TOWARDS A STRATEGIC PLAN FOR EARTH SCIENCES IN AUSTRALIA

A BACKGROUND ISSUES PAPER

NATIONAL COMMITTEE FOR EARTH SCIENCES
AUSTRALIAN ACADEMY OF SCIENCE

JUNE 2002

The goals in developing a strategic plan are to provide a framework within which the discipline can develop the contribution that it can make to major national and global issues and to ensure the maintenance of research excellence. The strategic plan will play an important role in identifying areas of strength in Earth Sciences and those in need of improvement. It will define the research priorities of the Earth Sciences' community and will contribute to the current national discussion regarding research policy and planning. The intention is to deliver the strategic plan by June 2003.

This background issues paper has been developed to assist you in developing submissions to the committee. Submissions should be made as responses to the questions asked in the companion document *Invitation to Provide a Submission*. Electronic versions (Word 97) of this document and of the Invitation to Provide a Submission can be downloaded from **www.science.org.au/earth.doc and www.science.org.au/submission.doc.**

For consideration in the process, submissions must be made by **30 August 2002**. The preferred method for submission is as a Word document (preferably Word 97) e-mailed to:
nr@science.org.au
and the subject line of your e-mail should be **Submission to Earth Science Plan**.

Alternatively, submissions in writing or on disk should be sent to:

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The Committee comprises:

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Dr Peter Cook	Australian Petroleum CRC
Dr David Denham	Australian Geoscience Council
Prof Andrew Gleadow	University of Melbourne
Prof David Groves	University of Western Australia
Prof Mark Harrison	Australian National University
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Towards a Strategic Plan for Australian Earth Sciences

Introduction

To a greater degree than most developed nations, Australia's ability to maintain a sustainable society requires solutions that arise in the Earth sciences. Continuing to obtain the energy, mineral, and water resources that fuel our economy – and remediating the effects of withdrawing these assets from the Earth system (e.g., greenhouse gas sequestration, mine clean-up, salinization) – requires a vital cadre of Earth scientists addressing the changing problems that these challenges present. However, the state of health of any field of inquiry is critically dependent on the supply of fundamentally challenging questions of basic science. For example, the practical benefits of post-WWII physics (e.g., semi-conductors, magnetic resonance imaging) stemmed from the pre-war revolutions in relativity and quantum theory. When the brightest young minds focus on the most important scientific questions of the day, a vibrant community of the most talented problem solvers results. In this view, the most effective solution to problems of sustainability is not to focus research priorities exclusively on questions of societal need, but first to foster a dynamic Earth sciences community by identifying the most compelling and exciting research questions in that field and then providing the support that this group needs to prosper. The intellectual ferment that results is a component part of the infrastructure from which resource issues can then be addressed. Ultimately, curiosity driven research is the underpinning of a knowledge economy.

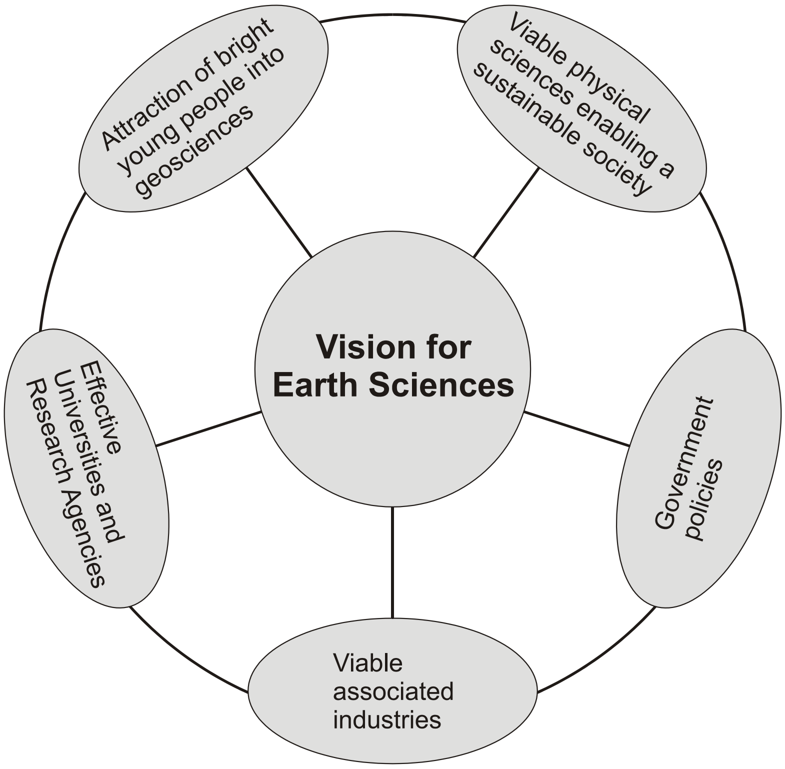
We now recognize the complex interdependence of Earth systems – decisions that in the past were taken independently have implications and impacts that are temporally and spatially far reaching and that interact in unanticipated ways. The mediating medium is, of course, Earth, for each decision sets in place a new and different evolution for the Earth system and so changes the underlying context in which future decisions should be taken. That underlying context provides life with its basic support, and so quite naturally imposes constraints on what is appropriate human activity. Thus in order to develop a sustainable society it is necessary to understand the origin and evolution of our support system; its resources, its limitations, its flexibilities, and its ongoing processes. We are compelled to understand the origins of life on this planet and the subtle interactions between the evolution of life and the evolution of Earth. When dealing with societal issues such as sustainability, it is a common approach to investigate and treat symptoms (e.g., increasing salinity in an agricultural area). Instead, in order to be able to translate knowledge from one specific instance to another (to be able to separate and understand causes, effects, and random perturbations) it is critical to understand the system. Issues of sustainability are almost always rooted in geological systems and so a systemic approach demands that our understanding of these problems start with the geology.

Recognition that the future health of the Earth sciences in Australia stems from a compelling vision, requires that our community cooperate in identifying the most promising avenues of scientific investigation and form a coherent plan that permits our research efforts to stimulate the practical solutions demanded by society.

A Vision for Australian Earth Sciences

Vision concepts

Evaluating the relative merits of possible research strategies involves a number of considerations that include:



Focus

Does this question create an effective and useful focus for research?

Impact

Will the development of an answer to this question drive a major change in our understanding of Earth and its processes?

Feasibility

Is it realistic to expect significant progress in our ability to answer the question? Would we be able to make useful advances in a reasonable time frame? What is the most appropriate structure of resources to address this question effectively? What are the major impediments currently in place? Are appropriately skilled people available (bearing in mind that Earth sciences can only operate effectively within a supporting context of the enabling sciences; e.g., mathematics, physics, chemistry, etc.), and if not how can we grow the skill base?

Unique Australian Context

The large amount of regolith cover, the amenability of Australian geology to test possible strategies for CO_2 sequestration, the apparently unique antiquity of our rocks, the setting of the Indo-Australian plate, and the vastness of our ocean territories all provide matchless opportunities to elucidate fundamental principles of Earth system science. For the relatively small size of our nation, Australia has fostered a tradition of brilliant and eclectic thinkers in Earth sciences (e.g., Carey, Jaeger, Ringwood, Stacey) that has profoundly influenced the rest of the world. Is it our small population inhabiting an enormous land area, or our intellectual isolation, that has promoted such creativity in Earth Science? If so, how do we sustain our unique style of leadership? Is the value of the research question leveraged by Australia's unique geologic context.

Opportunities

What are the opportunities that will flow from addressing the question? Will it draw in international collaborators wanting to work in the unique laboratory that is Australia? Will it help train a cadre of outstanding geoscientists? Will it help drive improved infrastructure?

Excellence

Will this question drive the creation of excellence in research?

What are the most fertile research questions in the early 21st century?

How do continents work?

In the next decade, the crucial question to be addressed in solid-earth geophysics is: 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 can strain be localized along lithospheric-scale faults? At a smaller scale, we recognise that our 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. Resolution of these questions is closely linked to our understanding of how the Australian continent was assembled and therefore to the evolution and location of mineral and petroleum resources.

How did life originate and co-evolve with the atmosphere and hydrosphere?

At a fundamental level the key problem in this field, and one in which Australia holds unique natural resources, is: How did life begin on Earth and possibly elsewhere in the Solar System and the Universe? 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 – 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, early ore deposits (including those with fossilized products of oil), "primitive" plate tectonics, continental growth, the interactions with evolving life (e.g., oxygen-producing photosynthesis), how life and the environment co-evolved, and of human involvement in modifying the conditions of this co-evolution, are all linked.

How does the geologic record aid in assessing environmental and climate change?

The Earth's climate is a complex, non-linear system of clear societal importance. To fully appreciate this system we must understand its history, equilibrium dynamics, intrinsic variability, response to external forcings (solar, volcanic, anthropogenic, etc.), and regional manifestations. Only with a proper understanding of these processes will it be possible for society to make effective climate-related decisions in such areas as water use, coastal development, and carbon emissions.

The geosciences make use of the Earth as an archive of climate history. Paleo-records (ice cores, marine sediment cores, corals, lakes, fjords, etc.) provide dynamic range in physical, geochemical, and ecological change 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. We can use this suite of natural experiments to probe the dynamics of the system and establish predictive skill. For example, the magnitude of the anthropogenically-induced increase in atmospheric CO_2 is matched only during the last deglaciation and is unprecedented in the past 10,000 years. Concomitant environmental and ecosystem changes are also likely to be better analogs for some projected future changes than are contemporary examples.

Earth sciences can also inform the life sciences, as the geological record allows us to place present day biological processes into the context of historical variability on a range of timescales including those encompassing major climatic change. The Earth archive allows greater insight into the sensitivity of ecosystems to environmental change by sampling a greater range of the realised environmental space experienced by the taxa representing the ecosystem responses we want to predict.

How do planetary systems form and evolve?
Since the first planet was discovered outside our Solar System in 1995, over 80 extrasolar planets have been identified. None resemble those in our planetary system. Thus the most pressing issues in planetary science are: How do solar systems form? How do they resemble and differ from each other? What are the processes that form low-mass stars? Although unable to simulate the creation of Jupiter-sized planets, our existing models of planetary growth were viewed as successful. The discovery of greater than Jupiter-sized objects in other solar systems at distances <<1 AU from their "Sun" suggests that the current nebular hypothesis may be fundamentally flawed. Opportunities for further discovery abound as major ground-based and sample return missions are being planned for next decade.

How do we maintain our land and water quality?

Australia has critical salinity and water quality problems that threaten the sustainability of our society. The immediacy of this threat is clearly recognised: in October 2000, the Federal Government committed $700 million to address salinity and water quality problems; the Federal Government has recently established a new Sustainable Environment Committee of Cabinet, chaired by the Prime Minister; the Commonwealth, State and Territory Governments will jointly invest $1.4 billion over seven years under the National Action Plan for Salinity and Water Quality. As yet, however, a truly systemic approach has not been taken in that the geological and Earth process origins of the problems have not been properly incorporated. Without a system approach it will not be possible to understand these problems on a continent-wide scale, which will cripple our ability to deal with them effectively. In order to understand these problems it is necessary to understand the evolution of the Australian landscape and of the processes involved. It is not possible to "fix" the environment, for it is a dynamic system that will always change: instead it is necessary to understand the processes well enough to be able to predict the evolutionary path that will be triggered by our management decisions, and then to pick appropriate evolutionary paths for our environment.

Structural issues

In developing a strategic plan for the Earth sciences that will galvanize the national community, it is necessary to consider the operating environment for research and education. It is vital to ensure that the best students are drawn from the largest possible catchment, that they are given the best possible education, and that they are then able to put their skills to use in the most effective way. It is important that the overall Earth science community be vibrant, that it be focused on important problems, that it be effective in obtaining the necessary funding, and that it operate in an environment conducive to excellence.

In all of this it must be remembered that for the Earth sciences to be effective, it is necessary that they operate within a technically competent society in which the enabling physical sciences are healthy.

Number of Earth science departments in Australia

For our population, Australia has a relatively large number of Earth science departments. As a consequence, departments are often understaffed in terms of being able to provide the full spectrum of geoscience education (indeed, some departments have only two or three staff members), student numbers per department are often low, and extramural funding may be dissipated through ineffective allocation. This had led to a trend where many geology and geophysics departments have been amalgamated into larger, more generic departments, and there has been a move away from training in disciplines such as geophysics and geochemistry – disciplines that are critical in solving many of the important problems.

Do we move to reduce the number of departments and create a handful of facilities that have critical mass and can drive genuine excellence across the full breadth of training and research? There are competing imperatives that inform this question; while a small number of units with substantial resources provide the best opportunity for world class facilities, without a large number of distributed geosciences units across the nation to maximize catchment of the best students these specialized facilities would lack the pool of talented young people necessary to create the next generation of truly excellent geoscientists. Surveys show that only a low percentage of Earth scientists entered the field because of a burning passion while at school. Most went to university with some other career path in mind and had their first introduction to geology as an ancillary subject.

An alternative is to create critical mass and to drive excellence through efficient networking. This would no doubt require funds for travel and would require highly co-operative interaction between departments, their staff, and their funds, but would maintain the resource base and student catchment. Is an efficient and effective network possible in Australia, and if so, how?

This leads to the general question of whether there are any key structural issues that need to be addressed in order to move Australian Earth science research, development, and education to a world-leading position. The issue of student catchment naturally raises the question of school teachers with geoscience qualifications. In particular, a critical question for the future of Earth sciences is how to attract and retain more teachers with geoscience qualifications. We note the declining numbers of high school science teachers in Australia. Indeed, at the present rate of decline of year 12 participation in physics, chemistry and mathematics, these subjects won't exist in 20 years[1]! (A similar extrapolation of the rate of decline of staff numbers experienced in Australian universities suggests that there will be no academics in these same disciplines by 2020.) While the functional form of this trend may not be linear, this nonetheless represents a substantial threat to Australian society and one that could in part be remedied by attracting young Earth scientists into science education. Indeed, how better to educate the next generation of young Australians on science matters than by emphasizing the systems approach that comes so naturally to Earth scientists.

[1] A National Initiative in Science and Mathematics Education for the New Millennium http://www.aip.org.au/initiative2001/

Government policies

The government has in place a range of policies that can significantly influence the emphasis universities place on student training and scientific research. In particular, there are policies relating to research priorities and performance criteria that stress quantity over quality. While it is evident from the opening speech to both Houses of Parliament that issues of sustainable environment (particularly salinity and water quality problems) are a high priority for the current government, as are questions of greenhouse gas abatement and responsible development and export of our minerals and energy resources, Earth sciences were, surprisingly, not articulated as a priority for ARC funding.

Whether positive or negative, it is widely agreed that if universities are funded on the basis of selected performance criteria then each of those criteria can have a significant impact on the nature of those institutions. For example, a criterion based on volume, such as student numbers, will produce a very different institution from a criterion based on quality. Do the current policies facilitate excellence or mediocrity? While Australia (with 0.3% of the world's population) contributes 5% of all geoscience publications, the citation impact of those papers is decreasing. Indeed, globally across all sciences, Australia had dropped in relative citation impact from seventh in 1988 to eleventh by 1993, and the distance from 10th place has continued to widen since[2]. Does this reflect performance criteria that emphasize quantity over quality? DEST's Institutional Grant Scheme distributes funding to graduate educational institutions based on student numbers, amount of research income, and number of publications without reference to the quality of the students, nature of the funding source (e.g., national contestable grants vs. contract income), or impact of the publications. These same performance indicators ignore the potential value in encouraging young scientists to develop the broadest perspective of their disciplines by gaining their tertiary education in as many different institutions as possible.

What are the policies that need to be altered, and in what way should they be altered to provide a more effective university and research system? Although the governmental perception of the value of Earth sciences is improving, as noted in the appendix, there is a clear need to raise the profile much further. Consequently there is a need to identify key mechanisms to elevate the profile of Earth sciences and to present a strong and unified position in the eyes of both Federal and State Governments.

National or regional facilities

Better use of available funds could probably be achieved by co-investing in national or regionally located, key scientific equipment centres, accessible to all Australian Earth scientists. This would require a high level of co-operation between researchers to ensure that the facilities cater appropriately for different specific needs. Unlike several other schemes that have provided funds for infrastructure but that have not covered operating costs, it would be necessary to have comprehensive business plans to ensure viability of such facilities. This would have to include a mechanism for adequate funding for staff and students in other locations to travel to, and be accommodated near, such centres.

It needs to be resolved whether there is sufficient real support for the development of such a scheme. A fundamental issue is of course the development of an effective mechanism for governance of such a scheme.

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[2] Butler, L. *Monitoring Australia's Scientific Research: Partial Indicators of Australia's Research Performance*. Australian Academy of Science, October 2001,

A critical issue in the development of such facilities would be the clear identification of the priority services (specifically types of equipment) that are needed, and an effective mechanism for the best choice of such services.

Research funding

Access to research funds has a major impact on the health of any research field. Are there any aspects of current funding mechanisms that work against the Earth sciences making a more effective contribution? Can current funding schemes be improved to provide a more efficient and effective distribution of research funding for Australian Earth sciences?

Impact of Earth scientists

Attractive careers and job prospects are a critical component of a vibrant Earth science community. As noted in the appendix it is critical to expand the training and employment of Earth scientists into all those human activities for which Earth science can provide valuable knowledge. The discipline of Earth science demands that its practitioners have an unusual breadth of knowledge and look at systems rather than narrow disciplinary fields. It is second nature for geologists to examine problems from a broad range of length and timescales. Indeed, it is an attractive proposition to infuse Earth scientists into all levels of Australian society (policy, education, applied science, basic research, mass media, etc.). Consequently it is necessary to identify key mechanisms by which the contribution of Earth scientists to the national interest can be more effectively harnessed.

Appendix: Drivers for a strategic plan

"Old economy" perception/New economy reality

The Earth sciences and the resource industries in Australia provide a pioneering example of an effective knowledge economy. Universities, government research agencies, and companies operate in a matrix that provides a pervasive environment of knowledge that is and has been the wellspring of innovation in industry. We need to raise the profile of this activity until it becomes recognised as an archetypal example of how other sectors should operate. While it is widely appreciated that over 50% of Australia's exports continue to be from the minerals industry (A$43.8 billion in 1999-2000), the intellectual property associated with that industry also provides nearly A$2 billion in mineral services exports[3]. This latter figure alone is 40% greater than the total value of Australian wine exports. The effectiveness of Earth sciences as a knowledge-based economy is illustrated by the leverage that funding basic geologic research provides to society. For every $1 provided by governments for pre-competitive data and research, $5.60 is spent by industry on exploration, $363 is obtained in mineral export income, $15.70 is earned as mineral services export income, and $11.70 in taxation and $7.9 in royalties are returned.

Despite this extraordinary record, there seems to be a perception within government, and indeed within the community at large, that the Earth sciences are firmly linked with "old economy" rather than "new economy". This has recently been underscored by the Federal Government's articulation to the ARC of priority areas for research: nanotechnology–biotechnology; the genome–phenome link; complex systems; and photon physics. Despite the fact that the Academy of Science (*Priorities in research and innovation for the next Australian Government* October 2001) identified complex Earth systems science and

[3] PMSEIC presentation, June 28, 2001

environmental sustainability as priority areas, the Government did not include Earth sciences as a priority for ARC funding. However, in the opening speech to both Houses of Parliament for 2002 it was stated that "The government will also actively promote the responsible development and export of our abundant minerals and energy resources", "A whole of government approach to sustainable environment issues is to be one of the highest priorities in the government's third term. To this end, the government has established a new Sustainable Environment Committee of Cabinet, chaired by the Prime Minister", and "Immediate action to tackle salinity and water quality problems is essential".

In many instances the perception of old economy is due to the narrow view that Earth science is synonymous with resource exploitation, an industry seen as being mature. The problem seems to be exacerbated by the misconception that the basic geology is now sufficiently well understood that it has reached its potential in terms of its ability to underpin the resource industries. Nothing could be further from the truth – a tremendous amount of basic research is required to allow us to "see through" the Australian regolith to identify buried resources and understand near surface processes that have environmental significance. The world continues to demand resources at an ever growing pace and to remain effective and efficient the resource industries have had to be, and will need to continue to be, highly innovative in ideas, methodology, and technology. In this sense the industry remains dynamic, and highly relevant. Indeed, mineral and energy resources industries will remain the cornerstone of Australian export earnings for the foreseeable future.

Changing employment patterns of Earth scientists to create value to Australian society

A significant number of resource geologists are currently out of work in Australia. This potentially sends the message that the Earth sciences offer poor employment prospects and does little to attract bright students into the broader field. However, the minerals industry is cyclic and the concern this employment pattern generates is out of balance with expectations in other fields of science (e.g., physics, biology, psychology). This concern reflects our success in creating the expectation of full employment for Earth scientists in industry and academia such that there has been insufficient consideration of employment of our graduates across a wider spectrum of areas of Australian society. It is critical to change public and government perceptions of Earth sciences to recognise our full range of endeavour and to recognise that today the resource industries represent only a small component of the contribution that Earth sciences make to society. For example, Earth scientists already contribute significantly to areas such as land rights, Aboriginal affairs, environmental monitoring, financial services, national park management, information technologies, eco-tourism, to name only a fraction. These employment avenues need wider recognition in Earth science training and education.

In that Earth provides the context for everything we do it will become more rather than less necessary to understand Earth processes that support (and therefore provide constraints upon) life. In particular there are many aspects of the Australian continent that are unique and that require basic research so as to provide the Australian community with unique opportunities and to protect the Australian community from unique threats. For example, the large amount of regolith cover in Australia demands significant research effort before we will be able to understand from a systemic perspective the surficial processes so intimately involved in problems such as land degradation and salinity. Substantial research is required to understand the unique opportunities presented by Australian geology for sequestration of CO_2. (The USA and Western Europe are beginning to recognise the vast economic and lifestyle implications of CO_2 sequestration. Australian research, on a tiny budget, is already several years ahead of the game and the nation needs to invest in such a way as to take advantage of this.) The enormously ancient rocks in Australia provide unique opportunities for understanding the origin of life on Earth. The setting of the Australian plate (with, for example, a conjugate margin and data on both sides of that margin) provides a unique opportunity for understanding deep Earth processes and for understanding critical questions about how continents work.

It is critical to expand the training and employment of Earth scientists into all those human activities for which Earth science can provide the necessary knowledge about the underlying Earth process context within which those activities occur. From the perspective of Earth sciences it is necessary to expand the implication of the word resource to include things such as land, soil, water and to recognise that much of the future of Earth sciences is in resource management rather than resource identification. In the future it will be more important to understand the geology relevant to human interaction with Earth.

Stress within Australian universities

University training in Australia of Earth scientists is under significant stress. Student numbers are falling. Many departments are understaffed and unable to provide the necessary breadth and depth of education. Amalgamation of departments has often seen a move towards more descriptive topics while solutions to the important problems of the future will more and more demand quantitative and mathematical capability. Faculty salaries are steadily dropping[4]. It is becoming increasingly difficult to find well-trained geophysicists. Government policies and performance criteria are often counter-productive in the creation of excellence.

It is critical to rectify these problems within the university sector: to draw quality students from as broad a catchment as possible, to provide them with relevant, effective training, to value the efforts of teachers, to network university staff so as to make best use of their capabilities.

Optimising our use of funding

Within the Earth sciences there is a mixed record of collaboration and co-investment in state-of-the-art equipment, although there are some notable exceptions. Consequently there are several instances where the national capacity probably exceeds the national requirement, yet some researchers continue to have inadequate access to such equipment.

There are several reasons for this, including unproductive competition, a feeling by individual researchers that they require direct control over instrumentation that is specifically tuned to their particular needs, lack of forethought, etc. Better co-operation and co-investment would free up national resources for optimal use. Funding bodies are likely to be responsive to a disciplined community attacking important scientific problems if they perceive that it has its house in order (hence the drive for national facilities, key centres etc.).

International investment in Earth sciences

Other countries are investing heavily in frontier research in the Earth sciences. The current United States budget request contains US$1 billion over 10 years to develop EarthScope, a multi-disciplinary observing system designed to measure how the North American continent is deforming in response to ongoing plate tectonic forces and to image features that make up the internal structure of the continent and underlying mantle. An international initiative is underway to replace the Ocean Drilling Program (ODP) with the Integrated Ocean Drilling

[4] Academic salaries as a proportion of average weekly earnings dropped by 25% from 1985 to 2001 (calculated from Academic Salaries Tribunal data (to 1966), ANU salaries data and ABS AWE series 6202.0

Program (IODP) from 2003 onwards with a new scientific program and enhanced and expanded drilling capability. The United States and Japan have committed to new drilling platforms at a cost of about US$600 million. Annual operational costs will be on the order of US$140 million, with the United States and Japan each committing to fund approximately one third. Japan is creating the Institute for Frontier Research on Earth Evolution to leverage IODP activity and to develop a significant capacity to understand the evolution of Earth. Such programs provide enormous opportunities for Australia to invest in Earth sciences in a way that provides us a high degree of financial leverage. For example, if you add up the total costs and value to Australia of being in the ODP from 1988-2001, the benefit:cost ratio is 5.75[5].

The need for prioritisation

Other scientific communities, such as the astronomers, have gone to government with clearly-articulated priorities. Given the breadth of issues in which the Earth sciences are involved, it is probable that our community may not be able to bring as sharp a focus to its overall priorities as the astronomers have been able to do. However, it is critical that the Earth science community learns how to prioritise its requirements better than it currently does and speak with a unified voice. In doing so, we can leverage tremendous benefits for the nation.

[5] Australian ODP RIEF renewal application for 2001-2002