO, the Department of Defence, the Bureau of Rural Sciences, and the State and Territory geological surveys and increasingly policy agencies are realising the need for geoscience to underpin their deliberations. This provides a great opportunity for the geoscience community to maximise use of the available infrastructure by improving collaboration between universities and government research agencies. Initiatives such as the new ARC Research Networks program offer an excellent opportunity for this. However, the opportunities for co-investment and improvement in the overall effectiveness of the available infrastructure would be greatly enhanced if the ARC were to recognise appropriation funds from government research agencies in granting schemes such as the ARC Linkage Grants. The current restrictions severely compromise the ability of the universities to leverage off major research personnel and infrastructure concentrations in the government sector and so dissipates the overall effectiveness of the total geoscience funding.

In order to maximise the overall national capacity, it is important to have the university, government, and industry sectors working together in a collaborative manner that achieves synergy between their different strengths and needs. Over the past decade, there has been increased emphasis placed on 'self-funding' for the

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[23] Australian Academy of Science, *Australia's Major National Research Facilities: Issues to consider for the next phase of Backing Australia's Ability*, Australian Academy of Science, Canberra, 2003.

university sector and for some government-funded bodies. This has been accompanied by a reduction in government support. Typically, 'self-funding' manifests itself as consulting and analytical services offered to commercial and government bodies. This has led to a decline in the standard of academic research outcomes because of the time and resources devoted to commercial pursuits, rather than to the pursuit of knowledge. It has also led to a loss in potential revenue for the nation because the high-level entrepreneurial skills available in the small-to-medium enterprises are not being fully engaged in the exploitation of potentially valuable consultancy and analytical services. In some instances, government funds are unwittingly leveraged for the support of poorly-conceived commercial operations under the veil of research activity. Industry has therefore experienced increased competition by government-supported groups that are able to avoid a truly competitive environment. This is a poor use of the overall national skill set, causing significant frustration in each of the sectors involved and reducing cross-sector synergy.

To realise the benefits available from Australia's publicly funded geoscience research, a strong R&D culture in the private sector is critical. The House of Representatives Standing Committee on Science and Innovation recommendations on increasing business investment in R&D[24] are aimed at supporting such a culture. The challenge for geoscience research is to ensure it maximises the advantages that such reform has the potential to offer this nation.

Opportunities

Much of Australia's geoscience research benefits from operating within the context of a strong resource-based economy, and the nation has large holdings of fundamental digital geoscience data. For example, Geoscience Australia alone has approximately 500 terabytes of data and is familiar with associated information management issues. Within the CSIRO, universities, research centres, and innovative companies, new technologies are being developed to 'see' into the Earth, and there is a developing national super-computing and geophysical modelling capacity (e.g. APAC, VPAC, ACcESS). Australia supports an optical astronomy community with exoplanet search expertise and optimal viewing access of the southern hemisphere sky.

The Australian continent and plate are remarkable laboratories for understanding the Earth and its processes. Aspects of the geology are unique and can be used to draw international collaborators. Two thirds of Australia's jurisdiction is beneath the sea and is poorly documented and understood. There is a need to understand the marine realm if it is to be appropriately managed, and there are wonderful opportunities for outstanding research and discovery of new oil resources. Within Australia's marine jurisdiction, there is a conjugate margin with data on both sides, providing an exceptionally rare opportunity to understand deep earth processes. There is a huge continental shelf area, ranging from tropical to Antarctic climes, covered by one of the world's best regional seismic reflection and refraction seismic datasets. The continent has the oldest known terrestrial minerals, fossil evidence for life and impact craters. The Australian landscape is ideal for study by satellite radar interferometry (InSAR), which promises higher resolution imaging of surface deformation than GPS. Understanding the regolith (the surficial cover on the Earth), and overcoming the challenges that it presents, is a major issue for research with the opportunity for export of knowledge and skills to other countries.

An important step in drawing together the geoscience community and building a collaborative culture will be the development of, and support for, a plate-scale geotransect project (see box 4.1). This project should provide fundamental

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[24] House of Representatives Standing Committee on Science and Innovation, *Riding the innovation wave - the case for increasing business investment in R&D*, Parliament House, Canberra, 2003.

information about the Australian continent and the tectonic plate upon which it rides, from its basic structure and evolution through to its mineral and petroleum systems.

Box 4.1: LithOzScope: A national geotransect project

Australia is a single-country continent carried atop a tectonic plate of remarkable diversity. This singular occurrence presents a globally unique opportunity to extend a transect across a whole tectonic plate, from convergent to divergent margins, that encounters a continental transform fault, the greatest continent-continent collision of the past quarter of Earth history, a continental subduction zone, and anomalous belts of intraplate deformation. The setting of the Indo-Australian plate permits an investigation of plate tectonics at work, rather than cataloguing its stages.

Using the Australian continent – an old craton being mildly reworked by a neighbouring giant orogen – to develop new concepts about how our planet responds to mega-tectonic events would not only be an unprecedented development in geosciences, but would address key issues in Australia. For example, the fragile environments in which some of Australia's endangered species live (e.g. Leadbeater's possum of the Victorian Highlands) have likely developed in response to tectonic uplift and climate change related to far-field deformation and rapid northward movement of the Australian continent. Similarly, the morphology of the Adelaide Hills and the climate they presently experience – which makes the local wine industry so successful – are a direct consequence of the stress regime and climate that Australia is presently experiencing. With a better understanding of the factors controlling the evolution of our environment, we can better predict its future. This, in turn, can have economic consequences, such as understanding the role of regolith formation in the development of major ore deposits and how climate balance and soil type affects agriculture. It can also help us in hazard assessment (e.g. earthquake activity, landslides). The project should aspire to show how the main cratons, or building blocks, of Australia evolved to host the development of sedimentary basins, ore deposits, and groundwater systems.

In order to achieve the goals of a national project of such unprecedented scope, it will be necessary to use extensive geophysical data to probe the depths of the Earth's crust, to undertake geological studies to underpin the interpretation of the geophysics, to develop and utilise a greatly enhanced marine geoscience capability, and actively engage a wide range of geoscientists to develop the knowledge of all of the processes that act at the plate scale.

The resulting holistic approach to a multitude of natural resource management and resource issues will mean that Australia sets new standards for the application of geosciences for the benefit of a nation and provides the focus for a coordinated and effectively networked geoscience community.

In order to understand the complex earth system and its evolution it is necessary to manage, access, and analyse vast amounts of information, information that is often distributed through diverse sources. Recent developments in geoinformatics, e-science, and grid computing are opening new horizons for geoscience in this regard. The diversity of information needed to resolve complex geoscience problems, and the very size of the datasets involved, means that it will be necessary for geoscientists to be actively involved in developing these new technologies so that they can handle the unique requirements of geoscience.

Because the continent is flat, dry, old, and covered by regolith, Australia faces unique challenges in overall sustainability and environmental degradation. This has been recognised in the national research priorities. Basic research in the geosciences is central to addressing these challenges.

Emerging research opportunities

An inspirational research agenda is required to attract the highest quality researchers to generate world class geoscientific knowledge. The NCES applauds the overall excellence of Australian geoscience research but recognises the importance of creating a research environment conducive to exploiting emerging opportunities. Several research themes with the potential for significant breakthrough are recommended for consideration for priority funding.

Theme 1: Decoding the dirt — the environmental challenges on a dynamic Earth

Linked to NRPs 1.3, 3.2, and 3.4, the core aim of this aspect of the research agenda is to understand the geological record and how to use it in assessing environmental and climate change.

The Earth's climate is a complex, non-linear system. To fully appreciate this system, it is essential to understand its history, equilibrium dynamics, intrinsic variability, response to external forcings (e.g. solar, volcanic, anthropogenic), and regional manifestations. Only with a proper understanding of the relevant processes will it be possible for society to make effective climate-related decisions in such areas as water use, coastal development, and carbon emissions. An understanding of how landscape and biota react to climatic change is crucial to ensure a better management of the Australian environment.

The geosciences make use of the Earth as an archive of climate history. Paleo-records (e.g. ice cores, marine sediment cores, corals, lakes, fjords) provide information about the range in physical, geochemical, and ecological change that is unattainable in the instrumental record, as well as constraints on the persistence (or lack thereof) of climate phenomena such as El Niño. Similarly, such records provide a natural experiment for testing models of climate and ecology in that they contain climate and ecosystem responses to known forcings. This suite of natural experiments can be used to probe the dynamics of the system and establish predictive skill. For example, the increase in atmospheric carbon dioxide due to human society is matched only during the last deglaciation and is unprecedented in the past 10 000 years.

The key aspects of this research theme are:

- development of high-resolution records of the Earth's climate on 10, 1000, and 1,000,000 year timescales (NRP 1.3);
- accurate determination of the response of the Earth's surface environment to external forcings (NRP 1.3);
- development of predictive models of climate and environmental change based on understanding of the past (NRP 1.3, 3.1, 3.4); and
- development of models of modern process of sediment transport and geochemically and biologically mediated reactions in the regolith and in benthic systems (NRP 1.3);

The key strategies associated with this research theme are:

- to maintain access to properly equipped oceanographic and shallow-water coring capabilities;

- to obtain new geologic archives of environmental change and develop microanalytical methods to enhance temporal resolution of climate proxies and anthropogenic impact on modern sedimentary and geochemical processes;

- to provide support that permits broad access to Australia’s government-funded accelerator mass-spectrometry facilities, including those at the Australian Nuclear Science and Technology Organisation, CSIRO and universities; and

- to provide support that permits broad access to Australia’s government-funded synchrotron and neutron scattering facilities.

Theme 2: Exploring submerged Australia

Linked to NRPs 1.5 and 1.6, the core aim of this aspect of the research agenda is to understand Australia’s marine environment and to better manage its resources (see also section 5).

The surfaces of both the Moon and Mars are better surveyed than the ocean floor adjacent to Australia. Australia is a signatory to the Law of the Sea treaty, ‘girt’ by three oceans, has the longest continuous coastline of any country in the world, and claims an ocean Exclusive Economic Zone covering an area larger than onshore Australia. Thus, the nation needs to adequately understand the nature of its marine geologic and biologic resources, the link between the seabed and ocean ecosystems, the role that the oceans and large carbonate systems, such as the Great Barrier Reef, play in global climatic change, and anthropogenic impacts on the oceans.

The key aspects of this research theme are:

- understanding the nature and economic potential of the Australian continental shelf (NRP 1.6); and

- understanding the relationship between the seabed and marine ecosystems (NRP 1.5).

The key strategies associated with this research theme are to:

- maintain properly equipped deep-sea and shallow-sea oceanographic capabilities including a remote observing vehicle;

- collaborate with the Integrated Ocean Drilling Program (IODP);

- develop international cooperative agreements to undertake research in the waters of other nations; and

- ensure that the information gathered from these projects is publicly available.

Theme 3: Exploring covered Australia

Linked to NRPs 1.6, 3.2, 3.4, and 4, the core aim of this research theme is to image deep within the Earth’s crust in order to understand the fundamental nature of continental deformation and improve our ability to predict the location of Australia’s mineral and energy resources.

In the next decade, the nation will need solid earth sciences to answer the overarching critical question: How do continents work? At the largest scale, the fundamental nature of continental deformation and its relationship to mantle flow is unresolved – is tectonic convergence fundamentally accommodated diffusely or is most strain localised along lithospheric-scale faults? At a smaller scale, the current model of the mechanics of faulting is deeply flawed – further progress in mitigating the destructive effects of earthquakes awaits the next breakthrough in this field. The nature and processes involved in continental collision and break-up are poorly understood, especially those related to the deposition and preservation of mineral and energy resources. Resolution of these questions requires access to the geologic record hidden beneath the surface of Australian continent and leads directly to understanding the evolution, location, and preservation of deep Earth mineral and energy resources.

The key aspects of this research theme are:

- understanding of how tectonic convergence and break-up are accommodated within continents (NRP 1.6);
- understanding of how, and under what conditions, mineral deposits and petroleum accumulations develop (NRP 1.6);
- development of new geophysical and geochemical probes to image the crust at depth (NRP 1.6, 3.2, 3.4);
- understanding of the present and recent tectonic history of Australia (NRP 4, 3.1, 3.4); and
- development of a new model of earthquake mechanics that is consistent with observation (NRP 1.6, 4, 3.2, 3.4).

The key strategies associated with this research theme are to:

- provide appropriate support to permit the university sector to utilise the Australian National Seismic Imaging Resource and national centres of geochemical instrumentation;
- enhance the capability of geochemical instrumentation, including nanoscale probes, through instrument development and automation;
- support a national centre for forward, inverse, and inference modelling to enhance signal-to-noise recovery (geoinformatics);
- undertake a geotransect across the Australian plate to understand the framework of the continent, characterise geological provinces and their evolution, and understand the landforms and their longevity;
- support leading edge research in economic geology and exploration geoscience;
- identify and understand far-field Earth processes that have affected the geological evolution of the Australian continent and Indo-Australian plate (NRP 1;6); and
- utilise satellite radar interferometry to assess recent Australian tectonic activity.

Theme 4: Journey to the centre of the Earth

Linked to NRP 1.6, the core aim of this aspect of the research agenda is to image the deep Earth to understand its three-dimensional evolution leading to its present configuration.

Earth is a 4.5 billion-year experiment in the evolution of a complex system driven by energy transfer and feedback between many subsystems (the atmosphere, hydrosphere, crust, mantle, and core). Internal differentiation of the primordial material that accreted to form the Earth is the ultimate source of the atmosphere, oceans, crust and ore deposits. In this process, the architecture and composition of layering in the Earth have changed through time. Geoscientists now have the technology to quantify and image the physical properties (e.g. seismic tomography, magnetic properties) and geochemical nature (e.g. *in situ* microanalysis methods) of the Earth's mantle. Understanding and imaging very deep earth processes and architecture underpins understanding of the nature and rate of change in the earth system.

The key aspects of this research theme are:

- geophysically and geochemically imaging the very deep Earth (NRP 1.6);
- understanding the mantle as a system of great complexity and exploring the links between tectonic activity and the transfer of material and energy in the Earth through time (NRP 1.6); and
- understanding the nature and rate of change in the earth system, and the links between tectonics and the hydrosphere and atmosphere (NRP 1.6).

The key strategies associated with this research theme are to:

- develop technology to improve geoscientific ability to geophysically image the deep Earth;
- construct sections of the physical and chemical structure of the lithosphere and asthenosphere beneath Australia using a combination of geophysical measurements and incorporated fragments in magmas as probes of the deep Earth;
- strategically develop geoinformatics and e-science required to manage, access and employ the terabytes of information required for deep Earth geophysical and geochemical tomography; and
- correlate tectonic events mapped in crustal rocks with mantle processes through time.

Theme 5: The origin of life and its role in earth systems

Linked to NRP 1.5, the core aim of this research theme is to understand how life originated and co-evolved with the atmosphere and hydrosphere.

The question of how life began on Earth, and possibly elsewhere in the solar system and universe, is one for which Australia holds unique natural resource (e.g. the oldest known minerals and fossils). However, the leap from abiotic organic precursor molecules to functioning metabolic processes remains largely a mystery. Addressing this issue will involve understanding the co-evolution of the Earth and its biosphere, issues such as the history of life's origin, timing, and critical intervals, and the interaction of extraterrestrial, geological, and biological processes. Studies of the Earth's earliest environments, including the atmosphere, ocean, primitive plate tectonics, continental growth, the interactions with evolving life, the deep biosphere, how life and the environment co-evolved, and of human involvement in modifying the conditions of this co-evolution, are all linked.

The key aspects of this research theme are:

- determination of when and under what conditions life emerged on Earth (NRP 1.5);
- understanding the nature and extent of the deep biosphere (NRP 1.5); and

- understanding the interaction of extraterrestrial, geological, and biological processes in the co-evolution of the lithosphere, atmosphere and biosphere (NRP 1.5).

The key strategies associated with this research theme are to undertake:

- detailed field and laboratory studies of key areas that record early life and its environment, and of relevant modern analogues; and
- continuous shallow- to intermediate-depth drill-coring to recover key samples from critical periods in the evolution of the Earth and life for geochemical and micropalaeontological characterisation.

Theme 6: The science of other worlds — is anyone out there?

Linked to NRP 3.2, the core aim of this aspect of the research agenda is to understand the formation of planetary systems and habitable planets other than Earth to provide geoscientists with a fundamental laboratory they can use for testing their hypotheses about the Earth.

Since the first planet was discovered outside of the solar system in 1995, over 100 extrasolar planets have now been identified. None resembles the solar planetary system.

The key issues are: how do solar systems form; how do they resemble and differ from each other; are any of the planets habitable; and are any inhabited? Opportunities for further discovery and hypothesis testing abound as major ground-based and sample-return missions are being planned for the next decade.

The key aspects of this research theme are:

- understanding of how and under what conditions the solar system formed (NRP 3.2); and
- determination of the distribution of life in the solar system and beyond (NRP 3.2).

The key strategies associated with this research theme are to:

- participate in the pioneering field of extra-solar planetology to understand the fundamental nature of solar system formation in this galaxy;
- participate in major international extra-terrestrial sample return and ground-based discovery missions planned for the next decade;
- develop new analytical instrumentation to exploit possession of pre-solar grains;
- continue support for ground-based search for extra-solar planets and development of refined observation methods;
- support payload projects on planetary missions to search for evidence of life elsewhere in the solar system;
- develop and test theoretical models to explain the origin of extra-solar planetary systems; and
- apply geoinformatics and remote sensing analysis to determine the environment and evolution of the nearby planets.

Strategic goal and critical factors

Goal

A vibrant, world-leading, geoscience research community.

Critical factors

1. An inspirational research program that contributes strongly to future geoscientific knowledge and skills and attracts high-quality researchers and adequate funds (NRP 1, 3, 4 and SO 1, 2, 3, 4, 5).
2. An improved funding model for major research facilities and infrastructure to ensure effective use of the significant capital investment and to facilitate access (SO 2, 3, 5).
3. Development of an effective oceanographic research capability (NRP 1, 3 and SO 1, 2, 3, 4, 5).
4. Investment in a major geotransect to gain fundamental information about the Australian plate, from its basic structure and evolution through to its mineral and petroleum systems and surficial processes (NRP 1, 4 and SO 1, 3).
5. Relaxation of restrictions on recognition of government appropriation funds in granting schemes (SO 4, 5).

Recommendations

The NCES recommends the following.

1. That the ARC continues to support excellence, diversity and innovation in funding basic research including new opportunities detailed in this section.
2. That the ARC supports the basic, strategic and applied research outlined in sections 5 and 6.
3. That government provide strong and continuing support for major research infrastructure, particularly ensuring more effective use of the significant capital investment in national research facilities, by:
    - providing predictable opportunities for capital acquisition;
    - funding operational support, maintenance, and top quality technical support; and
    - funding travel and accommodation so that qualified researchers are able to access the facilities.
4. That government provide substantial new funding to develop Australia’s marine geoscience capacity, ensuring:
    - development of a vital marine geoscience community;
    - development of, and access to, a modern, effective national marine geoscience infrastructure, including a national shallow-coring facility; and
    - collaboration with the Integrated Ocean Drilling Program.

5. That the nation invest in a major geotransect study to gain fundamental information about the Australian plate, from its basic structure and evolution through to its mineral and petroleum systems and surficial processes by:
   - universities and government research agencies developing and implementing a collaborative plan for the most effective geotransect considering the unique opportunities in Australia; and
   - the ARC supporting this activity, including through its new Research Networks Program.
6. That government free up restrictions on recognition of appropriation funds from government research agencies in granting schemes such as the ARC linkage grants.
7. That the recommendations of the House of Representatives Standing Committee on Science and Innovation, with respect to increasing business investment in R&D, are implemented.

Section

5

Sustainability

Geoscience - Unearthing our future

Background

Introduction

‘Sustainable Use of Our Natural Resources’ is identified as the first of the four National Research Priorities (NRPs)[25]. The Academy has endorsed this priority, which the geosciences support as a matter of responsibility.

Never before has the need to achieve sustainability been so clear. Never before have there been such demands on environmental resources from industry, power and water utilities, agriculture, fisheries, mining, transport, housing, tourism and recreation, and never before have the geosciences been so clearly called on to join the other sciences – natural and social – to integrate their knowledge of the Earth and its workings, in order to achieve sustainability.

Analysis

For most Australians, sustainability means that clean water, good soils, adequate building materials, reliable clean energy, and safe waste disposal will exist in perpetuity, with no further damage to our natural ecosystems, and that degraded habitats will be rehabilitated.

Urban and agricultural development has placed huge strains on these resources, resulting in degradation and a direct financial burden. Land and water degradation alone are estimated to cost Australia up to A$3.5 billion per year. We use groundwater more rapidly than it is replenished; we lose soils faster than they can be produced, and burn ever-increasing amounts of fossil fuels. This is not sustainable. These are all geological resources, and geoscience is the field that embraces their generative processes, natural cycles and sequestration of waste products.

Sustainability is a matter for society and science together. To achieve sustainability, resource usage, societal priorities and personal lifestyles are likely to change. Debate on these matters is here to stay. It is vital that the community be engaged, that the community be knowledgeable, and that there be full collaboration between the science disciplines and with the public.

Water

Australia is a dry continent and our water use has increased by 65% since 1985. Sustaining the supply of clean water is a critical issue.

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[25] Details of the *National Research Priorities* are provided at appendix F.

Groundwater

Groundwater currently supports 21% of our water usage, but for several major groundwater basins the usage rates exceed recharge[26]. Overall, the total quantity of groundwater and sustainable rates of use remain undefined. Groundwater is fossil water, ranging up to hundreds of thousand years old in the Great Artesian Basin; inputs have changed with past climatic changes. Assessment of groundwater quantities, quality, and both past and present recharge rates is vitally important. Required knowledge includes groundwater ages, residence times, chemical interactions with host rocks, fresh-salt groundwater mixing, and aquifer connectivity. Patterns of salinisation through groundwater discharge and potential pollution of recharge areas remain to be mapped nation-wide.

Generating the information requires a coordinated national hydrogeology program, encompassing remote regions, that aims to eliminate the shortcomings that appear in the National Land & Water Resources Audit.

Surface water

Surface water quality and quantity are fundamentally affected by the substrate, particularly in stressed agricultural soils. Measured levels of phosphorous, nitrogen, nutrients, pH, turbidity and salinity of surface waters in southeast Australia reveal that water quality is a major issue, while for the rest of the country there are insufficient critical data[26]. Furthermore, in some regions the rain-fed water supply has dwindled: for example, average rainfall in southwest Australia has decreased by over 20% since the mid-1960s.

Actions

Surface water and groundwater move within a connected system, consisting of natural and human ecosystems, regolith and rock structures. As the nation strives to optimise its water usage while minimising water degradation, knowledge of water passage through rock and regolith is vital, as is full accounting of water usage.

In addition to a national hydrogeology program, critical geoscience issues include:

- past changes of climate and groundwater input;
- interaction of water and substrates in water courses and storages;
- chemical processes and flows of nutrients and contaminants to estuarine and marine sediments and seas;
- effects of ground cover and land use on runoff and groundwater recharge;
- infiltration and discharge zones in regions with rising water tables; and
- distributions of water quality hazards, including acids from sulphide oxidation.

Soil

Soil, like water, is potentially a renewable resource that can be used sustainably. Currently, soil losses through erosion, dryland salinisation and acidification are unsustainable.

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[26] National Land and Water Resources Audit February 2001, Australian Water Resources Assessment 2000: Surface water and groundwater availability and quality, NLWRA, Canberra 2001, http://audit.ea.gov.au/anra/water/docs/national/water_contents.htm.

Soil loss

Through erosion, our rivers receive 10-50 times more sediment than in pre-European times[27]. This is dwarfed by the amount eroded by wind, especially during droughts and bushfires.

Our style of agriculture mines the soil, but the renewal rates (soil production) are poorly known. Estimates of renewal rate range from 1 to 5 mm per century but can be faster on floodplains and sandy areas. Soil losses under agriculture are 10 to 100 times faster than this. Moreover, some present soils were generated under different climates in the past, and whether they will regenerate if lost is guesswork.

Salinisation

Dryland salinity currently affects at least 2.5 million hectares (5% of cultivated land) and is predicted to increase seven-fold by 2050[27]. Rising salt can rot city foundations and damage the nation's road network. Land use practices drive salinisation. However, this is clearly a geoscience problem because the primary sources reside in water movements through the landscape and underlying geology[27].

Acidification

Soil acidification is a major issue. Much of our most important cropping and grazing lands are affected, as are some coastal areas. Acidification develops as some elements are lost in cropping and others are added in fertiliser, causing essential nutrients such as phosphorus to be locked up, while toxic elements like aluminium become more active. The National Land and Water Resources Audit estimates that up to 60 million hectares will become acidic within ten years - far larger than the area of dryland salinity. Future production losses would exceed $1.5 billion annually, and broader impacts are not yet quantified but are considered likely to be far greater.

Through recent geologic processes, many coastal areas are underlain by organic, sulphur-rich sediments that generate acid when drained. Damaging impacts include mobilisation of toxic aluminium from clays, decline of fish and aquatic systems, and corrosion of built infrastructure.

Actions

As with water, soil degradation is a national issue. In November 2000, the Council of Australian Governments endorsed the National Action Plan for Salinity and Water Quality, which commits $1.4 billion over seven years for establishing regional solutions to salinity and water quality problems. A national response from the geosciences is called for. As a key step, Geoscience Australia, CSIRO, several universities and state organisations are collaborating through the CRC for Landscape, Environment and Mineral Exploration (LEME), to provide geoscience input to solving dryland salinity.

In building national strategies to achieve soil sustainability, critical issues for geoscience include:

- determination of soil residence times and production rates, including rate-enhancing methods;

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[27] National Land and Water Resources Audit February 2001, Australian Water Resources Assessment 2000: Surface water and groundwater availability and quality, NLWRA, Canberra 2001, http://audit.ea.gov.au/anra/water/docs/national/water_contents.htm.

- better knowledge of salt sources, pathways and fluxes that lead to dryland salinity, and of proposed mitigation methods;
- the extent of dryland salinity in cities; and
- the relationships between acidic soils, regolith history and environmental processes.

Urban and coastal development

Expansion of Australia's cities along the coastal fringe continues unabated: 84% of Australians live in such areas, generating polluted runoff in our most highly-prized environment, while reaching ever further afield for potable water. Moreover, coastal lands are dynamic, more subject to weather-driven changes than most other landscape elements and highly sensitive to human impacts.

City growth consumes earth resources and has relied on growth of quarries in size and number, with minimal materials recycling, while sprawling over areas of unextracted prime gravel, limestone and clay (for example, Heathrow Airport overlies some of the biggest gravel supplies near London[28]). To cope with projected growth of Melbourne, for example, the Victorian Geological Survey recognises the need to identify strategic deposits of sand, mineral and stone for the building industry. To strive for sustainability, land must be safe and useable after extraction.

Actions

Critical geoscience issues relating to environmentally responsible development include:

- dispassionate impact-assessment of tourism, urban and agricultural development in the coastal zone, together with proposed mitigation strategies; particularly the responses to raised levels of sediments, nutrients and other pollutants; and
- systematic evaluation of building resources that can be utilised with minimum residual degradation.

Biodiversity

At the time of European colonisation, Australia's ecosystems were rich and diverse. The situation has been greatly reduced since then, owing to human activities. In large tracts of the country, 90% of the native vegetation has been replaced in the past 200 years. To evaluate both the potential for recovery and the impacts of oncoming climate change, examination of the past is vital. Especially important is the Quaternary record, which furnishes the most detailed available record of past climate shifts and embraces the immediate predecessors of the modern biota.

Actions

Critical geoscience issues relating to Australian biodiversity include:

- high-resolution evaluation of the ranges and rates of climate, sea level and landscape processes in geologically recent time;

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[28] Anecdotal - source PJ Cook, former Director, British Geological Survey.

- understanding the effects on ecosystem composition, structure and diversity of past climatic shifts, and of changes of land-area driven by sea level changes; and

- improved forecasts of future sea level and climate.

Clean energy and waste disposal

The Australian community is increasingly interested in consuming energy that has minimal environmental impact, on the condition that it is affordable. However, in 10 years from 1988, our energy production increased 54% (compare with 34% for Canada; 5% for USA). Furthermore, to generate electricity, Australia's percentage of coal exceeds any other OECD country[29]. As a result, Australia produces more greenhouse gas emissions per unit of energy than any other OECD country.

The renewable resources (wind, hydro, solar and geothermal energy) contribute 10% of Australia's power generation, mostly as hydro-energy in Tasmania. Doubling our wind and solar output is highly desirable but the impact on our energy usage will be small. To supply the nation's ever increasing demand for energy, for at least the next 50 years, will require efficient use of fossil fuels, while the use of renewable fuels is developed.

Australia has huge reserves of coal, natural gas and uranium and geothermal resources. We also are advanced players in development of greenhouse gas disposal, using underground sequestration.

Actions

For the period that fossil fuels, including uranium, remain our primary energy sources, geoscience holds the key to both establishment of resources and sequestration of wastes. In the field of renewables, geoscience holds the key to geothermal resources, and geoscientists interact with other disciplines in site evaluation for other renewables.

Critical geoscience issues relating to clean energy and waste disposal include:

- identification of new resources; and

- determination of the feasibility, methods and costs of safe, long-term storage of waste products.

Geohazards

The security of urban communities underpins national stability, but cities and towns are vulnerable to many natural and anthropogenic hazards. Natural hazards include sudden-impact events such as earthquakes, floods, cyclones, storm erosion, bushfires and landslides, and slow-onset phenomena such as sea level rise, soil-swelling, and ground subsidence. Humanly-enhanced hazards include salinity and acid-sulphate conditions, water contamination, and eutrophication in lakes and estuaries. These hazards can threaten lives and damage buildings, water and power supplies, transport, and communication services. They can also seriously affect employment, industry, commerce, and public administration.

In Australia, natural hazards are estimated to cost an average of $1.3 billion annually. Individual large events can cost much more — the 1989 Newcastle earthquake cost the community an estimated $4.5 billion.

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[29] Australian Bureau of Statistics, *Yearbook Australia 2002*, ABS, Canberra 2002.

As Australia's population increases, the potential impact of natural hazards also increases. Natural hazards that impact on Australia's urban communities where most Australians live — more than 65% now live in the five coastal cities — are of particular national concern given the potential damage that could result.

Actions

Critical geoscience issues relating to geohazards include:

- improved evaluation of the frequency, magnitude and spatial extent of future natural hazards and their likely impacts on Australia's urban communities;
- improved forecasting of the effect of climate change on natural hazards;
- participation in development of mitigation strategies; and
- contribution to development of knowledge-based systems for integrated planning and improved decision-making.

Greenhouse gases

Australia has the highest production of greenhouse gases per person and the highest production of greenhouse gases per unit of energy produced amongst developed nations. Australia has the potential to turn this liability into a significant asset, by leading the world in sequestration of carbon dioxide. There are enormous subsurface reservoirs near major cities that could be used for long term storage of carbon dioxide, for many thousands or millions of years[30]. Some reservoirs react with the carbon dioxide leading to permanent sequestration. Geoscience research in this area needs to be fast-tracked to enable Australia to satisfy its needs for affordable energy and turn carbon-trading into an asset as we transit to a hydrogen and renewable energy economy. For example, assuming a carbon credit of US$50 per tonne and a cost of capture of US$40 per tonne, it could be economic to store about 180 million tonnes of carbon dioxide per year. This is equivalent to about 70% of the current annual carbon dioxide emissions from stationary Australian sources and translates to a carbon credit of US$9 billion per year.

Critical geoscience issues relating to greenhouse gases include:

- behaviour of super-critical carbon dioxide in the subsurface environment, including required reservoir properties and fluid dynamics;
- reservoir and seal characterisation for carbon dioxide storage;
- characterisation of geochemistry and the interactions between carbon dioxide, fluid and rock; and
- opportunities for using carbon dioxide to form stable mineral products.

Australia's marine jurisdiction

Australia's marine jurisdiction is vast. This jurisdiction represents a massive store of biological and seabed resources, yet it is one of the least explored and understood jurisdictions. Australia's ratification of the UN Convention on the Law of the Sea

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[30] WG Allinson, DN Nguyen, J Bradshaw, 'The economics of geological storage of CO2 in Australia', *APPEA Journal*, vol 43(1), pp 623-36 and MN Watson, N Zwingmann, NM Lemon, PR Tingate, 'Onshore Otway Basin carbon dioxide accumulations: CO2-induced diagenesis in natural analogues for underground storage of greenhouse gas', *APPEA Journal*, vol 43(1), pp 637-53.

brings with it management obligations that, in turn, require scientific knowledge. There are also major resource opportunities for Australia, opportunities that would be lost in the absence of effective exploration of this jurisdiction. Yet, despite the existence of Australia's Marine Science and Technology Plan (1999)[31], Australia has yet to develop the necessary marine geoscience capacity. Indeed, the number of Australian blue-water research vessels has actually declined from three in 1998 to just one in 2003. Without effective infrastructure, it is not possible to grow the necessary scientific capacity. Australia's marine geoscience community has developed a strategy to assist in this regard (see box 5.1), but government needs to take a lead investment role in developing this pivotal capacity for the nation's future.

Actions

The geoscientific understanding needed to underpin marine-zone management has been identified in Australia's Marine Science and Technology Plan (1999) and includes:

- understanding of the marine and seafloor environment through integrated research into resources, ecosystems and processes;
- identification and characterisation of biological and mineral resources;
- linkage of geological understanding of the sea bed, and the associated processes, to the habitats of benthic organisms and the establishment and management of marine protected areas; and
- application of marine geological techniques to the detection and management of pollutants, including petroleum.

Research in the marine environment is expensive. Researchers need access to appropriately equipped ships — ships that must be shared with other disciplines. Due to cost of data acquisition, national strategies are required to obtain maximum return from the data acquired from the application of public funds.

Critical geoscience issues relating to Australia's marine jurisdiction include:

- determining the limits to Australia's marine jurisdiction as defined by the United Nations Commission on the Law of the Sea (UNCLOS)[32];
- determining the form, nature and crustal structure of the seafloor;
- elucidating the physical processes that occur over various time frames, like sea level rise and fall, the retreat or advance of coastlines, the infilling of estuaries, and the scouring and mobilising of the sea bed by waves and tides;
- establishing what needs to be understood about marine systems to ensure their sustainable management;
- elucidating the processes for chemical and physical cycling of pollutants in relation to geological framework and climate;
- establishing what exists in Australia's marine environment; and
- determining how marine systems behave in response to different types of usage.

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[31] Department of Industry, Sciences and Resources, *Australia's Marine Science and Technology Plan*, Marine Science and Technology Plan Working Group, AusInfo, Canberra, 1999.

[32] Geoscience Australia is in the process of completing a study that will enable Australia to submit a claim in late 2004.

Box 5.1: Cooperation to take marine geoscience forward

In spite of the national need and a decade of highly successful collaboration between universities and government institutions through the Ocean Drilling Program (ODP), Australian marine geoscience is fragmented, lacks critical mass and lacks capability. With the completion of the ODP, participating Australian universities and government institutions have understood the need to collaborate to achieve a critical mass of expertise and facilities to address the geoscience of Australia's vast marine jurisdiction. It has thus been agreed to form the *Australian Marine Geoscience and Ocean Drilling Council* (AMGOD) with the aim to:

- coordinate the development of a national marine geoscience strategy and associated infrastructure for Australia, including involvement in international programs; and
- promote marine geoscience research and training needs to government and associated funding agencies.

AMGOD recognises that growth in marine geoscience can only be achieved by improving ship facilities to attract excellent researchers, and by enhanced cooperation between institutions. Geoscience Australia has agreed to be the national custodian for marine geoscience data and to provide data access to facilitate research in universities and government agencies. The geoscience community has worked with the Marine National Facility Steering Committee to transfer the Marine National Facility from the small and under-equipped *R.V. Franklin* to the larger *Southern Surveyor* with an upgraded multipurpose capability encapsulating oceanography, marine biology and fisheries and geoscience.

CSIRO Marine Research, Geoscience Australia and the National Oceans Office are jointly funding a $2.5 million, multi-beam sonar swath-mapping system to be installed on the *Southern Surveyor*, which should vastly improve seabed mapping in shallow to moderate water depths. In parallel, AMGOD universities have applied for ARC funding to install a complementary $400 000 sub-bottom profiler in the vessel. When these upgrades are completed, Australia will have one multipurpose, blue-water research vessel, with limited range, available for six months of National Facility research per year. This will significantly improve Australia's marine geoscience facilities, but it is only the first step. AMGOD considers that:

- in the short term, government funding is required to increase the use of the vessel to a full year operation.

  Six months of Marine National Facility time on a single multipurpose vessel is inadequate to meet current needs or grow the research capability of marine geoscience, oceanography and marine biology.

- government should consider replacement of the *Southern Surveyor* on a five-year time frame by two ships equipped and designed to meet all marine science needs with adequate accommodation for researchers, students and technicians.

  Berths on the Southern Surveyor, and its predecessor Franklin, are inadequate for serious training of students.

- access to the Marine National Facility and ARC grants should be linked.

  At present, competitive access to the Marine National Facility is not accompanied by grants to fund the marginal cost of the use of the facility, which is the responsibility of the researcher. Separate ARC applications must be made to research the survey data and samples. It is a significant disincentive to research requiring at least two competitive grant applications to different bodies.

- government needs to consider participation in the Integrated Ocean Drilling Program commencing October 1, 2003, which replaces the Ocean Drilling Program.

  Australia has been highly successful in attracting ocean drilling and research to the Australian region. Participation requires a significant funding increase over that which has been available for ODP.

Geoscience information

Geoscientific datasets and associated information (e.g. airborne geophysical surveys and geological maps) have many applications in both sustainable resource management and wealth creation. See section 6 for further details.

Strategic goal and critical factors

Goal

A sustainable Australian society through understanding the origin and evolution of Earth's life-support system.

Critical factors

1. Investment in a modern, effective national marine geoscience capacity (NRP 1, 3 and SO 1, 2, 3, 4, 5).
2. A national program to provide information on the geological controls of groundwater distribution, resources and quality, and determine the causes and mitigation of dryland salinity (NRP 1 and SO 1, 4).
3. Improved information on the rate of change of climatic conditions and landscapes and their effect on Australia's land resources and biodiversity (NRP 1 and SO 4).
4. Improved information on the feasibility, methods, and cost of safe long-term storage of greenhouse gases (NRP 1 and SO 4).
5. Increased investment in research, training, and provision of data and information that results in cessation of land and water degradation (NRP 1 and SO 1, 2, 3, 4, 5).

Recommendations

The NCES recommends the following.

1. That government provide substantial new funding to develop Australia's marine geoscience capacity, ensuring:
   - development of a vital marine geoscience community;
   - development of, and access to, modern, effective national marine geoscience infrastructure;
   - establishment of a national shallow-coring facility; and
   - collaboration with the Integrated Ocean Drilling Program.
2. That government fund a coordinated national program involving government agencies, universities and other organisations that will provide information on the geological controls of groundwater distribution, resources and quality. Such a program should:
   - encompass remote regions, where the major potential use of groundwater could be for mining and mineral processing, and tourism, as well as for agriculture;

- determine the national stock of ground waters; and
- determine the quality of the groundwater.

3. That government agencies support a program to:

   - determine the causes and mitigation of dryland salinity;
   - map and understand the surface and near surface geology and hydrology (regolith, soils, bedrock, water, vegetation) with high-resolution geophysical and spectral remote sensing techniques using airborne and space platforms, and targeted ground truthing;
   - determine the range in, and rate of, change of climatic conditions, sea level and landscapes in geologically recent (deep) time and their effect on the size, diversity, location and migration of ecosystems (Australia's biodiversity);
   - determine the feasibility, methods and cost of safe long-term storage of greenhouse gases created by power generation and by hydrogen manufacture for fuel cell technology; and
   - determine a sustainable rate of use of groundwater. Specific initiatives are to determine the rates of water withdrawal and resupply, the age of the groundwater, the climatic conditions prevailing when it was supplied, its residence time in the aquifer, and the effects (e.g. subsidence) of its withdrawal.

4. That government agencies support a program to:

   - assess the quality, quantity and accessibility of sand, mineral and stone for the building industry near cities and sites of coastal development;
   - determine the residence time and resupply rate of Australian soils;
   - determine the extent and effects of dryland salinity in cities;
   - identify building material and other resources and plan their extraction before they become inaccessible as a consequence of land-development;
   - compare past changes in climate and ecosystems with the present effects of human occupation;
   - determine what, if any, geological conditions were required to help ecosystems to recover and for natural origination of new species and investigate if such conditions can be recreated to sustain Australia's biodiversity; and
   - quantify possible climatic changes and their effect on supplies of surface water. Specific initiatives associated with this strategy are to determine the range of climatic change in Australia recorded in the recent, deep time, rock record and its effect on water supplies, determine the rates of climatic change in the recent rock record, and compare the results with present climate change to predict rate and magnitude of change in future water supplies.

5. That government agencies support a program to:

   - investigate the enhancement of soil production and the creation of artificial soils; and

- determine the interaction of surface water with the substrate. Specific initiatives associated with this strategy are to determine residence time of water on the surface of Australia and in surface storages, determine substrate type for dams and irrigation to quantify and predict leakage, determine present interaction of water with the substrate and its effect on water quality, and predict interaction with eroded, and possibly salty, substrate to determine water quality in the future.

Section

6

Wealth

Geoscience - Unearthing our future

Background

Introduction

Australia has a rich endowment of natural resources and a stable political system, facilitating a large, mature and profitable resource industry that employs many geoscience graduates. Furthermore, two thirds of the continent remains unexplored for minerals and Australia's vast offshore jurisdiction contains several unexplored basins. Innovation in geoscience is essential to the discovery and development of new mineral and petroleum resources.

Analysis

The proportion of wealth that Australia derives from minerals and fossil fuels in Australia is two and a half time greater than that of the other 20 wealthiest countries[33]. Greatly increasing the nation's wealth through discovery of new clean energy and mineral resources that fuel national and regional economies is a key issue for the nation. Maintaining the geoscience skills base, human capital and innovation, upon which the resource industry depends, is vital to Australia's wellbeing.

The minerals and energy sector creates 25% of Australia's wealth[34]. In 2001-02 the minerals industry alone[35]:

- accounted for 8.5% of national GDP (by contrast, the combined agriculture, food, and beverage industries accounted for 5.5% of national GDP);
- was Australia's largest net export earner (A$41 billion) representing 37% of total merchandise exports;
- contributed A$5.7 billion to government revenue;
- has contributed some $500 billion directly to Australia's wealth over the past 20 years;
- was responsible, directly or indirectly, for 317 000 jobs, many in remote and regional Australia; and
- accounted for 16% of total private new investment on average in Australia.

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[33] N Phillips, *Regaining Australia's Global Leadership in Exploration*, CSIRO, Canberra, 2003.

[34] A Stoeckel, *Minerals: Our Wealth Down Under*, Centre for International Economics, Canberra, 1999.

[35] Minerals Council of Australia, *Annual Report 2002,* MCA, Canberra, 2003.

Minerals: our wealth down under

Australia is the sixth wealthiest nation on a per person basis, in large measure due to the rich endowment of minerals and fossil fuels. Creating sustainable wealth will improve the legacy left to the next generation[36]. It is important to look at *wealth* as well as national income, as the latter does not reflect changes in national assets, and cannot indicate whether economic development is sustainable over time[37].

The wealth of a nation is the value of its assets, the things that generate income, but it can include intangible benefits such as safety and clean air. When considering the wealth creating impact of an industry, it is necessary to include the negative impacts of resource depletion, environmental degradation and investment in education. To date, wealth creation by the mineral industries has far exceeded wealth reduction, so that the national wealth has increased over time.

The key to future wealth creation is innovation, requiring a large investment in R&D and in education, as well as a risk-taking business culture. Currently, Australia leads the world in geoscience mining technology, with some 60% of the world's mines using software created by Australian companies. Investing in education and R&D, to generate new knowledge to discover new mineral deposits and develop new technologies, will create substantial wealth for Australia.

New mineral discoveries in Australia, equivalent to a 10% increase in productivity for the industry, would increase national wealth by $42 billion in ten years.

Mineral exploration

The mineral industry is experiencing a major downturn in exploration investment, to the levels that are the lowest in real terms for 20 years. For the past decade, Australia has led the world in exploration expenditure, but global expenditure has declined by 50% and Australia's exploration expenditure has declined from $1.2 billion to $600 million[33]. While Australia's market share has remained stable, Canada has increased its market share and now leads the world in exploration expenditure. On a per square kilometre basis, exploration investment in Australia is less than half the level of Chile and Peru.

This trend is well illustrated by exploration for gold, Australia's third largest single export after coal and crude oil. Over the past five years, exploration expenditure for gold has declined from $728 million in 1996/97 to $331 million in 2001/02. In 1997, the annual gold production was 314 tonnes, whilst in 2002 it was 274 tonnes, equivalent to a loss of about $0.75 billion in export earnings from the 1997 level ($5.9 billion).

This downturn in exploration expenditure reflects a fundamental change in the mineral exploration and mining industry, which is characterised by mergers and consolidations as the industry attempts to provide better returns to investors. Exploration requires greater flexibility and agility than is usually possible in the very large companies that have been developed by recent mergers, and so exploration has been 'farmed out' to small- and medium-sized companies.

Geoscience issues for mineral exploration and mining

Australia tends to focus its exploration on the relatively small areas of outcrop with historical production, considered mature in the upper 100-200 metres. On the other hand, two thirds of Australia is unexplored due to cover by sediments and weathered rocks (regolith), so it is thought that less than half of the major mineral deposits in

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[36] RC Wells in A Stoeckel , *Minerals: Our Wealth Down Under*, Centre for International Economics, Canberra, 1999, pp iii.

[37] A Stoeckel, *Minerals: Our Wealth Down Under*, Centre for International Economics, Canberra, 1999.

Australia have been discovered. Moreover, some high-value commodities, such as platinum and chromium, are yet to be discovered in commercial quantities in Australia.

Australia uniquely faces the geoscientific and technological challenge of being able to see through the veneer of sediment and regolith to image and search the basement below. Furthermore, new techniques must be developed to detect large mineral deposits within that basement. Defining and characterising geological provinces within the basement will be an important guide to prospectivity.

The mining sector’s long-term aspiration is to be able to operate in what is described as a ‘closed loop production cycle’ that results in zero waste production and a minimal environmental footprint.

Reinvigorating exploration in Australia, and addressing the challenges of Australia’s unique environment, will require a consortium of the best brains in the country from the leading geoscience and mining-related organisations. Australia’s exploration future will depend upon a coalition of geoscience organisations to address these critical issues.

Geoscience inputs needed to help sustain exploration, minerals production and processing include:

- an enhanced precompetitive (regional-scale) information base;
- new and refined technologies for exploration through cover including tools for the efficient forward and inverse modelling of geophysical data, development of methods for deep sensing geochemistry, and improved understanding of the near surface geochemical signatures of mineralisation concealed by weathering or other cover;
- three-dimensional visualisation tools, particularly interactive tools tied to geophysical modelling software;
- accurate dating of geological events, including mineralisation;
- improved understanding of geological evolution of continents and mineral provinces;
- improved understanding of the sources of metals and what controls the distribution of mineral deposits at regional and district scale.
- better mineral-potential assessment techniques and environmental models for mineral deposits;
- new and improved technologies for mining and processing, including minimising and dealing with wastes, and improved data for life cycle assessments of mineral commodities; and
- identification of commodities that are likely to be required in future industries and technologies.

Exploration geoscience research

Australia has become a world leader in exploration geoscience research, in large part due to the decision by government to establish a series of research centres with a major focus on exploration geoscience. By supporting a critical mass of 20 to 40 geoscientists at each centre, it has become possible to maintain research excellence in a field central to national research priorities. These centres (see appendix E) have been funded jointly by government and industry grants with a limited funding term of six to nine years. They commonly involve crucial collaboration between several university geoscience departments, government research organisations and groups of mining companies. Despite the outstanding research, from basic through to applied, undertaken by these centres, only three are currently receiving ARC or CRC funding. Thus it is becoming increasingly difficult to maintain the critical mass of high-quality researchers for Australia to remain competitive in the field. Given the overall success of these research centres and their positive impact on the minerals exploration industry, it is critical that the government funding agencies continue their support. Otherwise there is the risk of eroding Australia's hard-won, world-leading position in exploration geoscience.

New discoveries of mineral and petroleum resources will now only be made by increasing our understanding of how complex earth processes operate to concentrate minerals and petroleum in the crust. Key issues for improving exploration are:

- Improved understanding of how, and under what conditions, a range of mineral deposits and petroleum accumulations develop in the earth's crust; and

- Determination of the controls on fluid transport through the crust.

Pre-competitive mineral information

Access to high-quality pre-competitive fundamental geoscience information is vital for successful resource exploration, particularly in the minerals sector. However, the present coverage is incomplete and patchy, varying considerably across jurisdictions. In general, the coverage of basic data acquired using modern techniques is weakest in the larger states of Western Australia and Queensland and these states together contribute about 75% of all mineral and petroleum exploration in Australia.

Mineral exploration uses a multi-disciplinary approach and requires access to a wide range of data, primarily in digital form. Industry attaches greatest importance to fundamental geophysical, geological, geochemical, mineral occurrence and topographic data to assess prospectivity and make area selections.

The key types of geoscience information that need to be acquired are:

- geophysical data, especially high resolution aeromagnetic and radiometric data, gravity data and digital elevation data;

- accurate digital maps of high quality, especially geological maps, but also topographic, bathymetric, cadastral, metallogenic, and regolith maps at 1:100 000 and 1:250 000 in particular, and more detailed scales; and

- other digital datasets including historical exploration data with drill hole information, geochronology, regional multi-element geochemistry including regolith and soil samples, bore water analyses, in a variety of formats, with the associated metadata.

The combination of new airborne geophysical datasets with stratigraphic drilling results and geochemical, geological and metallogenic data, is considered particularly effective in significantly lowering the exploration risk in frontier areas.

The increasing need for continent-wide seamless datasets requires systematic collection and storage of digital databases to defined standards. Information access and discoverability are critical standards issues for the geosciences.

Oil and gas

Australia has major reserves of natural gas along the NW Shelf, albeit far from the main cities. There is a need to find cheap gas close to the eastern Australia markets and near existing pipeline infrastructure to cover the transition to a coast-to-coast, national pipeline network.

The main problem for Australia is liquid hydrocarbons. Petroleum provides 53% of primary energy for Australia and over 70% of end use energy. Australia's estimated crude oil reserves peaked in 1995 (see figure 6.1) and have declined consistently since then (see figure 6.2).

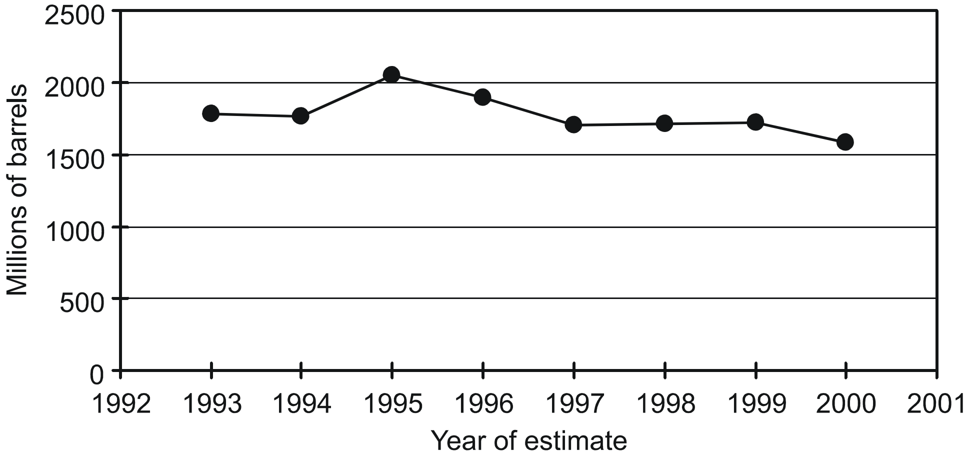

Figure 6.1. Australia's crude oil resources[38]

This is reflected in annual production rates and forecasts for the future. Self-sufficiency in liquid petroleum products is expected to decline from an average of about 85% over the past decade to less than 40% by 2010[39]. Even maintaining that supply will require between A$6.5 billion and A$14.5 billion in investment.

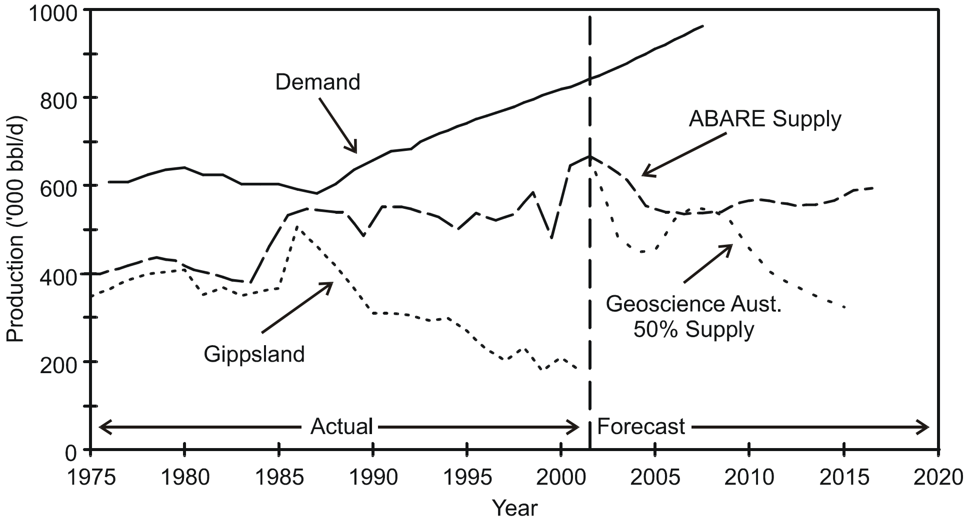

Figure 6.2: Increasing gap between demand and supply

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[38] Figure 6.1 is based on estimates published by Geoscience Australia (TG Powell, 2002).

[39] J Akehurst, World Oil Markets and the Challenges for Australia, presentation to ABARE Outlook 2002, Canberra 6-March-2002, www.woodside.com.au/NR/Woodside/investorpack/SG3682_3_ABARE.pdf and figure 6.2 from APPEA 2003, 23-26 March 2003, Melbourne.

It is noteworthy that a 1% increase in oil imports is equivalent to $100 million per year in the balance of payments. This means that, unless a major new oil province is discovered, Australia will need an additional A$3.2 billion to A$11.8 billion to fund imports in 2010.

If Australia is to maximise the opportunity to maintain oil production at similar levels to the recent past, and thus contribute to maintaining living standards, its knowledge infrastructure needs to develop to stimulate discovery of a new oil province whilst continuing to explore the full potential of the known hydrocarbon-bearing basins. Australia still has a remarkable number of basins that have received little or no exploration. Demonstrating that petroleum has been generated and has migrated is the key to further stimulating exploration interest.

The NCES applauds the Australian Government for its May 2003 budget, which added funding to Geoscience Australia's base to support the agency's core pre-competitive petroleum exploration program. This measure, costing $36 million over the next four years, will provide a new impetus for the search for oil resources – considerably increasing Australia's activities in deep earth resources.

The NCES also applauds the Australian Government for announcing funding of $25 million over the next four years for a scientific research program aimed at identifying new frontier areas for petroleum exploration in Australia's offshore basins. This program will collect and analyse seismic and other data to open up new frontier areas for exploration acreage release and will ensure the preservation of deteriorating seismic data tapes held by Geoscience Australia. The preservation work to be undertaken will benefit all those with an interest in accessing this invaluable collection for research into deep earth resources.

Geoscience issues for oil and gas

The search for additional reserves of oil and gas in basins with existing production requires innovation to develop new play concepts and application of new technologies. This includes 3D modelling of traps, and fluid flow and 3D visualisation. Onshore, the fracture potential of Palaeozoic-Jurassic reservoirs must be assessed, as well as the likelihood of carbon dioxide.

The greater challenge is in the unknown offshore basins with high potential but high risk. Australia's claimed offshore territory is vast, 1.5 times the land area, yet it is poorly known and management is in its infancy. A significant part of Australia's future wealth depends upon finding a major new oil and gas province in a virgin basin.

Geoscience research will play a major role in determining the prospectivity of these unexplored basins, by determining the 3-D basin evolution, tectonics, structure and sedimentary fill. It will be necessary to develop models of hydrocarbon generation and 3-D migration and entrapment. Australia has a unique conjugate margin with Antarctica, for modelling and testing observations. It will be necessary to have tools for high-resolution correlation of sedimentary events and age-dating using microfossil groups and isotopes. New multi-dimensional approaches that embrace microfossils as proxies for unidirectional time and indicators of past environmental conditions will also be needed. The potential of carbon, strontium, uranium/lead and other isotopes for dating and environmental characterisation needs to be realised within a geologic framework and concepts of event stratigraphy need to be developed further.

A significant new challenge will be adapting the standard geological and geophysical techniques to deep water, as most of the untested provinces are in 1-5 km water depth.

Education, research and development

‘Innovation is the mainspring of economic growth and is critically dependent upon research and development, that is connected to the industries using the product, and upon an abundance of educated talented people’[40]. The Mineral Exploration Action Agenda argues that education and training form the primary pillar upon which a successful exploration industry is built. The Agenda points to the significant recent drop in honours, masters and doctoral geoscience graduates with concern and states that: ‘across governments and industry, there needs to be an understanding that making a difference to the standard of education and training will ultimately translate into technological breakthroughs which will lead to enormous long-term benefits for resource development’.

Strategic goal and critical factors

Goal

A wealthier Australia through discovery of new clean energy and mineral resources that fuel national and regional economies.

Critical factors

1. Increased investment in developing pre-competitive information and data to stimulate resource exploration to find and develop large new mineral and oil deposits and provinces (NRP 1 and SO 1, 4).
2. New investment in Australian tertiary geoscience education, research and training systems to develop world’s best facilities and global outlook that will support the exploration industries (NRP 1 and SO 1, 3, 5).
3. Introduction of new government initiatives, especially through R&D programs, that encourage development of prosperous and competitive resource service industries in Australia and overseas (NRP 1 and SO 1, 2).
4. A program or series of new initiatives that build awareness in the community and amongst decision-makers about the opportunities for geoscience to create great wealth for Australia (NRP 1 and SO 4).
5. Maximisation of Australia’s ability to use geosequestration of carbon dioxide as an asset (NRP 1 and SO 4).

Recommendations

The NCES recommends the following.

1. That ARC and government research agencies support a program to:
   - ensure seamless access to digital geological, geophysical and geochemical data regardless of State and Territory boundaries and offshore-onshore divides. Specific initiatives associated with this strategy are:
     - to promote exploration through improved pre-competitive information including new regional gravity, magnetic, radiometric and reflection seismic datasets and their interpretation,

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[40] A Stoeckel, *Minerals: Our Wealth Down Under*, Centre for International Economics, Canberra, 1999.

    - to audit existing geological maps and prioritise the ones for new mapping and upgrading, and
    - to develop and adopt national standards for the acquisition, digital conversion, storage, manipulation and online retrieval of all such data;
  - develop new geochemical, geological and geophysical technologies, particularly gravity, magnetics, seismic and electromagnetic, for Australia's unique conditions to detect covered and deep ore-bodies;
  - support a critical mass of researchers in Australia's world-class economic geology and exploration geoscience research centres;
  - determine the 3D basin evolution, tectonics, structure and sedimentary fill for Australia's poorly known offshore basins, to assess prospectivity. A specific initiative associated with this strategy is to:
    - model the hydrocarbon generation, 3D migration and entrapment in offshore and onshore basins, particularly in frontier regions.

2. That government agencies support a program to characterise the geological provinces of Australia. Specific initiatives associated with this strategy are to:
    - develop a regional scale understanding of the formation of mineral provinces;
    - define areas to explore for mineral deposit types that are known elsewhere in Australia; and
    - define terranes in which to explore for ore types currently unknown in Australia.

3. That ARC and government research agencies support a program to enhance exploration for oil and gas. Specific initiatives associated with this strategy are to:
    - identify productive source rocks in frontier regions and understand the timing of oil and gas generation, and
    - apply 3D visualisation and new technologies to extend existing oil and gas fields and trends.

4. That ARC and government research agencies support a program to determine the feasibility, methods and cost of safe long-term storage of greenhouse gases created by power generation and by hydrogen manufacture for fuel cell technology. A specific initiative associated with this strategy is to determine the viability of geosequestration of carbon dioxide in Australia.

Appendix A

Recommendations

Education

1. That government moves to a funding model for higher education that recognises the national significance, and education costs, of geoscience so as to ensure the long-term viability of geoscience education and training, including:
   - relocation of the geosciences from *Cluster 8* to *Cluster 10*[41];
   - extension of funding under the Higher Education Innovation Program for a further five years; and
   - strong support for science, engineering and technology disciplines in general.
2. That government and universities collaborate to modify the university funding model and its implementation, ensuring:
   - provision for stable, base-level funding to maintain viability of a diverse group of university geoscience departments, despite cyclicity in undergraduate enrolments — specifically, implementing the 'variable rate learning entitlement' funding model proposed in the Higher Education Review, to give direct recognition to the costs and significance of geoscience, as an area of national priority, and of small but vital disciplines such as geophysics;
   - investment in critical core-skills, including those highly specialist skills where the need is critical but is satisfied by a small number of highly competent graduates;
   - provision of scholarships by industry, government and other employers, particularly geoscience-scholarships[42] that encourage students to fill skill-gaps in the nation's ability to address the NRPs; and
   - increase incentives for universities to create graduates with the multi-disciplinary and inter-disciplinary skills necessary to address the NRPs.
3. That the geoscience community expand and broaden existing and emerging networked geoscience centres (e.g. Victorian Institute of Earth and Planetary Sciences, Sydney Universities Consortium for Geology and Geophysics, Earth Systems Dynamics Network) in order to establish world-class graduate centres, networked with smaller departments. Specific initiatives associated with this strategy are:

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[41] Section 2 of *Backing Australia's Ability*[#] details a new model for Australian Government funding of student places from 2005 - with disciplines grouped into 10 clusters.

[#] Department of Industry, Science and Resources, *Backing Australia's Ability - an innovative action plan for the future,* AusInfo, Canberra, 2001.

[42] Sectors requiring geoscience graduates, include, for example, the resources sector, environmental management sector, and city planners. Consideration should be given to providing some scholarships that cover tuition and living expenses so that access is available to those with the brightest minds regardless of economic circumstances.

- provision of dedicated personnel for networking with smaller departments, state government agencies, Geoscience Australia, CSIRO and industry;
- use of infrastructure for networking;
- geoscience promotion, by a dedicated geoscience teacher in each centre, to schools and to the general public;
- establishment of new chairs, particularly in areas of national priority (including geophysics and marine geoscience);
- introduction of a '50 early career explorer' scheme for new graduates and doctorates, with staff to be rotated between government research agencies and industry; and
- increased research and teaching collaborations between geoscience departments, and those in environmental science, geomorphology, meteorology, geoinformatics, engineering, commerce and social science.

4. That all national and state geoscience bodies (government agencies, professional and peak industry associations and lobby groups) work with the Australian Academy of Science, the Academy of Technological Sciences and Engineering and the Australian Science Teachers Association to provide professional development to teachers and schools with inspiring K-12 teaching resources. This should:
    - include excellent geoscience-based learning experiences for primary and secondary students, underpinned by affordable professional development in how to use them;
    - ensure program gaps, specifically including at the K-3, 4-6, 7-10 and 11-12 levels, are effectively targeted through cooperatively funded strategies; and
    - provide geoscience-based learning experiences, including case studies that can be used by non-geoscience disciplines.
5. That the geoscience community encourage government to:
    - undertake a more rational distribution of existing funds to university-based geoscience programs to reduce the large amount of time lost in applying for funding of research positions; and
    - increase the general level of science education funding so that Australia is internationally competitive.
6. That government, universities and industry collaborate to:
    - determine and implement degree structures that will maximise the effectiveness of the geosciences, particularly in addressing the national research priorities;
    - ensure that a geoscience component is in undergraduate and post-graduate courses for primary and secondary science-teacher trainees; and
    - establish effective, affordable, programs and incentives that encourage teachers and trainee teachers, at all levels and across specialist areas, to acquire the knowledge and skills they need to effectively teach the geosciences.

7. That, whenever it is practical and feasible to do so, the geoscience community adopts a coordinated and integrated promotion of the geosciences and their relevance.
8. That government reinstate its support for the Mineral Council of Australia's Mineral Tertiary Education Council program and support other similar private sector initiatives.

Research

1. That the ARC continues to support excellence, diversity and innovation in funding basic research including new opportunities detailed in section 4
2. That the ARC supports the basic, strategic and applied research outlined in sections 5 and 6.
3. That government provide strong and continuing support for major research infrastructure, particularly ensuring more effective use of the significant capital investment in national research facilities, by:
    - providing predictable opportunities for capital acquisition;
    - funding operational support, maintenance, and top quality technical support; and
    - funding travel and accommodation so that qualified researchers are able to access the facilities.
4. That government provide substantial new funding to develop Australia's marine geoscience capacity, ensuring:
    - development of a vital marine geoscience community;
    - development of, and access to, a modern, effective national marine geoscience infrastructure, including a national shallow-coring facility; and
    - collaboration with the Integrated Ocean Drilling Program.
5. That the nation invest in a major geotransect study to gain fundamental information about the Australian plate, from its basic structure and evolution through to its mineral and petroleum systems and surficial processes by:
    - universities and government research agencies developing and implementing a collaborative plan for the most effective geotransect considering the unique opportunities in Australia; and
    - the ARC supporting this activity, including through its new Research Networks Program.
6. That government free up restrictions on recognition of appropriation funds from government research agencies in granting schemes such as the ARC linkage grants.
7. That the recommendations of the House of Representatives Standing Committee on Science and Innovation, with respect to increasing business investment in R&D, are implemented.

Sustainability

1. That government provide substantial new funding to develop Australia's marine geoscience capacity, ensuring:
    - development of a vital marine geoscience community;
    - development of, and access to, modern, effective national marine geoscience infrastructure;
    - establishment of a national shallow-coring facility; and
    - collaboration with the Integrated Ocean Drilling Program.
2. That government fund a coordinated national program involving government agencies, universities and other organisations that will provide information on the geological controls of groundwater distribution, resources and quality. Such a program should:
    - encompass remote regions, where the major potential use of groundwater could be for mining and mineral processing, and tourism, as well as for agriculture;
    - determine the national stock of ground waters; and
    - determine the quality of the groundwater.
3. That government agencies support a program to:
    - determine the causes and mitigation of dryland salinity;
    - map and understand the surface and near surface geology and hydrology (regolith, soils, bedrock, water, vegetation) with high-resolution geophysical and spectral remote sensing techniques using airborne and space platforms, and targeted ground truthing;
    - determine the range in, and rate of, change of climatic conditions, sea level and landscapes in geologically recent (deep) time and their effect on the size, diversity, location and migration of ecosystems (Australia's biodiversity);
    - determine the feasibility, methods and cost of safe long-term storage of greenhouse gases created by power generation and by hydrogen manufacture for fuel cell technology; and
    - determine a sustainable rate of use of groundwater. Specific initiatives are to determine the rates of water withdrawal and resupply, the age of the groundwater, the climatic conditions prevailing when it was supplied, its residence time in the aquifer, and the effects (e.g. subsidence) of its withdrawal.
4. That government agencies support a program to:
    - assess the quality, quantity and accessibility of sand, mineral and stone for the building industry near cities and sites of coastal development;
    - determine the residence time and resupply rate of Australian soils;
    - determine the extent and effects of dryland salinity in cities;

- identify building material and other resources and plan their extraction before they become inaccessible as a consequence of land-development;

- compare past changes in climate and ecosystems with the present effects of human occupation;

- determine what, if any, geological conditions were required to help ecosystems to recover and for natural origination of new species and investigate if such conditions can be recreated to sustain Australia's biodiversity; and

- quantify possible climatic changes and their effect on supplies of surface water. Specific initiatives associated with this strategy are to determine the range of climatic change in Australia recorded in the recent, deep time, rock record and its effect on water supplies, determine the rates of climatic change in the recent rock record, and compare the results with present climate change to predict rate and magnitude of change in future water supplies.

5. That government agencies support a program to:

   - investigate the enhancement of soil production and the creation of artificial soils; and

   - determine the interaction of surface water with the substrate. Specific initiatives associated with this strategy are to determine residence time of water on the surface of Australia and in surface storages, determine substrate type for dams and irrigation to quantify and predict leakage, determine present interaction of water with the substrate and its effect on water quality, and predict interaction with eroded, and possibly salty, substrate to determine water quality in the future.

Wealth

1. That ARC and government research agencies support a program to:

   - ensure seamless access to digital geological, geophysical and geochemical data regardless of State and Territory boundaries and offshore-onshore divides. Specific initiatives associated with this strategy are:

     - to promote exploration through improved pre-competitive information including new regional gravity, magnetic, radiometric and reflection seismic datasets and their interpretation,

     - to audit existing geological maps and prioritise the ones for new mapping and upgrading, and

     - to develop and adopt national standards for the acquisition, digital conversion, storage, manipulation and online retrieval of all such data;

   - develop new geochemical, geological and geophysical technologies, particularly gravity, magnetics, seismic and electromagnetic, for Australia's unique conditions to detect covered and deep ore-bodies;

   - support a critical mass of researchers in Australia's world-class economic geology and exploration geoscience research centres;

- determine the 3D basin evolution, tectonics, structure and sedimentary fill for Australia's poorly known offshore basins, to assess prospectivity. A specific initiative associated with this strategy is to:
    - model the hydrocarbon generation, 3D migration and entrapment in offshore and onshore basins, particularly in frontier regions.

2. That government agencies support a program to characterise the geological provinces of Australia. Specific initiatives associated with this strategy are to:
    - develop a regional scale understanding of the formation of mineral provinces;
    - define areas to explore for mineral deposit types that are known elsewhere in Australia; and
    - define terranes in which to explore for ore types currently unknown in Australia.

3. That ARC and government research agencies support a program to enhance exploration for oil and gas. Specific initiatives associated with this strategy are to:
    - identify productive source rocks in frontier regions and understand the timing of oil and gas generation, and
    - apply 3D visualisation and new technologies to extend existing oil and gas fields and trends.

4. That ARC and government research agencies support a program to determine the feasibility, methods and cost of safe long-term storage of greenhouse gases created by power generation and by hydrogen manufacture for fuel cell technology. A specific initiative associated with this strategy is to determine the viability of geosequestration of carbon dioxide in Australia.

Appendix

B

Key stakeholder groups

Universities (see appendix D)

Education and vocational training institutions

CRCs and SRCs (see appendix E)

Government agencies & others, including:

- Agriculture, Fisheries and Forestry Australia (AFFA)
- Australian Antarctic Division (AAD)
- Australian Nuclear Science and Technology Agency (ANSTO)
- Australian Research Council (ARC)
- Chief Government Geologists
- Chief Scientist
- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Defence Science and Technology Organisation (DSTO)
- Dept of Education, Science & Training (DEST)
- Environment Australia (EA)
- Geoscience Australia
- Heads of Science Agencies
- National Oceans Office (NOO)
- Native Title Tribunal (NTT)
- Office of Spatial Data Management (OSDM)
- State Science Advisory Council

Professional associations, including:

- Association of Exploration Geochemists (AEC)
- Association of Science Teachers of Australia (ASTA)
- Australian Academy of Science (AAS)
- Australian Academy of Technological Sciences and Engineering (ATSE)
- Australian Geoscience Information Association (AGIA)
- Australian Institute of Geoscientists (AIG)
- Australasian Institute of Mining and Metallurgy (AusIMM)
- Australasian Quaternary Association (AQUA)
- Australian Society of Exploration Geophysicists (ASEG)
- Geological Society of Australia (GSA)
- International Association of Hydrologists (IAH)
- Petroleum Exploration Society of Australia (PESA)

Industry & associated peak bodies, including:

- Agricultural industry
- Association of Mining and Exploration Companies (AMEC)
- Australian Coal Association and many other resource-specific associations
- Australian Geoscience Council (AGC)
- Australian Mineral Industry Research Association (AMIRA)
- Australian Petroleum Production and Exploration Association (APPEA)
- Chambers of resources
- Environment industry
- Federation of Australian Scientific and Technological Societies (FASTS)
- Insurance industry
- Minerals Council of Australia (MCA)
- Minerals/petroleum exploration industry
- Natural resources industry
- Tourism industry

Appendix

C

NCES membership

NCES membership during the development of this plan was:

- Dr Phil McFadden (Chair), *Geoscience Australia*;
- Professor John Chappell, *Australian National University*;
- Dr Peter Cook, *Australian Petroleum CRC*;
- Dr David Denham, *Australian Geoscience Council*;
- Professor Andrew Gleadow, *University of Melbourne*;
- Professor David Groves, *University of Western Australia*;
- Professor Mark Harrison, *Australian National University*;
- Dr Bob Haydon, *Predictive Minerals Discovery CRC*;
- Dr Will Howard, *Antarctic CRC*;
- Dr John Kaldi, *National Centre for Petroleum Geology & Geophysics*;
- Professor Sue O'Reilly, *Macquarie University*;
- Professor Neil Phillips, *CSIRO*; and
- Dr Chris Pigram, *Geoscience Australia*.

Appendix

D

Survey of changing geoscience staffing levels.

In June 2003, Professor Andrew Gleadow conducted a web-based survey of geoscience staff numbers at Australian universities. His survey results[43] are summarised in table D.1 below.

Of the 28 departments listed on the next page, 13 departments are geology-focussed, with the remainder providing a broader geoscience focus.

Table D.1: Summary survey results

	Teacher staff	**Research staff**	**Total staff**
1991	268		
1992	212	107	319
2003	176	139	315

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[43] 2003 RMIT staff numbers were not provided, so a best-estimate approach was adopted in this case only.

University	Teach Staff 1991	Teach Staff 1998	Res Staff 1998	Other Staff 1998	All Acad 1998	Teach Staff 2003	Res Staff 2003	Other Staff 2003	Department Name
Adelaide	16	13	11	8	32	10	8	11	School of Earth and Environmental Sciences
ANU	9	7	6	3	16	9	7	23	Geology Department
Ballarat	9	5	1	0	6	4	0	1	Department of Geology
Bendigo	6	3	0	2	5	1	0	2	Department of Physical Sciences and Engineering
Curtin	9	9	3	3	15	11	1	2	Department of Applied Geology
Deakin	0	6	0	0	6	4	0	0	School of Ecology and Environment: Earth Sciences stream
Flinders	7	2	0	0	2	2	0	0	School of Chemistry, Physics and Earth Sciences
James Cook	12	11	6	3	20	13	9	9	School of Earth Sciences
Kalgoorlie	6	5	0	0	5	4	0	1	WA School of Mines
La Trobe	11	7	13	3	23	5	1	2	(Department of Earth Sciences)
Macquarie	20	13	14	2	29	12	19	19	Department of Earth & Planetary Sciences
Melbourne	12	10	4	3	17	10	24	8	School of Earth Sciences
Monash	17	11	7	3	21	12	17	8	School of Geoscience
New England	9	5	1	4	10	4	0	6	Division of Earth Sciences
Newcastle	6	6	1	3	10	7	0	3	School of Environmental and Life Sciences: Geology Discipline
QUT	7	6	0	4	10	3	1	0	School of Natural Resource Sciences: Geoscience
RMIT[43]	7	7	0	0	7	3	0	0	Natural Resources Engineering Discipline
Southern Qld	4	0	0	0	0	0	0	0	Department of Biological and Physical Sciences
Sthrn Cross	4	3	0	2	5	3	0	2	School of Environmental Science and Management
Sydney	13	12	2	2	16	9	8	10	School of Geosciences
Tasmania	12	12	11	7	30	12	15	4	School of Earth Sciences
Queensland	13	14	8	1	23	7	10	4	School of Physical Sciences - Earth Sciences
Canberra	6	4	0	0	4	2	0	1	School of Resource, Environmental and Heritage Sciences
South Aust	6	5	0	0	5	3	0	1	School of Geoscience, Minerals and Civil Engineering
UNSW	17	12	2	6	20	8	0	9	School of Biology, Earth and Environmental Sciences
UTS	9	5	0	4	9	2	0	2	Department of Environmental Sciences
UWA	12	12	17	4	33	10	19	4	School for Earth and Geographical Science
Wollongong	9	7	0	1	8	6	0	7	School of Geosciences
Totals (28)	268	212	107	68	387	176	139	139	

Appendix

E

Australian CRCs and SRCs of particular relevance to the geosciences

CRCs

The Cooperative Research Centres, generally known as CRCs, bring together researchers from universities, CSIRO and other government laboratories, and private industry or public sector agencies, in long-term collaborative arrangements that support research and development and education activities that achieve real outcomes of national economic and social significance.

The Australian Government funded program emphasises the importance of developing collaborative arrangements between researchers and between researchers and research users in the private and public sector in order to maximise the capture of the benefits of publicly funded research through an enhanced process of commercialisation or utilisation by the users of that research.

In 2002/03 there were eight CRCs focussing on minerals/energy specific issues and fifteen environment focussed CRCs. These were:

Minerals and energy focussed CRCs

- AJ Parker CRC for Hydrometallurgy
- Australian CRC for Renewable Energy
- Australian Petroleum CRC
- CRC for Clean Power from Lignite
- CRC for Coal in Sustainable Development
- CRC for Landscape Evolution and Mineral Exploration
- CRC for Mining Technology and Equipment
- CRC for Predictive Mineral Discovery

Environment focussed CRCs

- CRC for Antarctica and the Southern Ocean;
- CRC for Australian Weed Management
- CRC for Biological Control of Pest Animals
- CRC for Catchment Hydrology
- CRC for Coastal Zone, Estuary and Waterway Management
- CRC for Conservation and Management of Marsupials
- CRC for Freshwater Ecology
- CRC for The Great Barrier Reef World Heritage Area
- CRC for Greenhouse Accounting
- CRC for Plant-based Management of Dryland Salinity
- CRC for Sustainable Tourism
- CRC for Tropical Rainforest Ecology and Management
- CRC for Tropical Savannas Management
- CRC for Waste Management and Pollution Control
- CRC for Water Quality and Treatment

The following CRCs of particular relevance to the geosciences will commence in 2003/04.

- CRC for Coastal Zone, Estuary and Waterway Management (extension)
- CRC for the Great Barrier Reef World Heritage Area (extension)
- CRC for Greenhouse Gas Technologies
- CRC for Spatial Information
- CRC Mining (extension from MTE)
- CRC for Sustainable Resource Processing

SRCs

Special Research Centres (SRCs) are funded by the ARC on the basis of research excellence and potential to contribute to the economic, social and cultural development of Australia.

SRCs have generally been funded for nine years. SRC program objectives are to.

- establish concentrations of research workers and resources in Australian higher education institutions;
- encourage the pursuit of excellence in research, as measured at national and international levels;
- establish centres that will act as a major linkage to international centres and programs;
- provide high quality research environments for postgraduate research education and postdoctoral training;
- promote research in areas of national importance that will enhance Australia's future economic, social and cultural wellbeing; and
- establish centres of such repute in the wider community that they will serve as points of interaction among higher education institutions, government, industry and the private sector generally.

Although the ARC does not fund new centres under this program, it continues to fund many centres. SRCs of relevance to the geosciences include the:

- Tectonics SRC;
- Centre for Ore Deposit Research (CODES);
- Centre for Research on Ecological Impacts of Coastal Cities;
- Centre for Offshore Foundation Systems; and
- The National Key Centre for Geochemical Evolution and Metallogeny of Continents (GEMOC).

Other national research facilities

Major national research facilities

Major national research facilities (MNRF) are expensive, large equipment items or highly specialised laboratories that are considered vital for conducting leading-edge research in science, engineering and technology. Two MNRFs are of particular relevance to the geosciences.

Australian National Seismic Imaging Resource (ANSIR)

ANSIR is an MNRF for seismically imaging the interior of the Earth for use by the resource industries, for environmental and groundwater research, for the mitigation of natural hazards, and for understanding of global geological processes. The facility facilitates access to a vibroseis reflection system, 28 portable broadband seismometers, 85 short-period recorders and associated equipment.

Australian Computational Earth Systems Simulator (ACcESS)

ACcESS aims to provide a computational virtual earth facility serving Australia's national needs; empower the Australian earth science and industrial communities with a computational virtual laboratory facility with a never-before seen capacity that will fuel earth systems science and technology innovations, economic development, hazard management and environmental management through the 21st century; provide a national focal point for scientific and industrial earth systems simulations to form, together with climatic and oceanic research, a holistic earth simulation capability, and act as an international focal point within Australia in earth systems simulations, linking Australia with major overseas research programs and generating momentum in this emergent field within Australia.

Other national research facilities

ANSTO facilities

The High Flux Australian Reactor (HIFAR), the Australian National Tandem Research Accelerator (ANTARES), the 3 MV Van de Graaf accelerator, and the Metal Vapour Vacuum Arc Iron Source (MEVVA) are national research facilities that are used for many applications, including the geosciences.

Australian Synchrotron Research Program (ASRP)

The Australian Synchrotron Research Program (ASRP) provides Australian researchers, including geoscientists, with access to state-of-the-art synchrotron radiation research capabilities at overseas synchrotron light source facilities. These are the Australian National Beamline Facility (ANBF) at the Photon Factory, Tsukuba Science City, Japan, and the Advanced Photon Source, at the Argonne National Laboratory in Chicago, USA.

Appendix

F

National research priorities

On 5 December 2002, the Australian Prime Minister announced four national research priorities and their associated priority goals:

1) An Environmentally Sustainable Australia;

2) Promoting and Maintaining Good Health;

3) Frontier Technologies for Building and Transforming Australian Industries; and

4) Safeguarding Australia.

These four areas provide a vision for research by focusing government research effort on key challenges for Australia today and into the future. They build on Australia's strengths while seeking new opportunities in emerging areas. They also aim to strengthen collaboration between research bodies and with industry, and build critical mass of excellence in those key research areas.

All research and research funding bodies of the Australian Government are expected to participate in implementing the priorities to the extent that it is consistent with their mandates or missions.

Implementation of the priorities will be driven by the research community who will advise the government on the best way to proceed.

Key NRP goals and structural objectives for the geosciences

The NCES believes that the extent of geoscientific contribution towards the national research priorities (NRPs), particularly with respect to the following NRP goals and structural objectives, is critical.

NRP 1: An environmentally sustainable Australia

> Transforming the way we use our land, water, mineral and energy resources through a better understanding of environmental systems and using new technologies.

Water – a critical resource (NRP 1.1)

Ways of using less water in agriculture and other industries, providing increased protection of rivers and groundwater and the re-use of urban and industrial waste waters.

Australia is one of the driest continents and is dependent upon access to freshwater supplies for economic and social development. It has a complex geological structure and unique ecosystems, flora and fauna. Enhancing our understanding of the links between water availability and these factors will result in a better understanding of sustainable water management practices.

Transforming existing industries (NRP 1.2)

New technologies for resource–based industries to deliver substantial increases in national wealth by reducing environmental impacts on land and sea.
Resource-based industries underpin much of Australia's prosperity and have the potential to do so in the future. For example, Australia remains highly prospective for minerals discoveries and highly attractive for the development of new era foods from agricultural and marine sources. Our competitive advantage will depend on research and new technologies.

Overcoming soil loss, salinity and acidity (NRP 1.3)

Identifying causes and solutions to land degradation using a multidisciplinary approach (examples include incorporating hydrology, geology, biology and climatology) to restore land surfaces.
The Australian landscape is fragile: soil salinity, acidity, and nutrient levels pose significant, long term challenges for agriculture and the environment. Research is helping to find solutions to these problems. For example, the National Land and Water Resources Audit shows the extent of salinity in the Australian environment and illustrates Australia's leading edge in national mapping of critical resource data.

Reducing and capturing emissions in transport and energy generation (NRP 1.4)

Alternative transport technologies and clean combustion and efficient new power generation systems and capture and sequestration of carbon dioxide.
Australia is well positioned to produce world class solutions to reduce and capture greenhouse gas emissions and the government is committed to meeting the emissions target set for Australia at Kyoto. We are also well placed to develop alternative energy technologies and ecologically sustainable transport and power generation systems.

Sustainable use of Australia's biodiversity (NRP 1.5)

Managing and protecting Australia's terrestrial and marine biodiversity to develop long–term use of ecosystem goods and services ranging from fisheries to ecotourism.
Australia has unique and rich flora and fauna. Our complex ecosystems are resilient and have adapted to events such as drought and fire, and underpin the health of our agricultural, fisheries and tourism industries. There is a need for a more comprehensive understanding of these natural systems and the interplay with human activities.

Developing deep earth resources (NRP 1.6)

Smart high–technology exploration methodologies, including imaging and mapping the deep earth and ocean floors, and novel efficient ways of commodity extraction and processing (examples include minerals, oil and gas).
Many of Australia's known mineral assets may be nearly exhausted within the next decade. New land-based deposits are believed to be buried deeper in the crust and the deep marine areas surrounding Australia are also largely unexplored. New technologies, such as remote sensing, indicate scientists are on the brink of being able to 'see' inside the earth and identify deeply buried deposits.

NRP 3: Frontier technologies for building and transforming Australian industries

Stimulating the growth of world-class Australian industries using innovative technologies developed from cutting-edge research

Breakthrough science (NRP 3.1)

Better understanding of the fundamental processes that will advance knowledge and develop technological innovations (examples include bio-informatics, nano-assembly, quantum computing and geo-informatics).

Frontier technologies (NRP 3.2)

Enhanced capacity in frontier technologies to power world-class industries of the future and build on Australia's strengths in research and innovation (examples include nanotechnology, biotechnology, ICT, photonics, genomics/phenomics, and complex systems).

Smart information use (NRP 3.4)

Improved data management for existing and new business applications and creative applications for digital technologies (examples include e-finance, multimedia, content generation and imaging).

NRP 4: Safeguarding Australia

Safeguarding Australia from terrorism, crime, invasive diseases and pests, and securing our infrastructure, particularly with respect to our digital systems

1) Critical infrastructure

Protecting Australia's critical infrastructure including our financial, energy, computing and transport systems.

3) Protecting Australia from terrorism and crime

By promoting a healthy and diverse R&D system that supports core competencies in modern and rapid identification techniques.

4) Transformational defence technologies

Transform military operations for the defence of Australia by providing superior technologies, better information and improved ways of operation.

Appendix

G

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Appendix

H

Glossary of acronyms

AAS	Australian Academy of Science
ACcESS	Australian Computational Earth Systems Simulator
AMGOD	Australian Marine Geoscience and Ocean Drilling Council
AMIRA	Australian Mineral Industry Research Association
ANSTO	Australian Nuclear Science and Technology Organisation
ANU	Australian National University
APAC	Australian Partnership for Advanced Computing
APPEA	Australian Petroleum Production and Exploration Association
ASTA	Association of Science Teachers of Australia
ARC	Australian Research Council
ATSE	Australian Academy of Technological Sciences and Engineering
CRC	Cooperative Research Centre (see appendix E)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEST	Department of Education, Science and Training
EFTSU	Equivalent Full-Time Student Unit
GSA	Geological Society of Australia
HECS	Higher Education Contribution Scheme
K-12	Kindergarten to Year 12
LIEF	ARC's Linkage-Infrastructure Equipment and Facilities program
MCA	Minerals Council of Australia
MNRF	Marine National Research Facility
NCES	National Committee for Earth Sciences (see appendix B)
NRP	National Research Priority (see appendix F)
ODP	Ocean Drilling Program
OECD	Organisation for Economic Cooperation & Development
R&D	Research and Development
SRC	Special Research Centres (see appendix E)
SET	Science, Engineering and Technology
SHRIMP	Sensitive High Resolution Ion MicroProbe
SO	NRP Structural Objectives (see appendix F)
SRC	ARC Special Research Centre
VIEPS	Victorian Institute of Earth and Planetary Science
VPAC	Victorian Partnership for Advanced Computing